Introduction to NSAMT

June 2010

Overview of NSAMT

The NSAMT (Natural Source Audio-frequency Magnetotellurics) method involves the measurement of electromagnetic fields that are generated by natural electromagnetic activity above the earth's surface.

Natural source signals are generated in the atmosphere and magnetosphere. MT signals (low frequencies < 1 Hz) are generated by the interaction between the earth's magnetosphere and the solar wind, sunspot activity and auroras. High frequency sources (> 1 Hz) in the Audio range (AMT) are generated by worldwide thunderstorms and lightning. These time-varying electric and magnetic fields induce currents into the earth and oceans.

Electric currents within the earth produce magnetotelluric signals that are measured by the Zonge AMT / MT System. The fields are measured over a range of frequencies using grounded dipoles and magnetic field antennas. The system calculates ground resistivity values by measuring the magnitude of the electric and magnetic fields.

NSAMT measures changes in the electric and magnetic fields with time.

NSAMT has been used in mining, water resource management and geothermal programs. MT is also used in natural gas and petroleum exploration programs.

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

NSAMT for Exploration

Advantages of NSAMT for exploration include:

- A backpack portable system allows for use in difficult terrain.
  Stations can be acquired almost anywhere, and can be placed any distance apart. This allows for large-scale regional reconnaissance exploration, or detail surveys of local geology.
- Acquisition without artificial power source.
  NSAMT is a passive survey method with little – to no environmental impact.
- Used for petroleum exploration.
  Resistivity structure can be analyzed in areas where seismic is not feasible or cost prohibitive, and / or great depth of exploration is required.
- NSAMT is useful for imaging both deep geologic structure and near-surface geology, and can provide significant detail.

Zonge GDP-32^{II} multichannel receiver

The natural source AMT technique requires no high-voltage electrodes, and logistics are relatively easy to support in the field.

Field Logistics

The AMT system consists of a multichannel analog channel GDP-32^{II} geophysical data processor (the receiver), the SC-8 Signal Conditioner, ANT/6 magnetic field sensor(s), electric field array cabling and non-polarizing electrodes used for measuring ground potentials. The system is easily transported, and multiple AMT systems can be synchronized for remote reference processing of time-series data, which provides noise cancellation.

At each station, electrode pairs measure the electric (E) field, and magnetometers are used to measure the magnetic (H) field in the frequency ranges of interest, typically from 0.001 Hz to 10KHz. High sensitivity magnetometers and careful installation of low noise electric field sensors are required to measure extremely subtle MT signals.

NSAMT Field Equipment

The Zonge ANT/6 magnetic field sensor has a noise threshold level below typical AMT and MT natural source signal levels. With this setup it is possible to collect the most useful AMT data in the "attenuation band" under most conditions. Additional magnetic field sensors can be used for reference data collection.

Arrays used in NSAMT

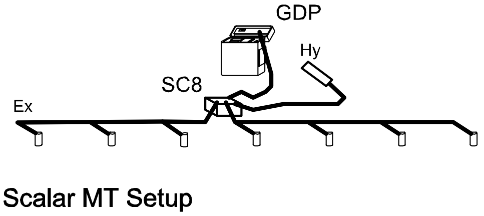
The amplitude, phase, and directional relationships of the E- and H-fields on the surface depend on the electrical conductivity in the subsurface. Different array types are considered for acquiring the most beneficial data for a particular survey area.

Ex and Ey refer to the directions of the array used to measure the electric field. Hx and Hy refer to the directions used to measure the magnetic field. Every Ex has an associated orthogonal Hy measurement, and every Ey has an associated Hx. Typically, Ex are scalar data collected in the traverse direction with multiple Ex measurements, and one Hy. Tensor NSAMT data measure additional components (Ey and Hx) which provide information about directionality.

