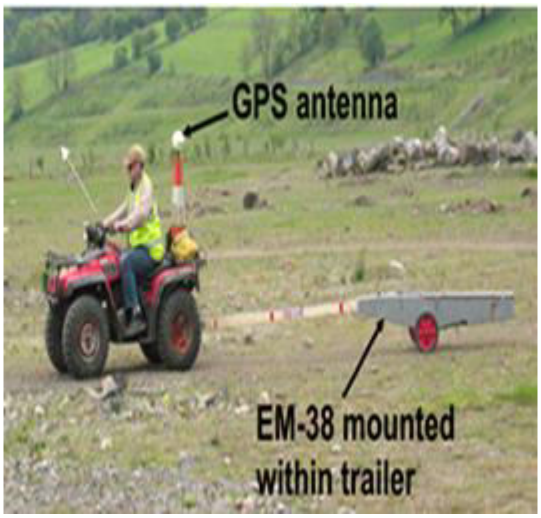
Ministry of Higher Education and Scientific Research

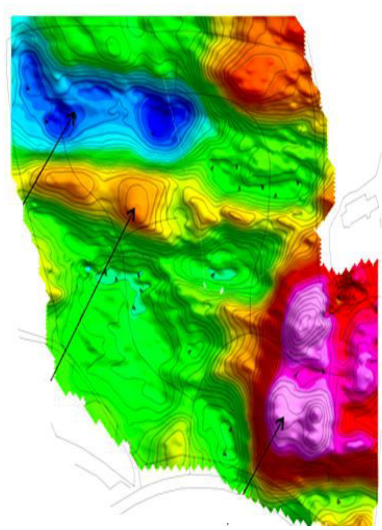
Al-Karkh University of Science

College of Geophysics and Remote Sensing

Department of Geophysics

Environmental Geophysics



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PhD. In Geophysics

Environmental Geophysics

Introduction

Environmental Geophysics is the use of geophysical methods to image and understand the properties and processes in the top ~100 meters of the earth. This is the region of the earth that has a direct and daily impact on our lives (and on which we have a direct and daily impact), yet we know surprising little about this near-surface region. Our work in environmental geophysics involves laboratory studies, theoretical modeling, and field work. We use these three different approaches to investigate the links between the geophysical parameters that we can measure and the physical, chemical and biological properties and processes of interest. Many of our research projects can be described as “hydro-geophysics” or using geophysics to address problems in hydrogeology.

Environmental geophysics is a relatively new field. It is primarily used to identify, map or predict the presence and potential movement of surface water and groundwater and to identify contaminants in the soil within the upper 10 to 50 m of the Earth's surface. It can also be used to help locate sites for underground waste disposal, examine archaeological sites or even assist the police in their investigations of possible burial sites.

Environmental geophysicists often are part of multi-disciplinary teams which include geological engineers, biologists, hydrogeologists and technicians. They can be involved in a wide variety of activities that are both geophysically and non-geophysically related.

Environmental geophysicists often welcome the chance to leave the desk behind, pack up their portable computer and travel out of the city to investigate problem sites, even in severe weather conditions. In addition to doing field work in the rural environment, some field work is done in urban settings. As flexible people, they become involved in water or soil sampling, mapping and statistics as well as conducting their own geophysical surveys.

Research in the environmental geophysics area combines the disciplines of geophysics, hydrogeology, statistics, and biogeochemistry to develop new approaches for characterizing shallow subsurface properties and for monitoring complex processes associated with natural or induced subsurface perturbations. This interdisciplinary field is unique in its development of complex petrophysical models that link hydro-biogeochemical-geophysical datasets, the application of emerging stochastic inversion techniques geared toward shallow subsurface systems, and the development of environmental geophysics field-imaging capabilities. Most of the hydro-geophysical and bio-geophysical research performed in this area is focused on developing methods to improve our ability to manage and monitor water resources and environmental contaminants.

Data Collection

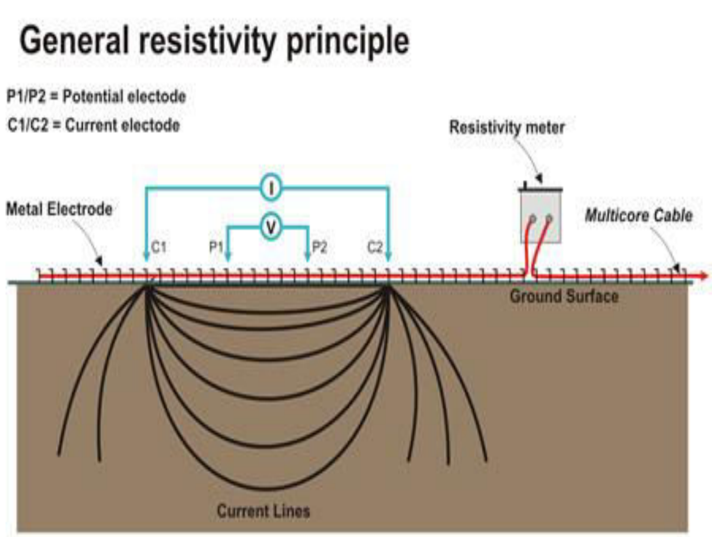
Environmental geophysicists use many of the instruments and techniques used in mining and petroleum geophysics such as magnetic, electrical and seismic methods. Adapted for use at shallow depths, these methods are very effective.

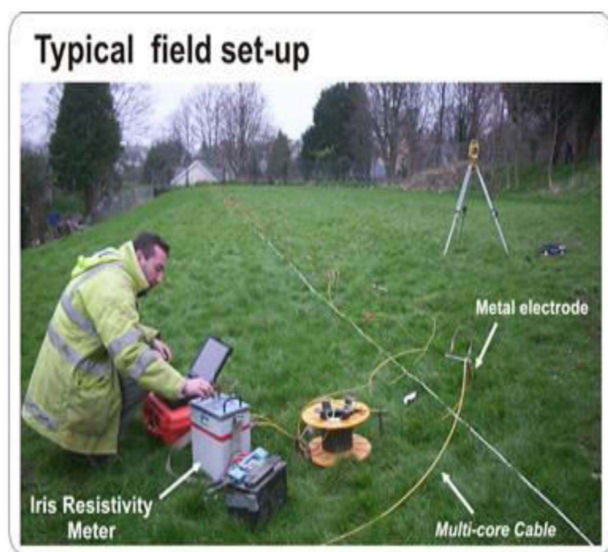
Seismic surveys, redesigned for shallow targets, are less common due to their higher cost but in some situations, their usefulness outweighs the extra dollars needed.

Electrical Resistivity Tomography (ERT)

The Resistivity technique is a useful method for characterizing the sub-surface materials in terms of their electrical properties. Variations in electrical resistivity (or conductivity) typically correlate with variations in lithology, water saturation, fluid conductivity, porosity and permeability, which may be used to map stratigraphic units, geological structure, sinkholes, fractures and groundwater.

The acquisition of resistivity data involves the injection of current into the ground via a pair of electrodes and then the resulting potential field is measured by a corresponding pair of potential electrodes. The field set-up requires the deployment of an array of regularly spaced electrodes, which are connected to a central control unit via multi-core cables. Resistivity data are then recorded via complex combinations of current and potential electrode pairs to build up a pseudo cross-section of apparent resistivity beneath the survey line. The depth of investigation depends on the electrode separation and geometry, with greater electrode separations yielding bulk resistivity measurements from greater depths.



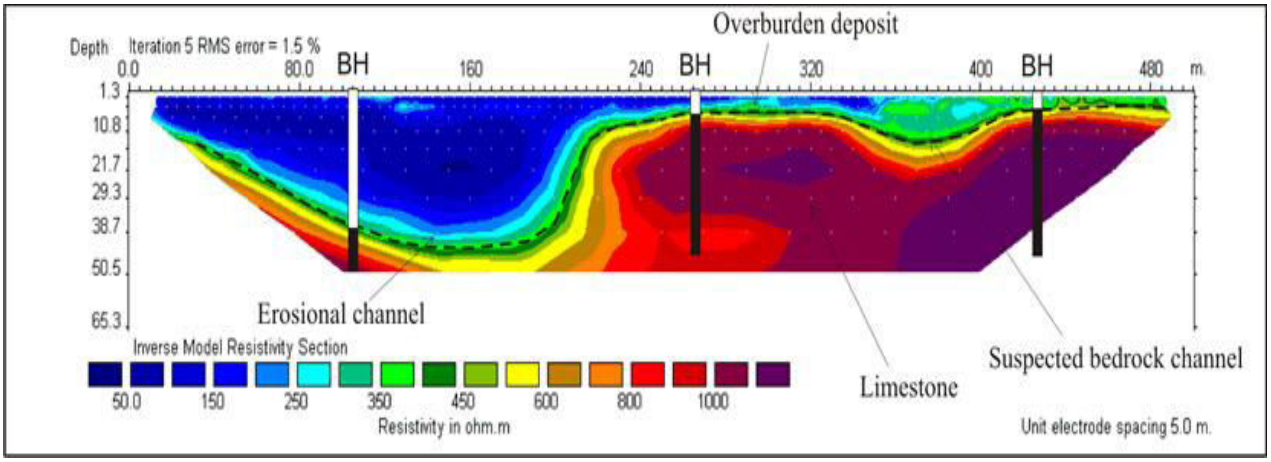


The recorded data are transferred to a PC for processing. In order to derive a cross-sectional model of true ground resistivity, the measured data are subject to a finite-difference inversion process via RES2DINV (ver 5.1) software.

