Basics of Near Surface Resistivity Imaging Techniques and Integration with Seismic Data

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Summary

How does one choose the best method when performing a geophysical survey? Every geophysical method can produce differing results, with certain advantages and disadvantages depending largely on the physical properties of the target and the scale of interest. Other factors that are not immediately obvious when survey planning may play a significant role in the final data quality – such as physical field conditions, nearby infrastructure, time of year, etc. This is especially evident when comparing two commonly used near-surface geophysical methods: electrical resistivity imaging (ERI), and time-domain electromagnetics (TEM). Both methods can produce a similar view of the subsurface by measuring resistivity, but with distinct advantages and disadvantages based on their underlying physical principles.

ERI uses a DC source to inject electrical current into the subsurface via electrodes hammered into the ground. This method allows for the rapid acquisition of many data points once the survey is set up. TEM uses a loop of wire and an intermittent electrical current in accordance with Faraday's Law, to temporarily induce an electromagnetic response in the subsurface. In this way, both ERI and TEM methods can measure the resistivity of the subsurface in a non-invasive manner, and at a relatively low cost. So which one to choose?

This presentation serves to introduce and compare these two near surface geophysical methods that measure the electrical resistivity of the subsurface. Assumptions, advantages, disadvantages, pitfalls, and field implementation will be discussed to illustrate where these two methods are most effective, and where they are not.

Finally, it will be shown where both methods can be combined with other traditional methods, such as seismic, to constrain the results and produce an enhanced interpretation of the subsurface. One method alone cannot always detect properties such as grain size, type of pore fluid, or other variations in the soil/rock layers, but can be more easily interpreted using combined methods.

Electrical Methods Introduction

Electrical Resistivity Imaging (ERI)

ERI employs basic physical principles of electricity to measure the subsurface. Generally, ERI surveys use an array of 4 electrodes per measurement. Two electrodes are used to inject current into the subsurface (via the “C” electrodes), while the other two are used to measure the electrical potential difference, or voltage (the “P” electrodes) at some distance away from the current electrodes (Fig. 1A)

A. B.

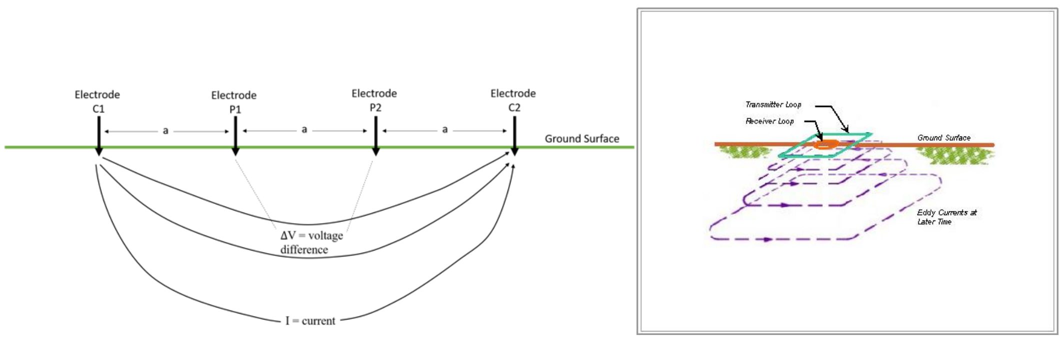

Fig. 1 **A:** A typical 4-electrode Wenner array deployed on the surface for ERI, showing theoretical ray paths of the injected electrical current. **B:** Schematic of a single TEM sounding, showing induced eddy currents in the subsurface at progressively later times.

The foundation of this method utilizes Ohm’s Law, where the resistance of a material can be measured experimentally. The material-specific property of resistivity (ρ) can be related to resistance when the physical parameters of the survey are known. In the context of electrodes, this must be related to the specific geometry of the electrode array (e.g. a Wenner Array as shown in Fig. 1A) and to the medium, or the subsurface, which results in the general formulation:

$$\rho_{app} = \frac{V}{I} K$$

Where ρ_{app} is *apparent* resistivity, V is the measured voltage difference between the “P” electrodes, I is the injected current, and K is a geometric factor that is dependent on the specific electrode array used and the spacing between electrodes.