Scalar vs. Tensor Arrays:

Scalar

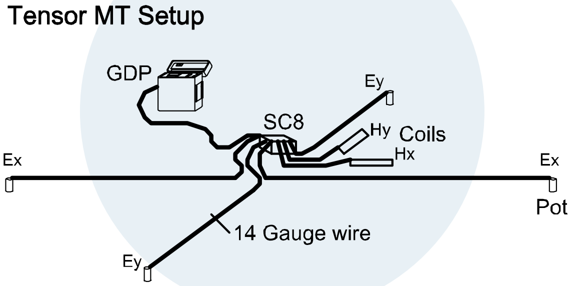
- More easily modified to accommodate needs in the field.
- Better linear production rates.
- May have difficulty resolving multi-dimensional targets.
- Great flexibility where survey line orientations can be changed to match geologic targets.
- Images most geologic contacts when data is collected roughly perpendicular to geologic strike.



A typical scalar setup might employ up to seven 100m electric field dipoles and a single magnetic field sensor.

Tensor

- Resolves ambiguity of strike which may not be known at the beginning of the survey.
- Lower production rates.
- Provides structural definition and directionality.
- Used to indicate direction of conductive region.
- Survey coverage tends to be more structured.

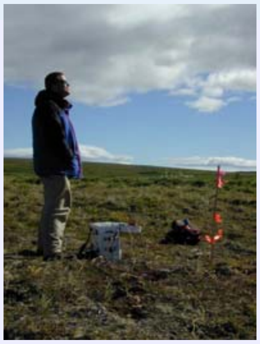


In practice, tensor data are often collected using several array configurations rather than the typical single-station "**X**" style array shown above.

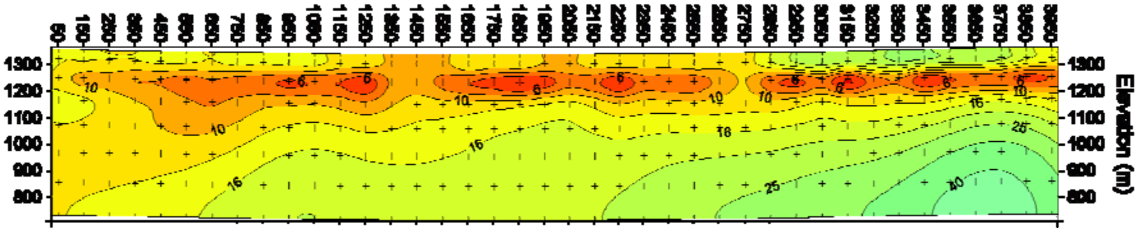
Processing and Inversion

Imaging Natural Source AMT / MT data is a multistage process. Cagniard Resistivity and Impedance Phase data are calculated from electric E-field and magnetic H-field data. Cagniard Resistivity is a frequency-dependent apparent resistivity calculation. The phase difference between the E- and H-components of the electromagnetic field is defined as Impedance Phase. Both resistivity and phase are used in Zonge 1-D and 2-D inversion models to image actual resistivity changes associated with geology.

Inversion models of NSAMT Cagniard Resistivity and Impedance Phase data provide detailed images of the conductivity structure at depth. 1-D and 2-D modeling programs are used to convert the measured results to profiles of resistivity versus depth. Smooth-model inversion mathematically "back-calculates" from the measured data to determine a likely location, size and depth of the source or sources of resistivity changes. Zonge 2D inversion algorithms allow for various types of input model parameters and geometry constraints to yield the most reasonable model.



Field operator at receiver.



Where possible, it is best to align NSAMT traverse lines perpendicular to geologic strike. Modeling will correctly image conductive and resistive features crossed by such lines.

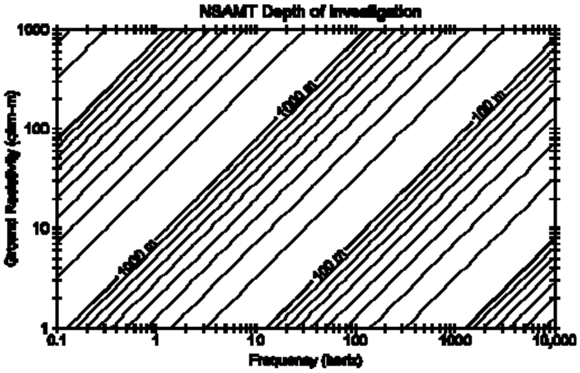
2-D inversion models have several advantages over 1-D models in that the 2-D inversion shows two-dimensional shaped structures (for example, edges associated with contacts at depth). Also, the 2-D inversion removes the need to perform static-shift corrections normally required for the 1-D inversions. The 2-D inversion is able to successfully model any dipole orientation, but assumes the survey line crosses geologic strike on the perpendicular. The 2-D inversion also assumes that the calculated conductivity extends infinitely perpendicular to the section.