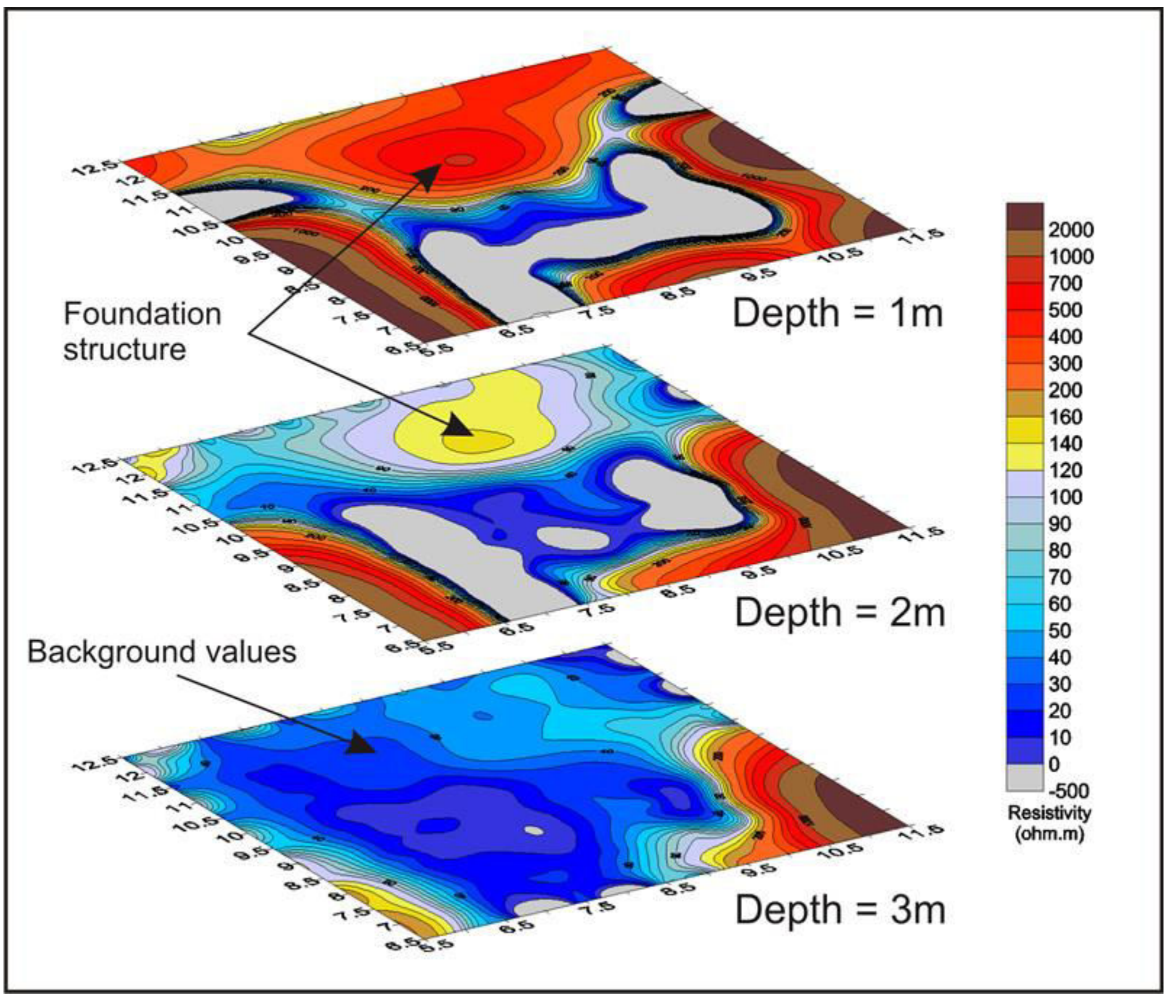
Data processing is based on an iterative routine involving determination of a two-dimensional (2D) simulated model of the subsurface, which is then compared to the observed data and revised. Convergence between theoretical and observed data is achieved by non-linear least squares optimization. The extent to which the observed and calculated theoretical models agree is an indication of the validity of the true resistivity model (indicated by the final root-mean-squared (RMS) error).

The true resistivity models are presented as color contour sections revealing spatial variation in subsurface resistivity. The 2D method of presenting resistivity data is limited where highly irregular or complex geological features are present and a 3D survey maybe required. Geological materials have characteristic resistivity values that enable identification of boundaries between distinct lithologies on resistivity cross-sections. At some sites, however, there are overlaps between the ranges of possible resistivity values for the targeted materials which therefore necessitate use of other geophysical surveys and/or drilling to confirm the nature of identified features.

Constraints: Readings can be affected by poor electrical contact at the surface. An increased electrode array length is required to locate increased depths of interest therefore the site layout must permit long arrays. Resolution of target features decreases with increased depth of burial.



As part of a hydrological study, a series of resistivity tomography profile lines were acquired to map variations within the overburden thickness. The example section above displays an extensive erosional channel feature together with more subtle overburden thickness variations.



A 3D resistivity survey was carried out to map the lateral and vertical extent of buried foundations. The grey zones represent noisy data due to buried services and the high resistivity values (red) reflect the foundation material. The resistivity suggests that the foundations extend to a maximum depth of 2m.

Ground Conductivity Electro-Magnetic (EM) Method

A ground conductivity or electromagnetic (EM) survey involves the generation of an EM field at the surface and subsequent measuring of the response as it propagates through the subsurface. The main components of the instrument are a transmitter coil (to generate the primary EM field) and receiver coil (to measure the induced secondary EM field). The amplitude and phase-shift of the secondary field are recorded and are then converted into values for ground conductivity and in-phase component (metal indicator).

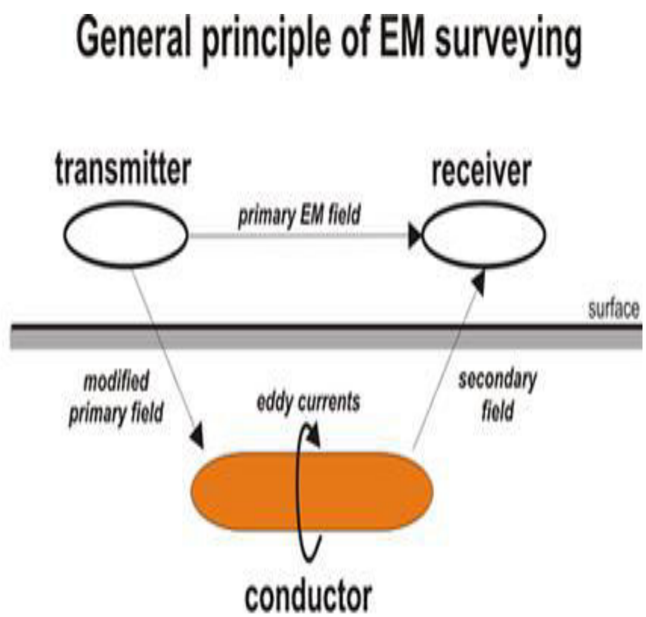
The ground conductivity (EM) instruments are either hand carried or mounted/towed behind a quad bike. Readings are usually taken on a regular grid or along selected traverse lines and positional control can be provided by DGPS if there is sufficient satellite coverage.

EM-38
Single frequency
Exploration depth ~1.5m

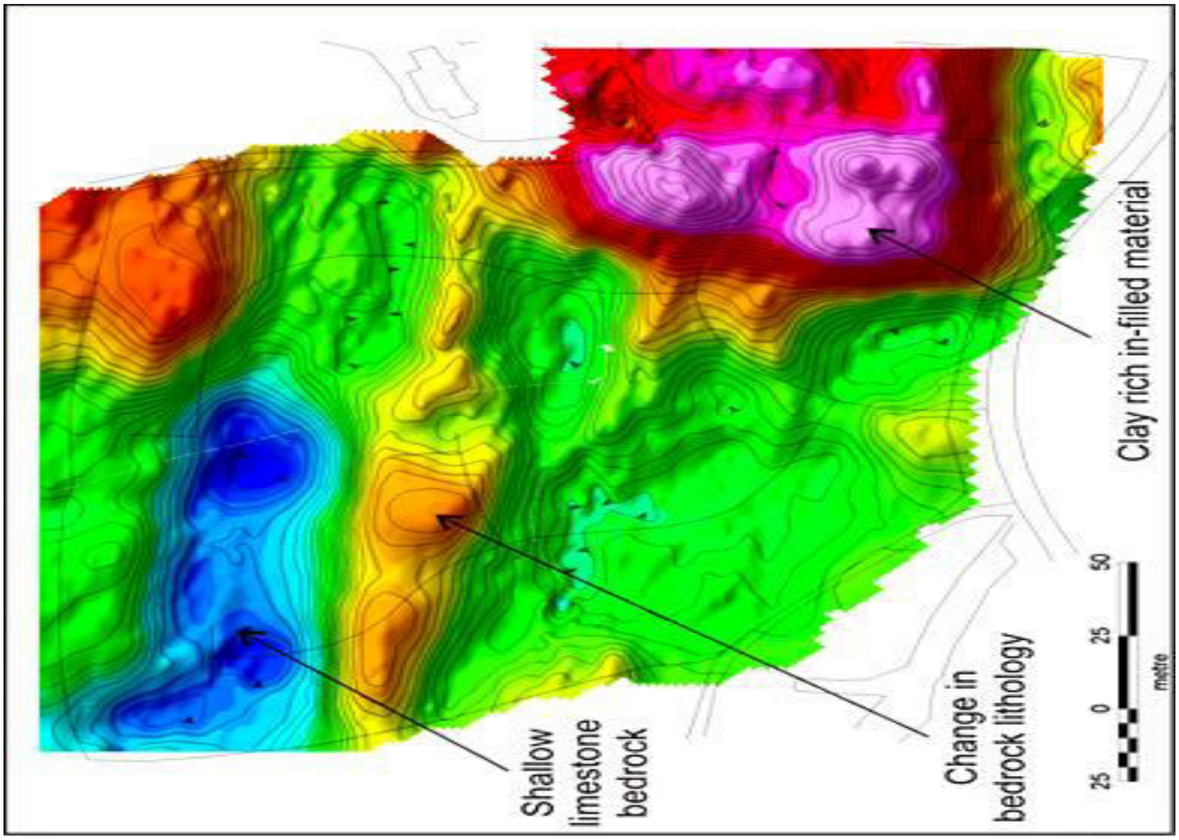
GEM-2
Multi-frequency
Exploration depth up to 10m

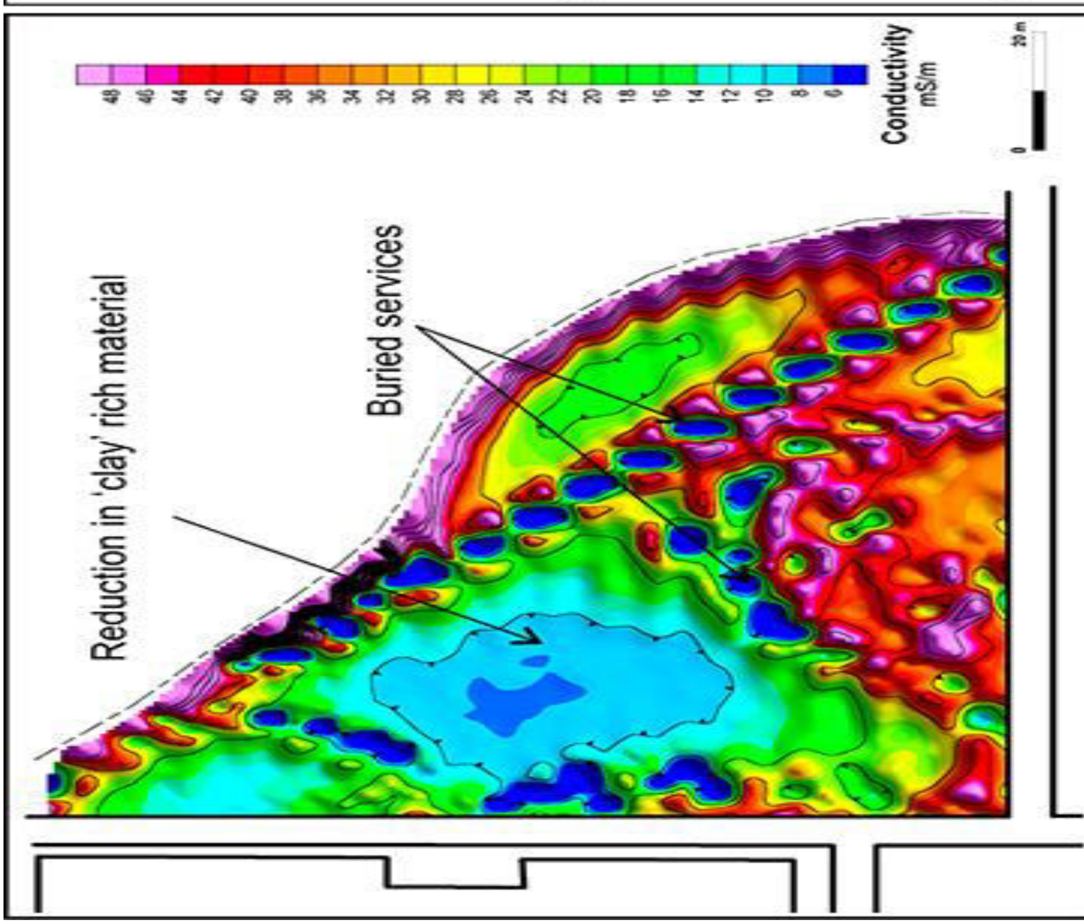
EM34
Single frequency
Exploration depth up to 50m

The selection of the particular EM instrument (EM-38/EM-31/GEM-2) is primarily based on the required penetration depth of the survey. However for most conductivity surveys the GEM-2 has replaced the more conventional EM-31 instrument due to its ability to simultaneously acquire data at different frequencies (i.e. different depth levels) and a greater depth of penetration. At the end of each survey, the survey data is downloaded to a field computer and corrected for instrument, diurnal and positional shifts. Additional editing may be carried out to remove any 'noisy' data values/positions.



