Introduction to AMT

Overview

Natural-source Audio-frequency Magnetotellurics (AMT) is an electromagnetic survey technique that uses naturally-occurring ionospheric currents and lightning storms — passive energy sources — to electrically map geologic structure to depths of 500 meters or more.

Natural-source electromagnetic (EM) signals are generated in the atmosphere and magnetosphere. The time-varying electric and magnetic fields induce currents into the earth and oceans, which produce magnetotelluric (MT) signals, which are measured by AMT and MT data acquisition systems.

Low-frequency magnetotelluric EM signals (< 1 Hz) are generated by the interaction between the earth's magnetosphere and solar wind. High-frequency sources in the audio range (> 1 Hz) are generated by thunderstorms worldwide.

The AMT and MT geophysical methods combine measurements made of site-specific electric and magnetic fields using grounded dipoles and magnetic field antennas over a wide band of frequencies. Low frequencies sample deep into the earth and high frequencies (AMT) correspond to shallow samples.

Ground resistivity values are calculated from the magnitude and ratios of these components and then mapped using Zonge inversion and modeling software. Ground resistivity relates to the geology.

AMT is a passive electromagnetic imaging method using the earth's magnetotelluric field to map geologic contacts and structure.

Advantages of AMT

- No need for power source or high-voltage electrodes.
- Minimal environmental impact.
- Stations can be acquired almost anywhere and can be placed any distance apart.
- Zonge's backpack portable system allows for use in difficult terrain,
- Relatively easy field logistics for large-scale regional reconnaissance exploration and for detailed surveys of local geology. Fast data collection.

AMT Exploration Applications

- Mineral, groundwater and geothermal exploration
- Excellent for imaging moderately deep geologic structure and near-surface geology to depths of about 500 meters in detail
- Onshore oil and gas exploration where seismic is not feasible or is cost prohibitive
- Mining and water resource management

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Field Logistics

The Zonge AMT equipment system consists of the GDP multichannel data processor (receiver), ANT/6 magnetic-field sensor(s), electric-field cabling, and non-polarizing electrodes for measuring ground potentials. This system is easily transported and multiple systems can be synchronized to provide a remote reference for noise cancellation.

AMT signals are extremely subtle and measuring them requires highly sensitive magnetometers, very low-noise electric-field sensors, and careful installation. The Zonge ANT/6 magnetic-field sensor has a noise threshold level below typical natural-source AMT signal levels. With this system, it is possible to collect the most useful data in the attenuation band under the most conditions.

At each survey station, electrode pairs are used to measure the electric (E) field, and magnetometers are used to measure the magnetic (H) field. The electrical conductivity of the subsurface affects the amplitude, phase, and directional relationships of the E and H fields on the earth's surface. The frequency ranges of interest are typically from 4 to 8192 Hz for AMT.

"Ex" and "Ey" are used to designate measured components of the electric field. "Hx" and "Hy" designate measured components of the magnetic field.

Different array types may be used to acquire the most beneficial data for a particular survey area and objectives.

Scalar AMT is collected by a series of electrode pairs, each measuring Ex, set up along a survey line with one magnetic-field sensor measuring Hy. Tensor AMT acquires additional electric-field Ey and magnetic-field Hx readings, which provide information about impedance directionality at a particular location. The Hz component used on lower-frequency MT surveys is not usually recorded for AMT surveys.

<u>Scalar AMT</u>

- Easily modified to accommodate terrain or other needs in the field
- Fast linear collection rates
- Limited in resolving or delineating multi-dimensional targets
- Images the most geologic contacts when data is collected roughly perpendicular to geologic strike (if known)

<u>Tensor AMT</u>

- Resolves ambiguity of strike which may not be known at the beginning of the survey
- Provides structural definition and directionality
- Slower production rates compared to Scalar array but still far faster than MT

Zonge's backpack portable AMT acquisition system allows for use in difficult terrain and relatively easy field logistics.

