FIGAS

9º FORO INTERNACIONAL DEL GAS Y ENERGÍA

GAS Y RENOVABLES EN EL NUEVO MIX ENERGÉTICO REGIONAL

TECHNOLOGÍA MAGNETOTELLÚRICA APLICADA A PROSPECCIÓN EXPLORATORIA

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Motivation

Magnetotelluric (MT) surveys aimed at hydrocarbon exploration have been carried out for more than 50 years.

During the last decade the amount of MT data collected has increased significantly, which requires further development of MT acquisition technology, data processing, analysis and inversion.

Joint interpretation of MT data with other geological and geophysical data and a considerable increase of quantity and improvement of quality of MT data allows to increase efficiency of magnetotellurics.

However still there is some skepticism about the method, especially related to hydrocarbon exploration.

Magnetotellurics as passive EM method

The magnetotellurics (MT) is a technique for probing **electrical conductivity structure** of the Earth. MT utilizes a **broad spectrum of naturally occurring geomagnetic variations** as a power source for EM induction in the Earth.

MT involves measuring fluctuations of **electric**, E, and **magnetic**, B, fields in **orthogonal directions at the surface of the Earth** (or seafloor) as a means of determining the resistivity structure at depth ranging from a few tens of meters to several hundreds of kilometers.

EM responses from any depth could be obtained simply by extending the period of variations.

Depth of investigation

For a given period, the depth achieved by passive EM sounding will be dictated by the average conductivity of the overlying sample of the Earth penetrated.

EM fields that are **naturally induced** in the Earth and are exploitable for MT studies have periods ranging from $\sim 10^{-4}$ to 10^{5} seconds. Assuming average resistivity of the Earth of 100 Ωm we can see how penetration depths in the range of ~ 20 m to $>$500 km might be possible.

The broad band span of depths that can be imaged using MT technique is one of **advantages of the method** compared with active source EM techniques for which maximum depth that can be probed is always limited by the size and power of an available source and realizable configuration of the receivers.

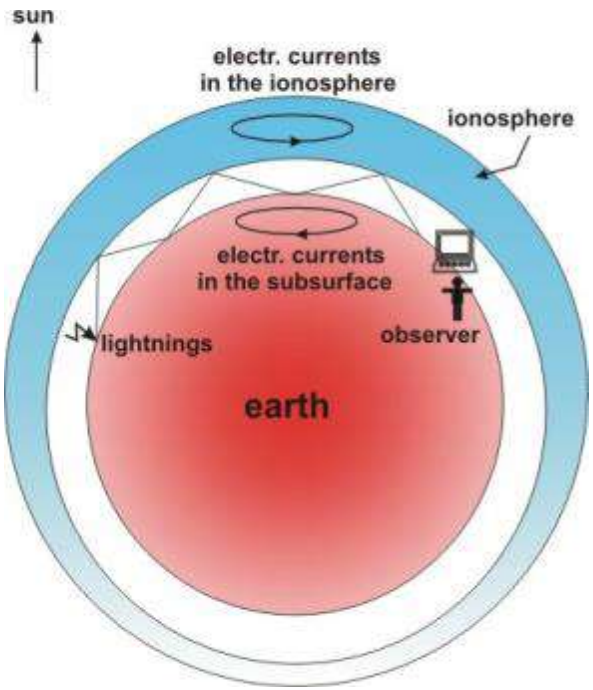
Types of external source

There are two main types of external natural source utilized in MT method:

1) remote lightings

2) magnetosphere-ionosphere current systems

Both sources are characterized by diurnal and seasonal variability. The second source also depends on the solar activity (solar-cycle) and latitude.