The results from the EM survey can be presented as color contoured plots of conductivity and inphase (metal response) data. In general terms, a relative increase in conductivity values usually indicates a local increase in clay content or water saturation. However, if there is a corresponding increase in the inphase response, the influence of some artificial source is likely (i.e. metal).


Shallow limestone bedrock
Change in bedrock lithology
Clay rich in-filled material
25
0
25
50
metre


Reduction in 'clay' rich material
Buried services
Conductivity
mS/m
48
46
44
42
40
38
36
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
0
20 m

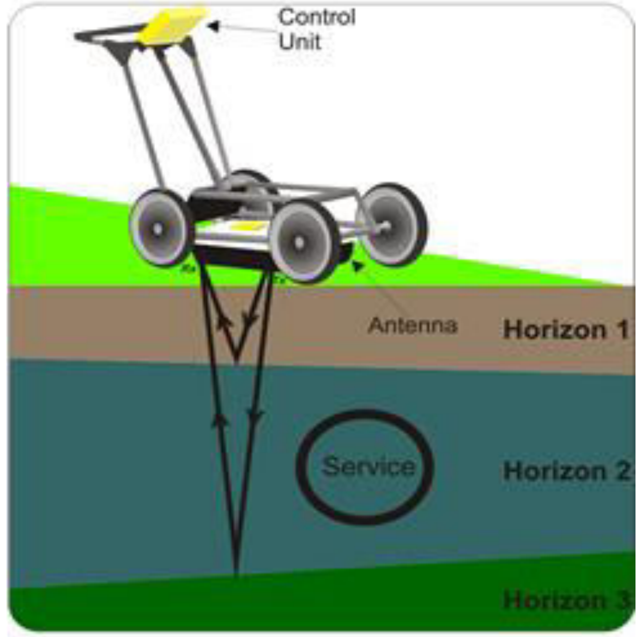
Ground Penetrating Radar (GPR)

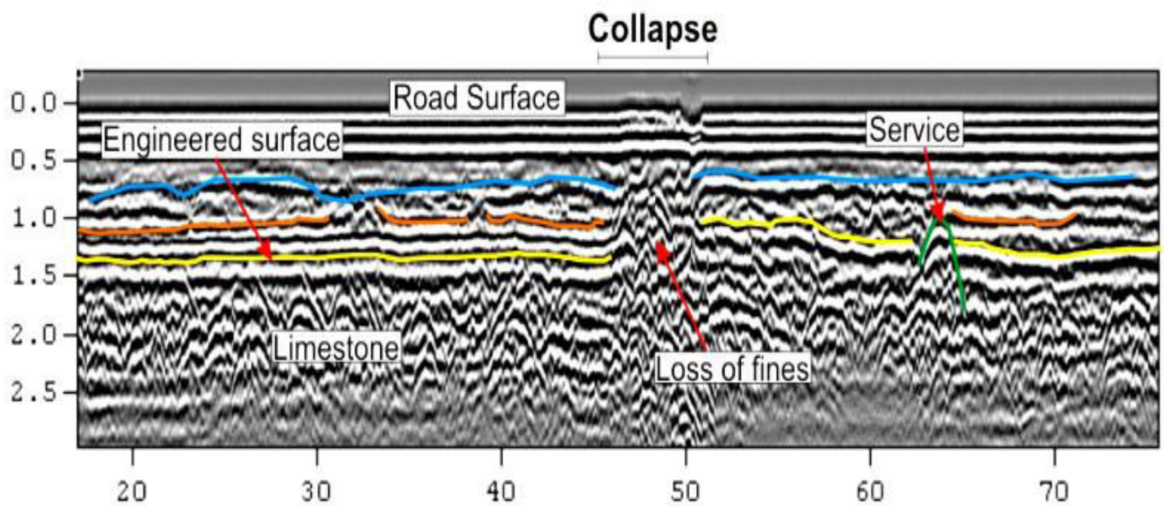
A Ground Penetrating Radar (GPR) survey involves one or two people either continuously towing a radar system or taking readings at very closely spaced intervals along selected traverse lines. GPR systems use a pulsed electromagnetic (radio wave) transmitted via a tuned frequency antenna that can penetrate soils, rock, concrete, and many other natural and man-made materials. Reflection events from geological or hydrological boundaries between sufficiently contrasting materials are recorded via a receiver antenna. A time-depth cross-section (radargram) of the shallow subsurface is constructed as the radar system is moved along a survey line. The radargram can be depth calibrated to enable detailed interpretation given known or measured velocities for the materials being investigated. While viewing relatively raw radar data can prove useful in the field there are numerous processing routines that can be employed to significantly improve the results. Final sections are presented showing annotated features of interest with apparent depth calibration.

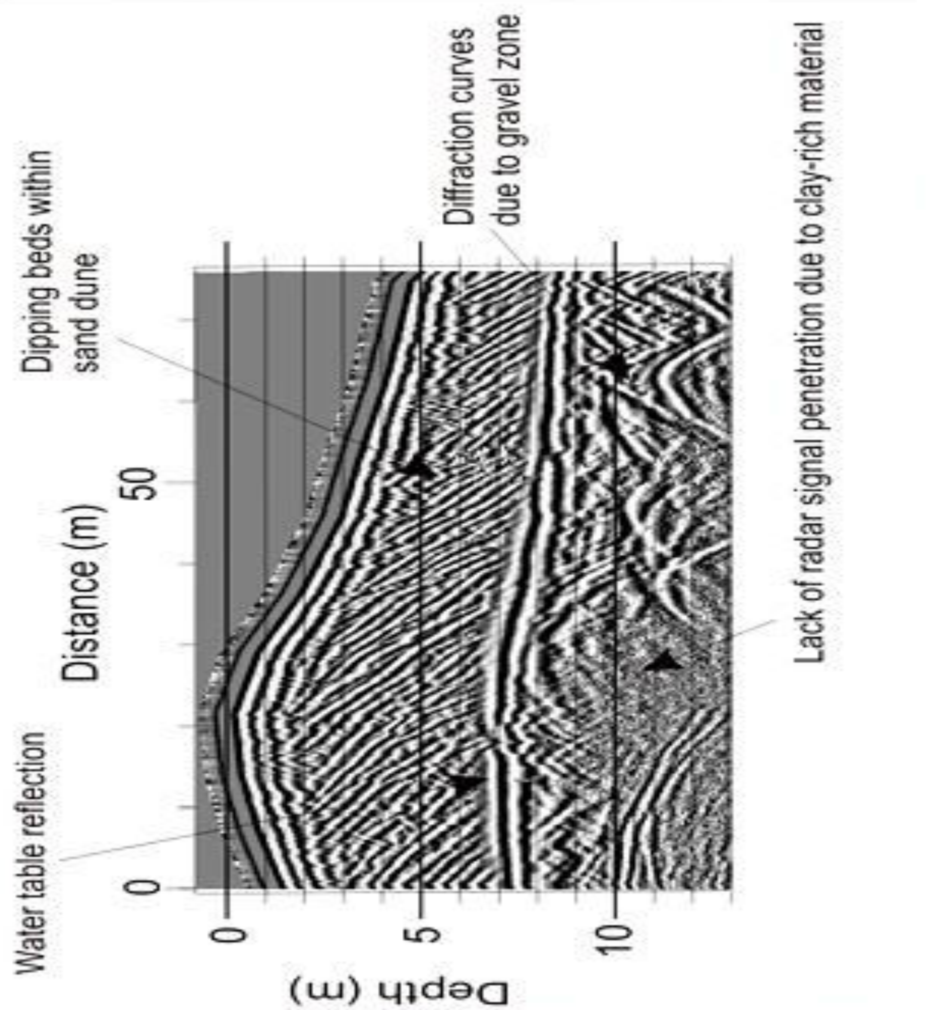
In order to improve the quality of the recorded radar data, a number of processing routines can be applied to the data using dedicated software (REFLEX). The final radar sections are converted to depth by applying a conversion velocity, which is usually based on an average velocity value for the local sediments. Without any additional calibration the measured depth to a particular feature is likely to be resolved within a 20% error margin depending on the local velocity structure.

GPR Survey in progress

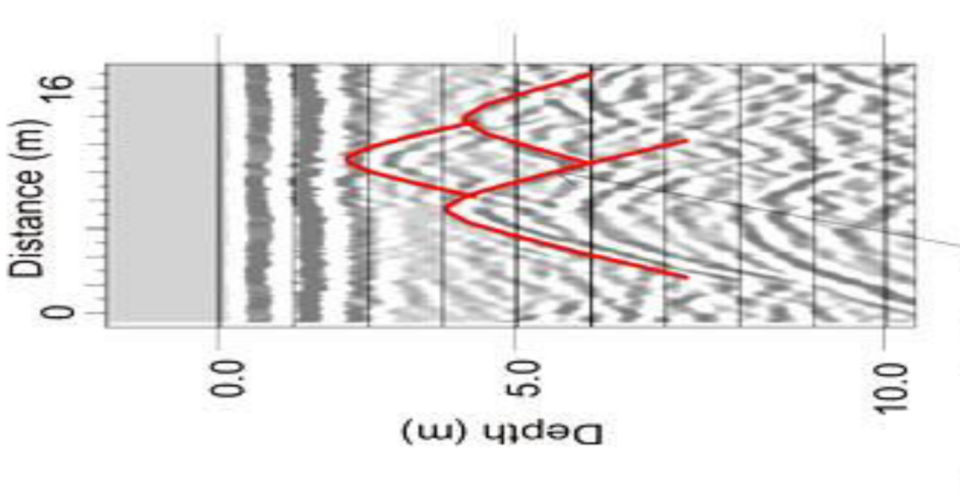
General principle of Ground Radar







Ground Radar profile over a parabolic sand dune (100MHz)

