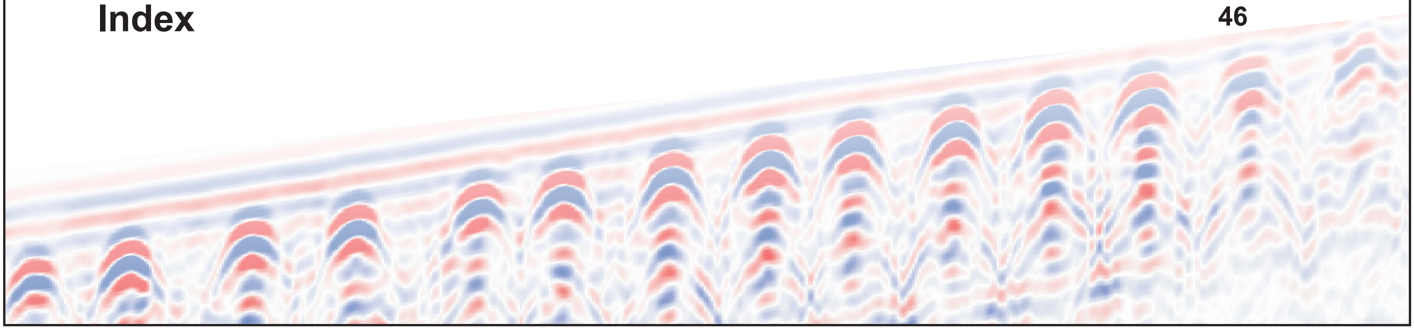
A REFERENCE FOR GEOPHYSICAL TECHNIQUES AND APPLICATIONS

RSK

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

CONTENTS



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

INTRODUCTION

The use of geophysical surveying

The deployment of the latest equipment, coupled with the field application of the latest processing and visualisation software can provide key information not available through other means.

Geophysical surveying techniques provide a toolbox of rapid, discrete and cost effective methods for the location and identification of subsurface features.

RSK Geophysics provide consultancy, survey design and site investigation services. We routinely apply state of the art geophysical instrumentation to the identification of subsurface features associated with man-made and natural phenomena. Our senior staff have international research profiles through their work in geophysical data collection and interpretation, with work ongoing into new equipment and data processing software.

To discuss the benefits of a well designed and executed geophysical survey contact RSK Geophysics. We can discuss in general terms, or for a specific site. We are happy to advise on principles and techniques, and provide courses and seminars on geophysical theory and applications.

Contact
George Tuckwell on: **01442 416656** **geophysics@rsk.co.uk** **www.environmental-geophysics.co.uk**

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical techniques

Geophysical surveying may be used to pinpoint locations within a site to target with conventional intrusive investigation, but by the same token may be deployed to eliminate the need for the disruption caused by boreholes, trial pits, cores or breakouts.

In each case the appropriate geophysical technique must be used in the correct survey manner in order to maximise the ability of the survey to yield clear results. Surveys should be designed and undertaken by qualified and experienced geophysical professionals, and should make full use of available instrumentation and software to provide the best possible interpretation in a timely and efficient manner.

Read more about the various geophysical techniques in the following chapter.

Rapid data collection

Deploying the latest survey equipment and software to site can minimise the time from arrival on site to the visualisation of survey data. Careful survey design, tailored to the target and to the environment, can avoid the collection of unnecessary data, and can also prevent inconclusive or misleading interpretations.

Data Collection and Visualisation

The latest data interpretation and visualisation software can be used in real time in the field. When coupled with the use of differential GPS for data location, delivering positional accuracy better than 0.25m, the software can eliminate the need to break the survey down into a number of rectilinear sub-areas, further improving the efficiency of data collection.

Integrated Surveys

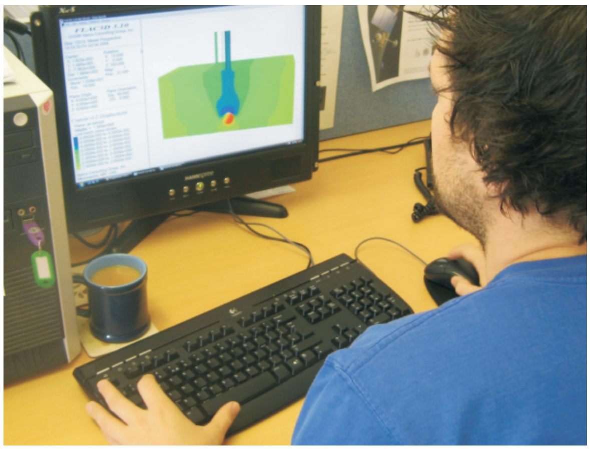
Multiple geophysical data types can all be collected in this manner at walking pace, or at greater speeds if towed on a mobile instrument platform. In many cases the collection of more than one type of geophysical data provides significantly more information than a single survey, therefore the rapid and efficient collection of data is imperative.

Data processing and reporting

Data should be quality checked on site as part of the data collection methodology, and also checked at the end of each site visit by the lead geophysicist. Often initial indications from the raw un-processed data can inform the ongoing data collection phase of the project. In some cases data can be transmitted back to the office to provide the client with early interpretations.

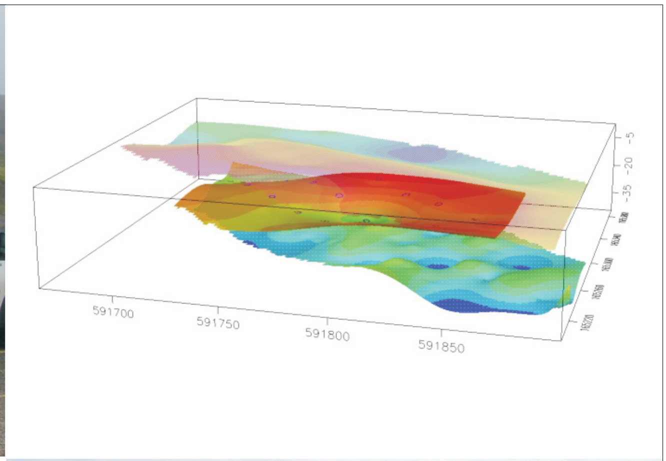
The collection of good field data is only half of the picture. Careful processing of the data must be undertaken by an experienced geophysicist in order to produce accurate interpretations, and in order to avoid the misinterpretation of spurious signals in the data. It can take several days to process the data collected during one day in the field.

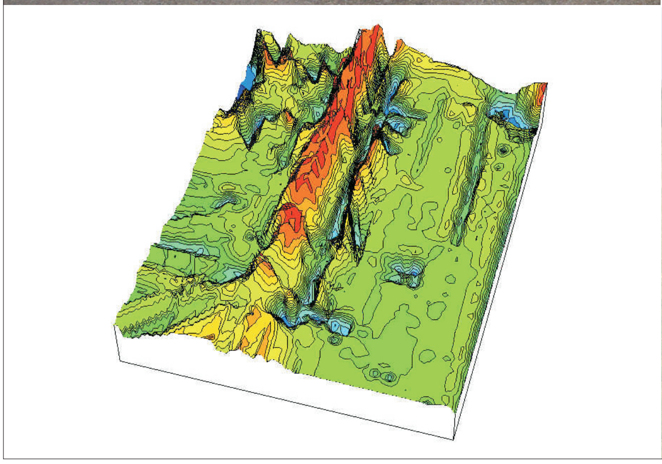
In every case the objective is to integrate the geophysical data intelligently with all other relevant site information, and produce an accurate interpretation that provides information that the client needs.



RSK's staff possess both commercial and research experience in geophysical data processing

GEOPHYSICAL TECHNIQUES AND EQUIPMENT





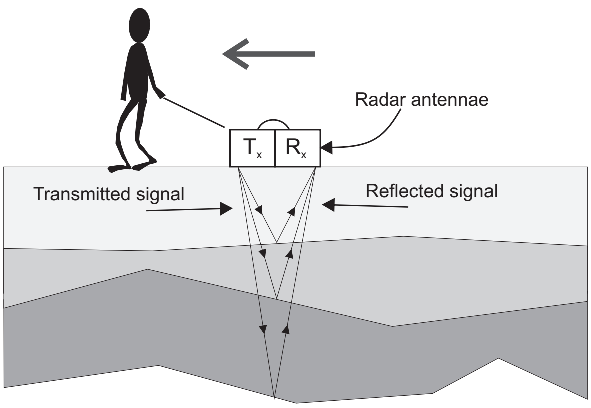

GROUND PENETRATING RADAR

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Applications

- *Construction details (e.g., location of buried foundations and basements, slab thickness, reinforcement placement, void detection, locating beams, bridge deck surveys, floor surveys)*
- *Depth to bedrock*
- *Depth to water table*
- *Locating fractures, sinkholes or cave systems*
- *Locating underground storage tanks and buried drums*
- *Archaeology (e.g., location of graves and artifacts)*
- *Mapping and monitoring groundwater pollution*
- *Locating below ground services*

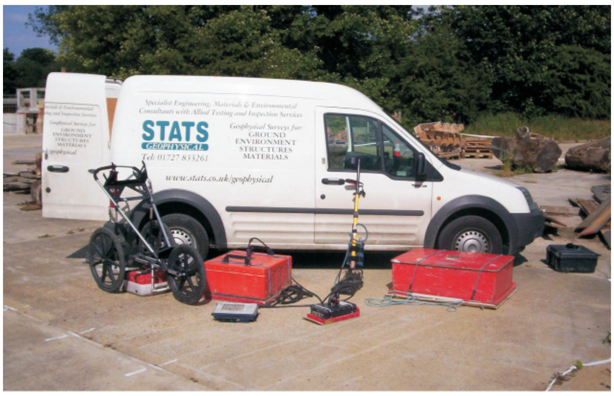
Basic Theory



In Ground Penetrating Radar (GPR) surveys, electromagnetic waves of frequencies between 50MHz and 2.5GHz are transmitted into the ground or a structure. This energy is reflected back to the surface when it encounters significant contrasts in dielectric properties.

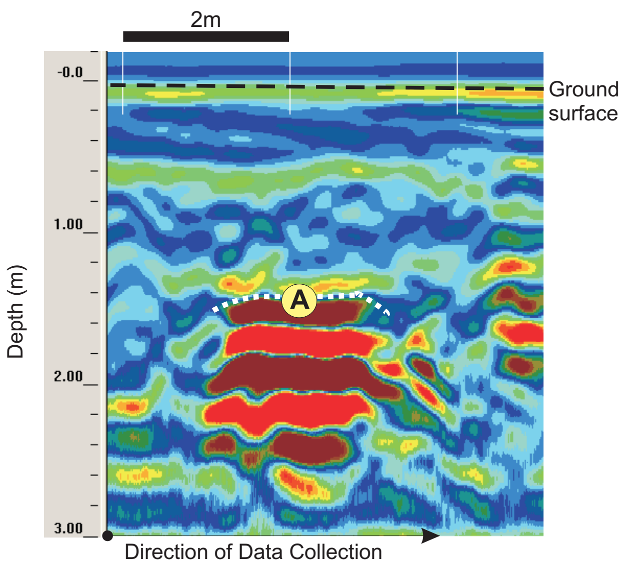
A radio wave transmitter (T_X) located at the surface is used to generate a short (<20ns) pulse of radio waves which penetrate into the subsurface. Some of the energy carried by these waves is transmitted to greater and greater depths, while some of the energy is reflected back towards the surface receiver (R_X) whenever a contrast in dielectric properties is encountered. The amount of energy reflected is dependent on the contrast in electrical properties encountered by the radio waves.

The receiver measures the variation in the strength of the reflected signals with time. The resulting profile is called a 'scan' and is a one-dimensional representation of the subsurface beneath the antenna. To build up a two dimensional section of the subsurface (a radargram), the antenna is traversed across the surface to collect a number of adjacent scans. Conversions to depth sections may be made providing there is sufficient information regarding the dielectric properties of the material(s) surveyed.



*RSK Geophysics own a range of GPR antennae of different frequencies (**above**). The versatility of GPR means that the radar antennae can be handheld, pushed on a cart or pulled across the ground. The type of GPR equipment is selected depending on the target object and site conditions.*

Data can be processed and presented as individual radargrams (see **below**). These are essentially two-dimensional cross sections of the sub surface. Modern software now enables stacking of adjacent radargrams and the construction of three-dimensional data cubes. Horizontal slices (or "time slices") through the data at the desired depth enables visualisation of the reflection strength across the survey area. This is an invaluable approach in the detection and tracing of linear targets (e.g pipes and walls) and complex three dimensional buried structures.



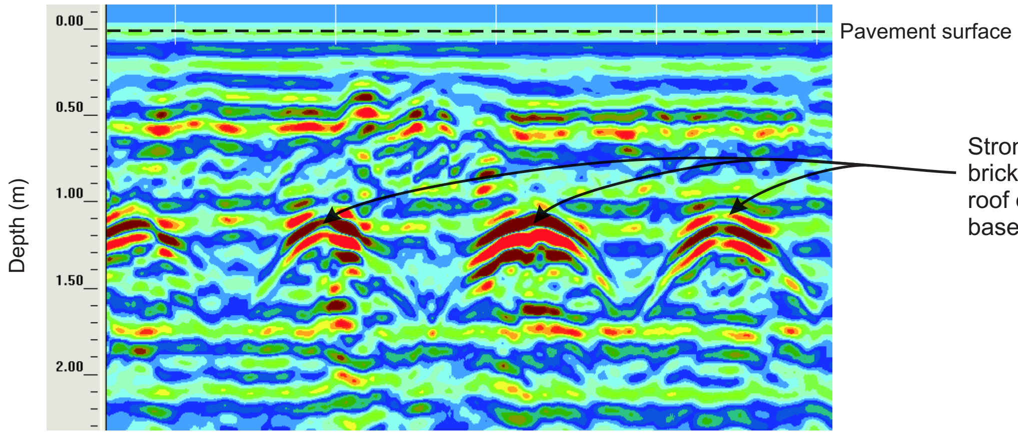
*In this GPR study of contaminated land (**above**), the location of a buried underground storage tank (UST) is clearly identified by a characteristic high amplitude reflection (top of which is labelled **A**). The strong negative amplitude suggests that the tank is air-filled.*

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

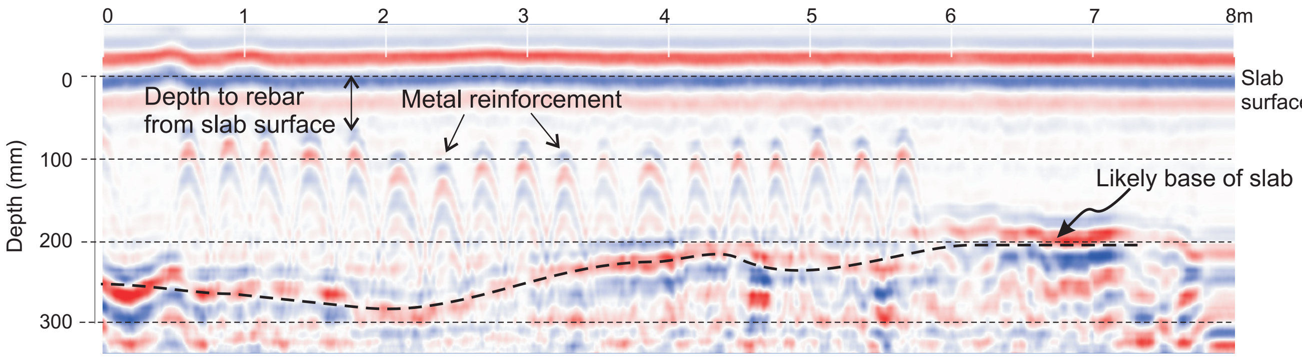
GPR over Voids, Structures and Foundations

1 An example of mid frequency (400MHz) radar data collected over voids

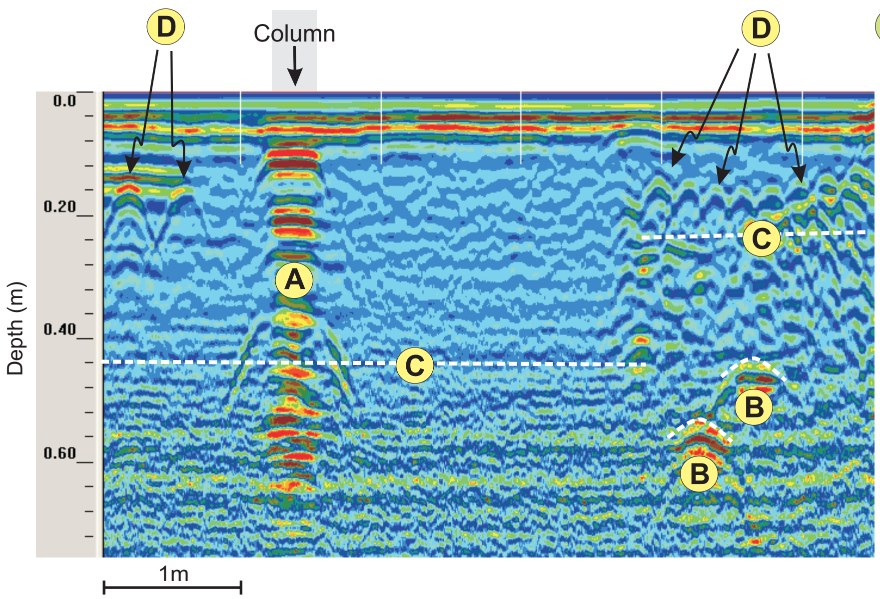


2 An example of high frequency (1.5GHz) radar data collected over a concrete slab

Individual rebar are identifiable from their triple hyperbolic diffractions.
The maximum depth of investigation here is approximately 300mm.



3 An example of 1.5GHz radar data collected over foundations



Interpretation:

- **A** Strong reflections indicative of metal object on foundation
- **B** Hyperbolic reflection indicative of possible services (i.e. pipe/sewer)
- **C** Interpreted location of concrete base
- **D** Multiple regular spaced reflections indicative of reinforcement in slab

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

EM GROUND CONDUCTIVITY

Applications

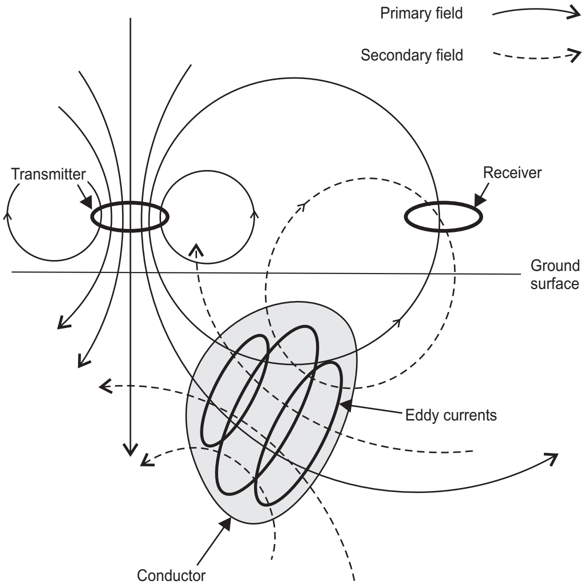
- *Locating sinkholes and sub-surface voids*
- *Mapping and monitoring groundwater pollution*
- *Mapping saline intrusions*
- *Locating underground storage tanks & buried drums*
- *Mapping buried foundations*
- *Locating the boundaries of landfills*
- *Mapping leachate migration*
- *Determination of layer thickness and conductivities*
- *Mapping buried utilities*
- *Mapping water filled fractures and fissures*
- *Mapping near surface chemical contamination*
- *Assessment of ground remediation*

Basic Theory

In electromagnetic (EM) surveying, the electrical conductivity of the ground is measured as a function of depth and/or horizontal distance. Different rocks (and buried structures/objects) exhibit different values of electrical conductivity. Mapping variations in electrical conductivity can identify anomalous areas worthy of further geophysical or intrusive investigation.

The electromagnetic method is based on the induction of electric currents in the ground by the magnetic component of electromagnetic waves generated at the surface.

An alternating current, of variable frequency, is passed through a coil of wire (a transmitter coil). This process generates an alternating primary magnetic field which, in turn, induces very small eddy currents in the earth, the magnitude of which is directly proportional to the ground conductivity in the vicinity of the coil. These eddy currents then generate a secondary magnetic field, a part of which is intercepted by a receiver coil. The interaction between the primary and secondary magnetic flux and the receiver coil generates a voltage that is related to the electrical conductivity of the subsurface, expressed as milliSiemen/metre (mS/m).



*The EM-31 instrument shown **above** uses transmitter and receiver coils at either end of the boom. No electrodes or ground contact is necessary.*

Rapid data collection

As shown **below**, for the collection of data over larger sites the Geophysical Equipment Exploration Platform (GEEP), developed at the University of Leicester in partnership with Geomatrix Ltd can be deployed by STATS. The platform provides a means of quickly and efficiently collecting densely sampled high quality data from EM and magnetic instruments simultaneously.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

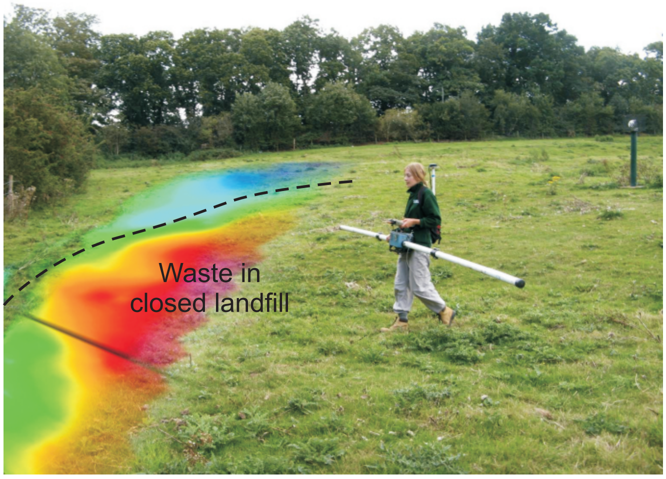
Data Examples

Delineating Landfill Boundaries

In this example (**right**) EM-31 ground conductivity data were collected over a closed landfill site to delineate the lateral extent of the waste, and to detect internal variations in waste type. Resistivity imaging and seismic refraction data were also collected as part of an integrated solution for the client.

A dGPS (differential Global Positioning System) can be used to accurately locate data. This survey methodology enables rapid coverage of the site area.

The figure right shows the landfill boundary that can be interpreted as the boundary between the areas of low and high conductivity values (coloured blue and red respectively to indicate areas of undisturbed ground and areas of buried waste).



EM-31 data is conventionally collected on foot along straight and parallel track lines across the target area.

Locating buried structures beneath a Brownfield Site

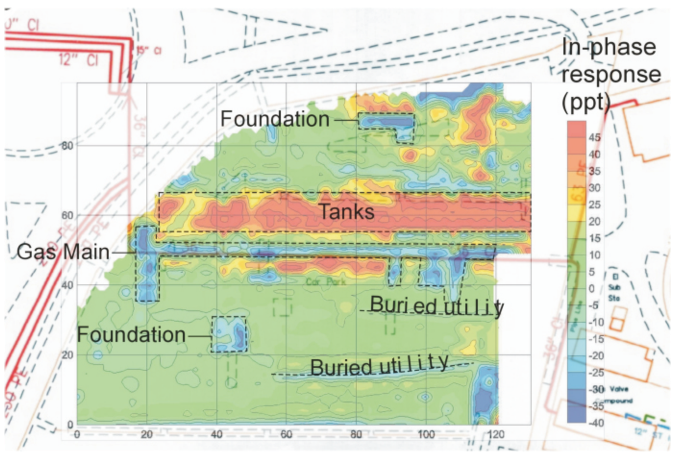
Brownfield sites are attractive targets for re-development but are riddled with potential pitfalls and risks to the developer. Geophysics can help reduce those risks.