Depth of Investigation

Inversion models show reasonable detail to a certain depth. The skin depth (depth to which field strength decreases to 37% in a homogeneous earth) is considered the depth of penetration.

It is possible for AMT/MT results to image the subsurface at greater depth in more resistive ground by decreasing the floor frequency. However there are practical limitations in resolving features below certain sizes at depth. This limitation relates to target size and conductivity contrasts. Because of these limitations, interpretations based on either 1-D or 2-D data at great depths should be viewed critically in terms of target expectations.

Only features the size of 15% of the burial depth, or more, will be reliably imaged at depth. This is one reason that survey strategies used in natural source AMT and MT surveys may radically differ. Not only are production rates significantly different because of the extending stacking and averaging time required for MT surveys, but also target sizes required for deeper MT soundings are much larger in comparison to near-surface features easily identified by NSAMT.



1-D and 2-D modeling programs are used to convert the measured results to profiles of resistivity versus depth.

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An employee-owned small business, Zonge integrates:

- *research and development programs,*
- *equipment manufacturing,*
- *field services.*

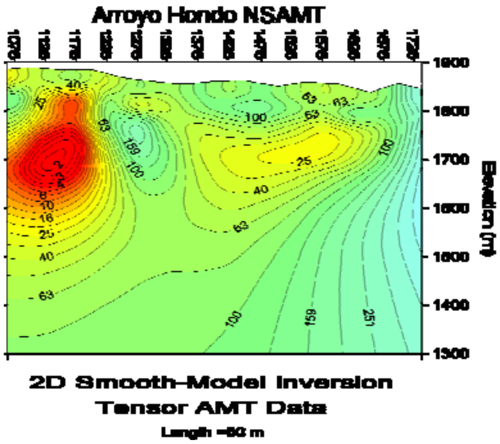
The integration of these roles allows Zonge to provide their clients complete and innovative solutions to their geophysical problems.

Zonge is a specialist in the development and application of broadband electrical and electromagnetic methods.

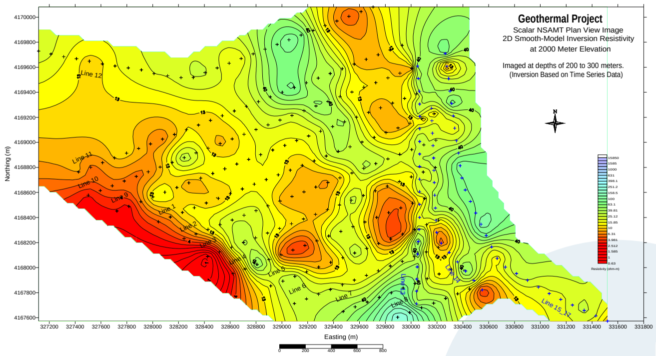
Final Products

The results of processing and modeling the NSAMT data can be presented in several forms:

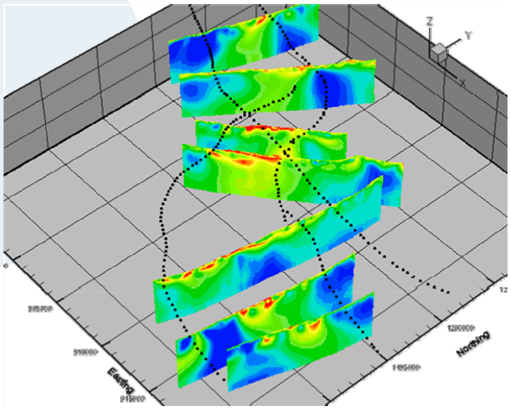
- modeled cross sections
- plan views
- fence or 3D diagrams.



Data provided by La Cuesta International



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 2-D cross sections of the resistivity inversion results in a spatially relevant 3-D context. Dotted lines represent mapped faults.

NSAMT Reference Material

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