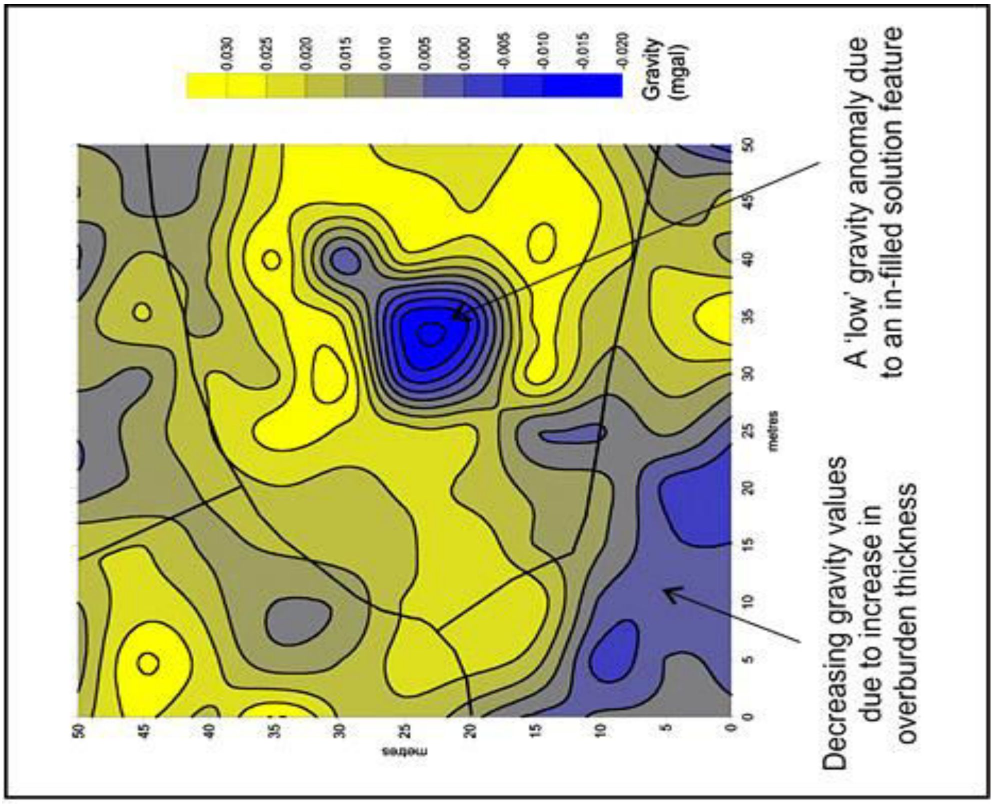


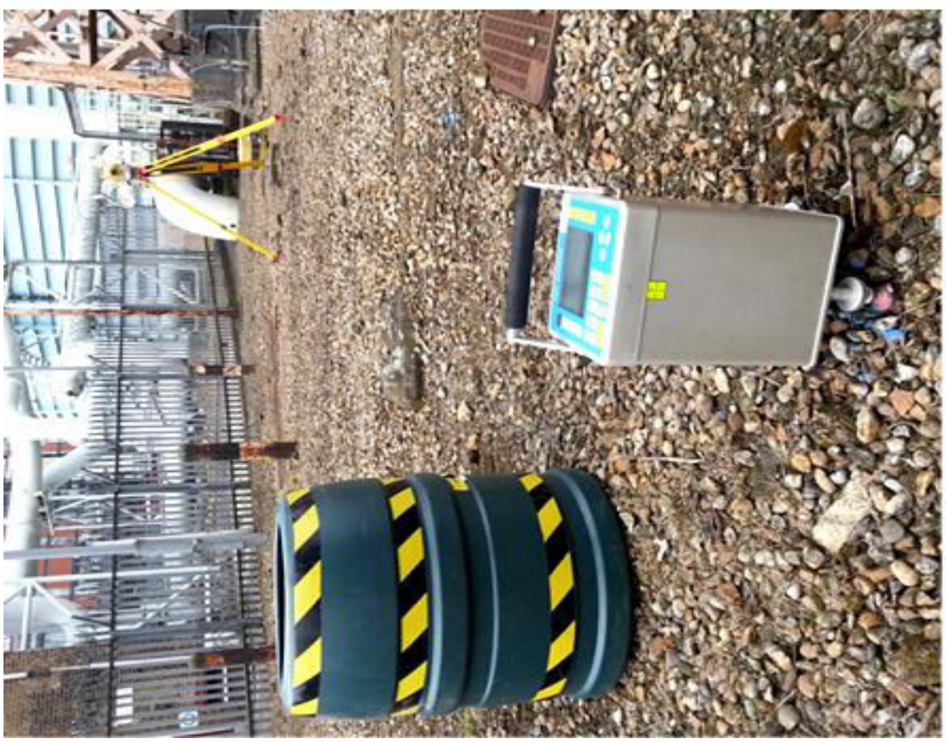
Observed diffraction curves over a sub-surface cavity within limestone

Microgravity surveys

The gravity technique is based on measuring localized variations in the Earth's gravitational field which are caused by materials of different densities. Typical targets for high resolution 'microgravity' surveys include (i) low density targets such as caves, fault zones, mine-workings and basements, and (ii) high density targets such as dykes, shallow rock, buried walls etc. The presence of an anomalously high (or low) density body in the subsurface causes a localised high (or low) anomaly in the measured gravitational field. The gravity effects described can be extremely small, however, modern instrumentation and exhaustive data processing techniques enable detection of both geological and artificial structures or voids. TerraDat also carries out regional gravity surveys targeting hydrocarbon traps or groundwater resources for local supply or geothermal energy.

The CG-5 gravity meter is a semi-automated system that enables statistical averaging and filtering of readings taken every second over a fixed period of time (typically 2-3 minutes). The elevation of the gravity instrument was recorded to a 1mm precision (<0.3cm error) at each survey station to facilitate accurate elevation correction. The results from the microgravity survey can be presented as a series of gravity profiles or colour contoured plot displaying the derived Bouguer Anomaly. Interpretation of the microgravity data is based on observing the shape, amplitude and wavelength of a particular anomaly and comparing it against the modelled gravity profile of a given target feature. In order to remove (reduce) background gravitational effects i.e. those that do not originate from the target feature, the following processing steps were applied to the acquired dataset using a combination of internal CG-5 software and TerraDat proprietary software GRED. Earth Tide, Temperature & Tilt Correction: Applied automatically by the gravity meter software.





Un-modeled Temporal Residual Correction: Obtained by least-squares fitting of a quadratic polynomial through the base station readings for each day. It is our normal practice to set the Bouguer anomaly at the base to zero so that the calculated values for the other stations are relative to a base station zero.

Latitude Correction: Calculated on the basis of the site latitude. Typically, due to the small latitude extent of the survey gird the correction is assumed to be linear per meter north.

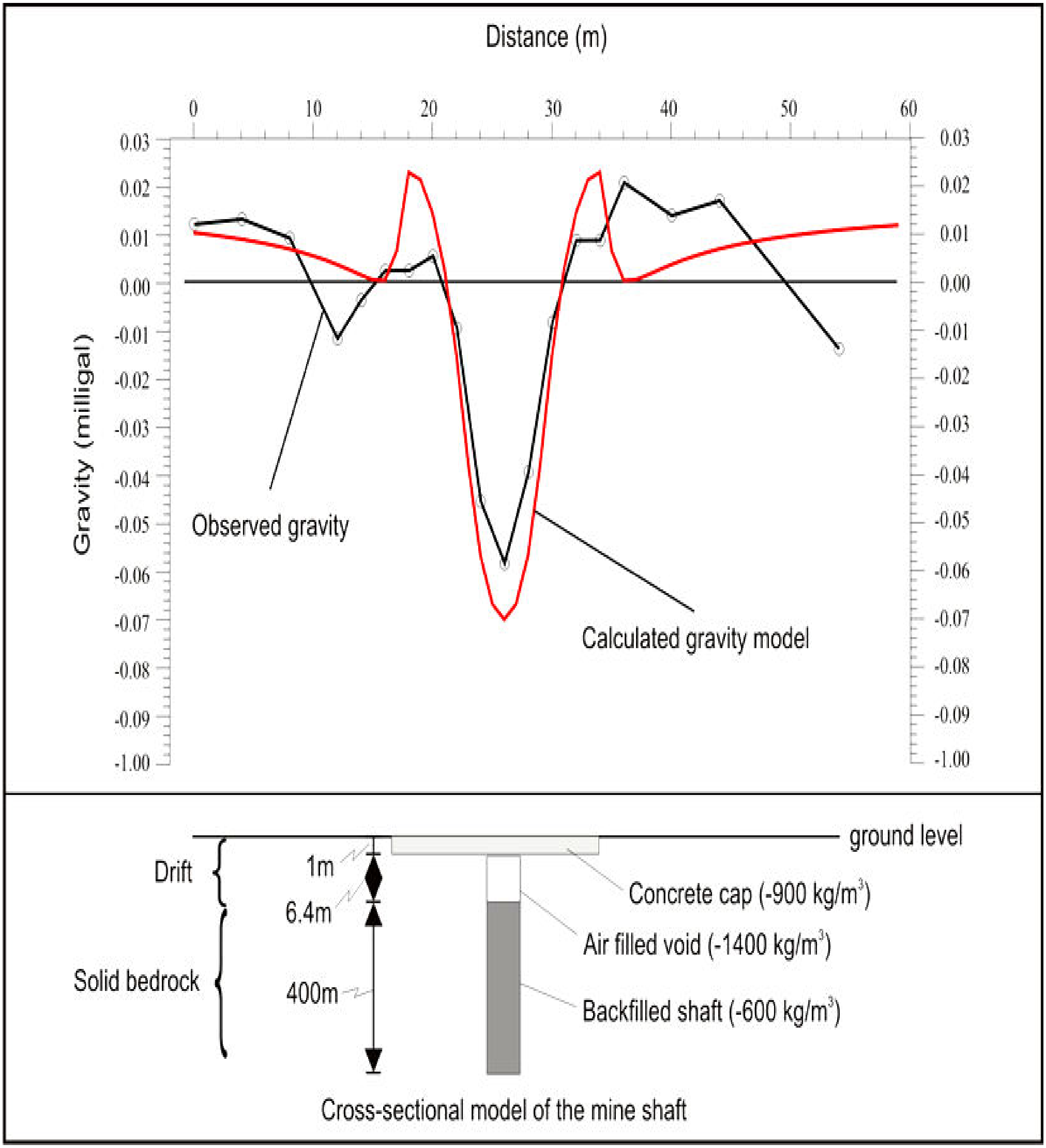
Free-air Correction: Applied to the dataset based on the instrument elevations, which were recorded to a 1mm precision (<0.3cm error) using an EDM survey system which is the Electronic Distance Measuring instrument. It is a **surveying** instrument for measuring distance electronically between two points through electromagnetic waves. This method of direct distance measurement cannot be implemented in difficult terrains. Also, station distances could be recorded by a network corrected GPS for regional scale surveys.

Terrain Correction: Based on the measured ground level at each gravity reading station and selected points beyond the survey grid. Bouguer Correction: The selection of the reduction density is based on site and geological consideration plus Nettleton's method where appropriate.

Constraints

The principal limitation on the use of gravity is the time required for careful acquisition and data processing. The detectability of a feature using the gravity methods is proportional to its size/depth ratio and its density contrast with the host material. There is a decrease in spatial resolution with increased depth of burial. In terms of site considerations, it is best to avoid sites with severe terrain or is have excessive vibrational noise.

A microgravity survey was carried out to target solution features beneath a site prior to a housing development. The microgravity data was acquired on a 5 x 5m grid and reduced to a Bouguer anomaly plan.