Broadband magnetotellurics

Frequency range from 10^{-4} to 0.001 Hz

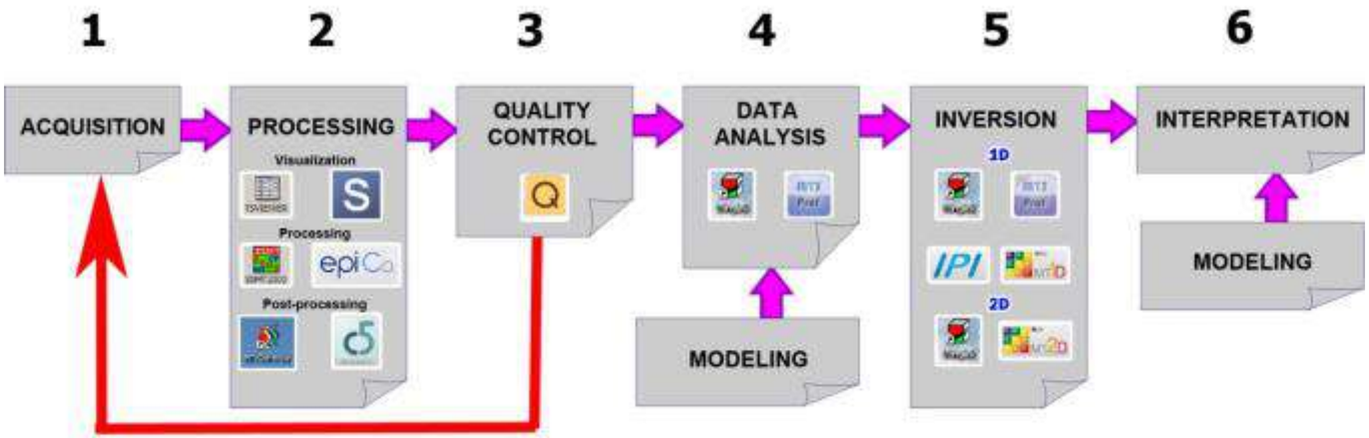
Modern instruments (e.g. by Phoenix Geophysics, Metronix Geophysics, Zonge International) could be effectively applied. **DOI covers broad span from a dozen of meters to 20-40 km, depending on the average resistivity of the cross section.**

Phoenix Geophysics developed an ultra broadband system, which allows to acquire the whole frequency band simultaneously with overnight recording.

UBMT technology has a number of advantages:

- **increased productivity (low price)**
- **enhanced data quality in high-frequency (AMT) band**
- **effective static shift correction**

MT flow chart



MT data inversion

Key stage of any MT survey is constructing of a resistivity model or data inversion.

There are three main approaches: unconstrained, constrained and joint inversions.

Unconstrained inversion is used when there is no good quality a priori geological and geophysical data available or at an initial stage of MT data interpretation.

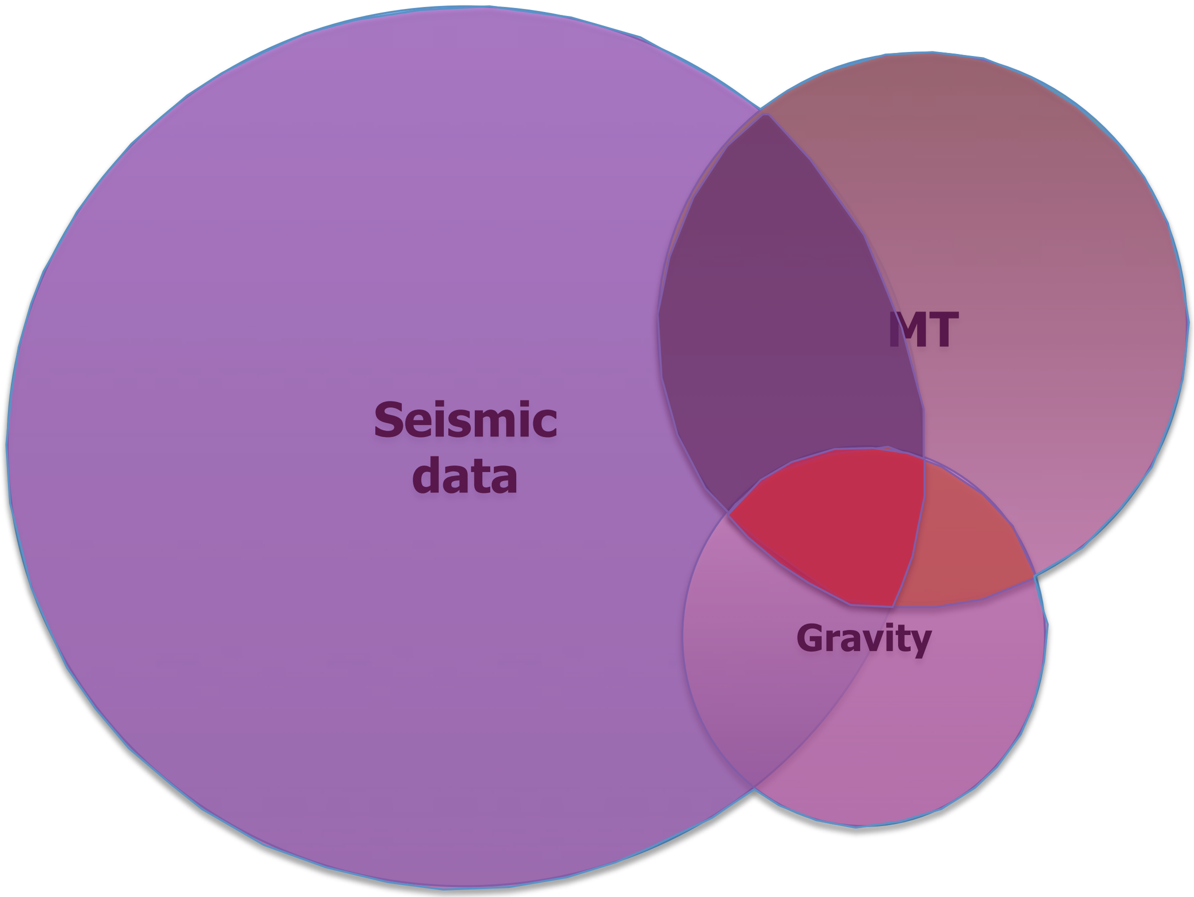
Constrained and joint inversions are partly competing partly complementary approaches. Both have advantages and disadvantages.