Shown to the **left**, the EM clearly marks buried obstacles such as the foundations of three old cooling towers and the location of underground services over the site of a former power station.

The information from the geophysical survey was used to inform the subsequent intrusive survey which was able to target trial pits more precisely across the foundations and safely avoid the buried

Detecting Buried Tanks and Ground Contamination

Mapping variations in the electrical conductivity of the subsurface across a site can highlight anomalously conductive targets such as metallic tanks, pipework, ground contamination, buried waste, solution features and old foundations. In the example shown **right**, buried tanks generate a strong response along with services and foundations.



ELECTRICAL RESISTIVITY IMAGING

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

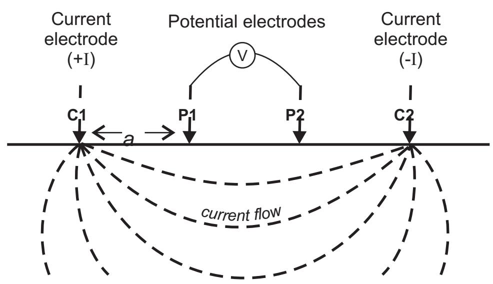
Applications

- Landfill Investigation
- Mapping and monitoring leachate plumes
- Mapping and monitoring of groundwater pollution
- Determination of depth to bedrock
- Locating sinkholes / cave systems
- Stratigraphic mapping
- Locating buried channels
- Mapping buried dykes and other ore bodies
- Locating fissures, faults and mineshafts
- Landslide assessments
- Buried foundation mapping
- Time-lapse infiltration studies
- Cross-borehole tomography
- Assessment of aquifer heterogeneity
- Soil corrosivity assessment

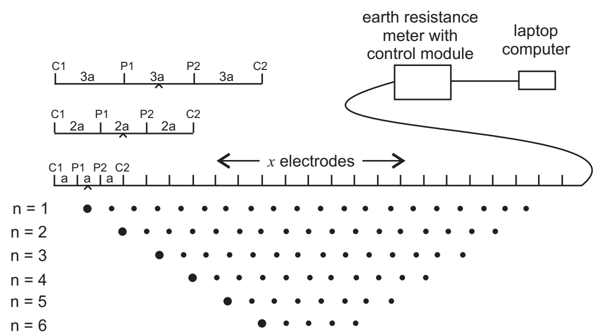
Basic Theory

The electrical properties of the subsurface vary with the ground material, the presence and saturation level of fluids, and the presence of buried objects. Electrical techniques seek to describe the distribution of these properties as a function of depth and horizontal distance.

The most commonly used electrical technique is Electrical Resistivity Imaging (or Electrical Resistivity Tomography, ERT). Measurements of ground resistance are made by introducing an electric current into the subsurface via two metal stakes (current electrodes) planted into the ground. The current passing through the ground sets up a distribution of electrical potential in the subsurface. The difference in electrical potential between two additional electrodes (potential electrodes) is measured as a voltage. Using Ohm's law, this voltage can be converted into a resistance reading for the ground between the two potential electrodes.



Ohm's Law: **V = I R**



Apparent resistivity, $_a$ = **2** ***a*R**

To build a cross-sectional image of ground resistance, a string of connected electrodes are deployed along a straight line with an inter-electrode spacing of ***a***. Once a measurement of ground resistance has been determined for one set of four electrodes, the next set of four electrodes is automatically selected and a second measurement of resistance is made. This process is repeated until the end of the line is reached. The line is then re-surveyed with an inter-electrode spacing of 2*a*, 3*a*, 4*a*, etc. Each increase in inter-electrode spacing increases the effective depth of the survey. The measured resistance values are converted to values of apparent resistivity, $_a$, (in ohm-metres) which can then be used to model the true subsurface resistivity distribution.

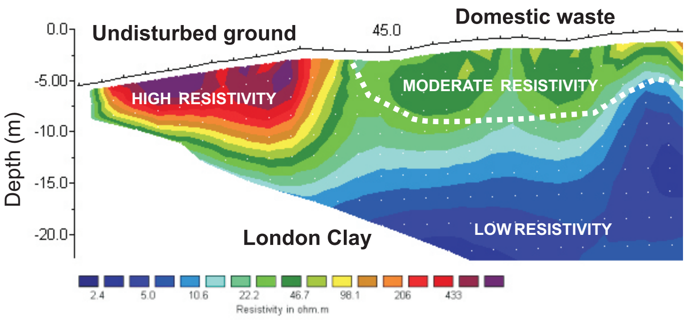
A typical resistivity imaging survey, ***above*** *comprises an array of ground electrodes connected to a resistivity meter. The length of line determines the depth penetration and resolution of the data.*

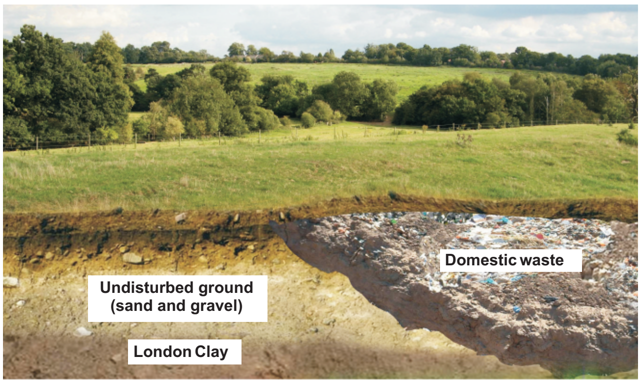
RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

Delineating landfill extent and geometry

Below is an example of a survey undertaken across a closed landfill site. The data provided information to the client on the thickness and extent of waste in the landfill.

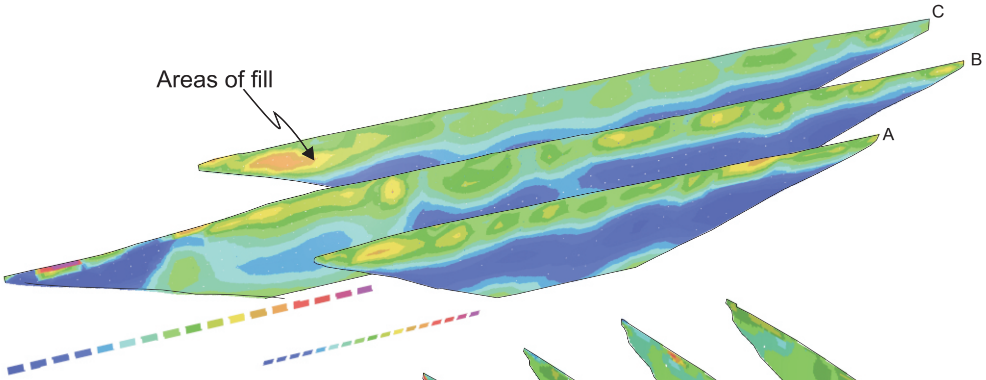




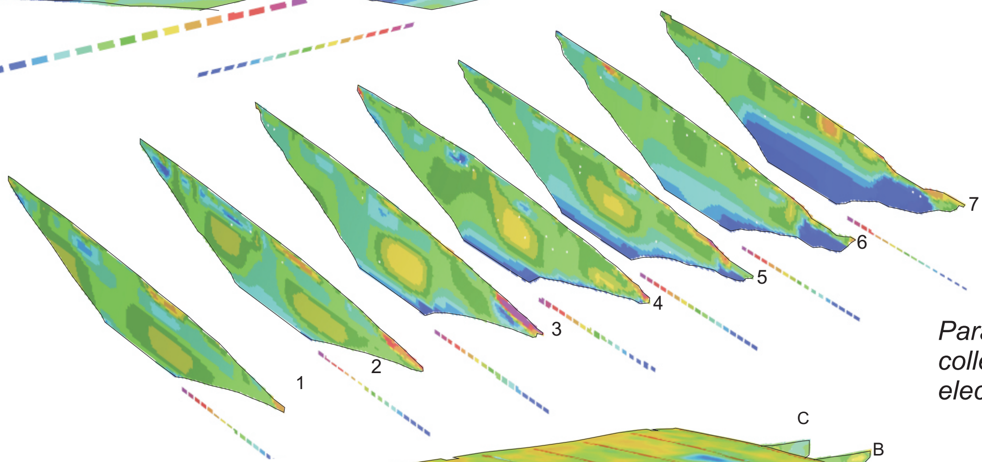
Collation and integration of resistivity imaging data

Below is an example of a survey carried out over a large waste site. A number of resistivity lines were collected in two orientations. During processing they have been corrected to allow for the topography of the surface, and have been combined in 3D fence diagrams to aid interpretation.

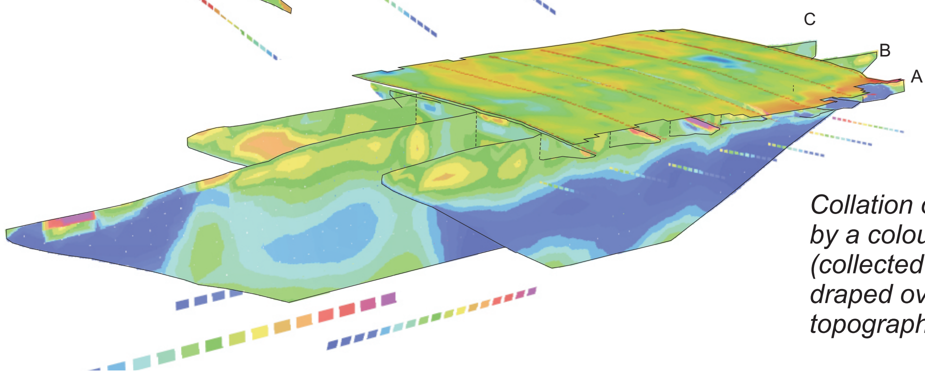
Within the same workflow it is possible to integrate other geophysical data sets and site observations, and overlay them to scale on a base map of the survey area. This integrated approach produces the best interpretation of a multi-method geophysical survey, and provides high-quality interpretative drawings for the client.



Parallel resistivity lines collected with a minimum electrode spacing of 5m.



Parallel resistivity lines collected with a minimum electrode spacing of 2m.



Collation of all resistivity lines overlain by a colour contour plot of conductivity (collected using an EM31 instrument) draped over accurately surveyed topography data.

INDUCED POLARISATION IMAGING

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Applications

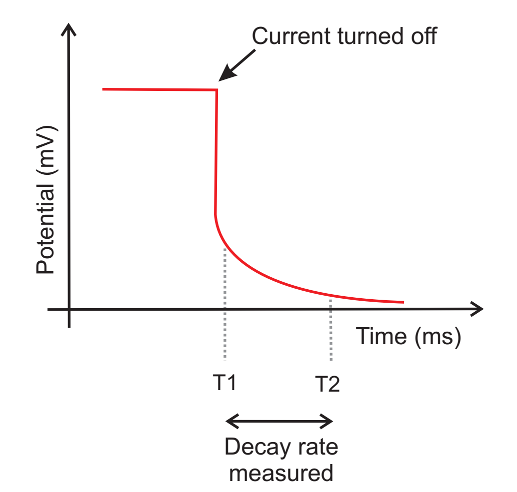
- *Landfill Investigation*
- *Mapping and monitoring leachate plumes*
- *Mapping and monitoring of groundwater pollution*
- *Determination of depth to bedrock*
- *Locating sinkholes / cave systems*
- *Stratigraphic mapping*
- *Locating buried channels*
- *Mapping buried dykes and other ore bodies*
- *Locating fissures, faults and mineshafts*
- *Buried foundation mapping*
- *Time-lapse infiltration studies*
- *Assessment of aquifer heterogeneity*

Basic Theory

Induced polarisation (IP) imaging is a complementary technique to electrical resistivity imaging and is concerned with the capacitance of the subsurface. The subsurface has the ability to both dissipate (resistance) and store (capacitance) the energy associated with an electric current flowing through it. Resistivity imaging measures how much energy is dissipated by the subsurface, whilst IP imaging measures how much energy is stored.

The capacitive action of the subsurface is evaluated by determining its chargeability. When a current is passed through the subsurface, a small charge is stored and the subsurface becomes charged. When the current is turned off, this charge decays with time and this decay is seen in the recorded potentials. By measuring the rate of this decay it is possible to calculate the chargeability of the subsurface.

Two materials that possess the same resistivity might possess contrasting chargeabilities. As such, IP imaging can provide additional discrimination of subsurface materials.



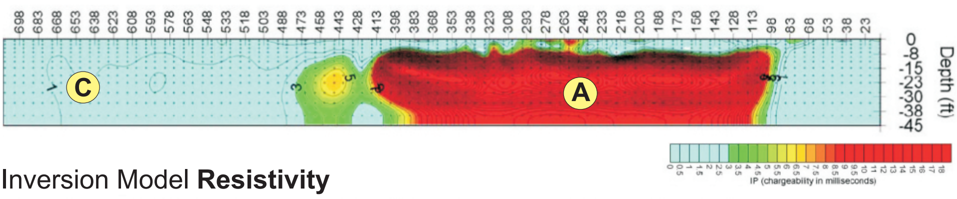
Calculation of chargeability

Data collection and presentation

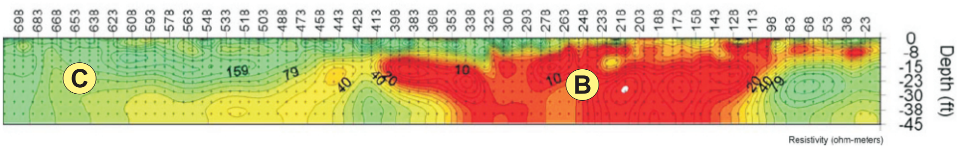
The equipment used in IP surveys is similar to that used for electrical resistivity, with measurements being made of both the resistivity and chargeability of the subsurface. The survey typically comprises a number of ground electrodes in deployed an array connected to a computer controlled multi-channel receiver as shown **right**. Data from IP surveys is commonly presented as one cross-section for resistivity and one for chargeability. The data example **below** shows data from a resistivity/IP line across a buried landfill site. In this example the delineation of the landfill boundary from the IP survey is much more defined.

Deployment of electrical imaging equipment

Inversion Model **IP**



Inversion Model **Resistivity**



Features

- **A** Well defined elevated IP response mapping extent of landfill waste
- **B** Broad low resistivity anomaly correlates to IP data
- **C** Undisturbed ground

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

SELF POTENTIAL IMAGING

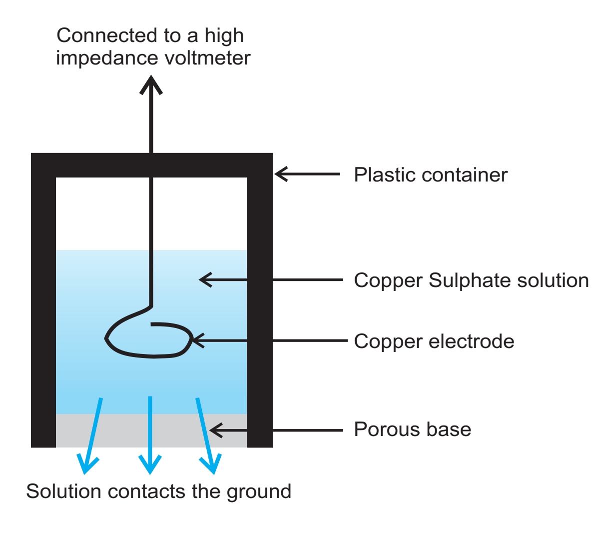
Applications

- *Hydrogeological investigations (e.g. groundwater flow determination, contaminant transportation)*
- *Leak detection in reservoirs and dams*
- *Landfill delineation*
- *Geothermal surveys*
- *Locating massive sulphide ore bodies*

Basic Theory

Self potentials (SP) are measurements of the difference in natural electrical potentials between two points on the ground surface. The natural electric currents responsible for these potentials may be generated by a number of different sources including groundwater flow, mineral deposits and chemical diffusion.

The magnitude of self potentials can vary from less than a millivolt to over one volt, and the polarity of the potential is a diagnostic factor in the interpretation of SP anomalies. Although there are many sources of self potentials, the common factor among them is groundwater. The potentials are typically generated by the flow of water, or by the involvement of water in natural chemical reactions.



Data collection and presentation

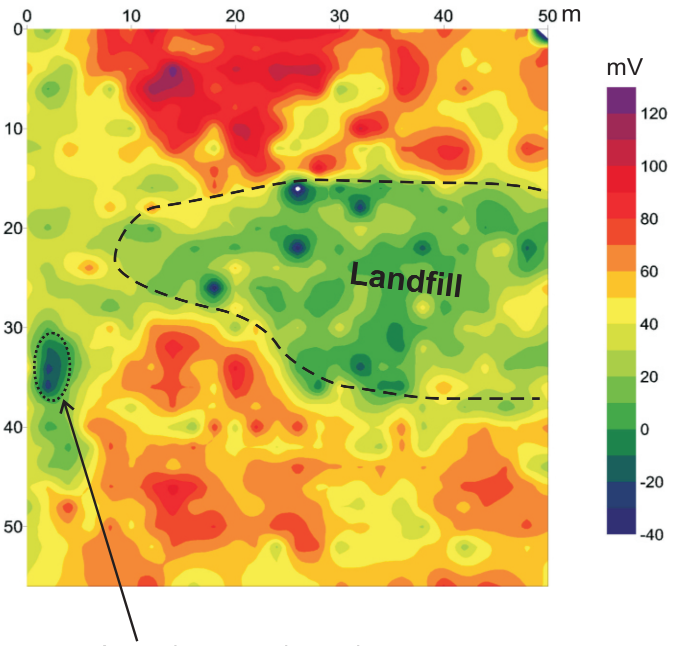
Measurements of self potentials are made with two non-polarisable porous-pot electrodes connected to a high impedance voltmeter. Traditional metal stakes, as used in resistivity surveying, cannot be used as they generate their own potential when they are inserted into the ground. Data is collected along a survey line (SP profiling) or across a grid to produce a contour map of self potentials. The data requires little processing as most interpretations are based on qualitative analysis of profile shape, polarity and amplitude.

Data Example

SP survey over a landfill to identify a leachate breach

Self potential measurements can be used to identify the movement of electrical charge associated with the flow of contaminants in the sub-surface.

In the example to the **right**, the technique was used to identify the possible presence of a breach in the liner, and the resulting escape of leachate fluids from the landfill interior to the surrounding ground



Anomalous negative region (evidence for possible breach in liner and subsequent flow of leachate)

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

MAGNETICS SURVEYING

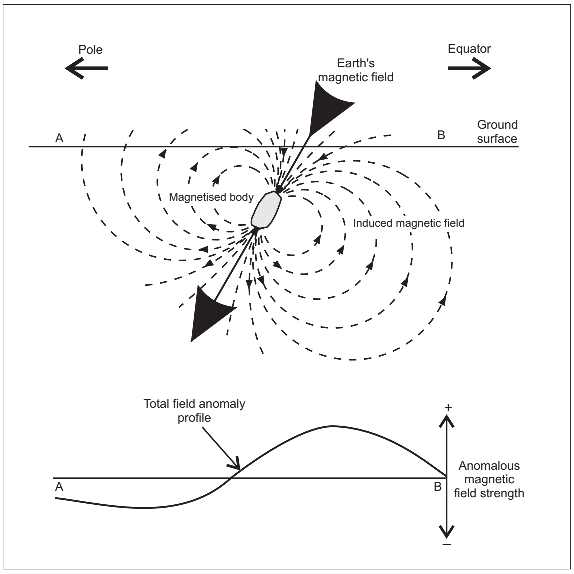
Applications

- Mapping underground storage tanks, buried drums, piles, reinforced concrete etc.
- Archaeological studies
- Mapping UneXploded Ordnance (UXO)
- Pile detection
- Detection of buried infill
- Mineral exploration (mapping buried dykes and ore bodies etc.)
- Locating landfills
- Detection of underground pipes and other utilities

Basic Theory

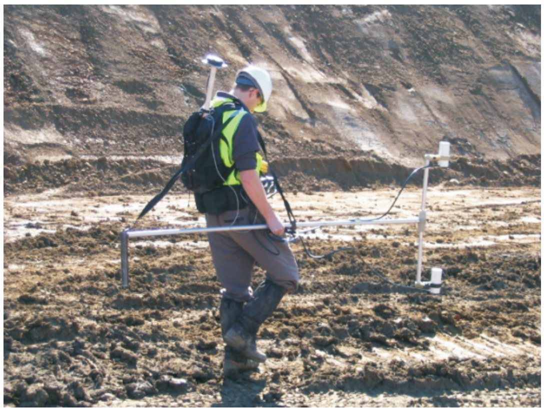
Magnetic surveying is a passive method based on the measurement of localised perturbations to the Earth's magnetic field caused by the presence of buried ferrous targets (e.g., pipes, cables, drums, military ordnance etc).

Gradiometry surveys, which determine the vertical gradient of the magnetic field, are increasingly common in environmental/engineering site investigations as they are particularly sensitive to the near-surface. Magnetic surveys can be conducted with a wide range of magnetometers, which can measure the amplitude of the field to within 0.01nT.



Data Presentation

Typically, data is collected in a systematic manner across a field site and then presented as a contoured map (nT or nT/m) which can be interpreted to produce a map of the subsurface. The amplitude and shape of an individual anomaly will reflect the dimensions, orientation and magnetic susceptibility of the buried target.



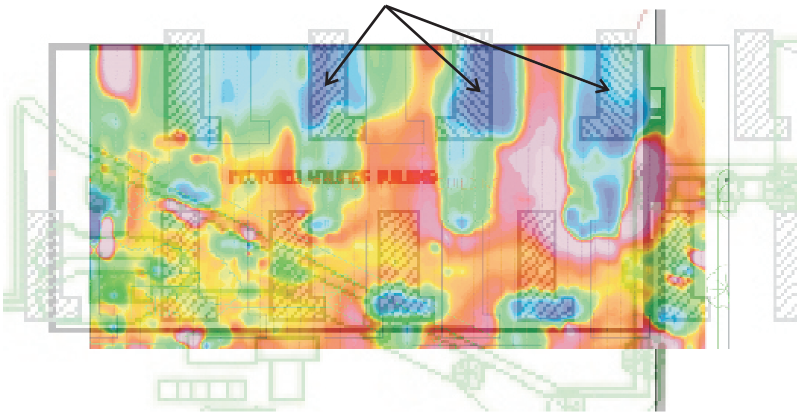
The collection of magnetic gradiometry data with dGPS location is an accurate and rapid means of data collection.

Data Example

Mapping underground air raid shelters

Magnetic surveying is useful in many situations, in particular to detect buried manmade metallic objects. In this example to the **right**, the survey has revealed the location of air raid shelters buried beneath the surface. The dark blue colours reflect the position of the shelters which also correlates to their position on the historic map.

