

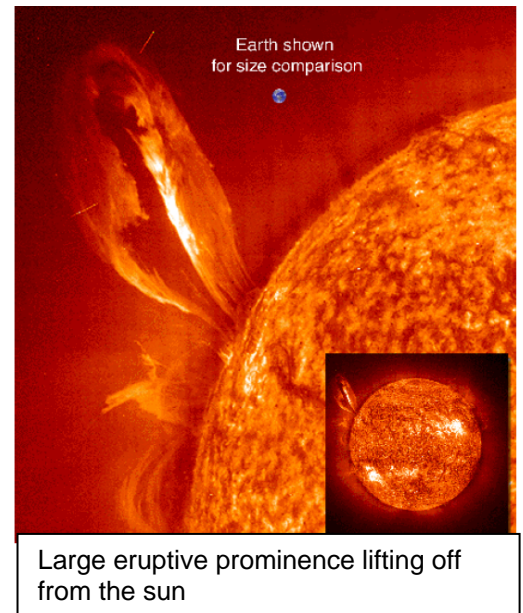
Introduction to MT & AMT



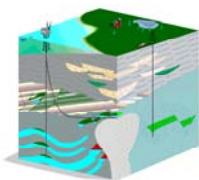
Geothermal Exploration with Electromagnetic Methods

Geothermal energy plays a large role as a generator of electricity and as a source for space heating. Zones of low resistivity that are associated with geothermal reservoirs can be detected by electromagnetic techniques such as the magnetotelluric (MT) method. The higher temperatures and salinity of the pore water and concomitant increased rock alteration associated with geothermal areas often contribute to this decrease in the bulk resistivity in a rock mass. The MT method utilizes natural variations in the Earth's magnetic field as a source. Natural MT signals come from a variety of natural currents including thunderstorms and solar winds as shown in the figure below.

The total frequency range of MT data spans 40 kHz to less than 0.0001 Hz. Data is acquired in a passive mode using a combination of electric sensors and induction coil magnetometers that can detect changes in resistivity at great depths. The electric sensors are used to determine the electric field which is derived from measurements of the voltage difference between the electrode pairs E_x and E_y . The magnetic coils are used to measure the magnetic fields H_x , H_y and H_z in three orthogonal directions, in this case NS and EW. The ratio of the recorded electric and magnetic values provides an estimate of the apparent resistivity of the Earth at any given depth.



Large eruptive prominence lifting off from the sun



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The Audio MagnetoTellurics (AMT) method is a subset of the MT sounding technique for audio frequencies ranging between 1 Hz to 20 kHz and higher. It achieves moderate exploration depths to about 2000 m depending on the subsurface resistivity.

To date, KMS Technologies has conducted successful geothermal surveys in several countries.

Acquisition Services

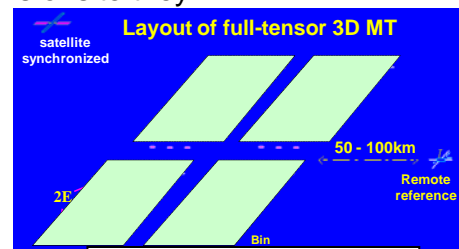


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KMS field crews are equipped with the latest 24 bit AMT/MT data acquisition systems. They have both "porous pot" type electrical sensors (electrodes) and induction coils systems. Two types of induction sensors are available to our crews: a high-frequency coil for AMT measurements, with an input frequency range from 12,500 Hz down to 0.35 Hz, and a low-frequency coil for MT measurements with a specified range of 400 Hz to 0.00025 Hz. Higher frequency sensors are available upon request. A field crew for each unit usually consists of three members: one observer and two assistants. KMS can mobilize multiple crews simultaneously and the MT/AMT surveys have minimal or no environmental impact.

Prior to commencing acquisition, a 2D or 3D modeling study is performed to optimize the survey design. Once the crew is onsite they will:

- Conduct pre-acquisition survey feasibility including site evaluation and finalization of design decisions,
- Calibrate equipment and perform a noise evaluation,
- Deploy sensors to optimize coupling and minimize noise,
- Collect data for required duration and store to field computers, and
- Move from site to site in the most operationally efficient and safe manner.

