GEM-2 electromagnetic ground conductivity mapping

Electro-magnetic (EM) ground conductivity mapping has been in use since the early 1960s and is one of the most frequently used geophysical methods in environmental and engineering applications today. The GEM-2, manufactured by Geophex, is the first widely-used multi-frequency instrument. It has been in use commercially since 1994. For discussion of the EM method see Reynolds (2011).

Principle of operation

An electro-magnetic field is transmitted in air using a coil of wire separated from a receiver coil by a fixed distance of 1.66 m, the two coils being housed in each end of a boom or 'ski' of 1.83 m length. The ski is carried horizontally; as there is no requirement to couple the coils with the earth it is usual for the operator to carry the ski a set distance above the ground. The transmitted energy propagates into the sub-surface where a secondary electro-magnetic field is generated due to the effect of soil moisture, conductive earth materials and buried objects. Both fields are detected at the receiver coil, but the instrument compensates for the primary field, enabling measurement of the secondary. The ratio of the field strengths is controlled by the apparent conductivity of the ground through which the EM radiation has passed.

Modes of deployment

As with popular single-frequency instruments, the instrument has two modes of deployment: horizontal magnetic dipole and vertical magnetic dipole, shortened to HMD and VMD respectively. The two operating modes are defined by the orientation of the coils relative to the ground surface. When the plane of the coils lies parallel to the ground surface, the Magnetic Dipole orientation is said to be vertical, hence the term Vertical Magnetic Dipole. Conversely, when the coils are at right-angles to the ground surface, the instrument is said to be in the Horizontal Magnetic Dipole orientation.

The depth penetration of the GEM-2 is dependent on the coil orientation and on the frequency. The GEM-2 can record up to fifteen frequencies simultaneously. The frequency band within which the GEM-2 operates is 330 Hz to 48 kHz. Higher frequencies generally respond to shallower parts of the ground than lower frequencies, so using a range of frequencies means that a greater range of depths is sampled than would be using a single frequency. However, the resistivity of the ground limits the depth to which any EM instrument can 'see'. Geophex estimate the GEM-2 should be able to see about 20-30 m in resistive areas (>1000 Ωm) and about 10-20 m in conductive areas (<100 Ωm). The more conductive the ground, the shallower the GEM-2 can see; for very conductive ground conditions the depth at which the lower frequencies sense is greater than the depth to which the EM radiation can penetrate, and the lower frequencies are effectively blinded. The more frequencies that are used, the less power is assigned to each frequency, so in noisy environments (for example urban sites) fewer frequencies are used than on quiet sites (for example rural areas). Generally, three to five frequencies are used on a typical survey, and the range of frequencies is carefully chosen to return the most usable data possible.

Figure 1: A GEM-2 survey in progress using a vertical dipole/horizontal coil orientation.

Interpretation

The GEM-2 measures two components of the field for each dipole orientation/frequency pair, termed the *in-phase* and *quadrature* components. This means that for a five frequency survey, ten datasets will be recorded. The quadrature component indicates the bulk *apparent conductivity* of the volume of ground sampled, in milli-Siemens per metre (mS/m). Conductivity is the inverse of resistivity; the value measured is an apparent conductivity because it represents an average of the true conductivity values of all materials within the sampled volume. Changing the GEM-2 frequency changes the sample volume, hence values obtained using different frequencies over the same ground will differ.

The true conductivity value is a physically diagnostic property and can be used to differentiate between ground materials. The apparent conductivity can be used to map broad changes in ground materials. To identify possible buried objects and contaminant plumes the interpreter will look for anomalous values in the data. Each frequency/component pair is usually plotted as separate 2D areal plans, although individual profiles can be extracted for detailed interpretation, so a knowledge of characteristic anomalies is important. Linear items such as pipes, wall bases and building foundations are good targets as they produce correspondingly-shaped anomalies in the data set.

Comparison of 2D areal plans for different frequencies gives insight into changes in the conductivity (and hence the nature of the ground) across a site (Figure 2). The 47 kHz data (*left*) reveal the presence of a shallow zone of lower conductivity (A), while the 15 kHz data (*right*) show a broader low-conductivity zone, implying that conductivity increases with depth in the near-surface of this site.

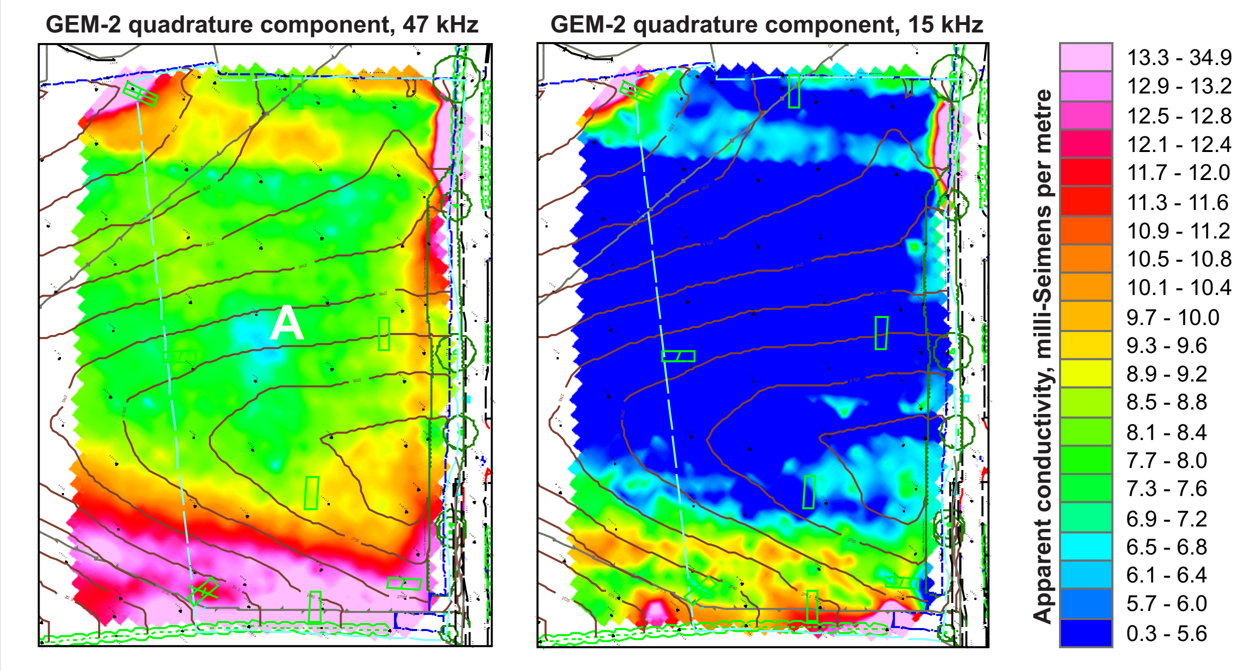

Figure 2: Quadrature data for two different frequencies over a site with varying thickness of overlying glacial till.

The in-phase component is expressed in parts per thousand (ppt). Phase changes between the primary and secondary field are used to indicate the presence of metallic objects. In-phase component data provide information on the likely presence of buried metal objects. Combined interpretation of in-phase and quadrature component data may inform the interpreter as to whether an anomaly is caused by a metallic item rather than increased moisture content or a change in the groundwater properties such as that caused by certain contaminants.

Reference

Reynolds, J.M. 2011. *An Introduction to Applied and Environmental Geophysics*. John Wiley & Sons Ltd, Chichester, 2nd ed., 712 pp.