Dark blue anomalies in magnetic data correlate with the location of buried air raid shelters on the historic map.



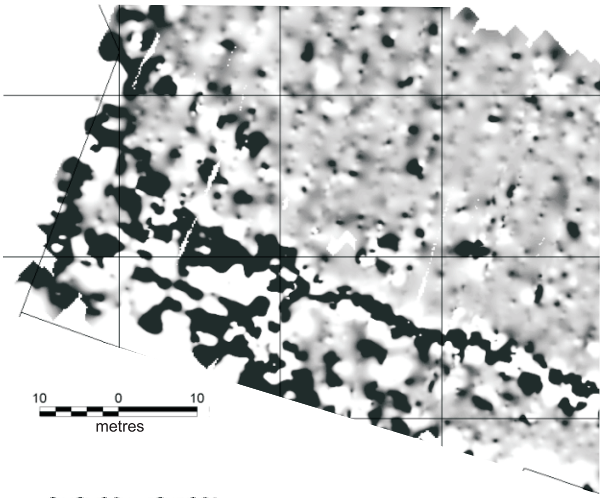
RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

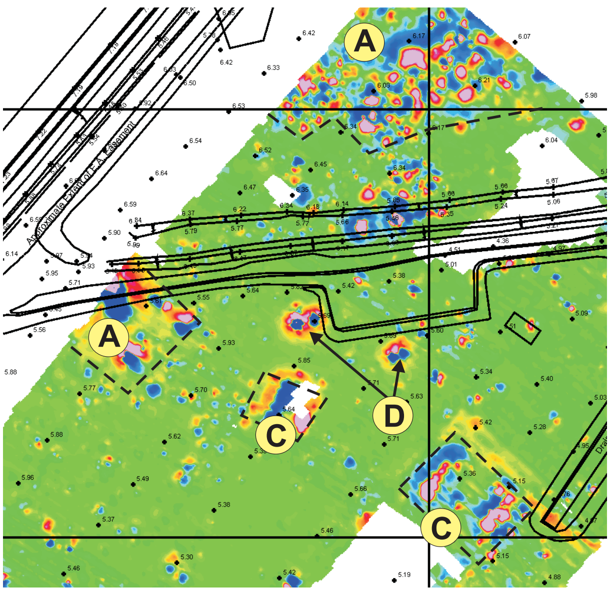
Magnetic Gradiometry

1 Magnetic anomaly locating historic ruins

In the example **right**, the data shows linear features such as buried ditches and walls together with isolated anomalies indicative of traces of human activity.



2 Magnetic anomalies locating buried foundations of former structures



Key features

- **A** Building foundation outline marked by high amplitude instrument response (dark blue and red colours)
- **B** Circular foundations of former cooling towers
- **C** Anomalies with regular geometric shapes indicative of buried manmade structures and other objects such as tanks
- **D** Small and discrete metal containing objects indicative of possible UXOs

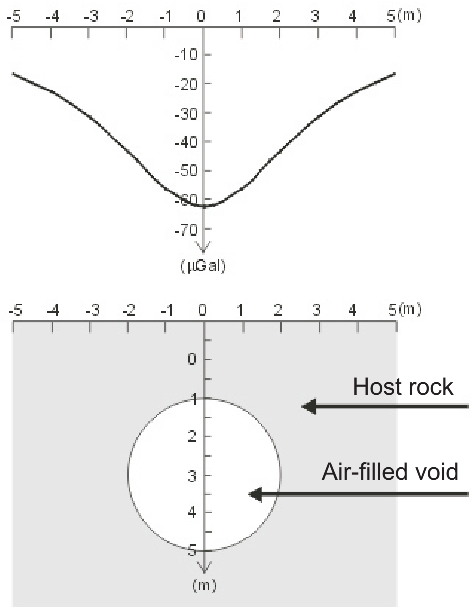
3 Magnetic anomalies locating buried obstructions and possible Unexploded Ordnance (UXOs)

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

MICROGRAVITY

Applications

- Cavity detection (e.g., bomb shelters, collapsed tunnels, old mineworkings, natural cave systems, sinkholes and other solution features etc)
- *Density determination*
- *Mineral exploration*
- *Locating buried tanks and reservoirs*



Basic Theory

Different subsurface materials have different bulk densities. Microgravity surveys seek to detect areas of contrasting or anomalous density by collecting surface measurements of the Earth's gravitational field.

A gravity meter is a highly sensitive instrument that measures the *acceleration* due to gravity. When positioned above a dense material it records the acceleration (g) as a relative high (a *positive gravity anomaly*). When positioned above a low density feature (e.g. an air filled cavity) a relative gravity low (or *negative gravity anomaly*) is recorded.

The diagram to the ***left*** *shows a negative gravity anomaly arising from an air-filled void (sphere) with a radius of 2m and a depth to centre of 3m.*

The density of the host rock = 2.5 Mg/m^3

Data Acquisition

Gravity anomalies arising from natural or manmade subsurface features such as voids and cavities are superimposed on much larger variations due to height, latitude and regional geological variations. In order to isolate the subtle signal of interest, careful data acquisition and processing is required.

For a successful survey it is imperative that the highest quality of data is collected. Micro-gravity surveys are particularly sensitive to the data collection methodology which must be carefully tailored to the site and environmental conditions, as well as being appropriate to the survey target.

Scintrex CG-5 Gravimeter

Data Processing and Presentation

Data recorded on site should include accurate position and height measurements for each recording station, and number of readings at each station from which to evaluate data quality, and a number of repeated recording stations at known time intervals from which to determine the repeatability of the results, and to correct for factors such as earth tides, instrument drift, and other time variant effects. Corrections are made for variations in latitude elevation, local terrain and large length-scale influences from regional geology. The result is a *residual microgravity map* from which both qualitative and quantitative interpretations may be derived.

An accurate micro-gravity anomaly map can be used to calculate the location, depth density contrast and therefore volume of the subsurface feature.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

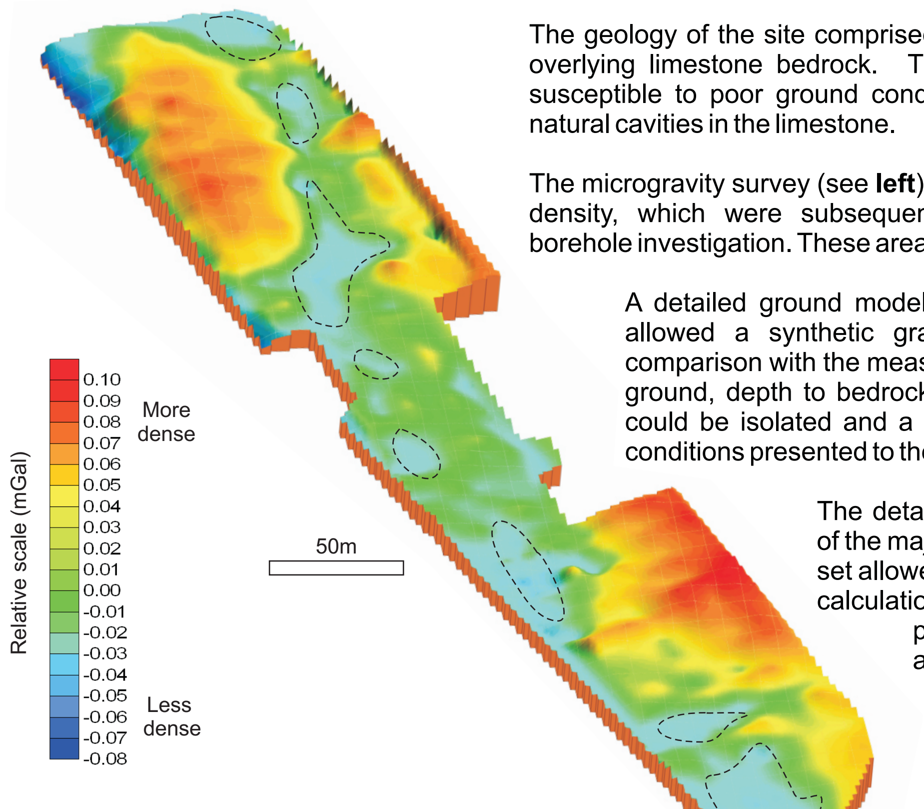
1 Microgravity survey along the proposed route of a bypass to detect voids & poorly consolidated ground

The geology of the site comprised approximately 14m of glacial till overlying limestone bedrock. The general area is known to be susceptible to poor ground conditions and voids associated with natural cavities in the limestone.

The microgravity survey (see **left**) identified areas of low subsurface density, which were subsequently targeted by a conventional borehole investigation. These areas are outlined in black on the map.

A detailed ground model constructed from borehole data allowed a synthetic gravity map to be calculated for comparison with the measured gravity. Poorly consolidated ground, depth to bedrock and surface topographic effects could be isolated and a clear interpretation of subsurface conditions presented to the project engineer.

The detailed borehole investigation of one of the major anomalies identified in this data set allowed, through some simple and quick calculations, a cause and effect link to be proven between ground conditions and the microgravity survey results.



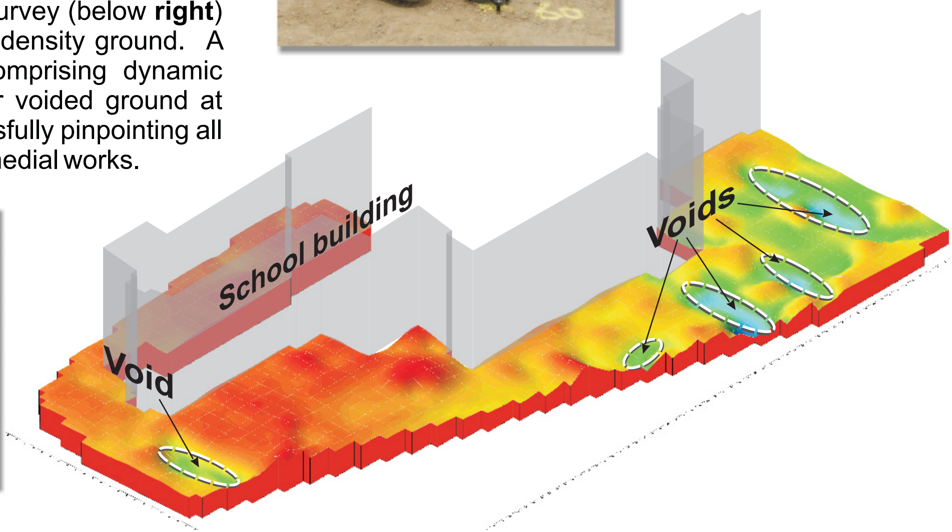
A Bouguer anomaly map of the survey area. Regions of poorly consolidated ground are outlined in black.

2 Microgravity survey over voids caused by solution features in the grounds of a school

The trigger event for the investigation was the formation of a small 1.3m deep hole in one corner of a school playground (see photo **below**). The hole had the characteristics of a small doline. The site is within an area known to be affected by natural voids within the chalk bedrock, which lies at about 7m depth.

The results of the microgravity survey (below **right**) show a number of areas of low density ground. A subsequent intrusive survey comprising dynamic probing confirmed very weak or voided ground at these locations therefore successfully pinpointing all the problem areas needed for remedial works.

Data is collected across a grid at ground surface level



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Applications

- *Stratigraphic mapping*
- *Estimation of depth to bedrock*
- *Estimation of depth to water table*
- *Predicting the rippability of specific rock types*
- *Locating sinkholes*
- *Landfill investigations*
- *Geotechnical investigations*

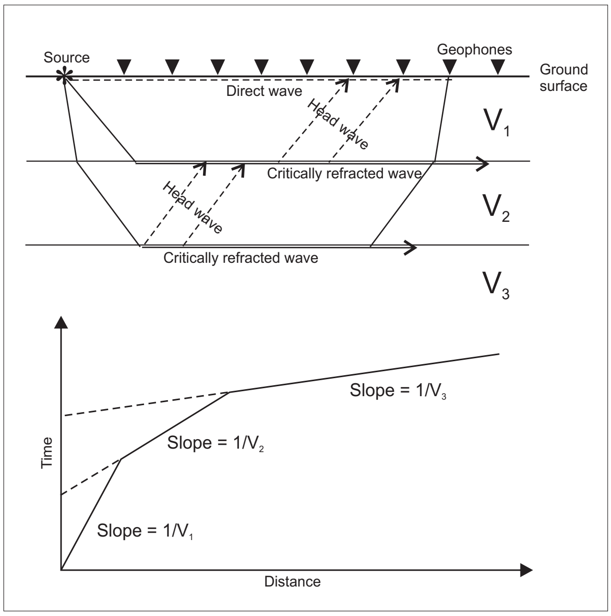
Equipment is computer controlled, portable and offers rapid data collection at relatively low cost.

Basic Theory

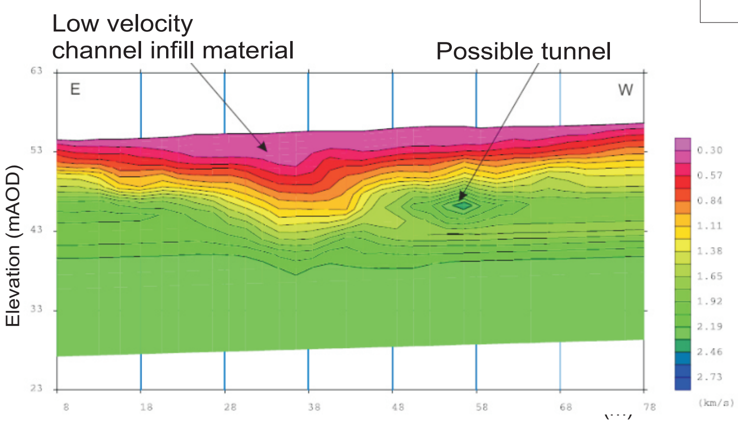
The seismic refraction technique is based on the refraction of seismic energy at the interfaces between subsurface/geological layers of different velocity. The seismic refraction method uses very similar equipment to seismic reflection, typically utilising geophones in an array, and a seismic source (shot).

The schematic diagram to the **right** illustrates the path of seismic waves propagating from a source at the surface. Some of the seismic energy travels along the surface in the form of a *direct wave.* However, when a seismic wave encounters an interface between two different soil or rock layers a portion of the energy is *reflected* and the remainder will propagate through the layer boundary at a *refracted* angle.

At a *critical angle* of incidence the wave is *critically refracted* and will travel parallel to the interface at the speed of the underlying layer. Energy from this critically refracted wave returns to the surface in the form of a *head wave*, which may arrive at the more distant geophones before the direct wave.



By picking the time of the first arrival of seismic energy at each geophone, a plot of travel-time against distance along the survey line can be generated. This type of graph is shown in the schematic to the **right**. The gradients of the lines in this type of plot are related to the seismic velocity of the subsurface layers. The final output is a velocity/depth profile for the refractors as shown **below**.



Seismic velocity cross-section showing the bedrock profile beneath a route of a proposed pipeline.

Another approach available for the interpretation of refraction data is the modelling and inversion of the acquired seismic velocities. By modelling the paths taken through the subsurface by the seismic energy, or 'ray tracing', the thickness of each layer in the model can be adjusted in an iterative manner until a solution is achieved. This produces a cross-sectional velocity model of the subsurface. Borehole records can further calibrate the data to provide levels of the subsurface layers across the survey line.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

Defining Geological Boundaries

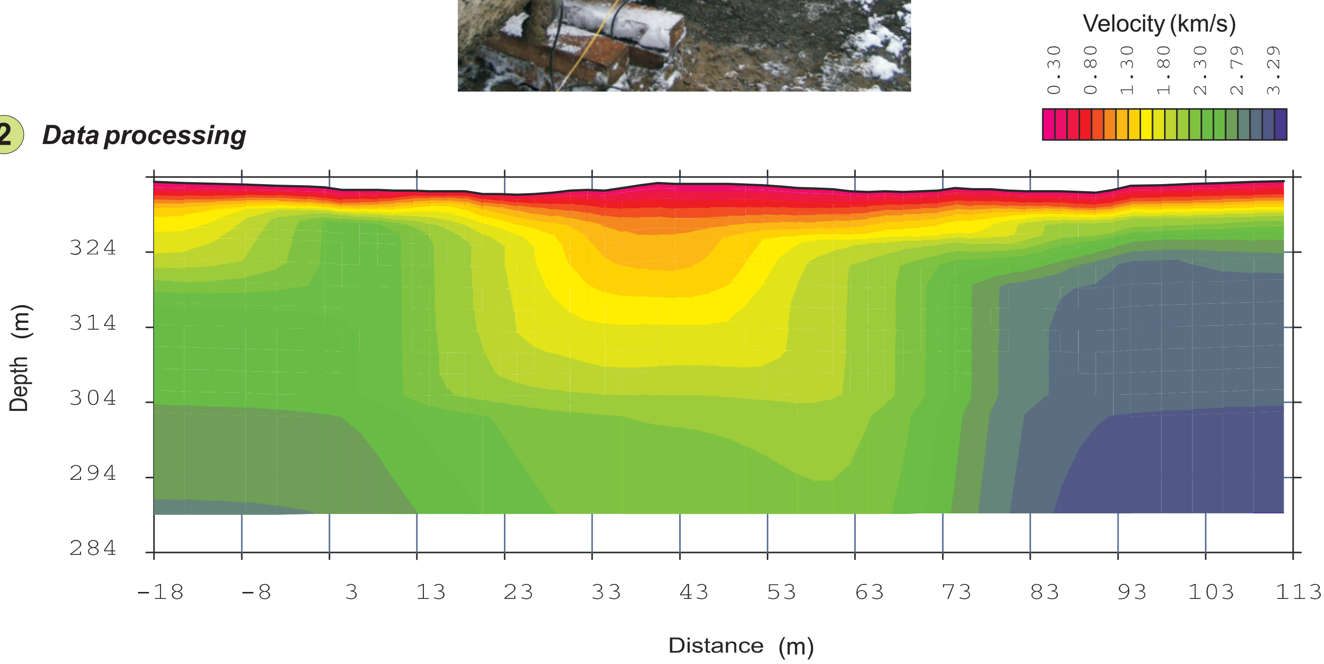
This seismic refraction survey locates the geological boundaries between layers. **Figure 1** shows the typical equipment used in this type of survey. **Figure 2** displays a colour cross section of the ground along the survey line reflecting the associated velocities.

A 4-layer model is suggested by the travel time data, with layer velocities of 0.3km/s, 0.6km/s, 1.4km/s and 2.1km/s. **Figure 3** shows the interpreted boundaries.

1 *Data acquisition stage*

Here an accelerated weight-drop seismic source was deployed as part of a winter-time survey in Georgia.

2 *Data processing*



3 *Data analysis*

Interpretation:

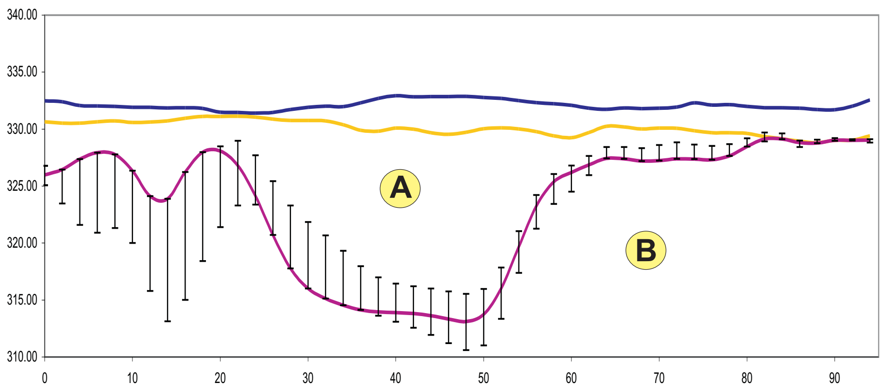
A Buried channel structure

B Competent bedrock

Topography

Top of gravel

Top of sandstone or siltstone



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

SEISMIC SURFACE WAVE GROUND STIFFNESS MEASUREMENT

Applications

- *Stratigraphic mapping*
- *Estimation of depth to bedrock including landfill base location*
- *Soil stiffness and ground improvement verification*
- *In-situ ground stiffness for geotechnical and civil engineering projects*

Basic Theory

Surface waves allow the measurement of the variation in soil stiffness with depth. A Surface wave (Rayleigh wave) has the property that ground motion becomes insignificant below a depth of one wavelength. By recording Rayleigh waves of different frequencies, and therefore wavelengths, the properties of the subsurface can be determined at different depths.

The characteristic velocity of the surface waves can be determined by measuring the signals received at a series of geophones. The data collected can be processed to produce values of maximum shear modulus (G_{max}) at different depths.

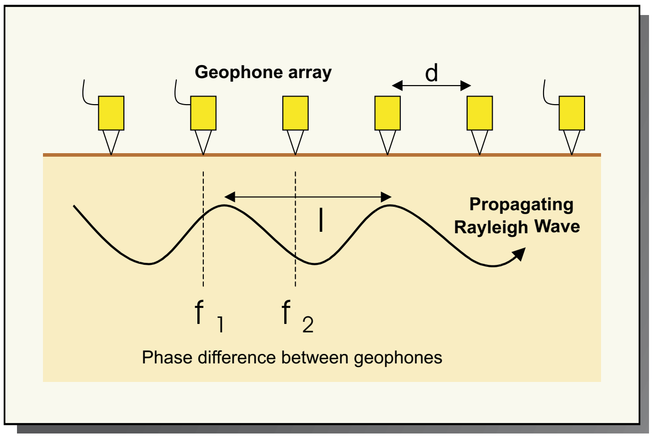
A stiffness profile can be generated for each adjacent pair of geophones. Profiles can be combined to produce cross-sectional images of the properties of the subsurface. Similarly, a number of adjacent cross-sections can be combined to produce a 3D image.

Data Acquisition

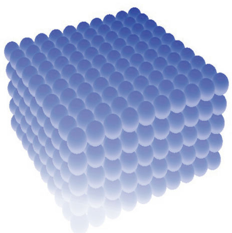
Two different methods of acquisition are available for the collection of surface wave data.

The Surface Wave Ground Stiffness (**SWGS**) system operates with either an active source (from vibration or hammer blow) or by utilising the seismic noise already present. This allows the technique to be used in active and noisy sites that would be unsuitable for other geophysical investigation techniques.

The Continuous Surface Wave (**CSW**) system employs a frequency controlled vibrator and geophones. The vibrator generates a Rayleigh wave at a specific frequency, within a range of stepped harmonic frequencies between 5 - 700 Hz. By collecting data over a range of frequencies, the effective depth of investigation can be varied.



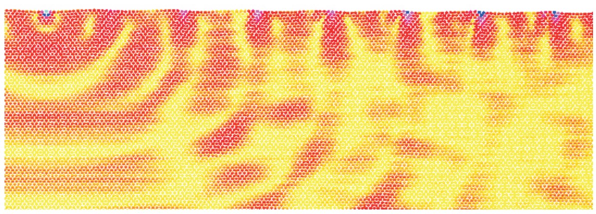
IMPROVED INTERPRETATION THROUGH MODELLING



RSK Geophysics have developed unique forward modelling software to aid interpretation of surface wave data. The implementation of this advanced technique provides significant improvements in the delineation and location of major boundaries in the subsurface, and also the accurate determination of ground stiffness variations with depth.