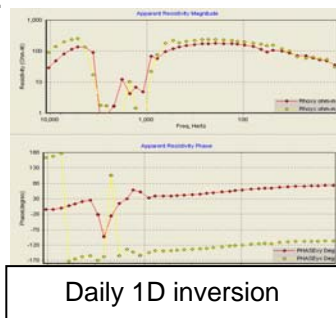


3D MT survey layout

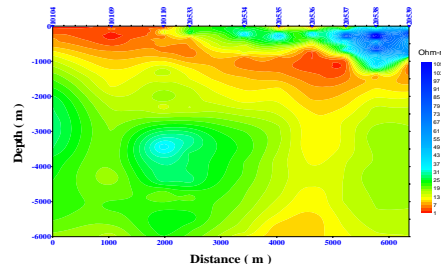


Deploying the electrodes

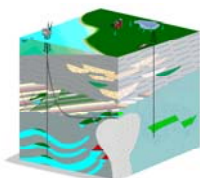
Throughout the operations, daily and weekly interpretation results are generated to provide quality control and provide survey design updates if needed.



Daily 1D inversion

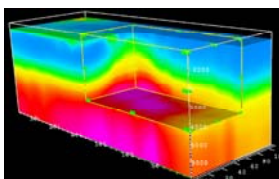


Weekly 2D inversion results

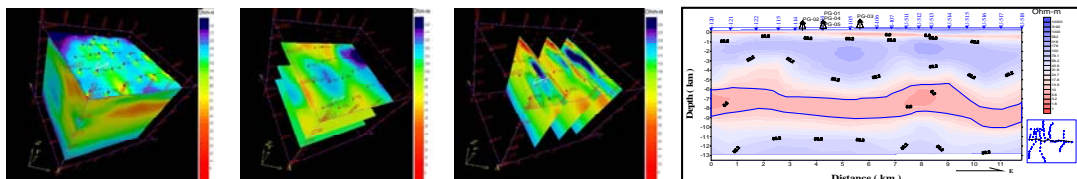


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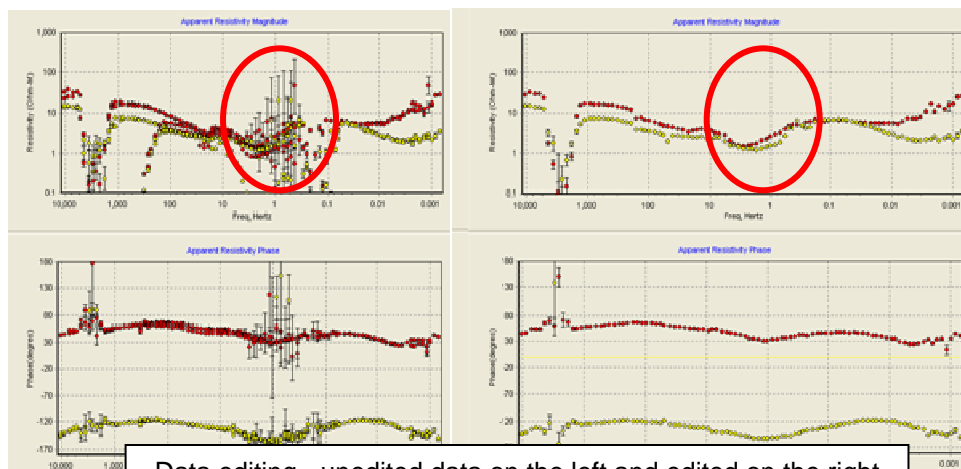
Processing Services



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Field data is pre-processed to remove noise and other artifacts that are not signals. The primary objective of this editing is to create a smooth apparent resistivity curve by eliminating from the calculation of each data point any cross powers that were affected by noise. During this process, various hand editing and coherency schemes are employed. Below is an example of data editing.

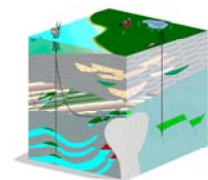
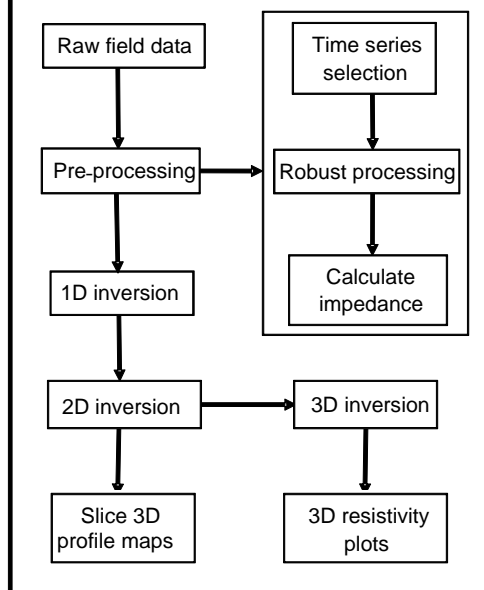


Data editing - unedited data on the left and edited on the right

There are two polarization modes utilized for MT surveys: TE mode and TM mode. Generally speaking, the TE mode is consistent with a structural strike, while TM is perpendicular to it. From a resistivity point of view, the distortion of the TM curve is strongly affected by electric lateral inhomogeneities; therefore it can clearly reflect resistivity layering. Determination of the two modes is the first step in interpretation.