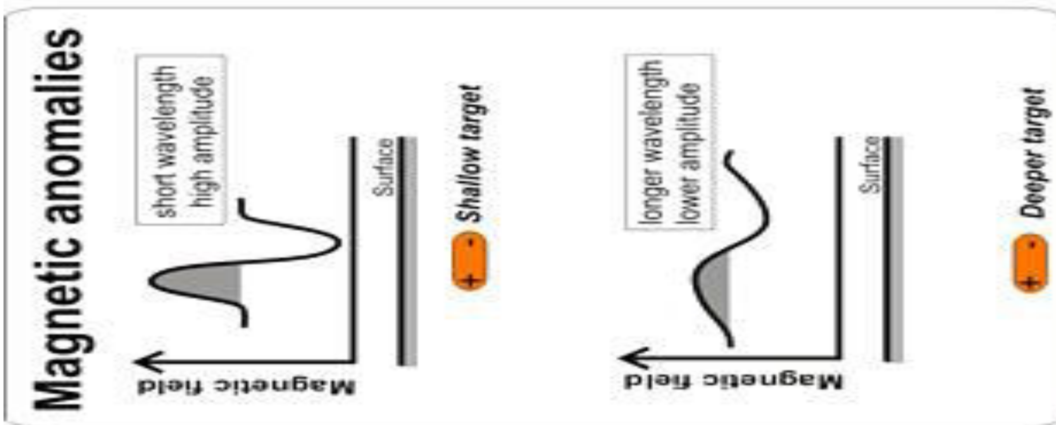


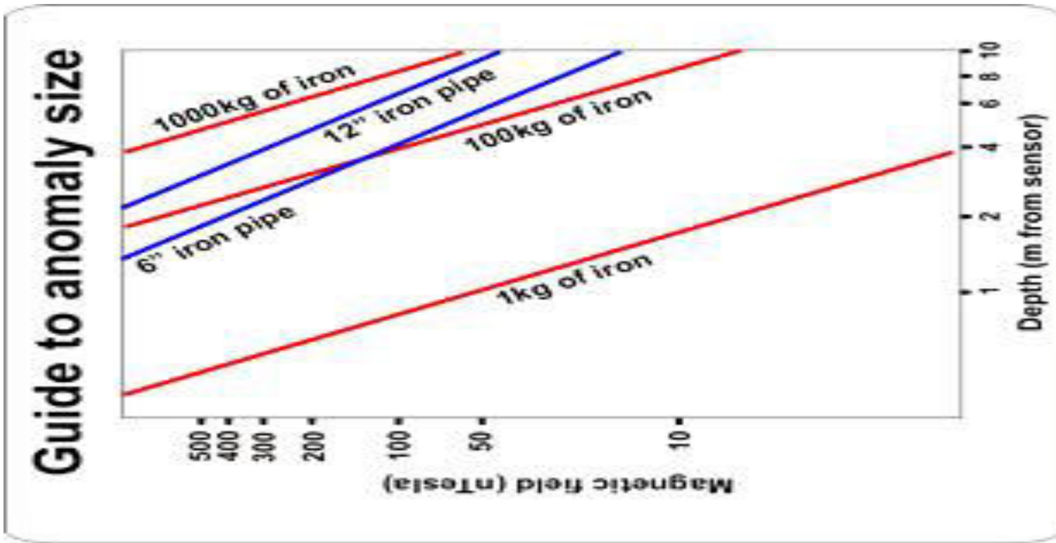
Magnetic surveys

The magnetic survey technique is based on mapping localized variations in the Earth's magnetic field caused sub-surface magnetic materials, which range from naturally occurring magnetic minerals to man-made ferrous objects. This leads to a wide range of applications from small-scale archeology and engineering surveys to detect buried metallic objects, to large-scale surveys carried out to investigate regional geological trends or mineralization.

Magnetic surveys are carried out using a man-portable instrument with readings taken on a regular grid or along selected traverse lines. The equipment functions by measuring the Earth's magnetic field to a very high precision at each survey station. Ferrous materials in the subsurface have an induced magnetic field that is superimposed on the Earth's field at that location creating a magnetic anomaly. The spacing of survey stations depends on the width of the expected anomaly, which broadens with the size, and depth of burial of the targeted feature. Continuous profiling methods may be used for a high-resolution dataset.


Gradiometer survey
top sensor
control unit/ data logger
bottom sensor

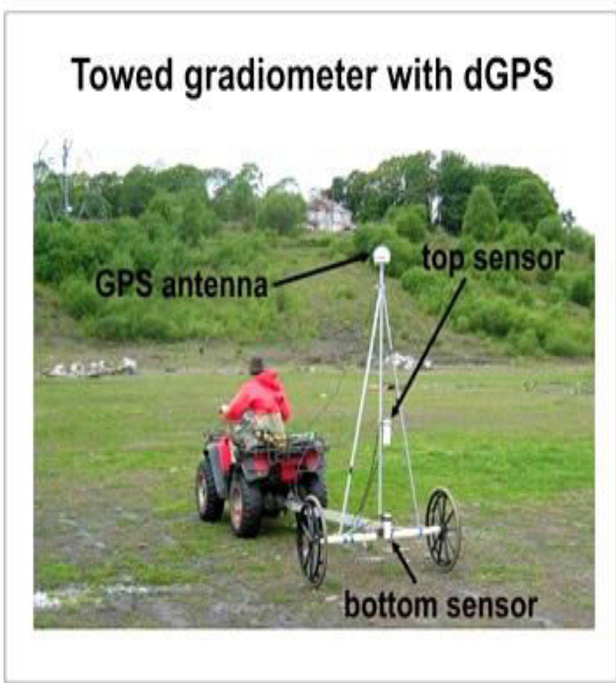

Magnetic anomalies
Magnetic field
short wavelength high amplitude
Surface
Shallow target
Magnetic field
longer wavelength lower amplitude
Surface
Deeper target

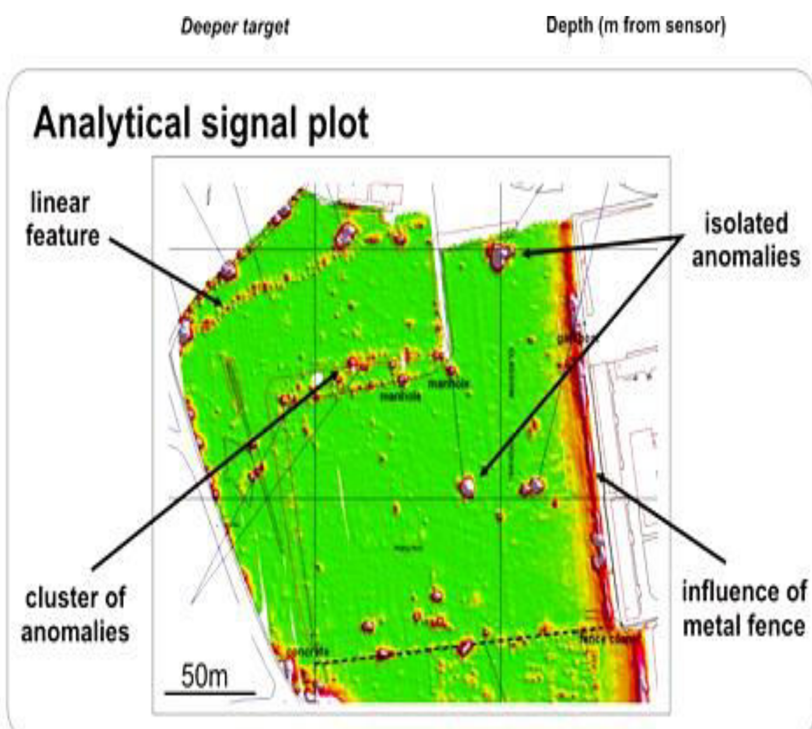

Guide to anomaly size
1000kg of iron
12" iron pipe
100kg of iron
6" iron pipe
1kg of iron
Magnetic field (nTesla)
500
400
300
200
100
50
10
Depth (m from sensor)
1
2
4
6
8
10

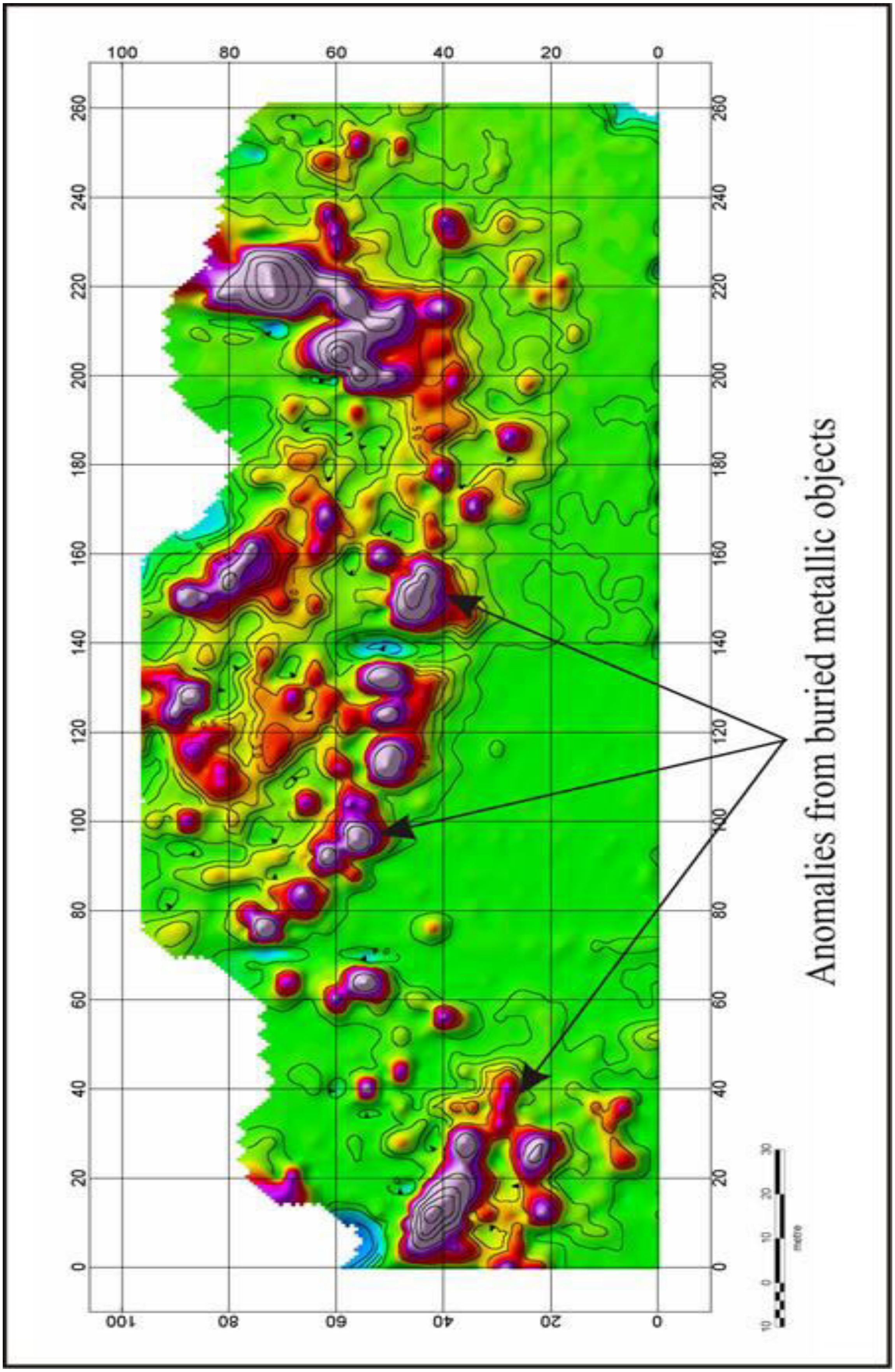
Magnetometer data are stored digitally by the survey instrument and down loaded to a field computer at the end of each day. The magnetic data are then processed to enhance any identifiable anomalies and presented on color-contoured plots overlain with site maps (when available).