Currently RSK Geophysics offer forward modelling and interpretation of surface wave data as a service, either as part of a complete site investigation by RSK, or as a stand-alone service for site data collected by others. This methodology for the accurate interpretation of seismic data is unique to RSK Geophysics, and is part of our ongoing research and development activities.

The software is an implementation of our GeoDEM3D discrete element code. The advantages of this numerical scheme over traditional finite difference or finite element schemes is its ability to accurately model the motion of the ground surface, cope with large contrasts in elastic properties, and include voids, disaggregated zones, delamination and fractures.



Example model of Rayleigh surface waves propagating through a homogeneous subsurface. Colours indicate displacement

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Data Examples

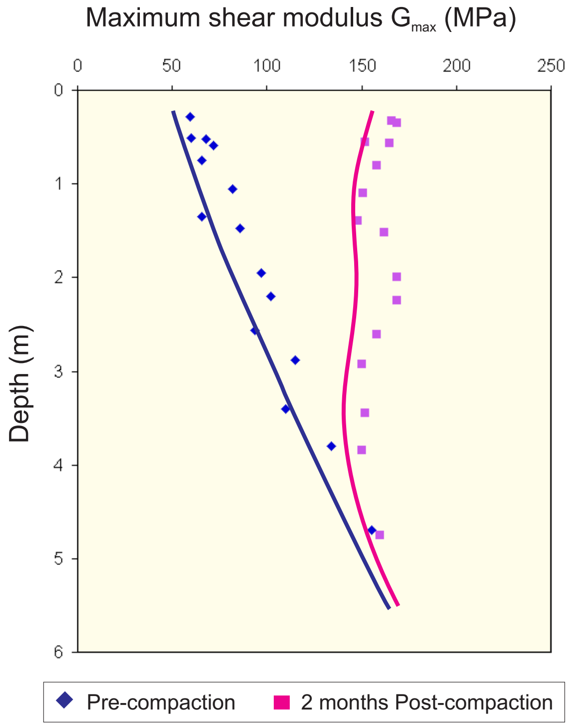
Ground improvement monitoring

A seismic surface wave ground stiffness profiling survey can determine the ground stiffness at depth.

In this example it was used to assess the change in stiffness after ground-improving compaction had been carried out, prior to the construction of a road.

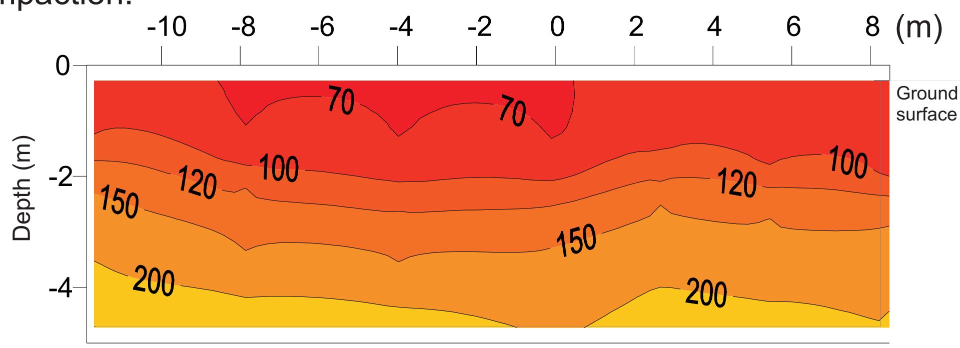
To the **right** is a graph displaying the maximum shear modulus of the ground versus depth. The results show a clear and measurable improvement after compaction.

The two diagrams **below** show a 2-dimensional stiffness profile from the same site, before and after ground improvement.

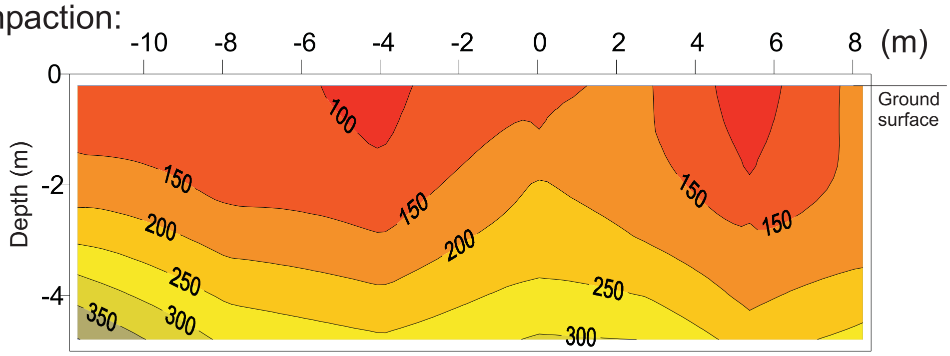


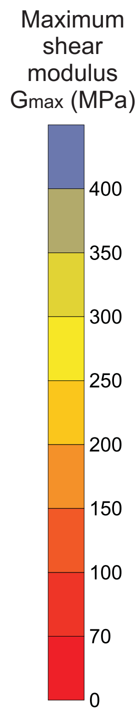
Surface wave testing can be carried out on soils of many types. No ground penetration is involved so stiffness values are not affected. This technique is a reliable means of measuring soil stiffness when other traditional methods (such as SPTs) may fail to produce results.

1 Pre-compaction:



2 Post-compaction:





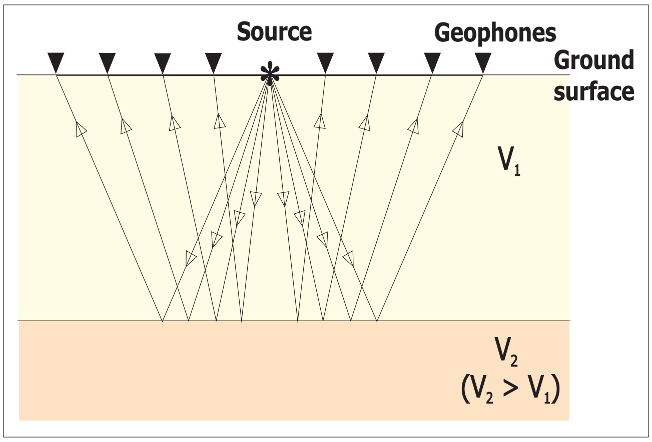
RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Applications

- *Stratigraphic mapping*
- *Geological mapping*
- *Estimation of depth to bedrock*

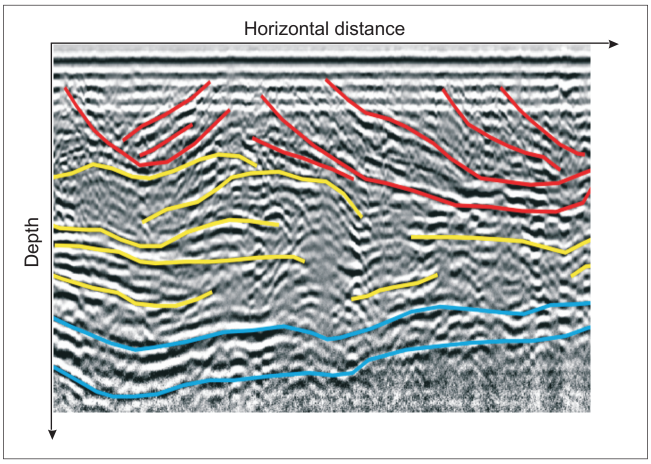
Basic Theory

Seismic reflection can identify variations in material type with depth and horizontal position. The technique images the interfaces between materials with contrasting acoustic/seismic velocities. This translates to differences in the elastic properties and/or density of the material. Mapping these contrasts across an area can identify the extent and depth to specific layers or interfaces of interest.



The seismic reflection method is based on the propagation of seismic waves through the subsurface, and their reflection at interfaces across which there is a sufficient contrast in velocity. This is illustrated by the schematic diagram to the **right**. The seismic energy is generated at the surface by an impact or an explosion.

Seismic waves arriving at positions along the survey line are recorded by geophones. Modern geophones consist of a coil wound on a magnetic core, spring suspended in the field of a permanent magnet. If the coils move relative to the magnet, a voltage is induced in an external circuit. The strength of this voltage is related to the strength of the oscillation. Each geophone is connected to the seismometer which records the arrival time and magnitude of the induced voltages (oscillations) at each geophone.



Seismic reflection surveys are primarily used to map subsurface geological boundaries and stratigraphic variations. A key advantage of the technique is that, after processing, it can provide a cross-sectional image of the subsurface.

The **above** image shows stratigraphically interpreted data. The different colours have been used to delineate the different geological units. Each of the coloured lines indicates a geological boundary. The high resolution of the cross-sectional data allows details of the internal structure of this alluvial channel deposit to be mapped.

*Seismic energy is provided by a shot on the ground surface. For shallow seismic surveys this typically involves a hammer and plate (shown **left**), a weight drop or an explosive charge. The greater the energy that the seismic source imparts, the deeper below the surface the survey will image.*

RSK

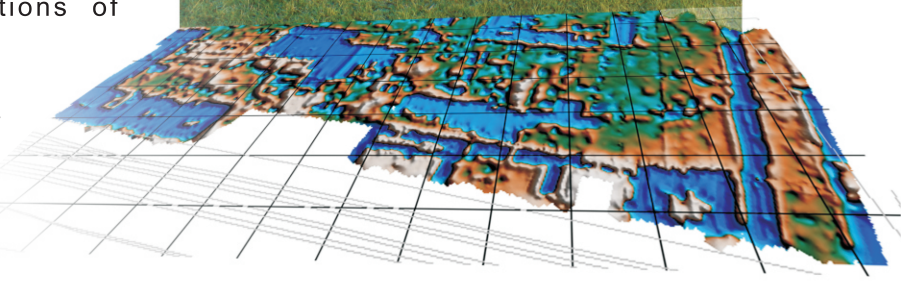
GEOPHYSICAL APPLICATIONS

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical Techniques Available

- *Magnetic Gradiometry*
- *Ground Penetrating Radar (GPR)*
- *Electrical Resistivity*
- *Electromagnetic Mapping (EM)*

Geophysics can aid archaeological investigations immensely. The use of the above techniques can provide rapid coverage of a site where archaeological remains are believed to exist. RSK has qualified and experienced geophysical professionals who use the latest instrumentation and software to provide a rapid and reliable interpretation. Our surveys are conducted with the appropriate methods and practices in accordance with guidance set out by the Institute of Field Archaeologists and English Heritage. Our data can aid greatly in targeting archaeological digs by supplying accurate data from which initial interpretations of archaeological remains can be made.



Geophysics can also play an important role in the detection of human remains and other buried objects as part of forensic investigations.

Survey examples

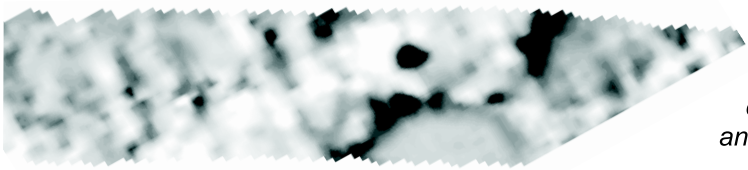
Archaeological Evaluation

In the example **below** , a magnetometer survey was conducted over a large proposed wind farm site. The survey was undertaken so that the most sensitive archaeological areas could be avoided. Due to the scale of the site, preliminary detailed surveys were conducted around each turbine position and along each construction route. Areas of particular archaeological potential were identified for targeted follow-up surveys.

Locating Historic Ruins

In the example **above** an integrated geophysical survey comprising earth resistance (photo above) and EM (coloured map above) was conducted on the site of a Medieval Abbey to determine the presence of buried foundations, walls or other remains of former standing structures of archaeological interest at the site.

This information was used by the client to target an archaeological dig. As a result of the geophysical investigation the time and expense of a large system of exploratory trenches was avoided.



Magnetometer survey data recorded along one of the tracks at the site showing circular anomalies to right (note: width of track is 25m)

Large areas such as at this site can be rapidly covered with non-intrusive, mobile data collection such as the GEEP with twin mounted G858 sensors coupled with integral GPS for positioning.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Characterisation of a Roman City

In this example to the **right** an array of Geometrics G823 caesium vapour magnetometers mounted on a mobile platform were used to collect total field data over a large Roman city site. The site had remained relatively undisturbed since abandonment with no evidence of the archaeology on the surface.

The advantages of using such instrumentation in archaeo-magnetic surveying include a high data sampling rate to provide a high spatial resolution, and the use of DGPS which achieves reliable location measurements to sub-meter accuracies.

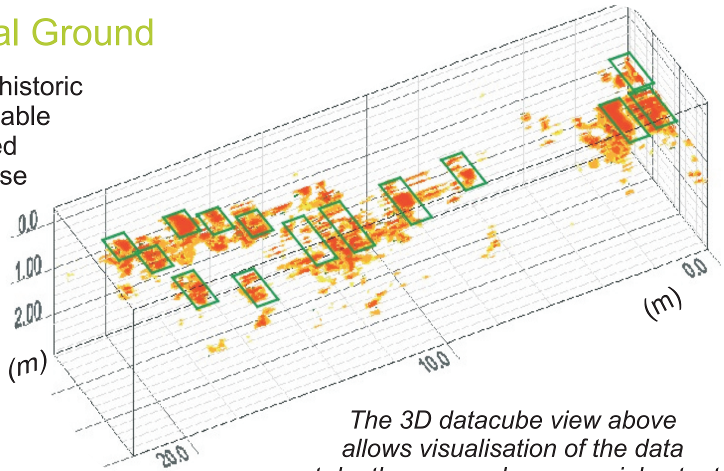
Linear features such as former ditches together with trenches and walls comprised of burnt material such as bricks give rise to clear magnetic anomalies, which can be targeted for further investigation.

Repeat surveys can also be undertaken to monitor the amount plough damage over time.

Image courtesy of Department of Geology, University of Leicester GRAMS Project

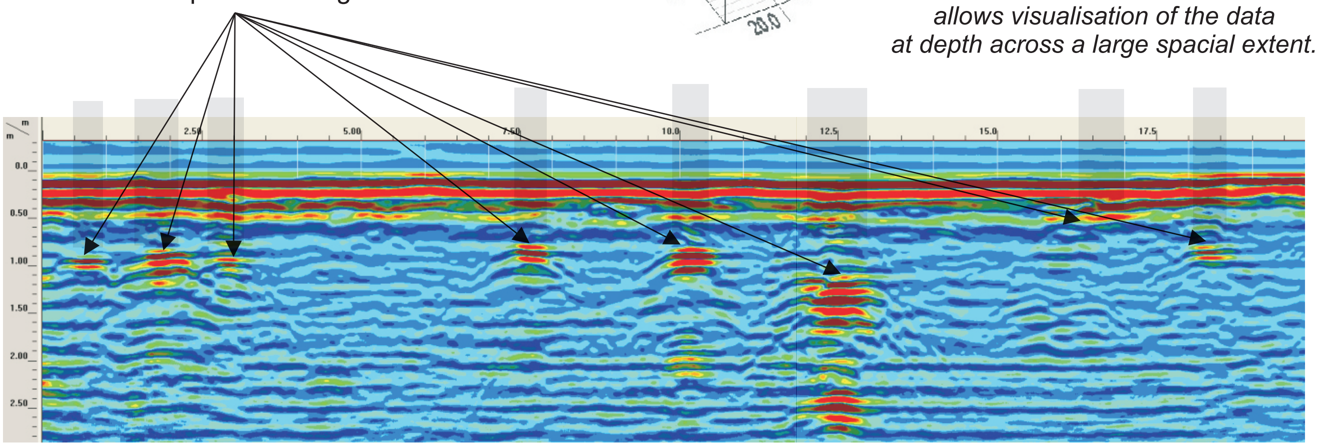
Locating Graves over a Historic Burial Ground

Ground Penetrating Radar (GPR) was used over a historic burial ground. The technique offers a quick and reliable means of detecting buried objects such as unmarked clandestine graves. The use of GPR is ideal because it is non-destructive therefore preserving the cemetery and the graves. As shown **below** the reflection anomalies recorded in the data are interpreted to provide depth and location.



The 3D datacube view above allows visualisation of the data at depth across a large spacial extent.

Reflection anomalies consistent with the presence of graves



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

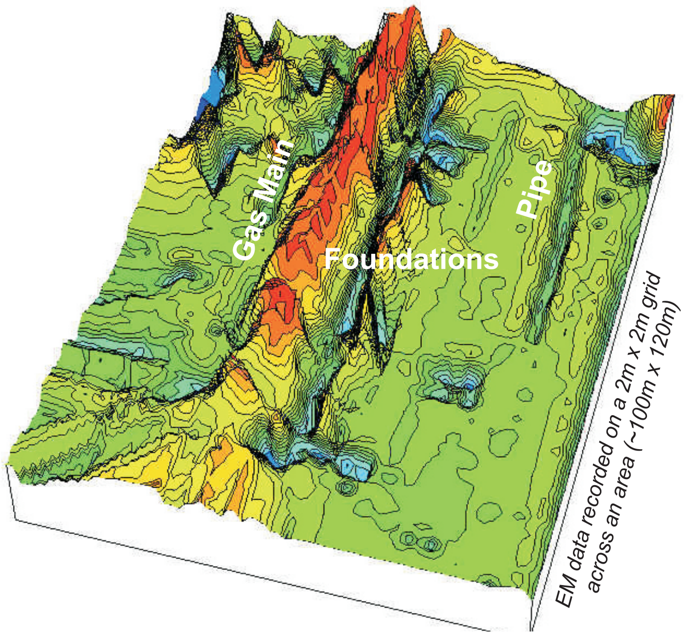
BROWNFIELD SITES

Geophysical Techniques Available

- Ground Penetrating Radar (GPR)
- EM Ground Conductivity
- Electrical Resistivity Imaging
- Magnetics Surveying
- Microgravity
- Seismic Refraction and Reflection
- Seismic Surface Wave
- Self Potential (SP)
- Induced Polarisation

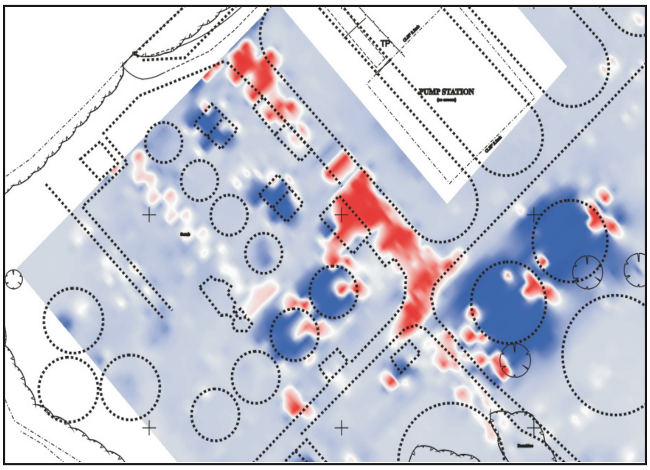
The UK Government has set a target of 60% for all new developments to be built on brownfield sites. These sites frequently contain poor ground conditions and a plethora of unknown underground obstacles which may cause costly engineering and environmental issues and delays to the developer.

Geophysical techniques can play an important role in reducing costs and risks by providing useful tools for the preliminary investigation of brownfield sites, with rapid site reconnaissance surveys being utilised to characterise subsurface features prior to any intrusive investigation. Rapid data collection rates (up to 2 hectares per day), and specialist data processing techniques, mean that preliminary results can usually be offered soon after the completion of a survey, providing an invaluable tool in the engineer's armoury.



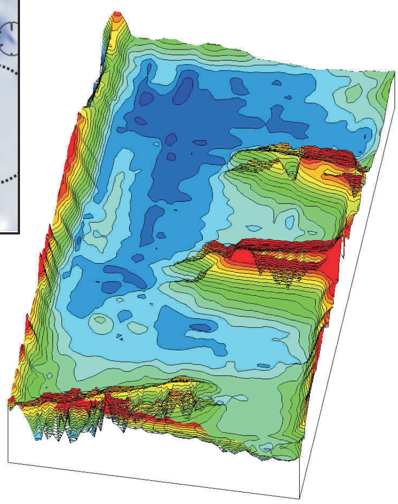
EM data recorded on a 2m x 2m grid across an area (~100m x 120m)

In the example **above**, electromagnetic mapping was employed to locate underground storage tanks, a large gas main and other obstacles prior to intrusive geo-environmental investigation of a former gas works, now used as a car park.

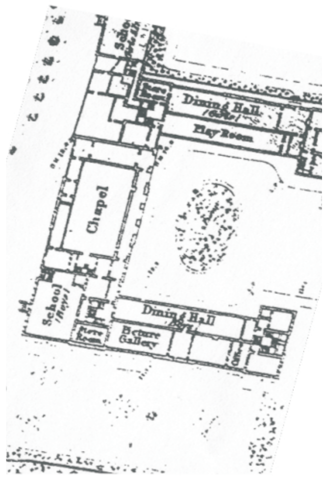


The data **above** was recorded over a former industrial site that was proposed for residential development. A Phase 1 desk study of the site revealed the possibility of buried infrastructure, and hence possible sources of contamination. However, there was no logical distribution of the features that remain in-situ and those that have been excavated.

The resulting electromagnetic survey of the site and correlation with historical maps has clearly identified which structures remain in-situ, and which structures have been removed. This provided invaluable information for the redevelopment of the site, from both an environmental and geotechnical viewpoint.



EM data recorded on a 2m x 2m grid across an area (60m x 120m)



Historical map (circa 1850's) showing layout of former hospital

The example data **above** presents a survey conducted on an artificial sports pitch that suffered from drainage problems. An EM survey was employed, and successfully located brick and masonry foundations from a former central London hospital. Although the hospital was demolished in the mid 1900's, it is thought that the poor drainage is a result of the in-situ foundations.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

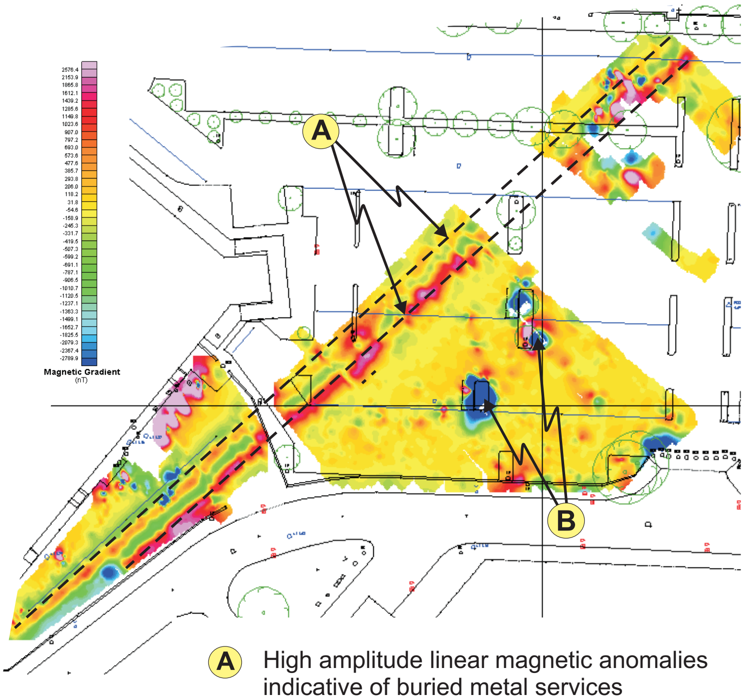
Former Land Use Determination

As part of geoenvironmental site investigations, determining the former landuse of a site can provide a useful base for determining the likely sources and locations of contamination and/or obstructions prior to re-development of a site. Historical maps can provide an insight into this, but do not reveal any information on whether the structures are still present or not.