After the data has been properly edited, it is then Fourier transformed and impedance calculations are generated. The data is then processed through 1D, 2D, and 3D inversion algorithms.

Data processing flow chart

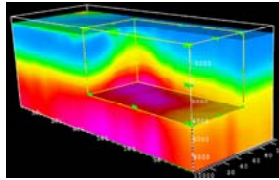


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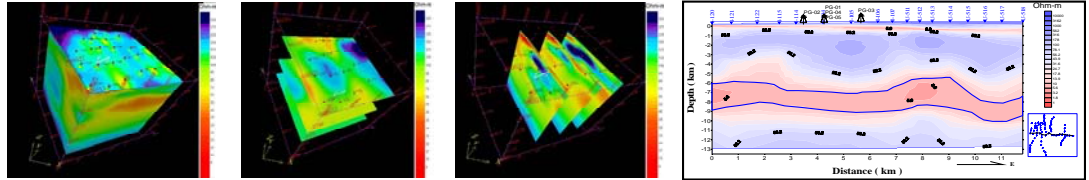
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Interpretation Services

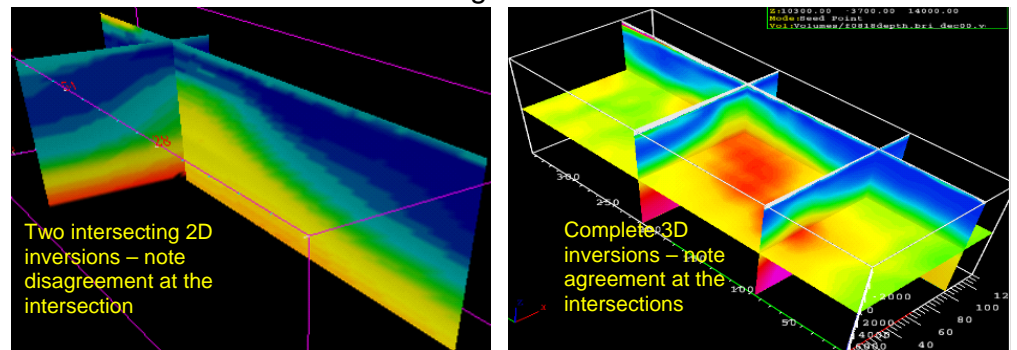


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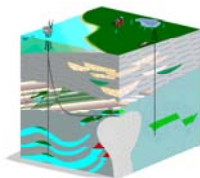


High-temperature hydrothermal systems produce resistivity contrasts. Fissure swarms, or fault zones, typically control geothermal fluid circulation and these fissure swarms are buried below the surface and are hard to delineate using only surface geological mapping tools. Resistivity (or electrical) imaging of the magnetotelluric data can characterize the geothermal reservoir or fracture zones.

This data can be interpreted and analyzed using raw resistivity curve types, 2D inversion sections (profiles), resistivity contour maps at different depth levels, and the three-dimensional (3D) inversion results are normally analyzed. It is critical that final interpretations are performed in three dimensions as can be seen in the figure below.

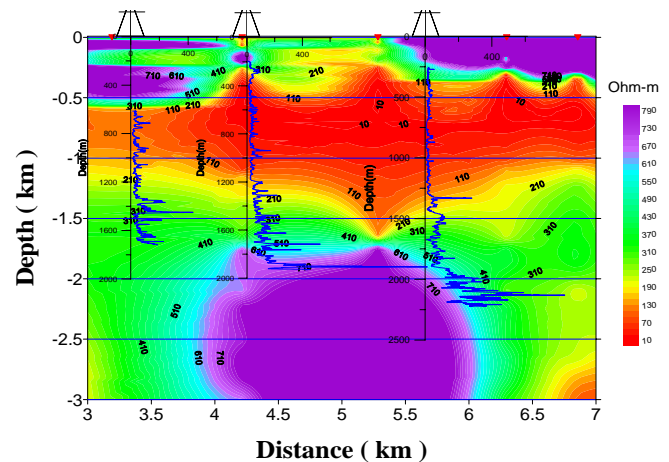


3D inversion of MT data is required for accurate interpretation



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Once a consistent MT interpretation is derived, a more detailed Earth model building exercise begins and integration of all other geoscientific data leads to an integrated interpretation. We offer a complete range of 1D, 2D, and 3D inversion techniques and the ability to integrate MT data with both seismic and other data. Geoscience data is shown to the right.



3D inversion of MT ties to resistivity from wells control