The results of the magnetic survey are usually presented as total field and analytical signal plots. The total field data may be used to observe the general character of the magnetic field across the survey area while the peak values (pink) displayed on the analytical signal plot indicate the source positions for dipole type magnetic anomalies. In general terms, the interpretation of a magnetic anomaly is based on observing the type (pole/dipole), amplitude and wavelength of the anomalous features.

Metal objects or structures close to the survey area (fences, vehicles, debris etc.) produce a strong signal that can overshadow more subtle effects of sub-surface anomalies.






Anomalies from buried metallic objects
metre

Crosshole Seismic survey

Seismic methods can provide detailed information about rock properties and geological structure between boreholes. Fewer boreholes are needed to achieve a continuous picture of the subsurface thereby reducing overall costs and the risk of missing target features. Borehole seismic methods largely fall into two categories, namely, Crosshole Seismic and Seismic Tomography.

Crosshole Seismic typically involves shooting at regular depth intervals from one borehole to another and simply deriving velocity of the signal travelling between them. Given the measured velocities it is possible to derive elastic modulae for the material between the boreholes as it varies with depth. Carrying out a survey using compressional (P) waves and shear (S) waves enables derivation of Poisson's ratio while the introduction of density information (from measurement or estimation) enables derivation of Bulk Modulus and Shear Modulus values.

TerraDat's New Electro-mechanical (S & P) wave source for Crosshole Surveys

Down-hole Shear wave survey through colliery spoil, South Wales

Borehole Seismic Tomography typically involves shooting at discrete depth intervals in one borehole and measuring the velocity of signal travelling to multiple receivers at different depths in another borehole. Using this method, data are acquired along a great number of ray-paths between boreholes enabling derivation of a detailed image of the rock mass through tomographic inversion of the data. The method can be used to resolve features such as voids, large fracture zones and geological structure where contrasting lithologies are encountered.

Typical Targets: Geological Hazards

Elastic Modulae

Fracture Zones

Caves/Stopes/Adits

Rock Structure

Benefits of Borehole Seismic:

Cost Efficient

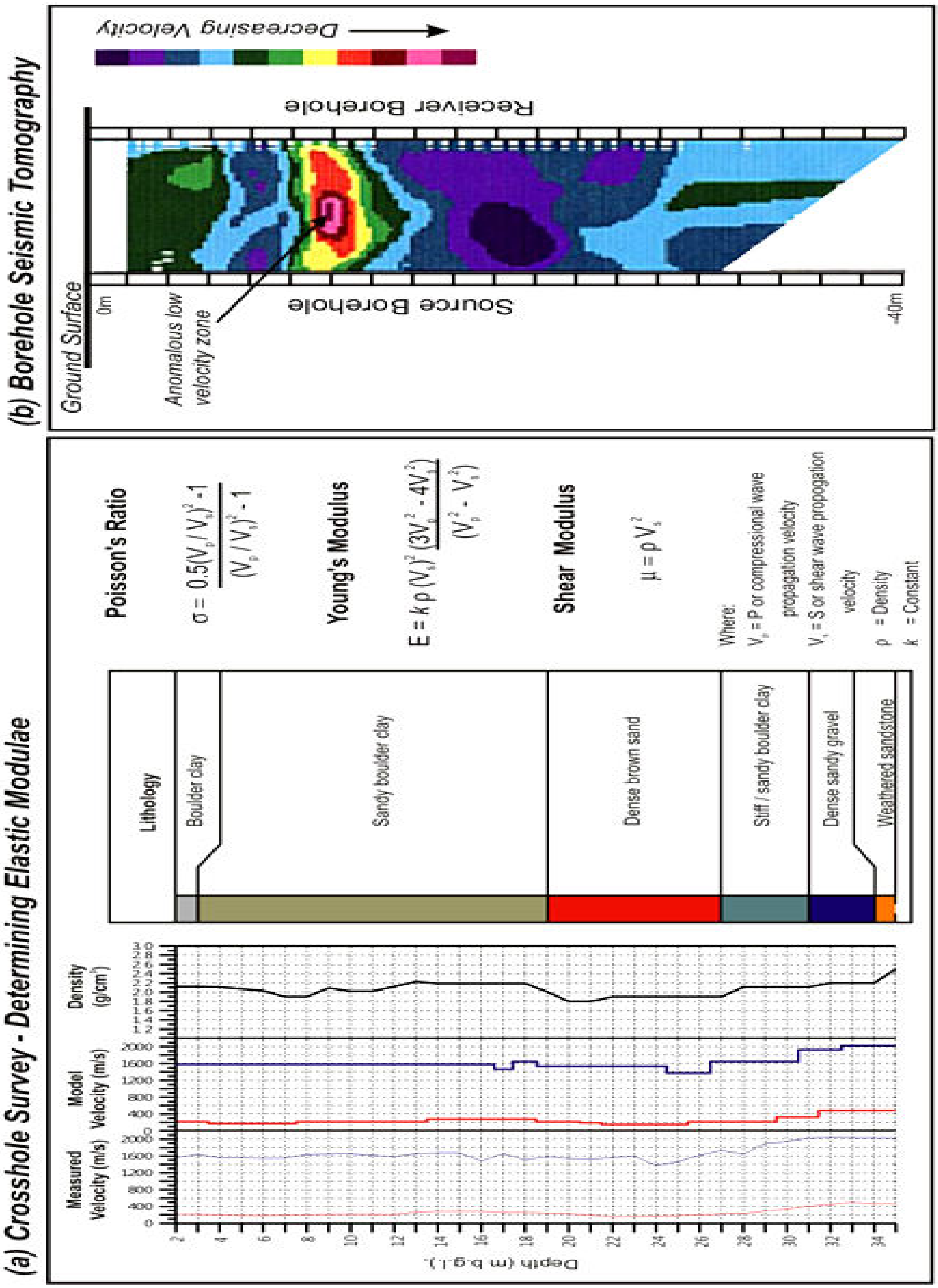
Images between Boreholes

Good Productivity

Non-invasive

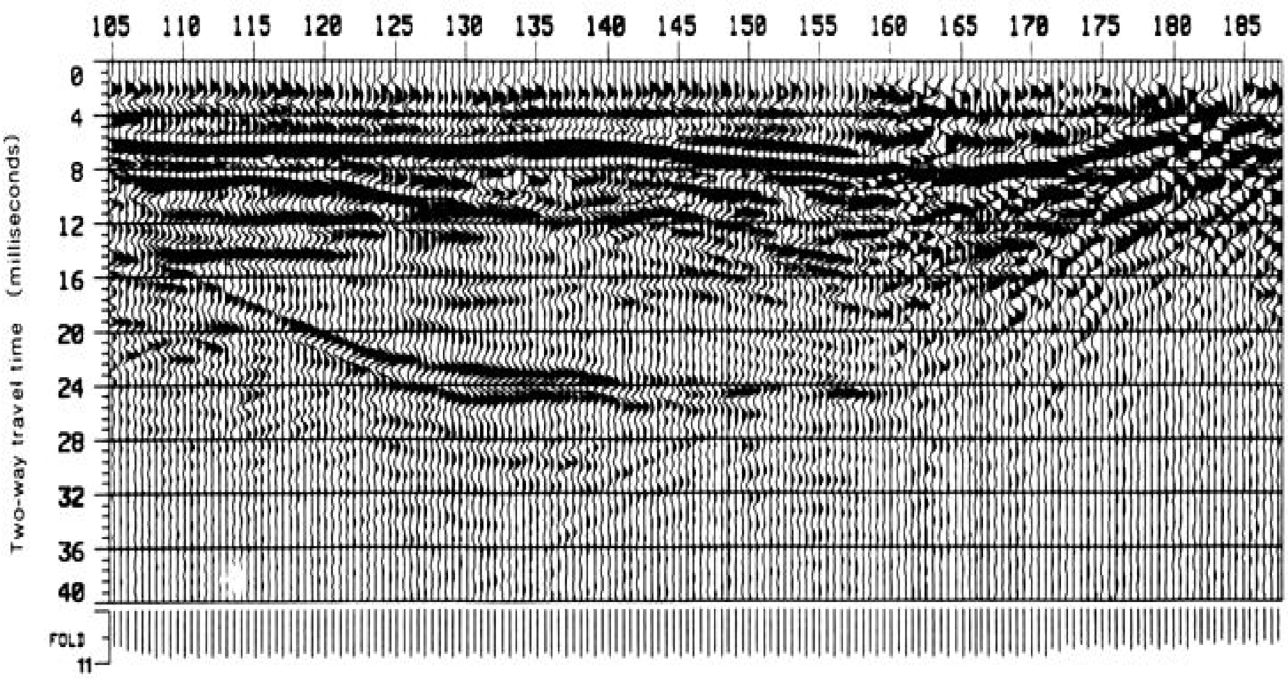
Environmentally Friendly

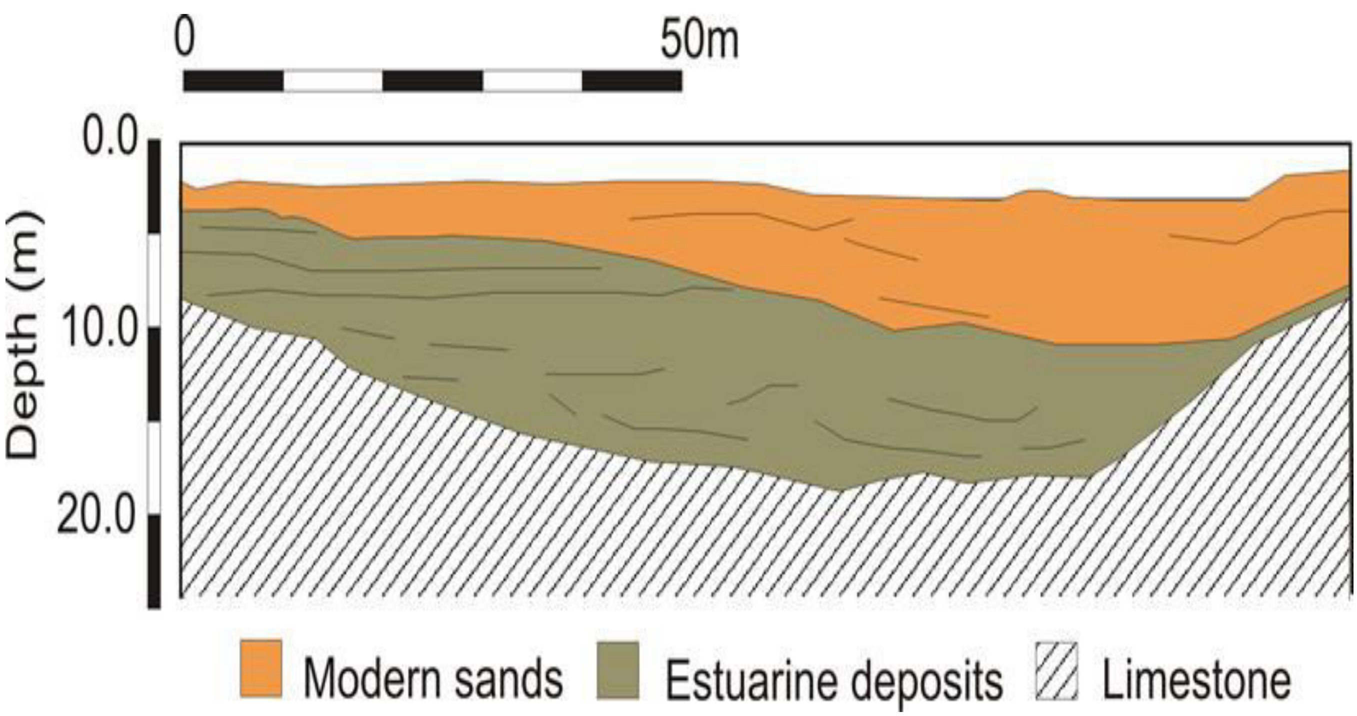
The dynamic elastic modulae of the rock mass between boreholes can be readily derived using Crosshole seismic methods. Density information is required for some modulae and may be estimated from known lithological properties, measured directly in the field/lab or derived from a borehole logging survey. (b) the identification of low velocity zones such as a cavity/solution feature, fracture zone or workings are common requirements of a seismic tomography surveys and are clearly observed on the resulting tomogram.