Data Examples

Locating metal pipes using Magnetic Gradiometry

In this example to the **right**, the client was unaware of the location of two deep metal pipelines running beneath a supermarket car park. Geophysics was used to locate the pipelines so the proposed building extension could be built around them.

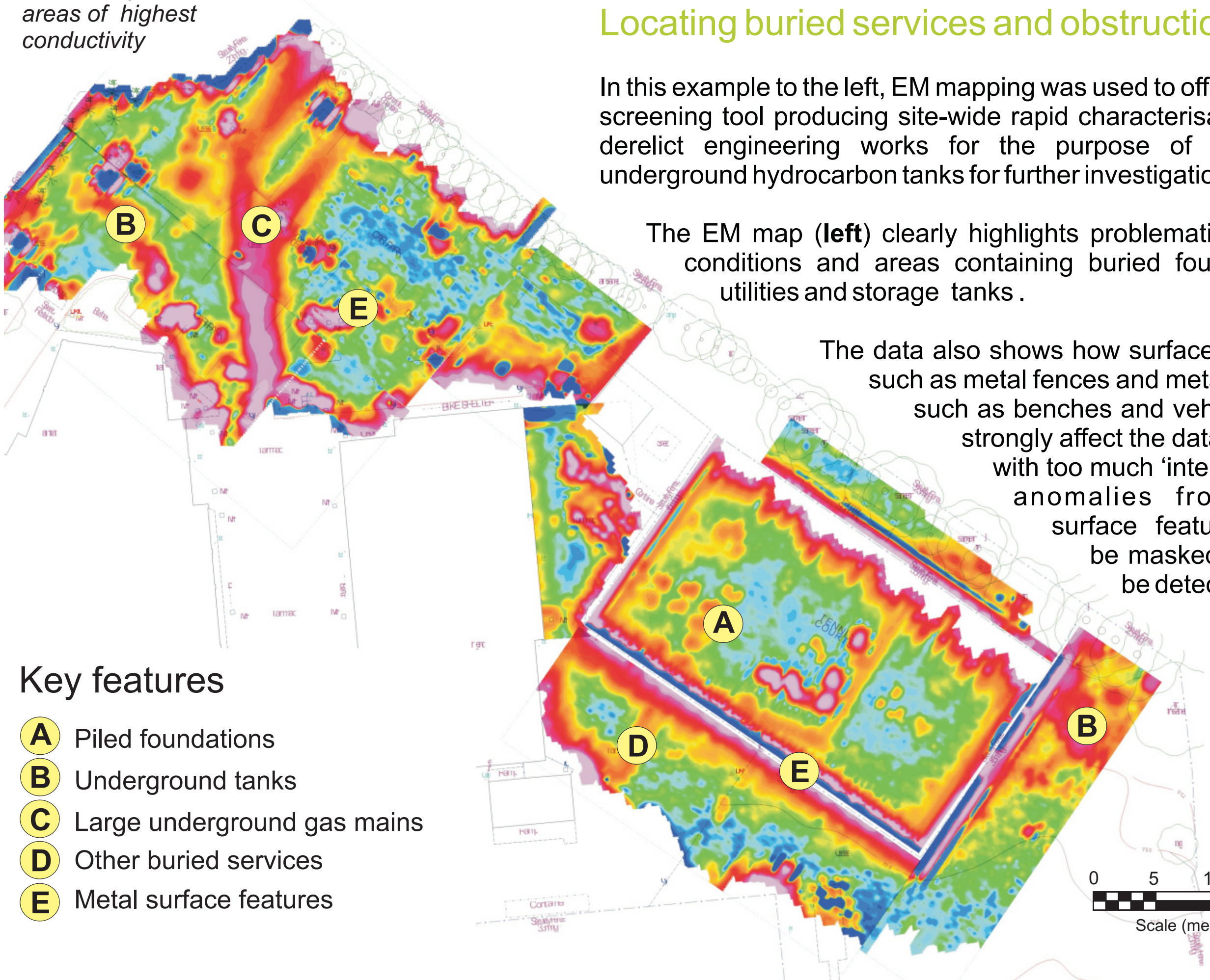


(A) High amplitude linear magnetic anomalies indicative of buried metal services

(B) High amplitude discrete anomalies caused by surface trolley parks

- - - - INFERRED PIPELINE ROUTE

Reds and pinks show areas of highest conductivity



Locating buried services and obstructions

In this example to the left, EM mapping was used to offer a quick screening tool producing site-wide rapid characterisation of a derelict engineering works for the purpose of detecting underground hydrocarbon tanks for further investigation.

The EM map (**left**) clearly highlights problematic ground conditions and areas containing buried foundations, utilities and storage tanks .

The data also shows how surface features such as metal fences and metal objects such as benches and vehicles can strongly affect the data. In sites with too much 'interference', anomalies from sub-surface features may be masked and not be detected.

Key features

- (A) Piled foundations
- (B) Underground tanks
- (C) Large underground gas mains
- (D) Other buried services
- (E) Metal surface features

LANDFILL SITES

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical Techniques Available

- ☑ *Electrical Resistivity*
- ☑ *Electromagnetic Mapping (EM)*
- ☑ *Ground Penetrating Radar (GPR)*
- ☑ *Magnetic Gradiometry*
- ☑ *Seismic Refraction*

The UK has around 8,000 existing and closed landfill sites, many of which are not engineered and are unprotected to the environment. Even new landfill sites based on the principal of engineered containment are at risk of leachate leaking through the landfill base and sides to cause contamination of surrounding land and groundwater pollution, with potentially serious consequences to drinking water resources.

Geophysical surveys are often the only practical method of investigation on landfills as they do not involve penetration of the cap or liner and exposure of any wastes.

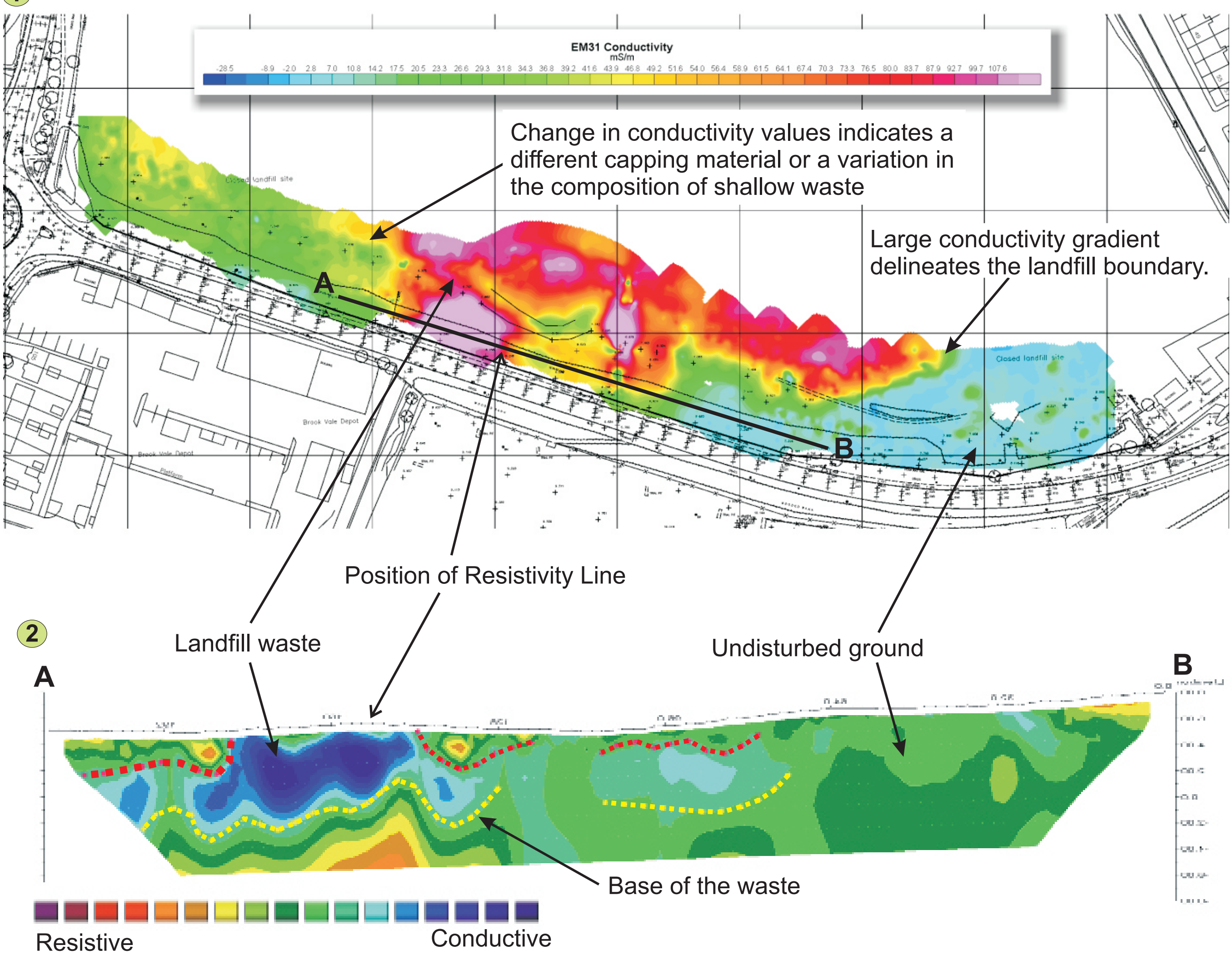
Geophysics can be used in a wide range of landfill applications from determining the location and geometry of old landfills, through to aiding the investigation of groundwater pollution and migration pathways in the subsurface, essential for demonstrating compliance with IPPC requirements.

Survey examples

Defining Landfill Boundary and Depth of Waste

Figure (1) shows the results from the EM-31 marking the Landfill boundaries.
Figure (2) shows a resistivity line marking the depth of the waste.

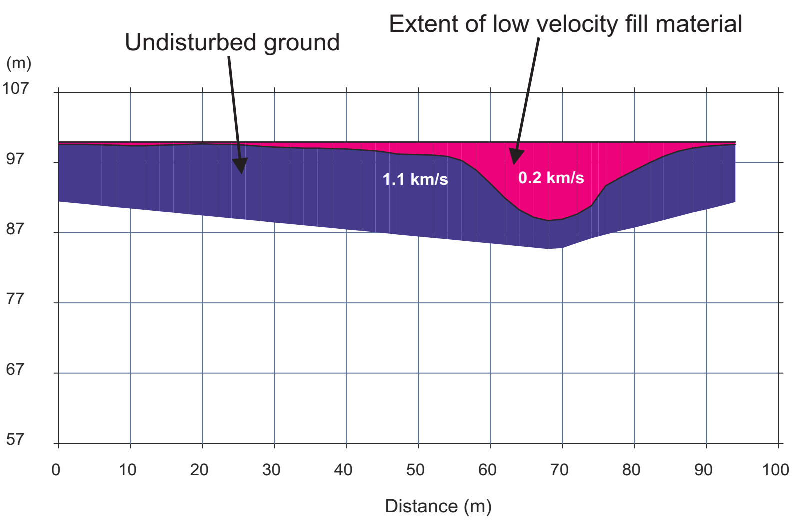
(1)



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

LANDFILL SITES

A Seismic refraction results



Defining Landfill Boundaries with Integrated Data Sets

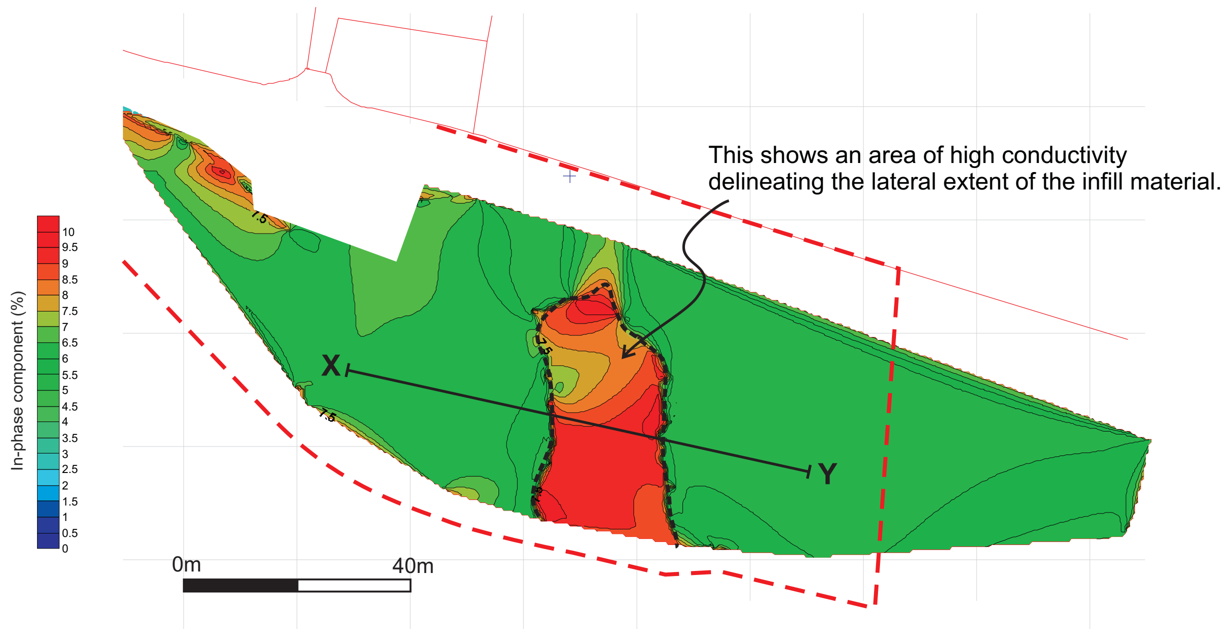
By integrating data sets from different techniques a more accurate determination of landfill characteristics can be achieved than from a single technique alone:

A Seismic refraction identifies the boundary between the waste and bedrock.

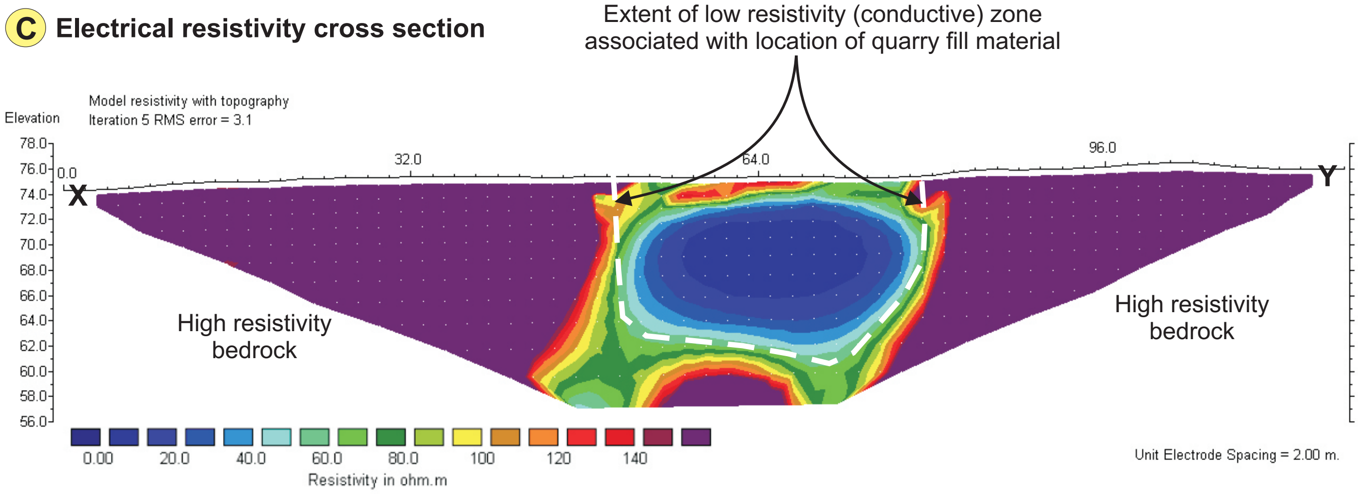
B Surface mapping of subsurface conductivity defines the landfill periphery.

C Electrical resistivity imaging provides a cross section of the landfill defining the vertical extent of the waste and it can also identify any leachate beneath the landfill liner and in the surrounding ground.

B EM Conductivity Data



C Electrical resistivity cross section



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

CONTAMINATED LAND

Geophysical Techniques Available

- *Electrical Resistivity*
- *Electromagnetic Mapping (EM)*
- *Ground Penetrating Radar (GPR)*
- *Self Potential*
- *Magnetic Gradiometry*

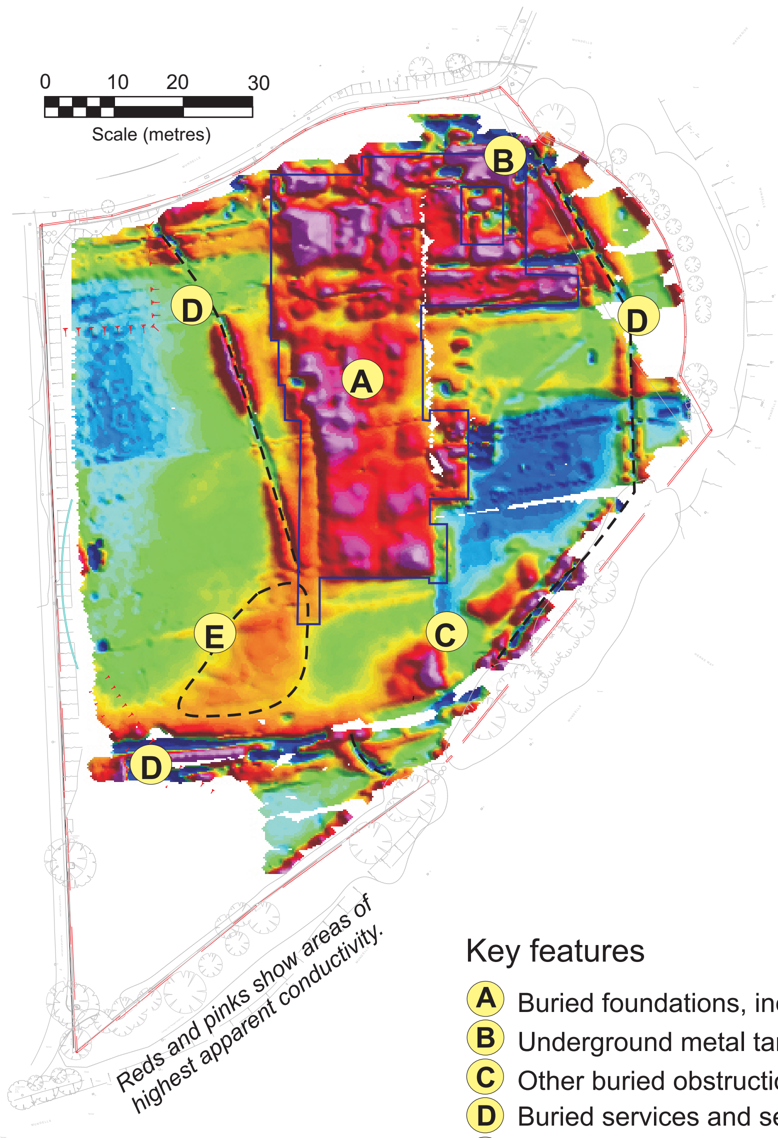
As part of the Part IIA regime, all potentially contaminated sites in the UK need to be investigated.

The use of geophysical techniques is an invaluable tool in the investigation of contaminated sites and can be used as rapid site reconnaissance tool without the exposure of site personnel to the hazards of contaminated sites.

Geophysical techniques can form an integral part of the site investigation at all stages, from the preliminary Phase 1 investigation to highlight areas of potential contamination to target conventional intrusives; to the main Phase 2 investigation to augment and confirm borehole information to improve the Conceptual Site Model; through to the latter phases such as the monitoring and validation of remedial measures.

Survey examples

Identifying land use with electromagnetics



Site characterisation

Site characterisation is the first and most important step in contaminated land investigation. Features missed by conventional site investigation techniques can be identified in the initial stages by geophysics. A comprehensive understanding of the ground conditions and contamination issues at a site is vital to the process of producing an accurate and cost-effective remedial strategy. Where risk assessment requires total site coverage to trace all possible sources and pathways of contamination the use of geophysics has to be considered.

In this example to the **left**, EM ground conductivity was used to offer a quick screening tool producing site-wide rapid characterisation of a site which had been demolished entirely to ground level.

The results clearly highlight potential sources of contamination such as tanks and utilities, subsurface pathways like buried foundations of former structures and also an area of possible contamination where a broken pipe had leaked to the surrounding ground. This information was used to inform the subsequent intrusive investigation and dictate the best location for targeted trial pits and boreholes.

Key features

- (A) Buried foundations, including pile locations
- (B) Underground metal tank
- (C) Other buried obstructions
- (D) Buried services and sewers
- (E) Potential pollution plume

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

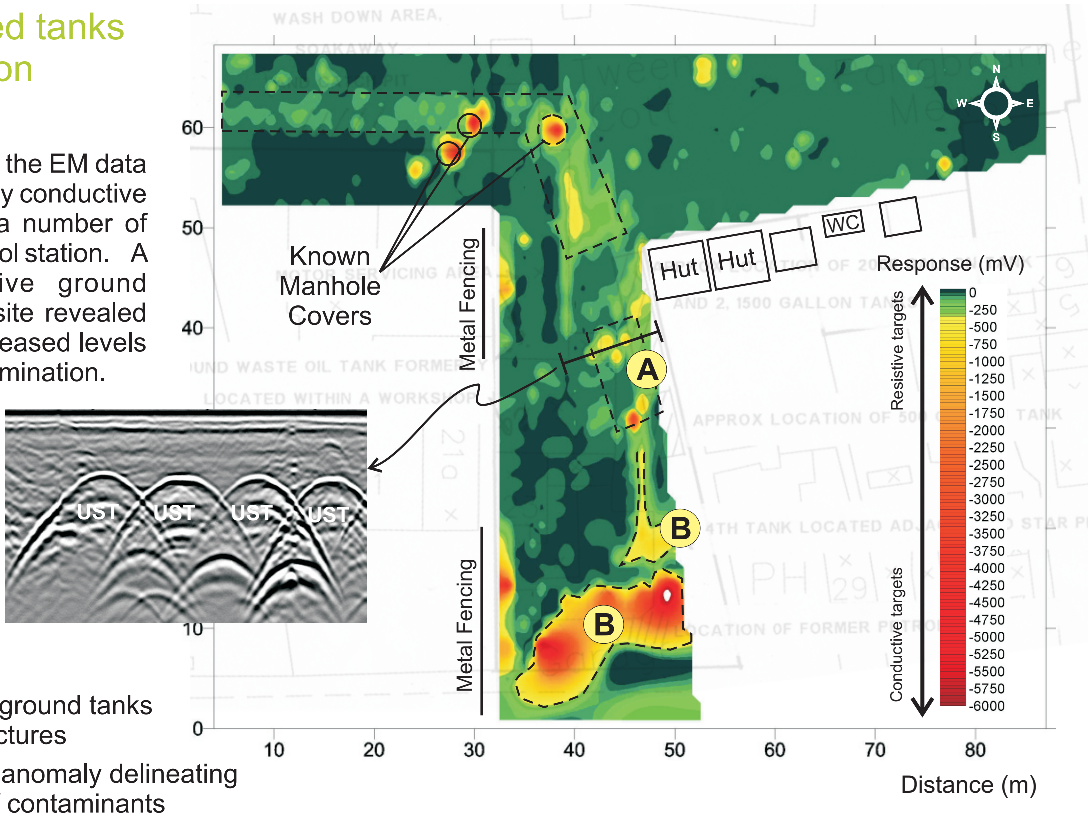
Mapping contamination

Mapping variations in the electrical conductivity of the subsurface across a site can highlight anomalously conductive targets such as metallic tanks, pipework and also any ground contamination.