Knowing the geometry of our survey allows us to calculate a specific value for K, and therefore the apparent resistivity of the subsurface. This measurement can then be inverted to infer approximate values for the resistivity of each underlying geological layer/fluid.

Time-domain Electromagnetics (TEM)

TEM incorporates Faraday's Law to induce a voltage within the subsurface. Faraday's Law implies that a measurable voltage is induced at any point where a change in the magnetic field through a coil occurs. In practice, this method uses a square loop of wire, where a current is injected through it to induce a primary magnetic field (Fig. 1B). When the current is rapidly turned off, a change in the magnetic field is induced, creating a secondary voltage in the subsurface, which then decays rapidly with time proportional to the chargeability of the subsurface. The electrical waveform propagates into the subsurface and creates secondary magnetic fields/eddy currents with a voltage that is proportional to the geological layers it travels through. These properties can be measured at the surface using a receiver coil, thus providing a time-dependent measurement of the subsurface.

Performing ERI rather than TEM or vice versa depends on a host of factors when considering the scope of the project. A solid understanding on the background theory allows us to better decide which method is most appropriate for what conditions. Cost, depth of investigation, physical properties of the target, scale of the data, and physical field conditions all play a role in determining the feasibility of one method over the other, and ultimately to decide which method produces the best result, for the best value.

Integration with Seismic Data

Once the data from either ERI or TEM is collected, appropriate data processing must follow. As with any geophysical method, the results suffer from equivalency issues, or "non-uniqueness," meaning that multiple solutions can exist for the model result. To best approach this, inversions that are constrained by geological data (i.e well logs, lithology data, geochemical data, etc.) should be implemented whenever possible. Additional practices include joint inversion, in which multiple geophysical methods are combined into a single inversion to produce results that fit the various constraints.

Similarly, multiple geophysical methods can be integrated in the interpretation stage to better constrain the results – an example is given in Fig. 2, which is a combination of TEM and reflection seismic. As shown, TEM helps to delineate lateral variations in the sediment layers that would be difficult to interpret in the seismic alone, along with interpreting regions of high clay content and fluid-saturated sands.
This kind of integration helps to inform the exploration and development of resources, providing an enhanced interpretation of the subsurface and providing a better picture within zones of interest.
Another example is given in Fig. 3, where ERI and seismic refraction have been combined (top) to provide a better-informed interpretation of the subsurface (bottom).