Seismic Reflection Method

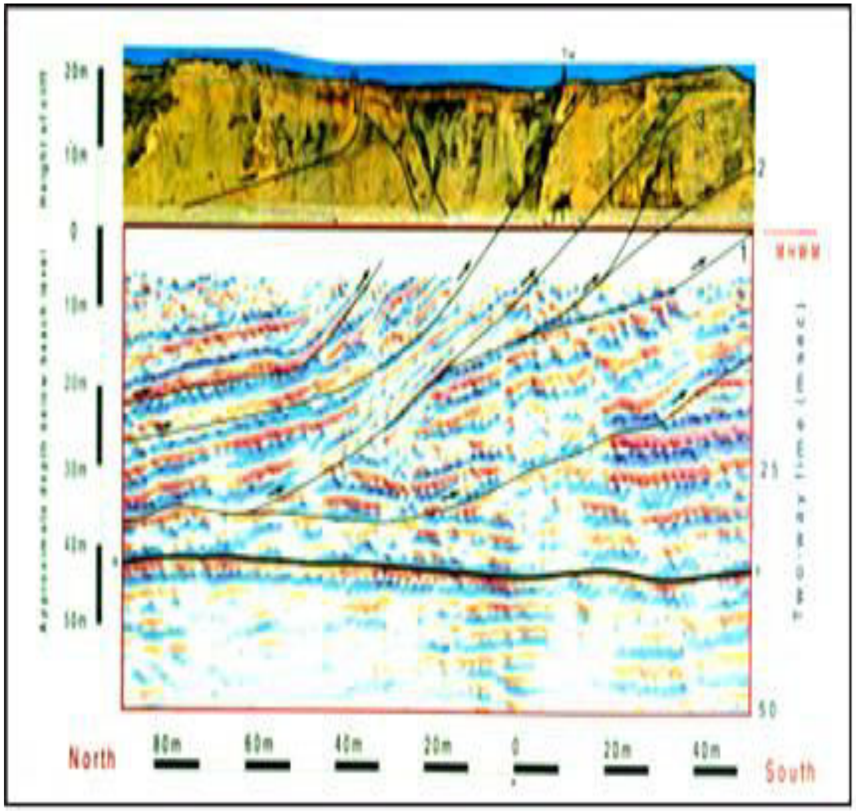
High-resolution seismic reflection surveys are designed and implemented for onshore and shallow marine environments. The geophysical surveying company routinely carries out seismic survey work for geotechnical and environmental applications as well as larger scale work for oil/mineral exploration.



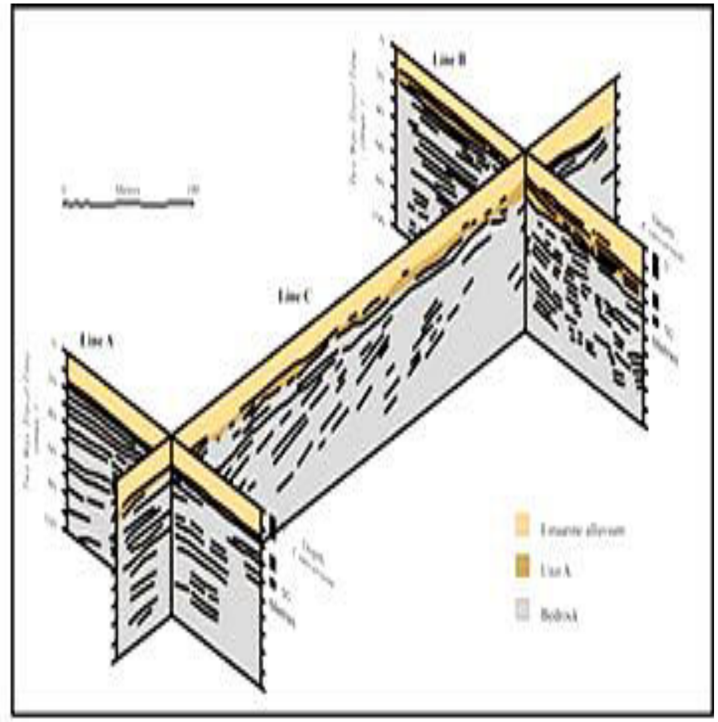


The range of seismic systems could be configured to meet the particular project requirement. These range from a simple 24-channel seismograph with PC based processing software to the latest 120 channel telemetry seismic systems and PROMAX software.

Surveying is actively involved with ongoing research into the use of shallow seismic reflection in testing environments with an incentive to promote its use for a more diverse range of applications. Several publications have been produced over the years and are available on request. The method requires careful planning where very shallow depths are to be investigated but the results can prove to be invaluable.



(ABOVE) High resolution seismic reflection data showing the internal structure of glacio-tectonic deposits in North Wales.

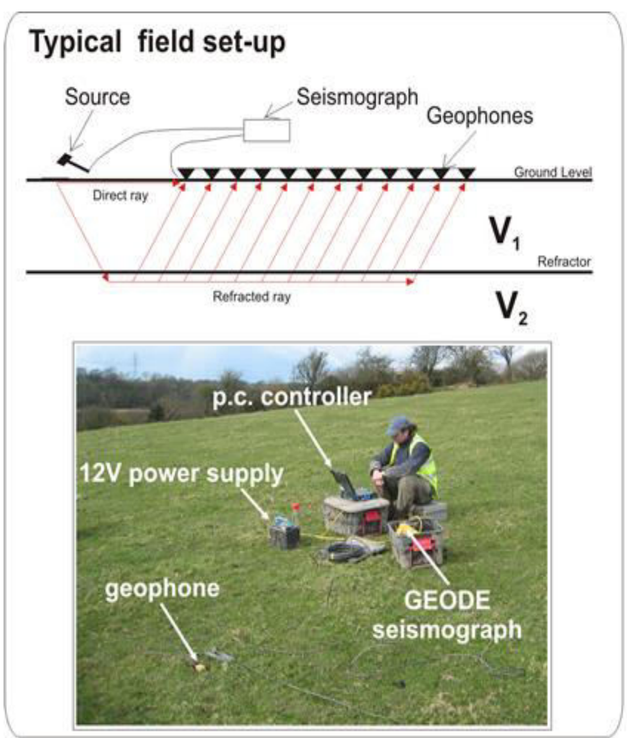


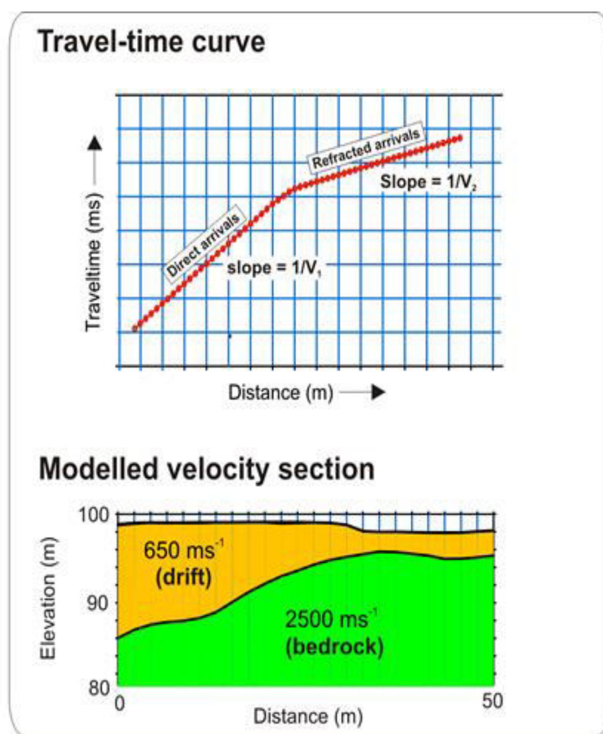
(ABOVE) Three dimensional representation of coal measure structure beneath a South Wales estuary.

Seismic Refraction Method

Seismic refraction is a useful method for investigating geological structure and rock properties. The technique involves the observation of a seismic signal that has been refracted between layers of contrasting seismic velocity, i.e., at a geological boundary between a high velocity layer and an overlying lower velocity layer.

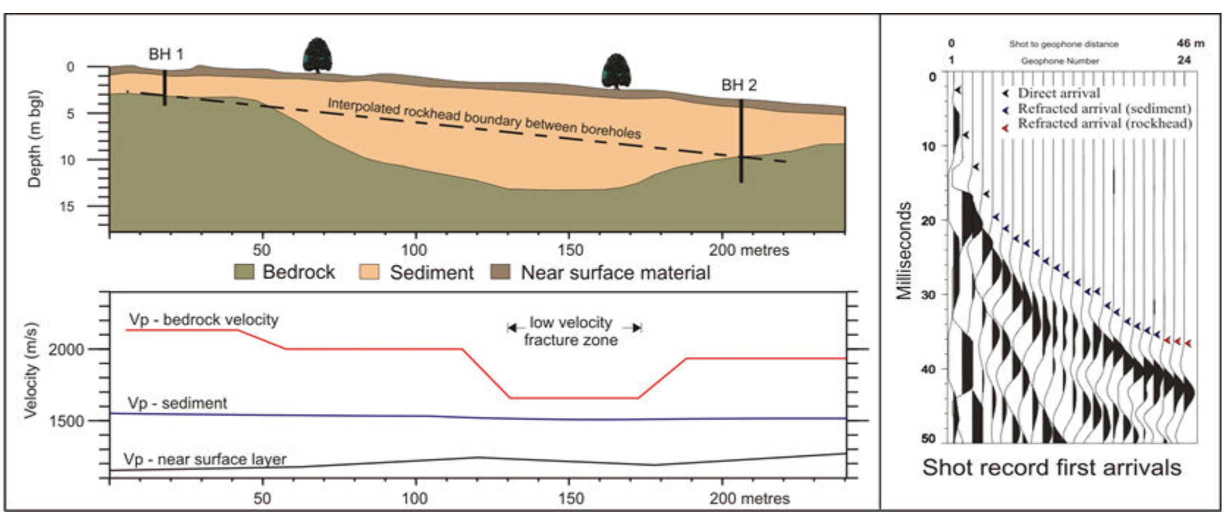
Shots are deployed at the surface and recordings made via a linear array of sensors (geophones or hydrophones). Refracted seismic signal travels laterally through the higher velocity layer (refractor) and generates a 'head-wave' that returns to surface. Beyond a certain distance away from the shot, the signal that has been refracted at depth is observed as first-arrival signal at the geophones. Observation of the travel-times of refracted signal from selectively deployed shots enables derivation of the depth profile of the refractor layer. Shots are typically fired at locations at and beyond both ends of the geophone spread and at regular intervals along its length.