Although water is generally not a good conductor of electricity, groundwater - especially contaminated groundwater - contains dissolved compounds and ions that greatly enhance its ability to conduct electricity.

Detecting buried tanks and hydrocarbon contamination

In the example **right**, the EM data show an area of highly conductive ground adjacent to a number of tanks at a former petrol station. A subsequent intrusive ground investigation of the site revealed the presence of increased levels of hydrocarbon contamination.



Broad hyperbolic reflectors in the radar data can confirm the presence of USTs

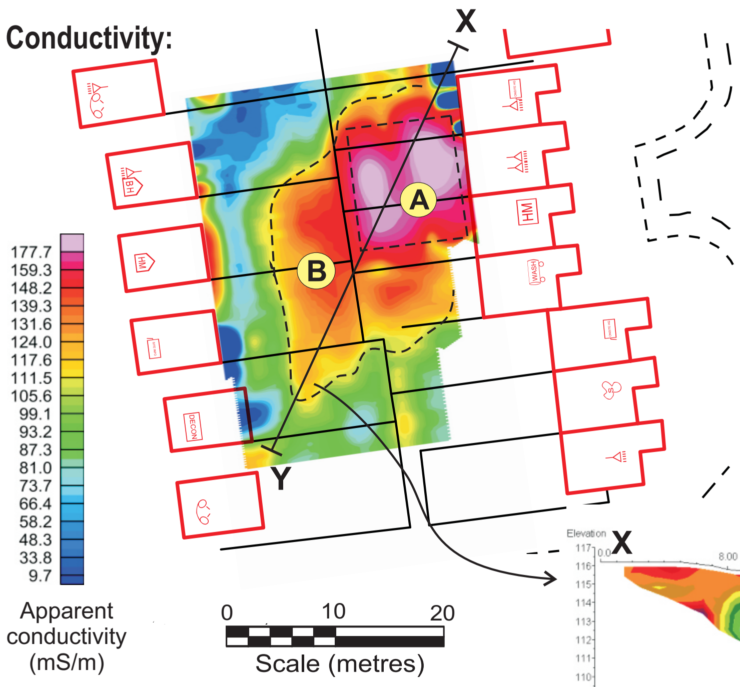
A Location of underground tanks or reinforced structures

B High conductivity anomaly delineating possible plume of contaminants

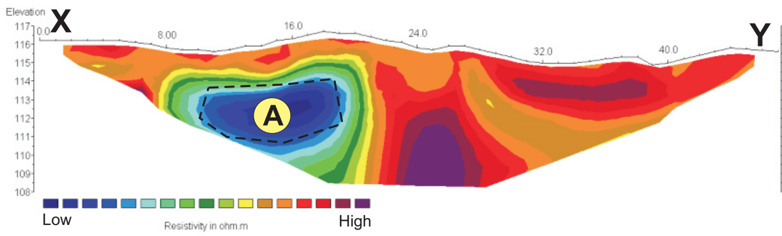
Locating pollution plumes with integrated geophysical techniques

In this example to the **left**, EM conductivity and resistivity imaging were used to detect the presence of possible buried tanks and contamination present in the ground at a former chemical works. Prior to the geophysical survey, high concentrations of DNAPL carbon disulphide were recorded in soil samples taken from the ground. The EM and resistivity both successfully located a buried reinforced structure which has likely led to the pooling of the DNAPL in the vicinity. The results of the geophysics aided the subsequent risk assessment and remediation of the site in order to render it fit for purpose.

Conductivity:



Resistivity:



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical Techniques Available

- *Electrical Resistivity Imaging*
- *Electromagnetic Mapping (EM)*
- *Ground Penetrating Radar (GPR)*
- *Microgravity*
- *Magnetometry*
- *Seismic Refraction and Reflection*
- *Surface Wave Ground Stiffness*

Some of the earliest applications of geophysics were to determine the geological structure of the subsurface. Changes in subsurface lithology often represent variations in physical properties. These variations can be detected by geophysical methods. Our experienced staff are then able to interpret these results in terms of the local geology, allowing maps of the survey area to be produced.

In situations where the geology or depth to bedrock is poorly constrained, geophysics can provide valuable information. Natural voids, sedimentary structures, or fractures and faults can cause significant engineering problems if they remain undetected.

Survey examples

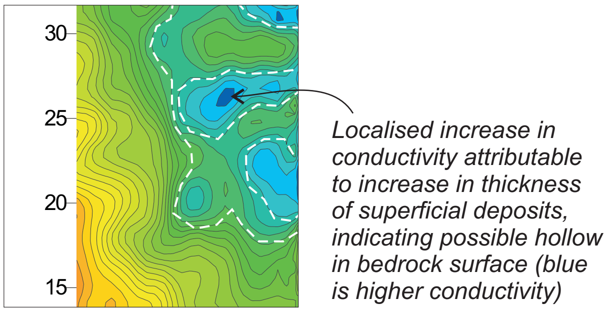
Stratigraphic Mapping

Geophysical surveying across a site can highlight variations in sediment thickness and bedrock depth. Detailed mapping of such variations can target intrusive testing of likely solution features or assist in the design of containment walls around contaminated sites.

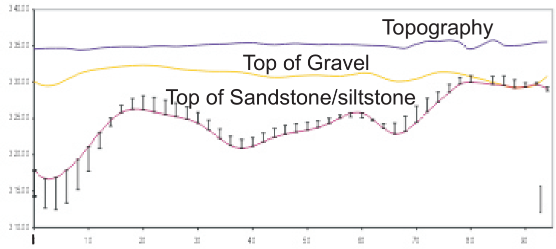
To the **right** and **below** is a comparison of a seismic interpretation and a resistivity pseudo-section identifying a sandstone/siltstone boundary. Note the similarity between the two data sets in tracing the boundary.

EM conductivity (**upper right**) can also be useful to locate a variation in ground conditions in the shallow sub-surface.

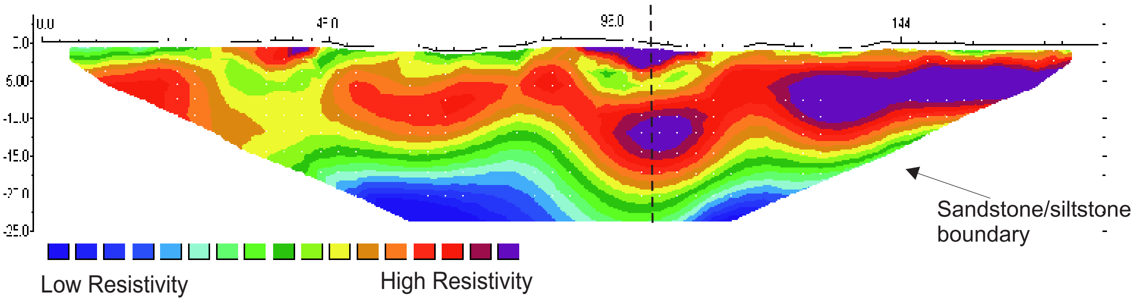
Conductivity:



Seismic interpretation:



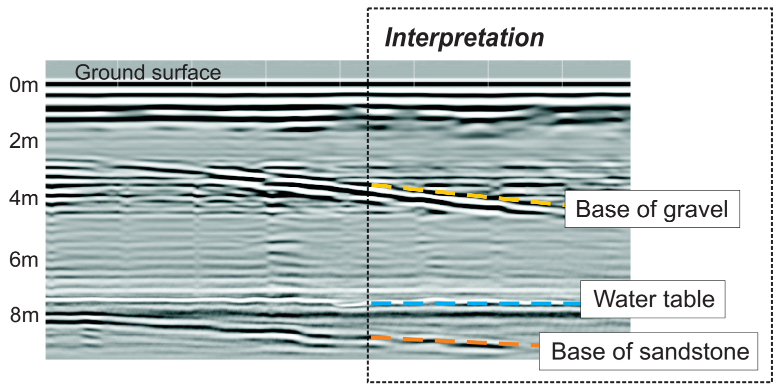
Resistivity:



Imaging stratigraphy with GPR

Low frequency GPR surveying can penetrate the ground to several tens of meters and image significant geological structures including stratigraphy and the presence of voids.

In the example to the **right** the 100 MHz GPR has been used to identify and locate stratigraphic layers in the bedrock.

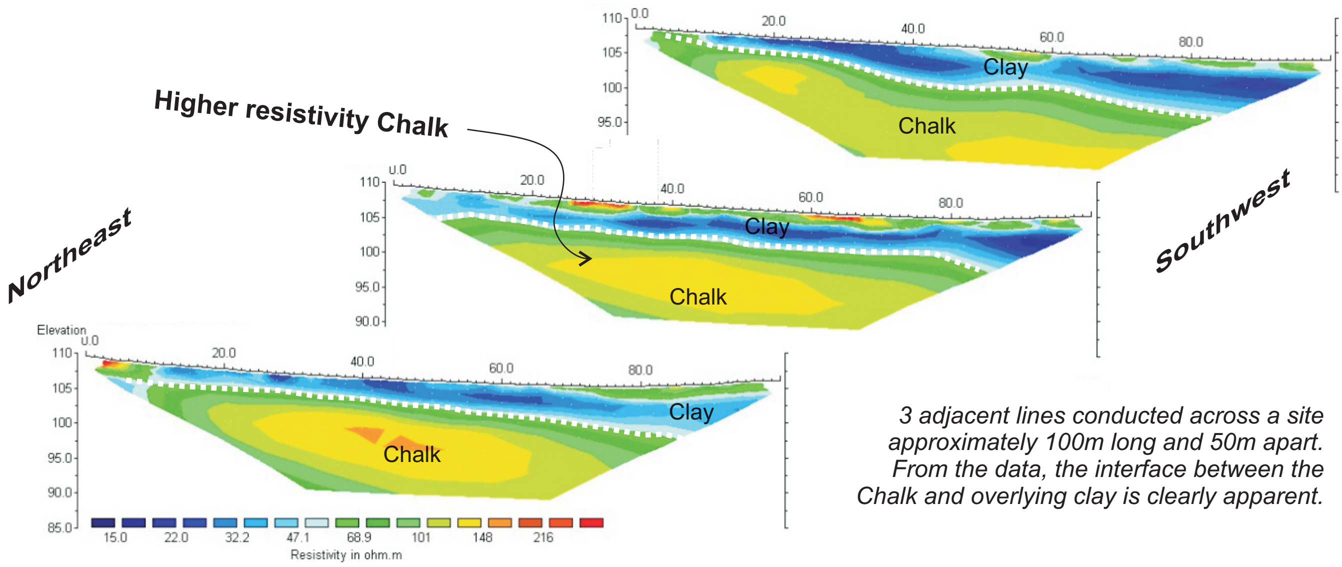


RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

GEOLOGY

Mapping Depth to Bedrock with Resistivity Imaging

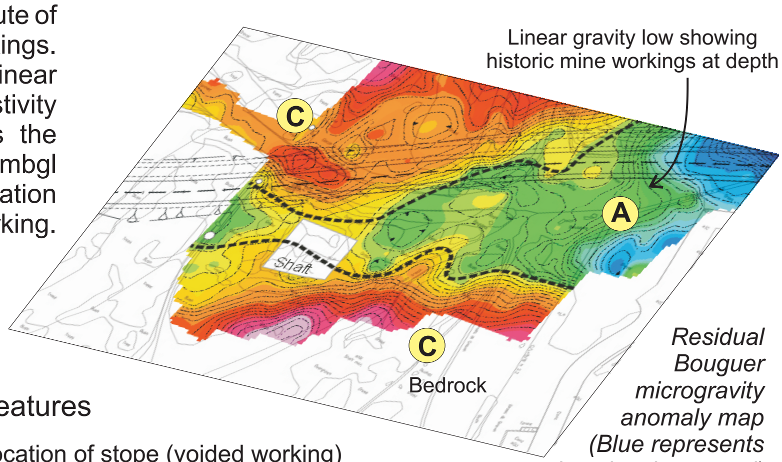
In the example **below**, a series of electrical resistivity imaging surveys were conducted across a 4Ha site proposed for a housing development. Combined with calibration data provided by a window sampler investigation, the survey successfully defined the depth to the Chalk and the nature of the geological contact across the entire site. The geophysical survey was able to be completed in just two days.



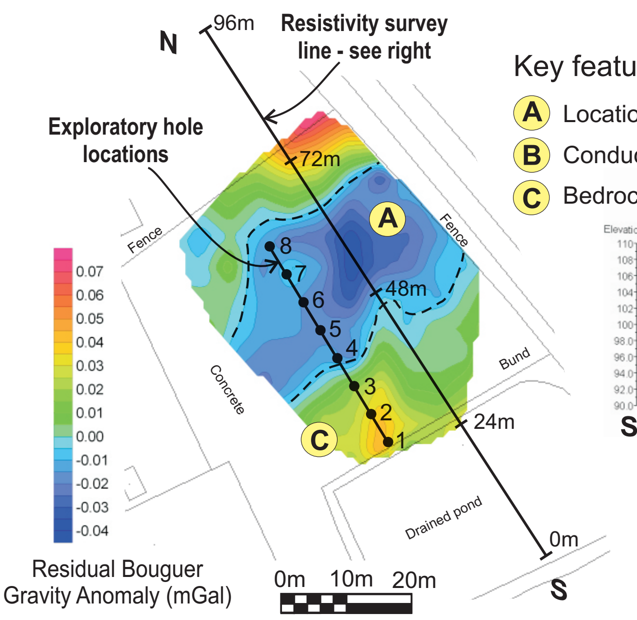
3 adjacent lines conducted across a site approximately 100m long and 50m apart. From the data, the interface between the Chalk and overlying clay is clearly apparent.

Locating Mineworkings using Integrated Geophysical Techniques

A microgravity survey was conducted over the route of a proposed road to locate former tin mine workings. The gravity data (**below left**) clearly shows a linear anomaly indicating low density ground. A resistivity survey (**below right**) was carried out across the anomaly and shows an area of high resistivity at 6mbgl indicative of a void. A follow up intrusive investigation confirmed the presence of the voided mine working. Further gravity surveys (**right**) revealed the presence of additional mine workings across the site.

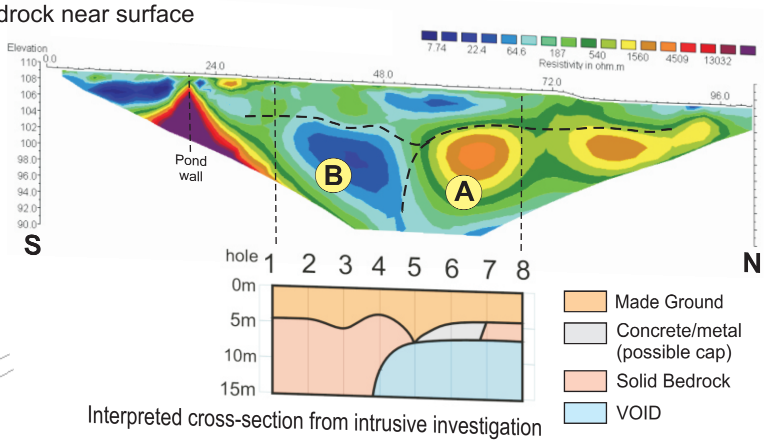


Residual Bouguer microgravity anomaly map (Blue represents low density ground)



Residual Bouguer Gravity Anomaly (mGal)

Key features
- **A** Location of stope (voided working)
- **B** Conductive mineralized ground
- **C** Bedrock near surface



Interpreted cross-section from intrusive investigation

VOIDS AND SOFT GROUND

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical Techniques Available

- *Ground Penetrating Radar (GPR)*
- *Electromagnetic Mapping (EM)*
- *Electrical Resistivity Imaging (ERI)*
- *Microgravity*
- *Surface Wave Ground Stiffness (SWGS)*

Subsurface voids (whether naturally occurring or manmade) and associated areas of soft ground present a significant risk to future, and existing, infrastructure and buildings. Unknown voids can be discovered during construction and can cause hazards and expensive delays to a construction project.

Geophysical techniques provide a suite of site reconnaissance tools that enable site characterisation and provide total site coverage. The examples below illustrate how relatively simple geophysical surveys can be applied to a site in order to plan and design a targeted intrusive investigation and subsequent remedial works to problem areas of ground. The use of geophysics reduces the associated risks and saves the developer time and money during the project.

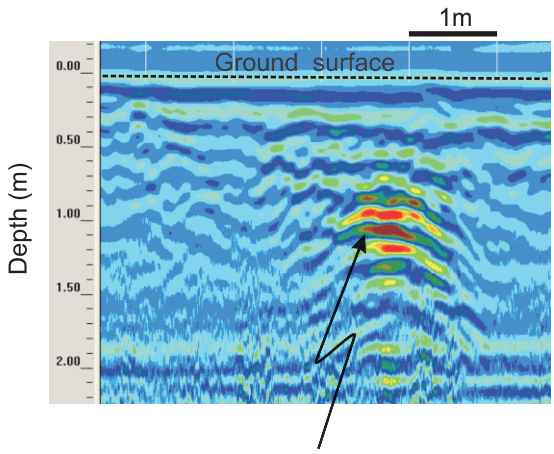
Survey examples

Ground Penetrating Radar (GPR)

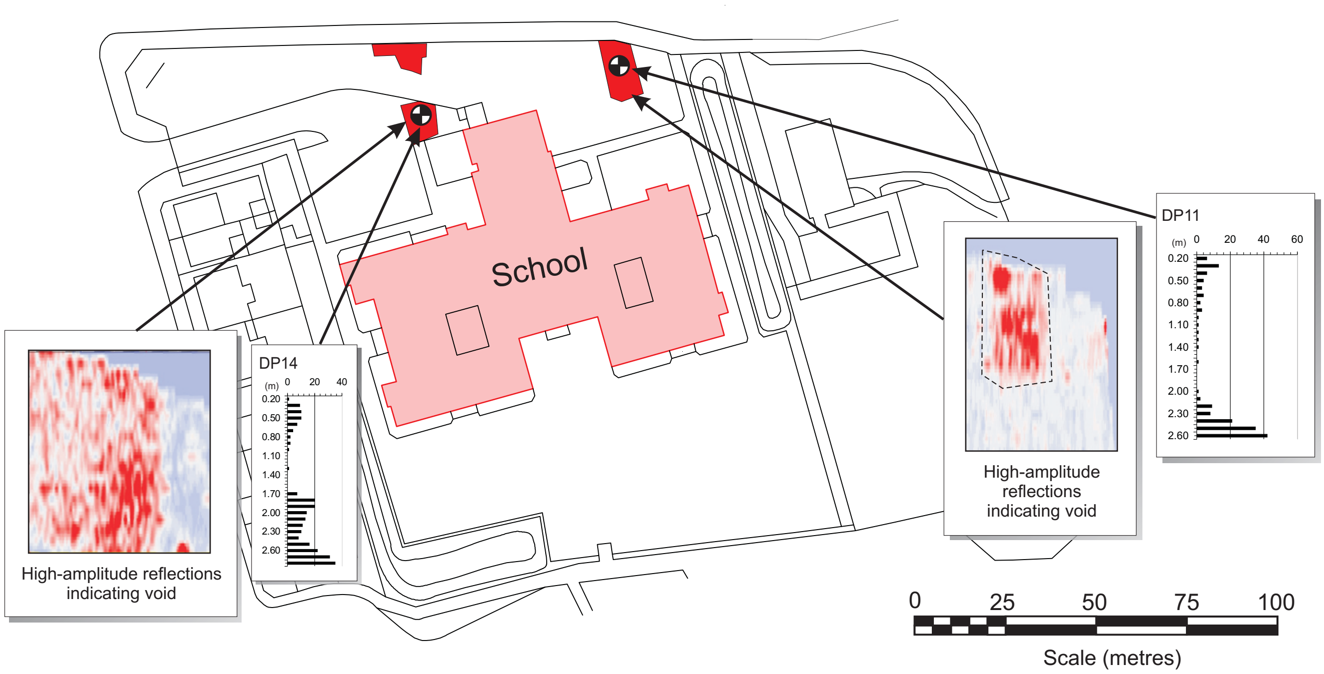
A primary school was experiencing localised settlement in the playground. Historical maps showed the presence of former buildings at the site which may have had basements. A GPR survey was undertaken to identify the location of any remaining basements present, and the possible presence of voids or poorly compacted backfill material.

The GPR survey was completed in a single day and provided total site coverage around the school grounds in the shallow sub-surface.

The data showed a number of discrete areas exhibiting anomalies indicative of the presence of basements. Secondary to the GPR survey a targeted dynamic probing investigation was implemented in order to seek to validate the findings of the GPR survey. Over the anomalous areas recorded in the GPR data the dynamic probe results were found to be very low thus confirming the presence of very loose backfill material, or possible voided areas.