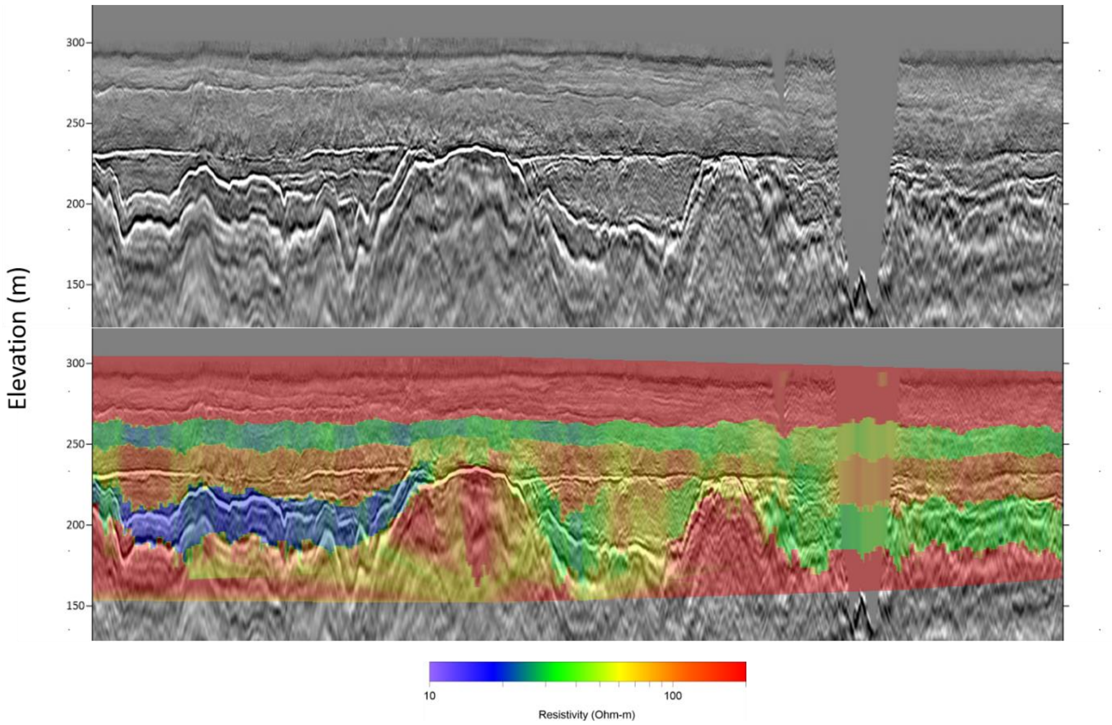

Fig. 2 **Top**: Typical seismic reflection section. **Bottom**: example of seismic overlain with TEM resistivity data. Combining multiple geophysical methods allows for an enhanced interpretation of the geological subsurface. Note the increase in delineation of sediment/fluid layers, including information gained within the sediment layers.

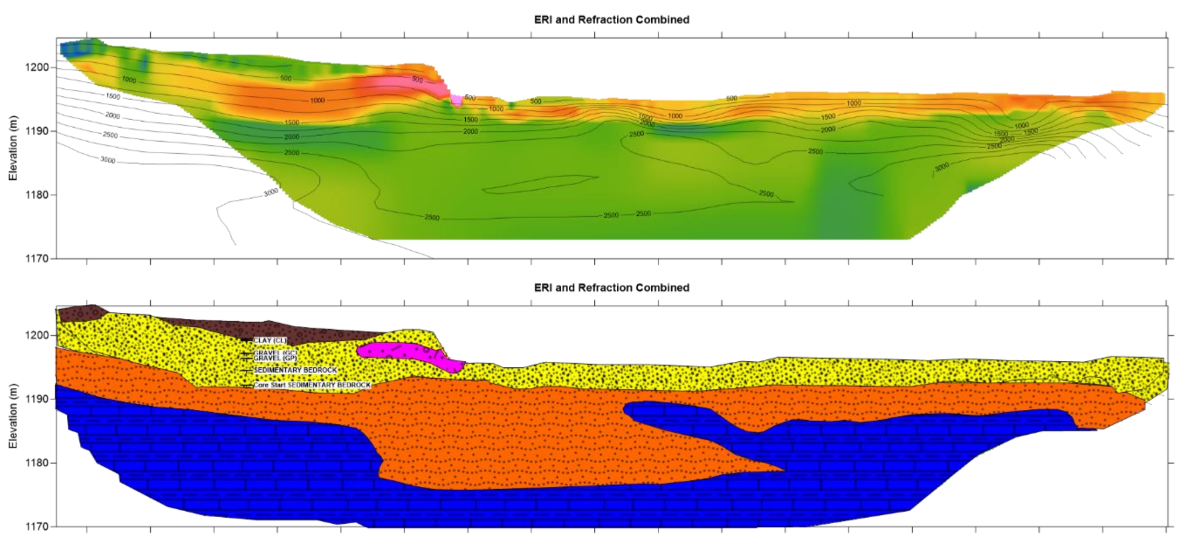

Fig. 3 **Top**: ERI section coloured, where hot colours represent high resistivity values and cold colours represent lower resistivity values; overlain over the ERI section are the results from the seismic refraction, shown as velocity contours. **Bottom**: interpretation of the subsurface showing sands, clay, and interpreted bedrock where a velocity low illustrates a zone of weathered bedrock in the middle of the section.