The results of the seismic refraction survey are usually presented in the form of seismic velocity boundaries on interpreted cross-sections. Seismic sections represent the measured bulk properties of the subsurface and enable correlation between point source datasets (boreholes/trial pits) where underlying material is variable. Reference to the published seismic velocity tables enables derivation of approximate values.

The data processing is carried out by using software like: PICKWIN & PLOTREFA (OYO ver2.2). The first stage involves accurate determination of the first-arrival times of the seismic signal (time from the hammer blow to each recording hydrophone) for every shot record, using PICKWIN. Time-distance graphs showing the first-arrival times were then generated for each seismic shot record and analyzed using PLOTREFA software to determine the number of seismic velocity layers. Modeled depth profiles for the observed seismic velocity layers are produced by a tomographic inversion procedure that is revised iteratively to develop a best fit-model. The final output of a seismic refraction survey is a velocity model section of the subsurface based on an observed layer sequence with measured velocities that correspond to physical properties such as levels of compaction/ saturation in the case of sediments and strength/rippability in the case of bedrock.



Constraints

Layer velocity (density) must increase with depth; true in most instances. Layers must be of sufficient thickness to be detectable. Data collected directly over loose fill (landfills) or in the presence of excessive cultural noise may result in sub-standard results. In places where compact clay-rich tills and/or shallow water overly weak bedrock an S-wave survey may be used to profile rockhead where insufficient velocity contrast may prevent use of a P-wave survey.

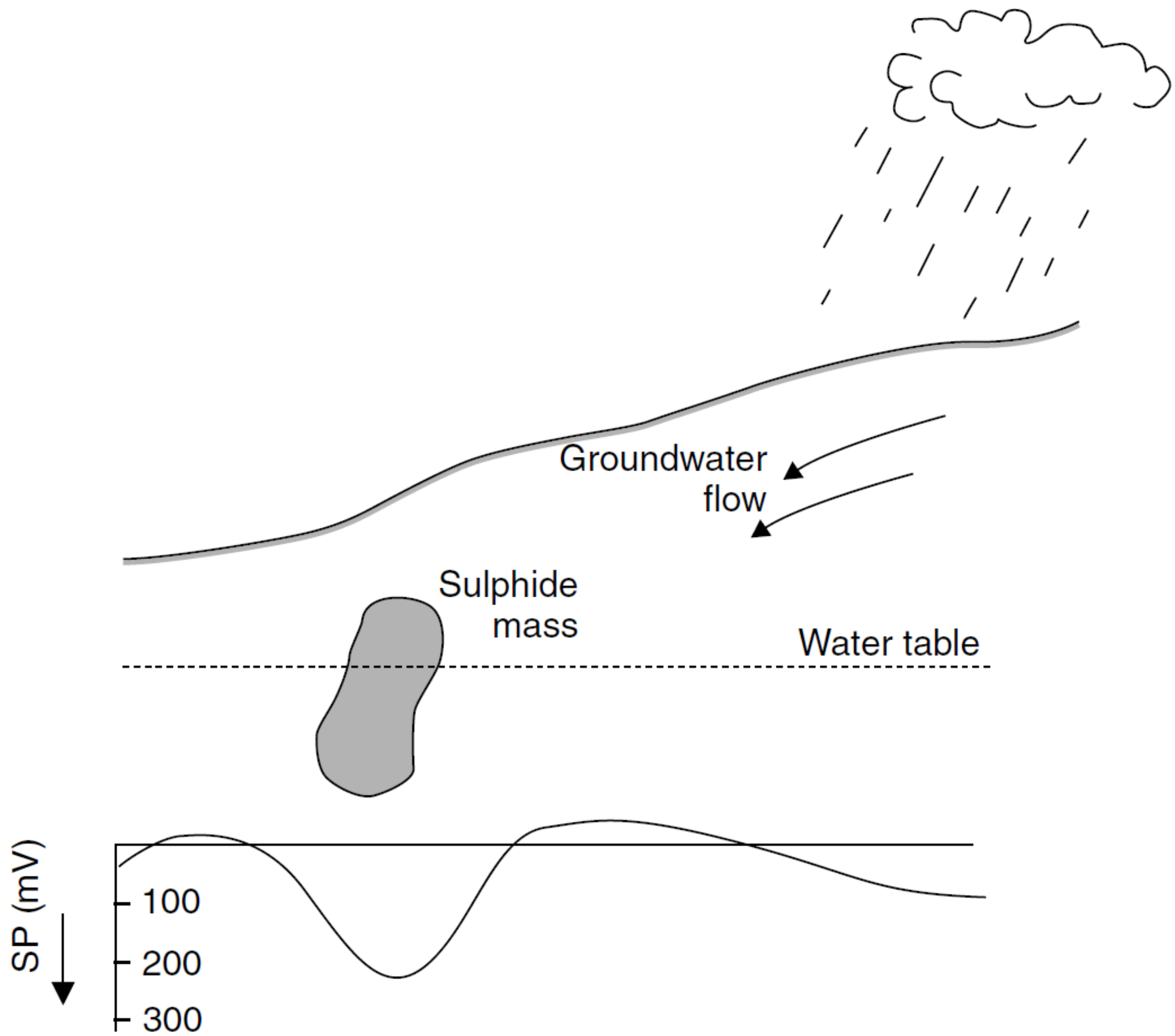
Electrical Self Potential (SP) Surveys

SP surveys were at one time popular in mineral exploration because of their low cost and simplicity. They are now little used because some near-surface ore bodies that are readily detected by other electrical methods produce no SP anomaly.

Origins of natural potentials

Natural potentials of as much as 1.8 V have been observed where Alunite (**Alunite** is a hydroxylated aluminium potassium sulfate mineral, formula $KAl_3(SO_4)_2(OH)_6$), weathers to sulphuric acid, but the negative anomalies produced by sulphide ore bodies and graphite are generally less than 500 mV. The conductor should extend from the zone of oxidation near the surface to the reducing environment below the water table, thus providing a low-resistance path for oxidation–reduction currents (see the following figure).

From the following figure Sources of SP effects. The sulphide mass straddling the water table concentrates the flow of oxidation–reduction currents, producing a negative anomaly at the surface. The downslope flow of groundwater after rain produces a temporary SP, in this case inversely correlated with topography.



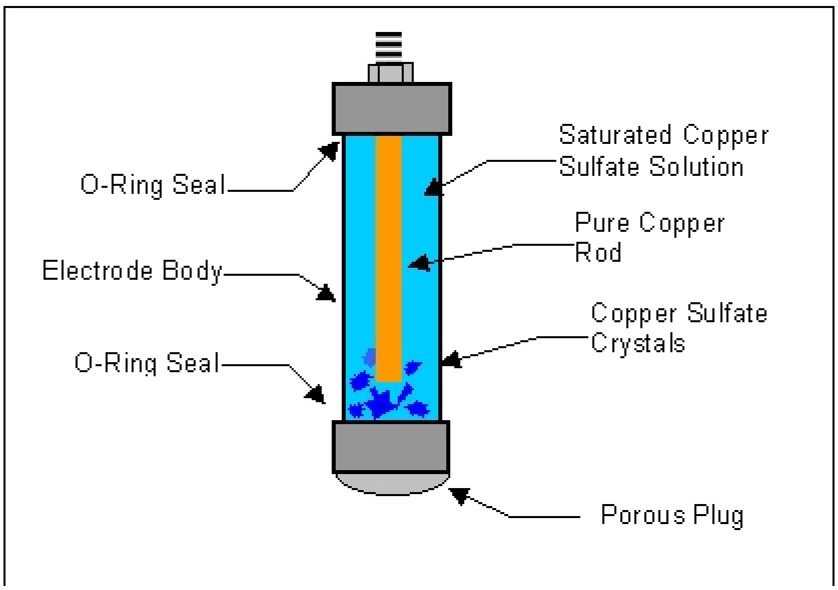
sometimes SP surveys are useful in hydrogeology but can make mineral exploration surveys inadvisable for up to a week after heavy rain.

Movements of steam or hot water can explain most of the SPs associated with geothermal systems, but small (<10 mV) voltages, which may be positive or negative, are produced directly by temperature differences. Geothermal SP anomalies tend to be broad (perhaps several kilometres across) and have amplitudes of less than 100 mV, so very high accuracies are needed.

Small alternating currents are induced in the Earth by variations in the ionospheric component of the magnetic field and by thunderstorms. Only the long-period components of the associated voltages, seldom amounting to more than 5 mV, are detected by the DC voltmeters used in SP surveys. If, as is very occasionally the case, such voltages are significant, the survey should be repeated at different times of the day so that results can be averaged.

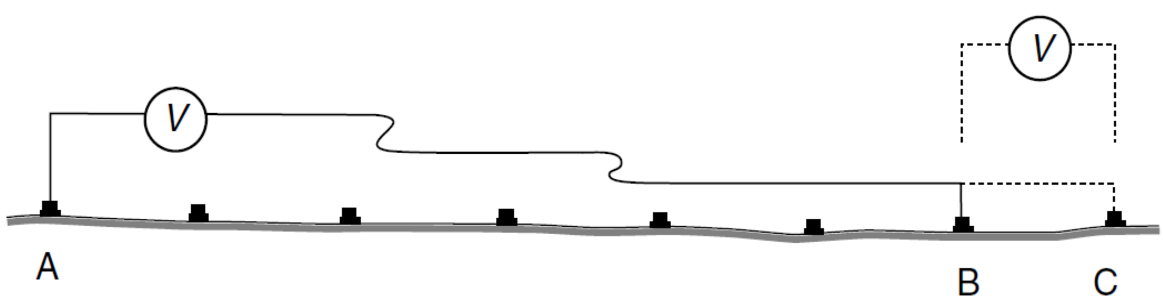
SP surveys

Voltmeters used for SP work must have millivolt sensitivity and very high impedance so that the currents drawn from the ground are negligible. A pair of Copper/ copper-sulphate 'pot' electrodes are almost universal is used; see the following figure, and linked to the meter by lengths of insulated copper wire.



An SP survey can be carried out by using two electrodes separated by a small constant distance, commonly 5 or 10 m, to measure average field gradients. The method is useful if cable is limited, but errors tend to accumulate and coverage is slow because the voltmeter and both electrodes must be moved for each reading. More commonly, voltages are measured in relation to a fixed base. One electrode and the meter remain at this point and only the second electrode is moved. Sub-bases must be established if the cable is about to run out or if distances become too great for easy communication. Voltages measured from a base and a sub-base can be related provided that the potential difference between the two bases is accurately known.

The following figure shows how a secondary base can be established. The end of the cable has almost been reached at field point B, but it is still possible to obtain a reading at the next point, C, using the original base at A. After differences have been measured between A and both B and C, the field electrode is left at C and the base electrode is moved to B. The potential difference between A and B is thus estimated both by direct measurement and by subtracting the B to C voltage from the directly measured A to C voltage. The average difference can be added to values obtained with the base at B to obtain values relative to A.



The figure above shows how to move a base station in an SP survey. The value at the new base (B) relative to A is measured directly and also indirectly by measurements of the voltage at the field point C relative to both bases. The two estimates of the voltage difference between A and B are then averaged.

Constraints

If two estimates of a base/sub-base difference disagree by more than one or two mill volts, work should be stopped until the reason has been determined. Usually it will be found that copper sulphate solution has either leaked away or become under saturated. Electrodes should be checked every two to three hours by placing them on the ground a few inches apart. The voltage difference should not exceed 1 or 2 mV. Accumulation of errors in large surveys can be minimized by working in closed and interconnecting loops around each of which the voltages should sum to zero .

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