Inversion and Modeling

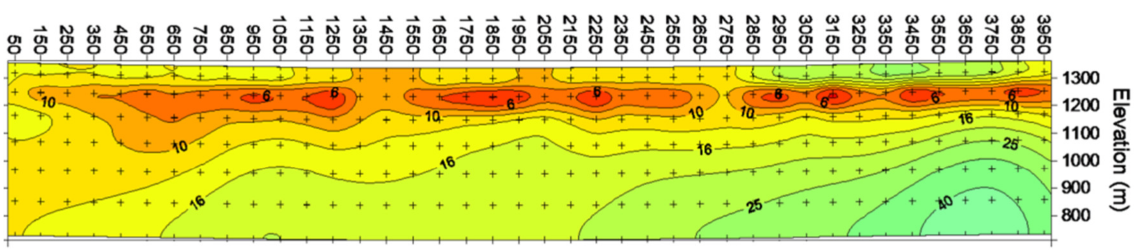
Both 1D and 2D Smooth-Model inversion software is used to convert measured E and H components to resistivity versus depth profiles. Smooth-model inversion mathematically back-calculates ("inverts") from the measured data to determine a likely location, size and depth of the source or sources of resistivity changes.

Imaging natural-source AMT data is a multistage process in which both resistivity and phase are used in the inversion to image resistivity changes associated with the geology. Cagniard Resistivity and Impedance Phase data are calculated from the collected electric field and magnetic field data. Cagniard Resistivity is a frequency-dependent, apparent resistivity calculation based on the ratio of the E and H magnitude components of the electromagnetic field. Impedance Phase is defined as the difference between the E and H phase components.

Inversion models of AMT Cagniard Resistivity and Impedance Phase data provide detailed images of the conductivity structure at depth.

The Zonge AMT modeling software allows various parameters to be used to create the most geologically reasonable model. 1D and 2D software will produce modeled depth sections for scalar AMT. 2D software will produce modeled depth sections for tensor AMT.

2D inversion produces two-dimensional shaped features (e.g., edges associated with contacts at depth) and is able to model any dipole orientation, but in doing so assumes the survey line crosses the geologic strike on the perpendicular.



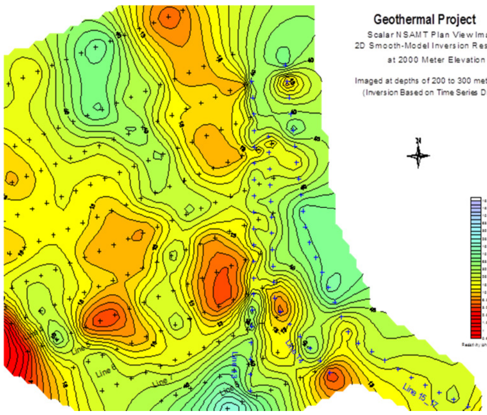
Zonge 2D smooth-model inversion corrects data for topographic effects. When possible, AMT survey lines should be aligned perpendicular to geologic strike for best results.

Lateral and Vertical Resolution

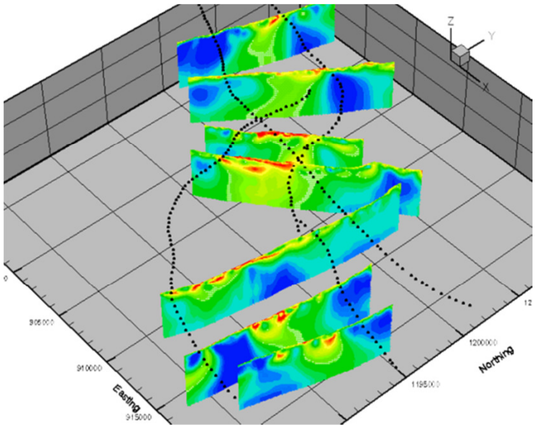
Inversion models show reasonable detail to certain depths. The skin depth (depth where field strength decreases to 37% in a homogeneous earth) is considered the depth of penetration. It is possible for AMT results to image the subsurface at greater depth in more resistive ground by decreasing the floor frequency. However there are practical limitations related to size with resolving features at depth. Survey resolution is also a function of target size and conductivity contrasts. Lateral survey resolution is estimated at 15% of the depth of investigation. This is one reason that survey design for natural source AMT often differs radically from that used for MT surveys.

Final Product

The results of processing and modeling natural-source AMT data can be presented in several forms: modeled cross sections, plan views, fence or 3D diagrams. When stations are collected along several lines in the same area, data can be displayed in plan-view plots at a constant elevation or depth. Plan views can help highlight trends between lines. Fence diagrams show 2D cross sections of the resistivity inversion results in a spatially relevant 3D context. Dotted lines in the fence diagram below represent mapped faults.



Plan views can help highlight trends between lines of stations.



Smooth model inversion results. Fence diagrams in 3D context.

Zonge International is an employee-owned company providing ground geophysics field services, consulting and customized equipment to geoscientists and engineers worldwide.

The company is known for its expertise in the development and application of broad-band electrical and EM methods.

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