Where the backfill is poorly compacted, or contains voids, the GPR signal reverberates, generating large amplitude reflections in the radargram



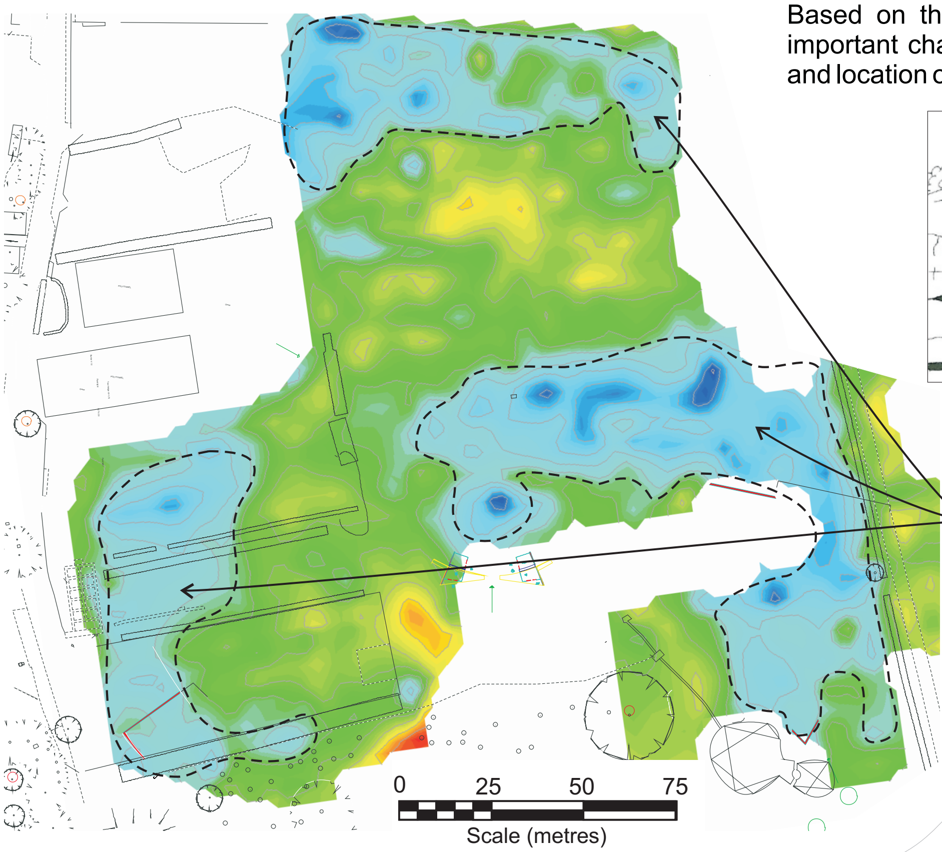
RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

VOIDS AND SOFT GROUND

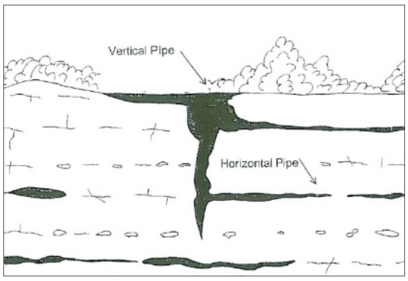
Microgravity Mapping

Solution features were identified within chalk bedrock during drilling of a site prior to redevelopment of a sports centre. A microgravity survey was commissioned to seek to determine the lateral extent of solution features and voids within the chalk bedrock in order to provide a reliable interpretation of the sub-surface at the site. The gravity survey was conducted on a 5x5m staggered grid over the proposed footprint of the building, ensuring comprehensive cover.

Corrections were applied to the observed gravity to produce a final microgravity map (**below left**). The corrections applied included drift, latitude, free-air, and the Bouger correction. The residual gravity map displays three areas of broad gravity lows (coloured blue) across the survey area. The results were used to target further boreholes to prove the anomalies. Very weak to weak low denisty chalk or voided ground was found present in the gravity low areas.



Based on the findings of the investigation, important changes were made to the design and location of the development



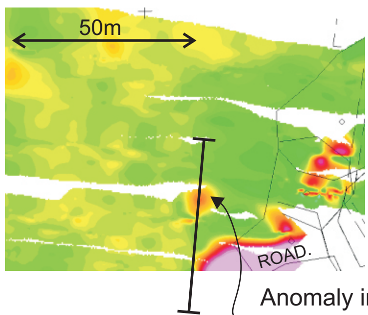
The anomalies are interpreted to represent possible solution features in the chalk bedrock (above).

Blue areas in the gravity map delineate areas of low density or possibly voided ground

(green dot) = high number of dynamic probe blow counts indicating competent ground.
(red dot) = low dynamic probe blow counts indicating poorly consolidated ground.

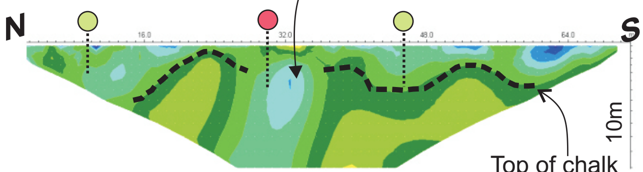
EM Ground Conductivity and Resistivity Imaging

Exploratory holes across a derelict site earmarked for redevelopment identified the presence of solution features and voids in the underlying chalk bedrock. An integrated geophysical survey including EM31&34 ground conductivity, and resistivity imaging was undertaken to determine whether further voiding was present. Due to the large size of the site, and the presence of chalk at shallow (<5m) depth, the EM technique was chosen to rapidly image the variation in ground conductivity to a depth of ~10m across the entire site. Chalk solution features are likely to manifest themselves as conductivity highs due to an increased thickness of overburden or a change in ground conditions such as increased groundwater saturation. A number of resistivity lines (**right**) and targeted dynamic probing were deployed over the EM anomalies to confirm the presence of soft/loose ground in the subsurface associated with potential voids at depth.



EM-31 data. Oranges and reds show higher ground conductivity.

Anomaly indicative of a possible solution feature present in both datasets



Top of chalk bedrock

Resistivity data showing blues as areas of lower resistivity (more conductive).

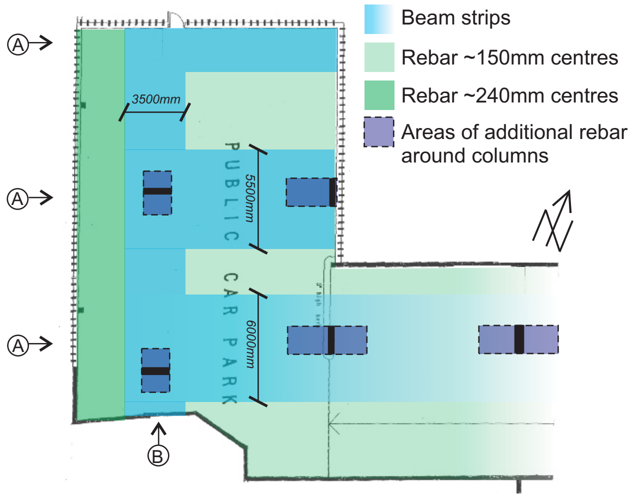
RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Structural Investigations using Ground Penetrating Radar (GPR)

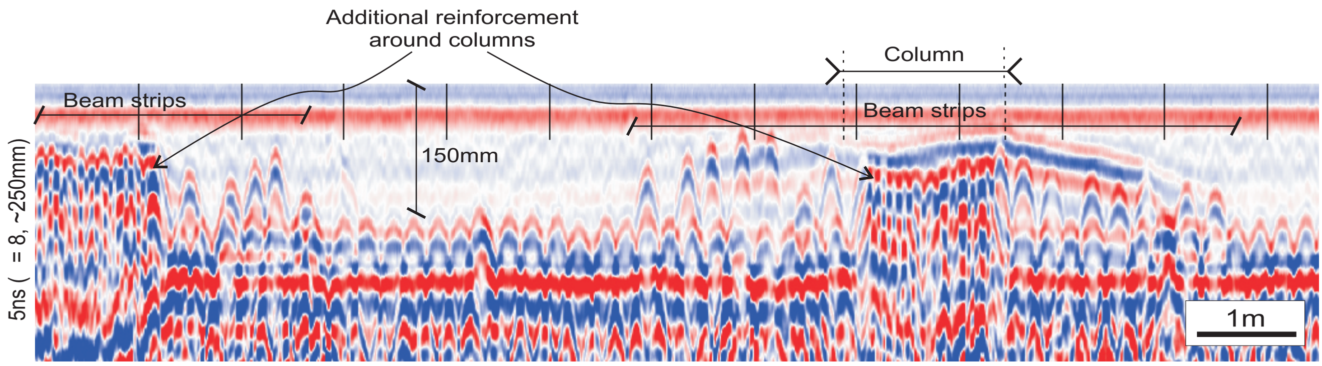
Ground Penetrating Radar (GPR) has enormous potential for use on engineered structures. Over the past ten years many structural investigations have been conducted by RSK Geophysics which has resulted in a large knowledge base of reflection types obtained from various structural features.

In conjunction with our Structures and Materials divisions we have conducted numerous investigations aimed at determining construction detail and internal metalwork in a variety of modern and historic buildings.

Using GPR allows rapid non-destructive coverage, with a depth penetration of up to 2m. The approach allows us to image multiple layers of construction detail, the calculation of thicknesses, and the location of internal metalwork including multiple layers of reinforcement.



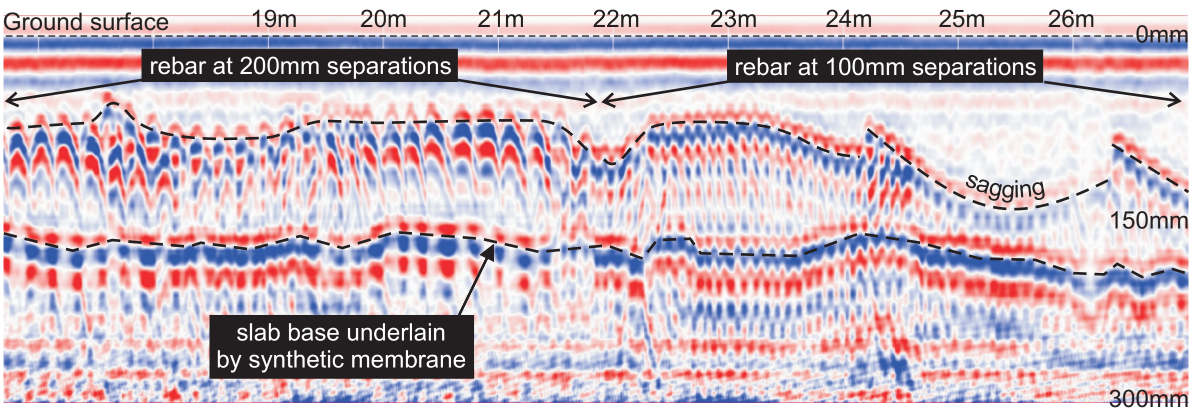
Summary of findings from a Car Park in Central London



A typical radargram recorded in the investigtion with annotated interpretations

Whereas traditional covermeters are somewhat limited in their penetration depth, a 900 to 1500MHz GPR system can provide high resolution data to depths of 1000mm and provide a permanent record of reinforcing mesh (*see example below and next page*).

The resulting radargrams can highlight variations in bar spacing and areas of poor mesh placement (sagging). In the example below, a reflection from the slab base is also clearly in evidence providing important data on the slab thickness.

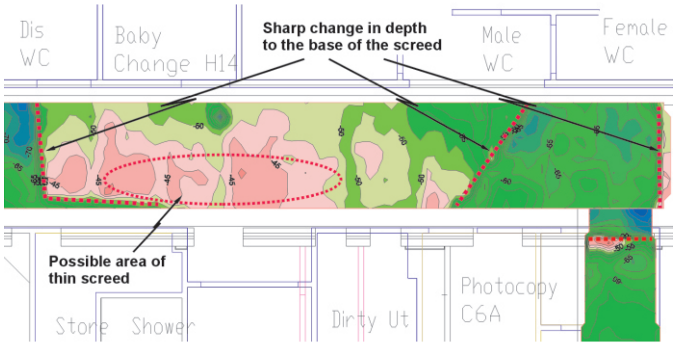


RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

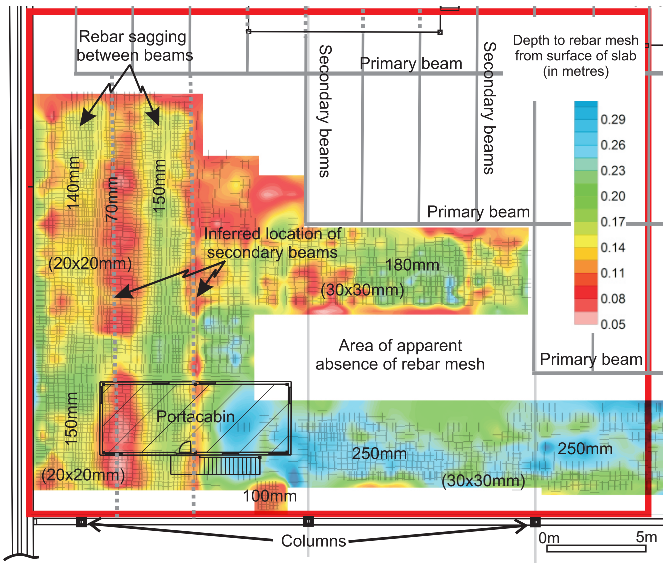
Survey examples

Defining the depth of screed in building flooring

Screed is the top finishing layer on a concrete slab. GPR can be used as a reliable, rapid, non-destructive means of testing the thickness and offers total coverage. Here a contour map (**right**) of calculated depth to the base of the screed layer has been produced based on the reflection time of the radar pulse over the survey area. The screed layer is clearly defined in the radar data by a high amplitude reflection. The results show a general variation as well as some sharp changes in the depth to screed.



Blue indicates thicker screed (>75mm) whilst pinks show less than 45mm



Defining the depth to rebar in a slab

In this example, GPR was used to determine the presence and location of metal reinforcement within a concrete floor slab of a former industrial building. Information on the orientation, depth to re-bar and re-bar spacing was also gathered. Using information from cored slab samples it was possible to calibrate the GPR data very accurately. The map (**left**) shows the location of the rebar picked from the data together with the depth within the floor slab. Sagging of the rebar is clearly visible in the data. The survey was completed in a single day and covered the entire floor slab of the building.

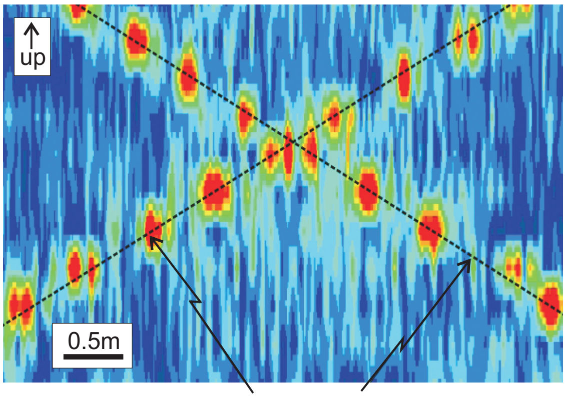
Plan view map of floor slab

Detection of internal metalwork and voids

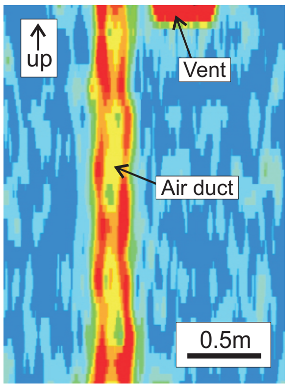
Here a GPR survey was used to determine the nature of the internal structure of walls at a university building. The survey (see photo **below left**) was undertaken using a high frequency 1.5GHz antenna at a 25cm line spacing to provide high resolution images of the wall interiors.

The survey was highly effective in showing areas of wall that contain internal metalwork (**below centre**). GPR has also been used very effectively in locating cavities and voids within structures. The radar time slice (**below right**) shows a metal flue which runs up the interior of the wall.

GPR data collection by hand



High amplitude reflections (coloured red) at 60mm cover depth indicate metal bracing in wall



Time slice at 140mm depth shows vertical air duct in wall

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

The application of Ground Penetrating Radar (GPR) to the non-destructive investigation of Historic Buildings

The utility of the GPR technique in the investigation of historic buildings is gaining increasing recognition. GPR surveys have proven to be very useful in the rapid, and non-destructive, location of metal structures such as cramps, dowels, beams and bolts.

Particular success is also recorded in the measurement of material thickness in facing stones.

Westminster Bridge is the oldest bridge in use in London. Here a GPR survey was undertaken to determine the nature of the internal metalwork and structural beams as part of major refurbishment works.

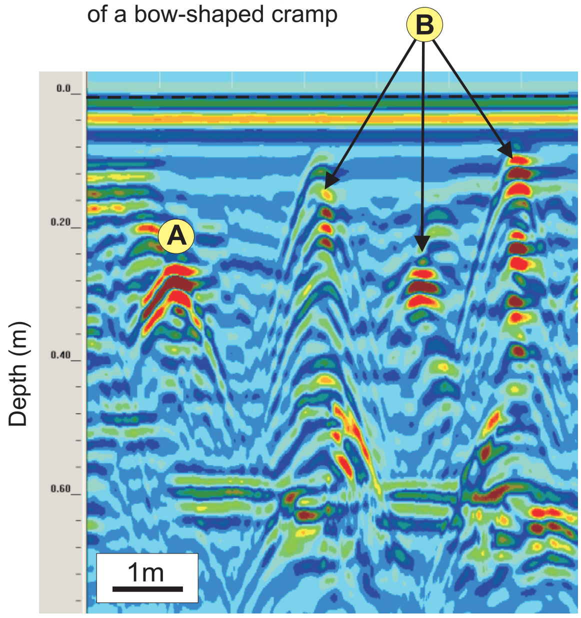
Survey examples

GPR Survey of an Old Town Hall

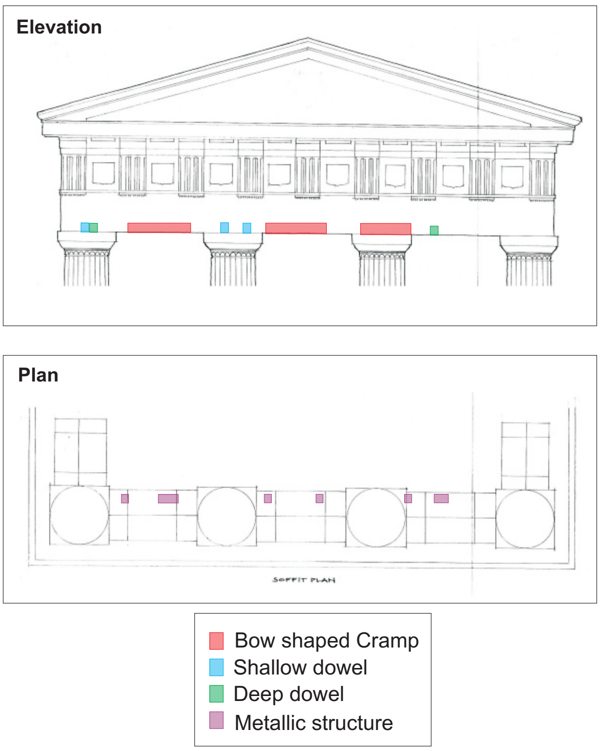
Here a GPR survey using a 1.5GHz antenna located metal fixings within the columns and lintel of the town hall facade. **Below** is an example radar trace displaying the different types of reflections recorded. It is possible to identify the type of metal structure from the reflection. The diagram opposite summarises the interpretation. The interpreted data suggest that corrosion of the metal fixings could be the cause of cracks appearing in the stonework of the Town Hall.

A High amplitude hyperbolic reflection possibly indicative of a dowel

B Group of three high amplitude hyperbolic reflections possibly indicative of a bow-shaped cramp



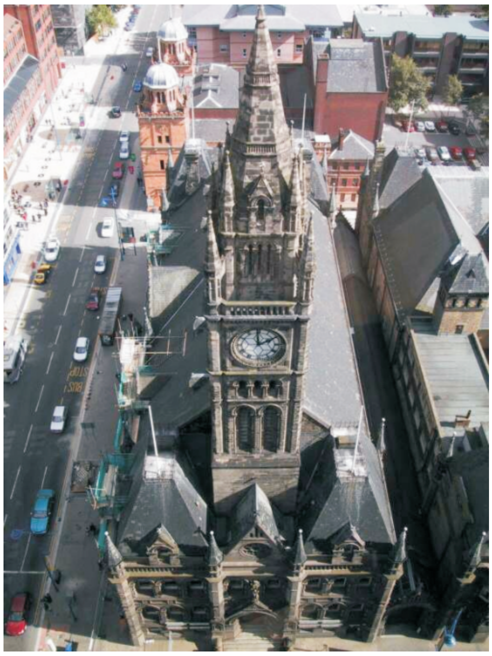
Interpretation:



RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

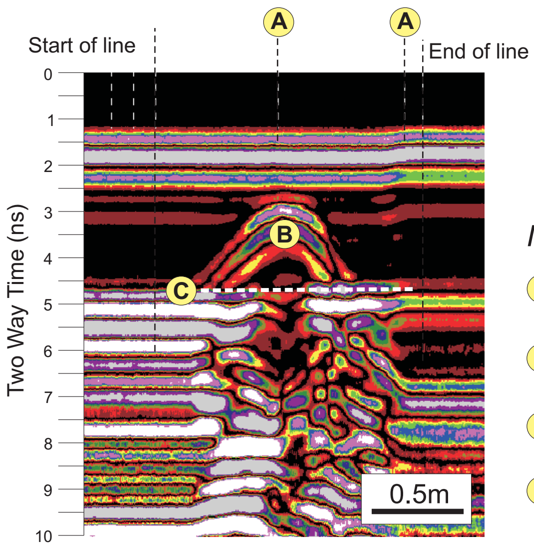
GPR Survey of Middlesborough Town Hall Clock Tower

The GPR survey was undertaken in partnership with Middlesbrough Council. The principal purpose of the survey was to identify the presence, depth and dimensions of metal cramps within the spire and the clock tower (**right**). Visual inspection had revealed that bed joints between some of the large stone facing blocks in the spire had begun to open up. It was suspected that this was due to weathering processes causing corrosion and expansion of the metal fixings.



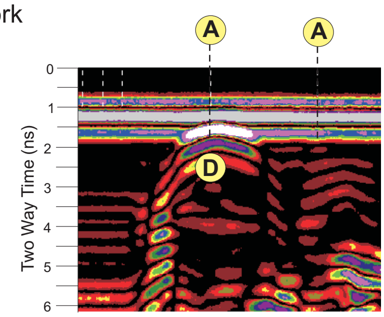
Data from the GPR survey provided important insight for the external repair works to this Grade II listed building.

As shown in the radargram **below**, the large contrast in dielectric properties between iron cramps and the surrounding stonework produced strong reflections in the radar data.



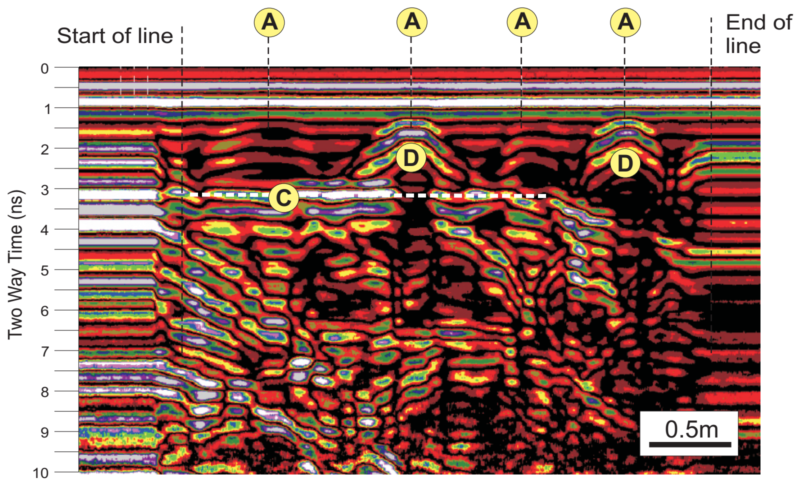
Interpretation:

- **A** Bedding planes in stone facing blocks
- **B** High amplitude anomaly indicative of a bolt or rod running through buttress
- **C** Back face of stone facing block and front face of internal brickwork
- **D** Likely iron cramps



There were a number of other features of interest to the engineers designing and undertaking the remediation work which were also clearly discernable in the collected data. In particular, bedding structures within the stone facing blocks produced clear reflections. It is unlikely that each peak in the data represents an individual bedding plane, however the data suggest planar variation in the properties of the material running parallel with the surface. Also clearly visible in the data was a reflection from the back face of the facing blocks (see example radargram to **right**).

