

Spectral Induced Polarisation (SIP)

Induced polarisation (IP) is a comparatively new geophysical technique. IP effects were first reported as early as 1912, and the method has been in use since the late 1940s. IP is used primarily for mineral exploration, and is also being developed as a tool for geothermal, hydrological and environmental applications. There are several types of IP techniques, but essentially IP is an extension of traditional resistivity surveying. The ground is characterised not only by its resistivity, but also by its *chargeability* (how well it holds electrical charge). In spectral induced polarisation (SIP), the ground is further characterised by how it reacts to electrical currents at different frequencies. More information about IP methods is given by Reynolds (2011).

Principles of operation

The IP and SIP methods involve passing a current through the ground through two current electrodes ('C') and measuring a voltage across two potential electrodes ('P'). The same configurations of electrodes, or arrays, can be used as in resistivity surveying, but the most popular are the dipole-dipole and pole-dipole arrays (Figure 1). Greater depth of investigation can be achieved by increasing the distance between the electrodes.

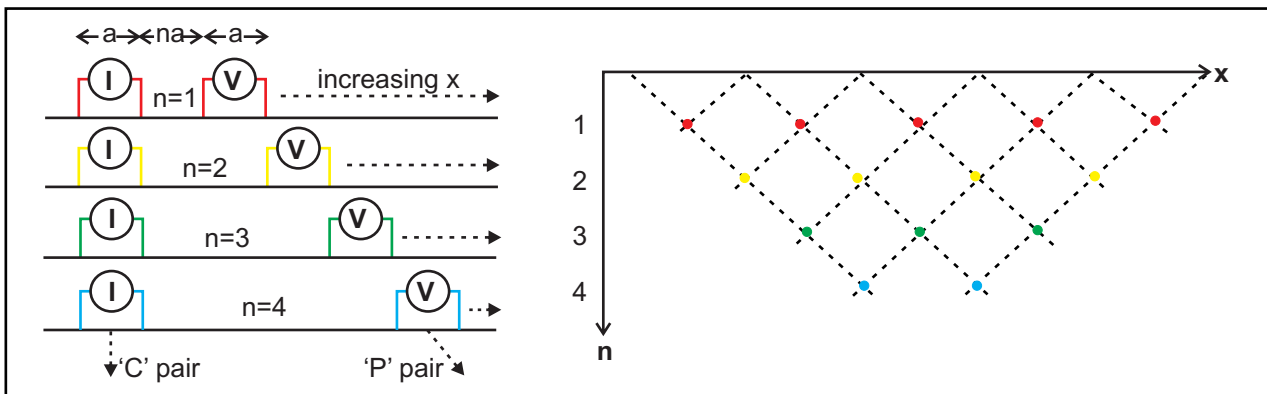


Figure 1: Reading geometry for SIP surveying using the dipole-dipole array. *Left:* Electrode positions on the ground. *Right:* Plotting positions for each x, a, n combination.

When a current is injected into the ground, the ground charges up, or polarises, like a capacitor. When the current is turned off, the induced charge takes a finite time to dissipate. The time taken for the charge to build up (or dissipate) varies not only with the chargeability of the ground, but also with the frequency of the applied current. In IP and SIP surveying, non-polarisable electrodes are used (electrodes that do not retain any charge) so that all the signal observed comes from the ground itself. IP and SIP surveying can be carried out in vertical sounding, horizontal profiling or 2D and 3D tomography modes. In spectral IP, measurements are taken using input currents with a range of frequencies between 0.3 and 4 kHz. The magnitude of the induced voltage (V_o) and the time delay (alternatively *phase lag* or *phase angle*, ϕ) between the applied current and the induced voltage is recorded for each frequency.

The resistance (R) is calculated for each frequency using Ohm's law ($V=IR$). The voltage used to calculate the resistance is V_o . The resistance value resulting from this calculation is specific to the spacing of the electrodes; to obtain a unit value of resistivity (ρ) the effects of electrode geometry are corrected using a standard geometric factor. The resultant resistivity value is a non-geometric average of the resistivity of the volume of ground sampled, called the *apparent resistivity* (ρ_a).

Processing

In SIP, the resistivity and phase lag responses are plotted against the frequency; this plot is the diagnostic IP response spectrum. The resistivity and phase behaviours over the frequency range is described as the *relaxation* of the electrical system.

Several models have been developed to describe the relaxation using a small number of diagnostic parameters. One well known model is the Cole-Cole relaxation spectrum. A typical IP spectral response and Cole-Cole relaxation spectrum are shown in Figure 2.

