Application of magnetotellurics in geothermal reservoir characterization

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In this paper we examine Magnetotelluric (MT) data and analysis from a few different styles of geothermal resource. The geothermal resources examined include both shallow (<1000m depth) and deep (>2000m) scenarios. The implications with respect to survey and limitations imposed by survey design on the interpretation of the results are discussed. The results of 1-D, 2-D and 3-D inversions are compared and discussed in terms of their vertical and spatial resolutions and the reliability of the results in conjunction with the geology of the study areas. The continued improvement in the power and affordability in multi-core PC-platform computing allows for the relatively rapid inversion of MT data in 3-D. In the past it had been necessary to invert in 3-D with only a subset of the original dataset and with a limited number of frequencies (often <10 frequencies) in order to reduce the computational time and cost; this is no longer necessarily the case. The effect of number of frequencies used in the 3-D inversion process is discussed in terms of the choice of the acquisition data density and data distribution for a given dataset.

Keywords: acquisition 1-D, 2-D, 3-D, inversion, magnetotelluric, geothermal.

Magnetotellurics and Geothermal Reservoirs

The Magnetotelluric (MT) method is an EM technique allows one to construct plan maps and depth sections of resistivity variations in the Earth from the surface to depth. The resistivity variations are used to determine and provide insight into the location and character of geothermal reservoirs. Analysis of the resistivity data in terms of the signatures associated with various geologic units and alterations related to a geothermal system can be used to detect and delineate a geothermal reservoir. These resistivity signatures include subsurface resistivity variation associated with different alteration levels and mechanisms that result in a conductive clay reservoir cap which is underlain by a slightly more resistive core. In the case of an "active" geothermal system there is the possibility of the underlying hot water circulation being identified with a low resistivity signature. In the case of a "passive" geothermal system the reverse may be true. Through the evaluation of MT data in conjunction with other geological, geochemical and geophysical data sets, the definition and characteristics of a particular geothermal reservoir may be determined.

Acquisition Methodologies

The conventional method of MT acquisition involves the establishment of a series of individual MT sites consisting of dipoles for electric field measurements and magnetometers (usually low frequency coils) for magnetic field measurements. An example of such an acquisition system is illustrated by Figure 1.

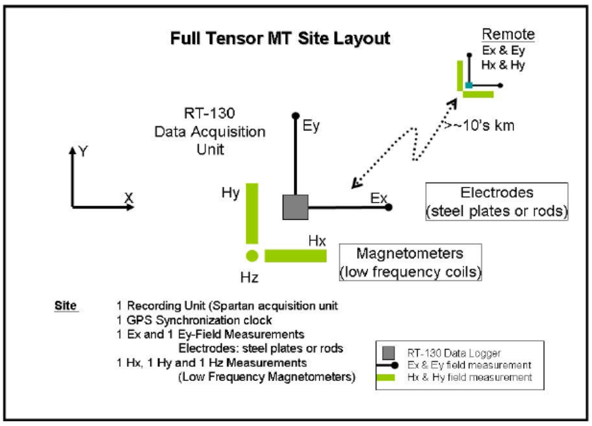

Figure 1: Full Tensor MT Site Layout

This type of system is well suited to investigations in irregular terrain, for deep targets (>2000m) and for reconnaissance type surveys whereby a large amount of ground must be covered in a limited amount of time and hence relatively wide site intervals are required ($\geq$ 500m). Detailed profiling can also be accomplished.

The past decade has seen the development of array type systems whereby a large number of MT sites can be deployed in a rapid fashion allowing for a detailed investigation to be completed in a short period time. Often these systems include the ability to acquire other complementary geophysical data sets (e.g. DC resistivity, IP chargeability, TEM). An example of such a system is illustrated by Figure 2. In general, these array type systems can be extremely effective in the delineation of near surface (<1000m deep) geothermal systems and reservoirs.

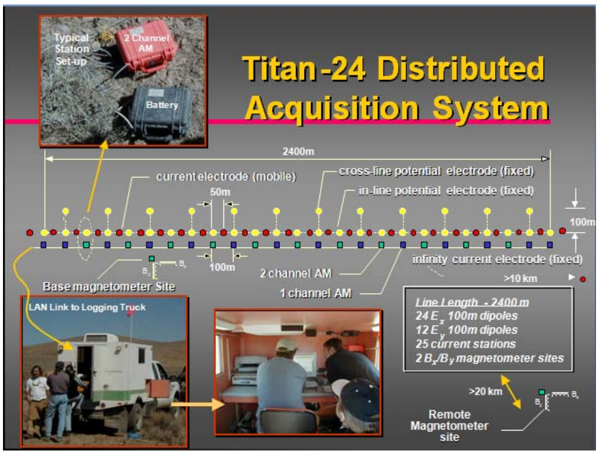

Figure 2: Example of an Array Type MT Acquisition System

Inversion Methodologies

Interpretation of the MT data is performed using the maps of true resistivity of the subsurface. Inversion algorithms in one-dimension (1-D), two-dimension (2-D), and three-dimension (3-D) are used to invert the apparent resistivity and phase data in to the maps of true resistivity of the subsurface. A simple layered subsurface structure generally can adequately be reproduced using the 1-D inversion. In the case of more complex 2-D or 3-D structures, the MT response will be affected by lateral variations in resistivity. Consequently, a 2-D or 3-D inversion algorithm is required to allow the lateral resistivity variations.

In 1-D earth assumption, the 1-D inversion of the MT data produces a resistivity-depth profile for each MT site. The results represent a first order approximation of the resistivity variations with depth using a layered-earth model. Often these inversion results are presented in pseudo-section form as “stitched” 1-D inversion sections.

If there are lateral variations in the resistivity of the subsurface along one direction only (perpendicular to the strike) then a 2-D inversion and interpretation is required. A cross-section of the true resistivity variations perpendicular to the assumed strike direction is created in the 2-D inversion and is used in interpretation.

For more complex geological structures a 3-D inversion is essential to adequately describe the resistivity variation of the subsurface. This is usually the case when mapping the geological settings hosting a geothermal system. In this case no simplifying assumption is made in terms of property of the MT data and dimensionality of the underlying subsurface. In highly heterogeneous environments MT phase data often exhibit an out-of-phase (phase-wrap) behaviour; caused by the complexity of the current paths in the subsurface. Modelling of these data is essential in order to resolve the heterogeneity of the subsurface. This kind of data, however, cannot be modelled using 1-D and 2-D inversions and the data must be mitigated or removed before the inversion. On the contrary, the 3-D inversion uses impedance data and is capable to handle this type of data; making the inversion a robust tool to produce a realistic representation of the subsurface.

In this discussion we contrast the differences between not only the 1-D, 2-D and 3-D inversions but also the effect of variations in MT field sample intervals and spacing on the effectiveness of the various inversion methods on the ability to discern and characterize geothermal reservoirs.

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