Constrained vs joint inversion

Joint inversion is a simultaneous inversion of data of two (or more) geophysical methods in a single procedure. All methods contribute to the resulting model that includes features derived from all types of data. Such approach is effective when different physical parameters (e.g. velocity, density, resistivity) or their gradients are linked one to another.

Constrained inversion is application of inversion or interpretation results of seismic or/and gravity data in MT inversion as an additional regularization parameter. Often reflection boundaries obtained by interpretation of seismic data are used to fix geometry of initial/starting model during MT data inversion.

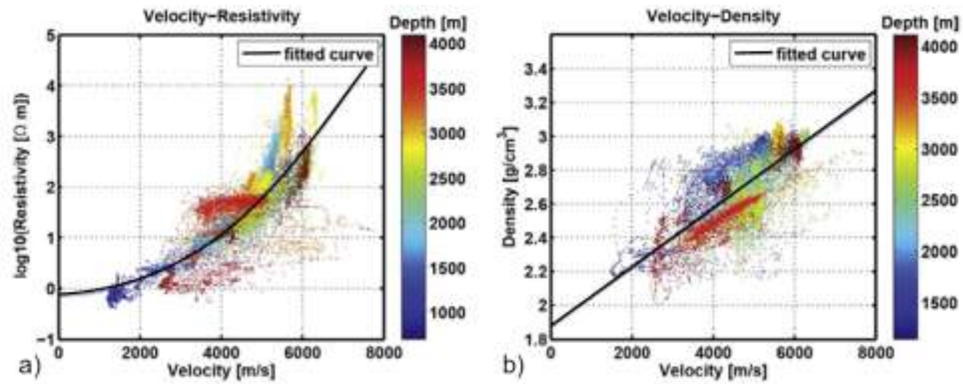
Constrained vs joint inversion

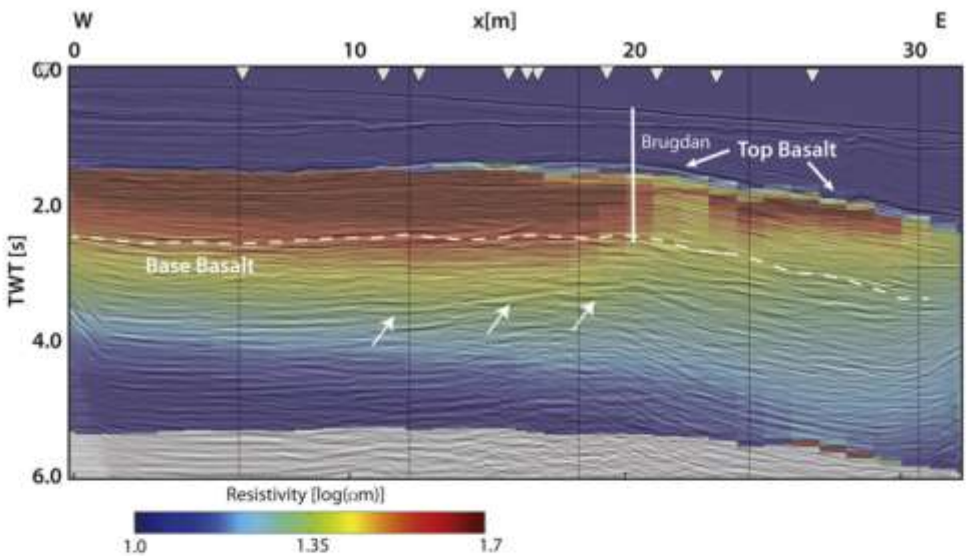


Union of data sets vs intersection of data sets

Joint MT inversion with seismic and/or gravity data

Joint inversion requires different petrophysical parameters to be dependent on each other.