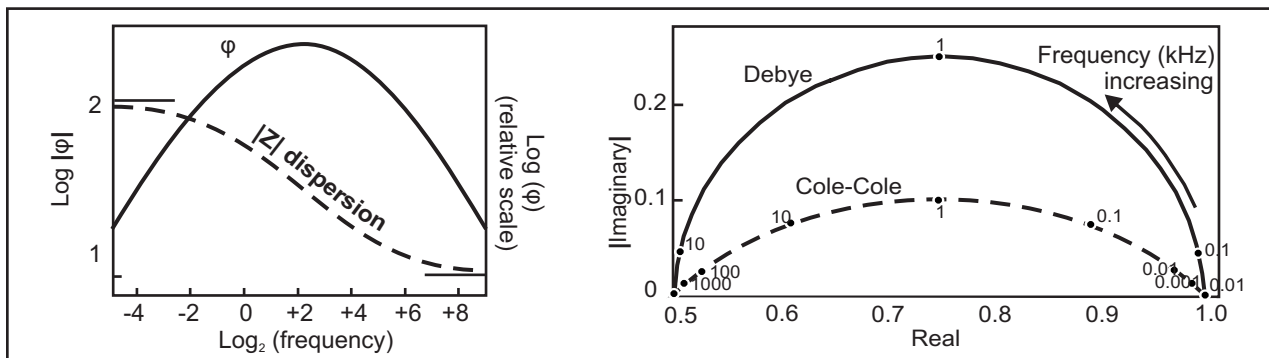


Figure 2: IP spectral response and Cole-Cole relaxation, after Pelton *et al.* (1983), by permission.

The shape of the Cole-Cole relaxation spectrum for a single data point can be fully described by four parameters; the ohmic resistivity, ρ_{DC} , the chargeability, M , the *relaxation time/time constant*, τ , and the *exponent of the angular frequency*, ω . Since the spectral IP parameters are found for a single datapoint, they are *apparent* parameters, *i.e.* non-geometric means of the real distribution of resistivity, chargeability, *etc.* in the volume of ground sampled by the IP measurement. Often for 2D surveys, the chargeability and resistivity will be processed to recover the true 2D chargeability and resistivity distributions in the ground, whereas the phase lag or relaxation time and frequency exponent will be plotted as 2D pseudosections, or plots of the apparent values.

Interpretation

Using SIP, the geophysicist can observe variations in up to four different geoelectrical parameters, significantly reducing the ambiguity in interpretation of the ground compared to conventional resistivity surveys. Different type of ore bodies can be distinguished based on the typical shapes of their spectral IP responses. Additionally, the spectral IP parameters can reveal important information about the subsurface, for example the grain size distribution.

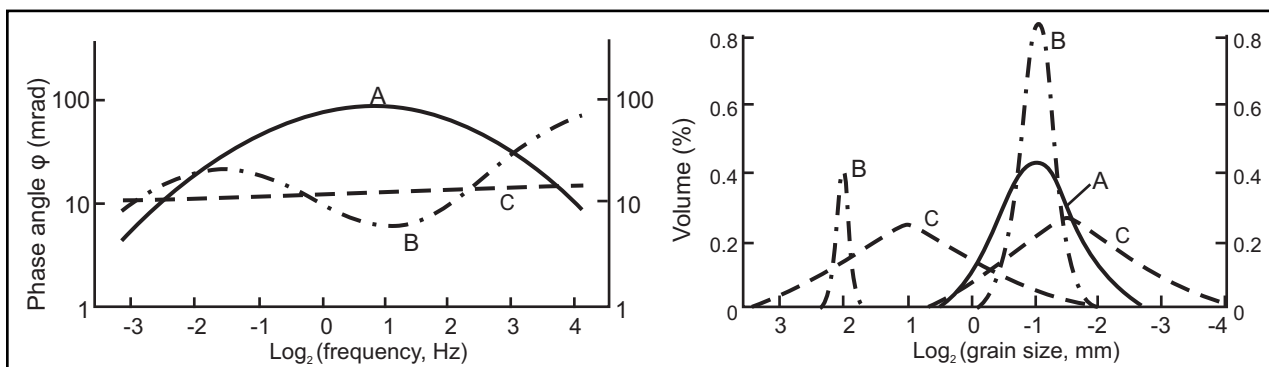


Figure 3: The effect of grain size distribution on the phase angle response, after Hallof (1983), by permission. *Left:* Spectral IP response. *Right:* Equivalent grain size distributions.

References

Hallof, P.G. 1983. *An introduction to the use of the Spectral Induced Polarization Method*. Markham, Ontario: Phoenix Geophysics Ltd.

Pelton, W.H., Sill, W.R. and Smith, B.D. 1983. Interpretation of complex resistivity and dielectric data, Part I. *Geophysical Transactions*, **29**(3):297-330.

Reynolds, J.M. 2011. *An introduction to applied and environmental geophysics*. John Wiley & Sons Ltd, Chichester & London, 2nd ed., 712 pp.