Correlation of this reflector across adjacent lines gave valuable information on the thickness of individual facing blocks, and also the distribution of facing blocks of differing sizes.



BOREHOLE GEOPHYSICS

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Applications

- *Pile and foundation analysis*
- *Estimation of depth to bedrock*
- *Estimation of depth to water table*
- *Locating solution features*
- *Fracture and void location*
- *Geological and hydrological mapping*

Geophysical Techniques Available

Borehole geophysics takes advantage of the higher spatial resolutions at depth afforded by deploying instruments down-hole. Techniques available include:

- **Seismics**
- **Ground Penetrating Radar**
- **Magnetics**
- **Resistivity**
- **Induced Polarisation**

The techniques operate in the same manner as they would on the surface, with the advantage of providing high resolution data at depth.

The borehole seismic method being used to determine the nature of the bedrock and presence of faults and fractures.

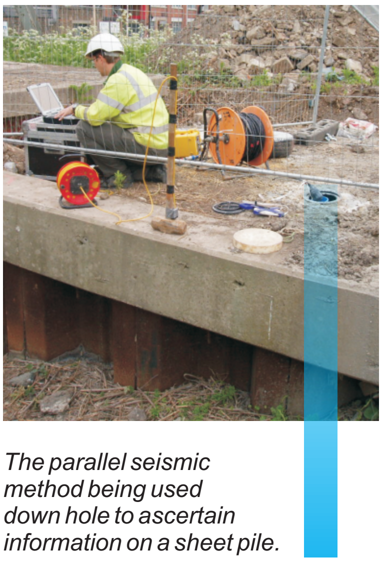
Parallel Seismic Testing

Many UK cities, and old cities world-wide, have been built over numerous times. The ground is often full of old foundations. Therefore the re-use of old piles is becoming increasingly necessary. As part of the investigation of old piles to test load bearing capacity, parallel borehole geophysics can be used successfully to characterise the length and geometry of piles.

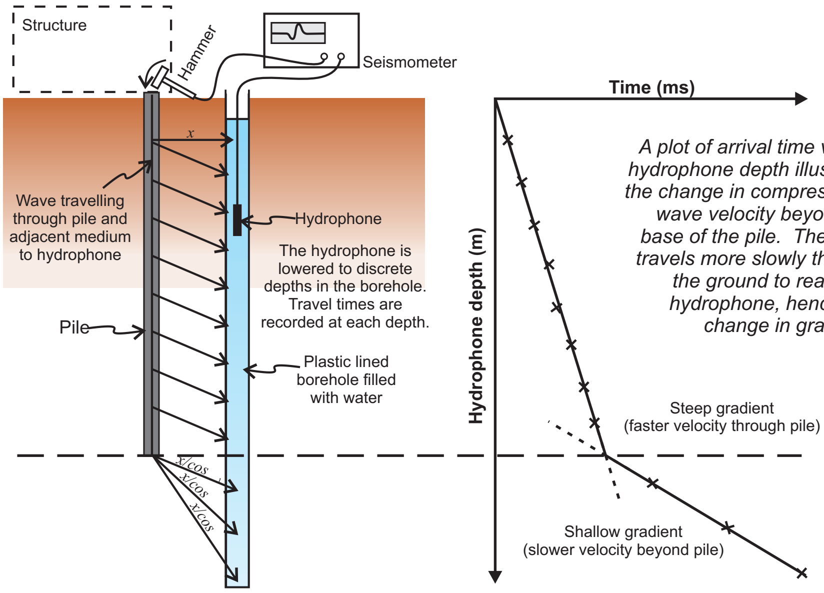
The depth of a pile can be determined from the change in velocity of a compressional wave induced at the top of the pile. As shown **below**, typically, the wave travels rapidly through the pile and then slows in the surrounding ground.

The parallel seismic technique requires a borehole to be drilled parallel, and close to, the target pile. The borehole should extend to a depth below the anticipated base of the pile. Typically the borehole has an internal diameter 50mm, is plastic lined and filled with water to provide acoustic coupling with the immersed hydrophone.

The hydrophone is immersed to discrete depths. At each depth a recording is made of the energy from a hammer blow. An evaluation of the travel time of this pulse down the pile and across the intervening material to the hydrophone permits an assessment of pile length to be made.



The parallel seismic method being used down hole to ascertain information on a sheet pile.

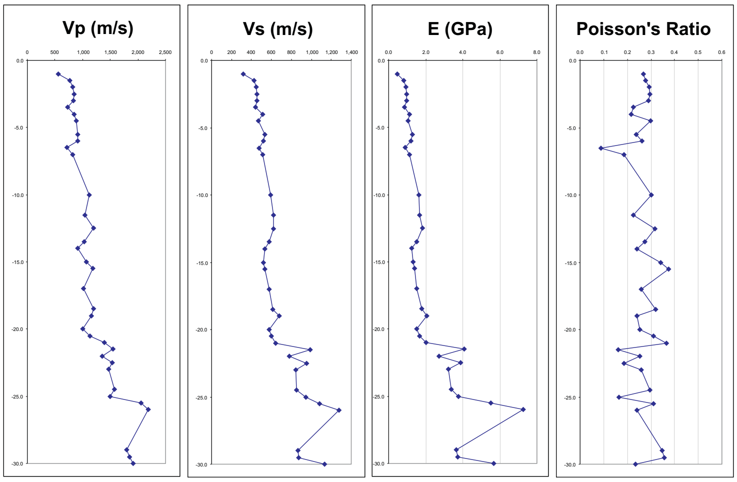


RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

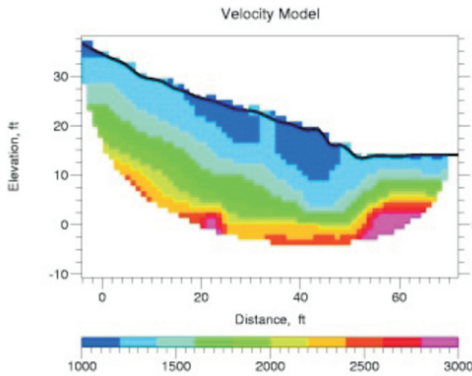
Survey examples

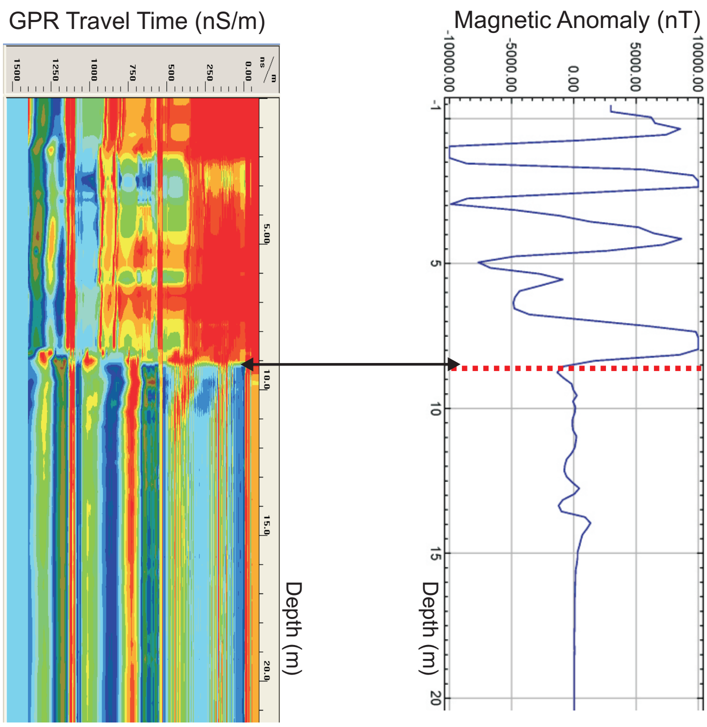
Cross-borehole Seismics

In this survey cross-borehole seismics was used to determine the elastic properties of a chalk bedrock with depth, prior to a vibration analysis for foundation design. By placing a seismic source in one borehole and recording the arrival of P- and S- waves in another borehole it is possible, when combined with rock density information, to calculate the bulk and shear moduli, and Poisson's ratio of the bedrock with depth.



Cross borehole tomography allows a 2D section of ground velocity to be generated (**far right**). The integration of cross borehole tomography with other seismic methods offers to better constrain seismic boundaries and improve the quality of geological and hydrological models of a site.





Downhole Magnetics and GPR

In this example to the **left**, downhole magnetics and ground penetrating radar (GPR) were used to locate the depth of pile casing and the depth of the piles. To the left is a magnetic and GPR example from a borehole which clearly marks the base of the metal casing in the hole.

The end of the pile casing is marked by the sudden drop in the measured magnetic field strength, and by the termination of a high amplitude reflector in the radar data. Both features occur at a depth of 9m.

Cross-borehole Electrical Imaging

Whilst electrical imaging surveys (both resistivity and induced polarisation) can be conducted in a single borehole, it is more commonly used with two (or more) boreholes. The surveys use the same four electrode set-up as a surface survey.

The survey can be conducted in water-filled boreholes, although slotted casing must be used. The holes are sited either side of the area of interest, with generally a horizontal distance of no more than two-thirds of their depth between them. One current electrode is placed in either hole, and the position of the potential electrodes is changed in order to build an image of the resistivity of the subsurface between the boreholes.

RSK Geophysics have particular experience in tailoring the data-collection strategy to optimise the results for different target geometries.

SERVICES AND UTILITY TRACING

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

Geophysical Techniques Available

- ☑ *Ground Penetrating Radar*
- ☑ *Electromagnetic Mapping (EM)*
- ☑ *Magnetic Gradiometry*
- ☑ *Radiodectection*

Failure to accurately identify the location of buried services may result in damage to property, cost to the client/developer, and at worst, result in death or injury to workers.

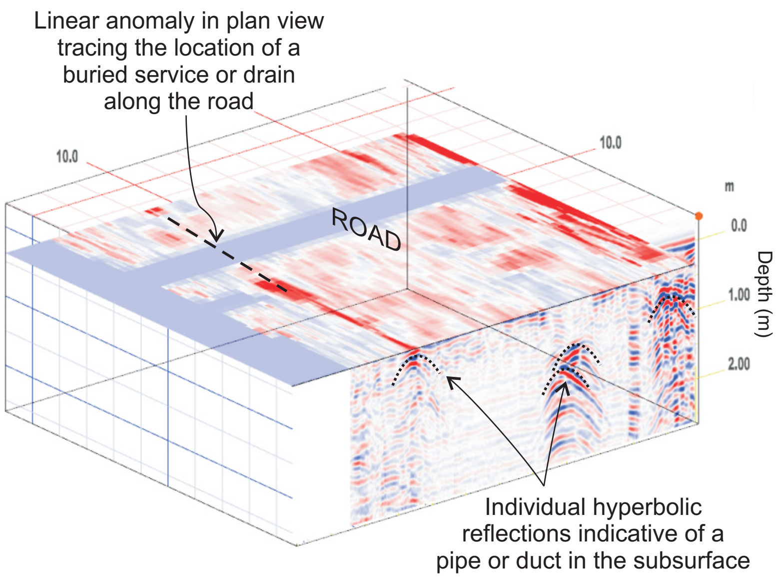
Geophysical techniques are capable of locating and determining the depth to services and hazards that can not be traced by traditional radiodetection or surveying approaches. Accurate location and depth information can be determined for non-metallic services such as cable ducts or plastic or clay pipes and sewers.

Successful determination of the location of utilities by radar is confirmed by subsequent ground-truthing.

Survey examples

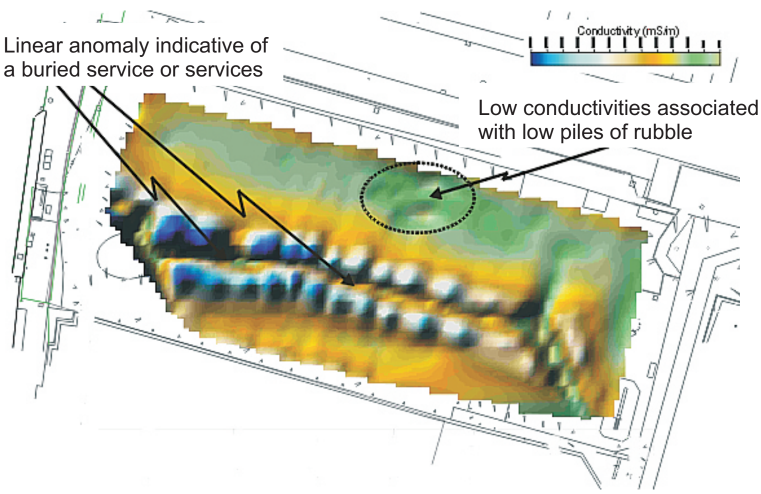
Mapping anomalies across radar traces

By conducting GPR over a grid in two directions, the data can be merged to form accurate three dimensional volumes - even in a crowded urban environments. The 3D volume can be manipulated to show slices through the data. It is then possible to map the presence of spatially persistent anomalies across multiple survey lines. This is shown **right** in this example to locate buried services.



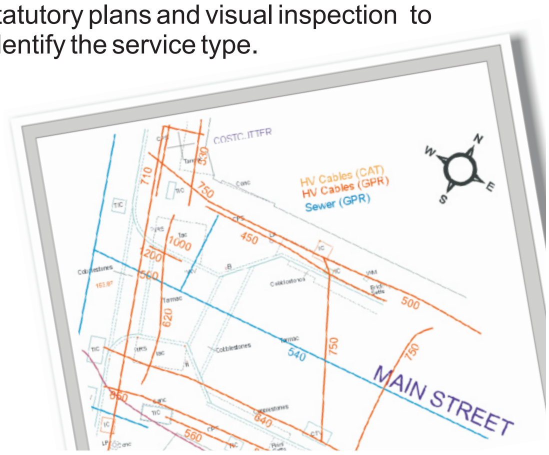
Electromagnetic Mapping (EM) displaying a buried service

Due to their metallic content, buried services are often detectable by electromagnetic mapping as shown in the example **below**.



Interpreted results plan

Our service search results can be lain over existing site plans, with the different services highlighted and depths given. These can then used in conjunction with existing statutory plans and visual inspection to identify the service type.



GLOSSARY AND INDEX

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

GLOSSARY

Apparent resistivity
The resistivity calculated from electrical resistances measured in the field. Varies from true resistivity due to subsurface heterogeneity. *c.f.* true resistivity.

Aquifer
A rock formation or soil zone that is saturated with groundwater and has adequate permeability to produce water from wells or springs.

Base station
An arbitrary point in the survey area where repeat readings are taken throughout the duration of the survey to allow correction of instrument drift and correlation between different surveys.

Bedrock
Consolidated mechanically competent rock underlying any loose superficial material such as soil, alluvium or marine sediments.

Bouguer anomaly
The resulting gravity values after tidal, latitude, free air, and Bouguer corrections have been applied to the data. It is commonly the final presented result, which is then interpreted, for a microgravity survey.

Bouguer correction
A correction applied to gravity data to account for the additional mass of rock between the survey point and the datum level.

CSW
Continuous Surface Wave. This technique uses the propagation properties of Surface Waves and their depth of penetration, which varies due to wavelength and hence frequency. An active vibrating source is used which provides a range of source frequencies. Surface Wave velocity is dependant on the soil stiffness with depth.

Critical angle
The least angle at which total reflection of an electromagnetic or seismic wave occurs. At the critical angle the wave is refracted along the interface between media.

Cultural noise
This can affect any geophysical instrument, particularly in urban areas, and includes the effects of man made objects, tree movements, or any other activity which can affect the geophysical signal.

Data artefact
An object in the data which, although looks real, is a product of distortion from an extrinsic agent.

Data processing
Consists of filtering the raw data to remove or reduce background noise, outliers and to enhance signals. Various algorithms, gains and data shifts can be applied to account for sensor position and other real world offsets and adjustments.

DGPS
Differential Global Positioning System. An enhanced version of GPS that allows greater accuracy.

Dielectric constant
The function of different materials within a medium. Determines the velocity an EM wave through a medium. Changes in the constant between two media result in wave reflections. The larger the contrast, the stronger the reflection (i.e. metal in concrete generates a strong reflection signal in GPR data).

DNAPL
Dense Non-Aqueous Phase Liquid. A liquid that is more dense than water and does not dissolve in water. (e.g. chlorinated solvents). Can be detected by electrical resistivity imaging, EM ground conductivity, and GPR techniques. *cf.* LNAPL.

Eddy current
Induced when a conductor moves through a non-uniform EM field. This generates a circular flow of electrons (the current) within the conductor, and thus opposes the change of the EM field.

EM
Electromagnetic.

EM Ground Conductivity
Electromagnetic waves are transmitted from the surface, and induce currents in conductive bodies in the subsurface. These eddy currents are then recorded at the surface. Variations in the electromagnetic field thus indicate contrasts in the ground conductivity.

ERT
Electrical Resistivity Tomography. Alternative name for Electrical Resistivity Imaging. A method of producing 2D and 3D models of the subsurface resistivity distribution.

Fourier analysis
The mathematical decomposition of a waveform into its constituent frequencies. Often used in the process of converting time domain (TD) data to the frequency domain (FD) and vice versa.

Free air correction
A correction applied to gravity data to account for the change in distance from the centre of the Earth between the survey point and the datum level.

Frequency domain (FD)
A representation of data to aid analysis of its variation over different frequencies. *c.f.* time domain.

Geophone
Sensor for detecting seismic waves in the subsurface. It works by producing an electrical response proportional to the velocity of the ground motion.

Geophysics
Uses the principles of physics to measure the properties of the Earth. These include local variations in the Earth's gravitational and magnetic fields, elastic wave analysis through seismology and electromagnetic pulses to determine contrasts in subsurface properties.

Groundwater
Subsurface water in the zone of saturation, including water below the water table and water occupying pores and openings in underlying rocks.

GPR
Ground Penetrating Radar.

Head wave
The basis for seismic refraction surveys, the head wave travels upward from an interface when incident waves strike it at the critical angle.

Hydrophone
A sensor for detecting seismic waves in water. It works by generating an electrical response proportional to changes in pressure.

Hyperbolic reflection
Energy from a GPR antenna is transmitted conically. Due to this broad energy pattern, when the antenna crosses a target (i.e. buried pipes or reinforcement) the shape of the reflection is hyperbolic in nature.

Induced Polarisation
The subsurface can both dissipate and store energy generated by an electrical current. IP measures this ability to store energy, whilst resistivity measures the amount of dissipation.

Instrument drift
The variation of an instrument's response to the same input over time; e.g. the change in repeat readings at the same base station.

Inversion
This process is used in resistivity surveys and uses an algorithm or code in order to generate a true resistivity model from the measured apparent resistivity in the raw data.

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

GLOSSARY

Latitude correction
A correction applied to gravity data to account for the global variation of gravitational attraction with latitude.

Leachate
The liquid that accumulates in a landfill mostly as a result of precipitation percolating through the waste. The presence of leachate (whether contained in a landfill or leakage beyond the landfill) can be detected by electrical resistivity and EM conductivity.

LNAPL
Light Non-Aqueous Phase Liquid. A liquid that is less dense than water and does not dissolve in water (e.g. petroleum hydrocarbons). Can be detected by electrical resistivity imaging, EM ground conductivity, and GPR techniques. *cf.* DNAPL.

Magnetic Gradiometry
A Magnetic Gradiomater can determine the local gradient of a magnetic field by employing two magnetometers that are separated by a fixed distance, and measure simultaneously the gradient in the direction of the line of the detectors.

MEC
Munitions and Explosives of Concern.
Another term for UXO.

Microgravity
A technique that measures relative variations in the Earth's gravitational field, once subjected to a number of processes. *c.f.* free air correction, latitude correction, Bouguer correction, Residual gravity anomaly, Base station.

NAPL
Non-Aqueous Phase Liquid. A liquid that does not dissolve in water. Can be sub-divided into LNAPL and DNAPL.

NDT
Non-Destructive Testing.

P-wave
A seismic wave in which particle motion is in the direction of propagation. Usually the first type of seismic wave to reach a receiver. *cf.* S-wave.

Penetration depth
The maximum depth at which a geophysical technique provides useful information about the subsurface. Dependant on the technique being used, the local conditions, and the type of target.

Plume
Contaminant plume - a mixture of waste chemicals, or leachate, and groundwater usually in solution form.

Pseudosection
A 2D graphical representation of how a measured parameter varies with location and depth. Requires inversion of the data to be converted into a 2D model (cross-section).

Raw Data
When data is collected in the field before any processing is applied, the data is termed raw.

Residual gravity anomaly
The resulting gravity data once all corrections have been made (c.f. microgravity) is termed the residual gravity anomaly. It indicates where there is a density contrast in the subsurface - eg a negative anomaly may indicate a void.

Resistivity
An intrinsic property of a material which resists the flow of an electrical current within the material. Typically calculated from the inversion of apparent resistivity data collected in the field. *c.f.* apparent resistivity

S-wave
A seismic wave in which particle motion is perpendicular to the direction of propagation. Usually the second type of seismic wave to reach a receiver. *cf.* P-wave.

Saturated zone
The saturated region of the subsurface beneath the water table.

Self Potential
The difference in natural electrical properties between two points on the ground surface is termed Self Potential. The potentials are typically generated by groundwater flow, mineral deposits and chemical diffusion.

Stacking
By adding together signals which have essentially the same content, one can improve the signal to noise ration, thus enhancing signals in the radar or seismic dataset.

Surface Wave
The term for a seismic wave that travels along the surface of the Earth, such as a Rayleigh Wave.

Surface Wave Ground Stiffness
Although the theory is similar to CSW, SWGS uses a combination of microtremor surveys - a low frequency passive source - and a high frequency active source, such as a hammer blow.

Tidal correction
A correction applied to gravity data to account for the diurnal variation in gravitational attraction due to the relative positions of the sun and moon.

Time domain (TD)
A representation of data to aid analysis of its variation over time. *cf.* frequency domain.

Travel Time
The arrival time of a wave from a source. Used in GPR and Seismic surveys.

True resistivity
See resistivity.

UST
Underground Storage Tank. Often found on former industrial sites, particularly petrol stations. Can be detected using GPR and EM ground conductivity techniques.

UXB
UneXploded Bomb. Explosive weapons dropped by aircraft that did not explode. Can be detected by magnetic, EM ground conductivity and radar techniques. *cf.* UXO.

UXO
UneXploded Ordnance. Explosive weapons that have not exploded. Includes artillery shells and UXBs. Can be detected by magnetic, EM ground conductivity and radar techniques.

Vadose zone
Also termed the unsaturated zone. The region of the subsurface between the ground surface and the water table.

Water table
The boundary between the vadose zone and the saturated zone. The form of the boundary is a function of the local topography, geology, and seasonal climatic variations.

Wavelet analysis
A wavelet is a waveform within a waveform, thus analysing its shape can indicate potential features within the data.

Need further help or advice?

We are happy to advice on principals and techniques. Feel free to contact us on:

T 01442 416657
E geophysics@rsk.co.uk
W www.environmental-geophysics.co.uk

RSK Geophysics
18 Frogmore Road
Hemel Hempstead
Hertfordshire HP3 9RT
Tel: 01442 416656
geophysics@rsk.co.uk
www.environmental-geophysics.co.uk

INDEX

Page numbers in **bold** denote principal section.
Page numbers in standard text denote examples.