Heinke et al., 2016

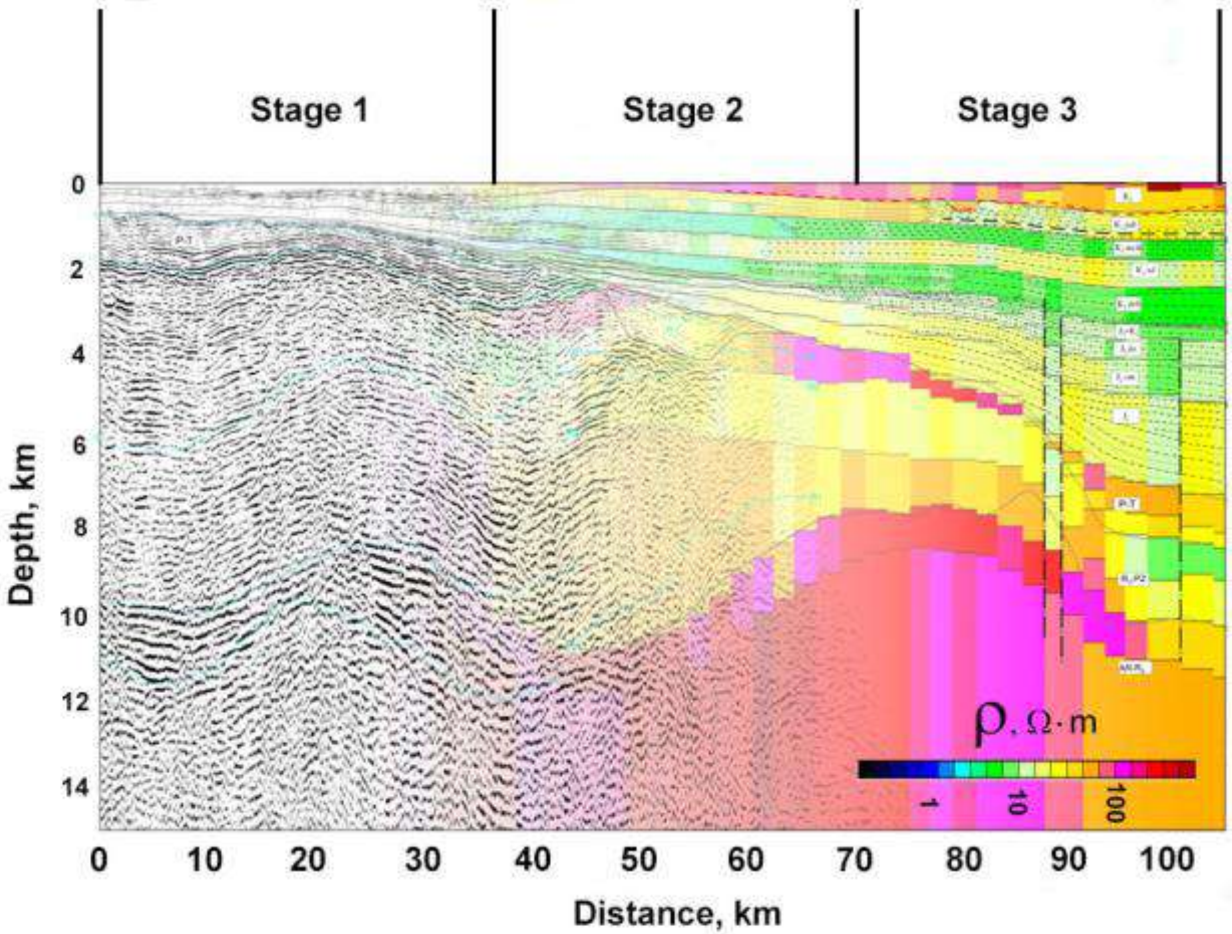
Constrained MT inversion

Constrained inversion of MT data collected in sedimentary basins is based mostly on application of seismic and logging data.

Subhorizontal sharp discontinuities in sediments, which correspond to reflectors, could correspond also to sharp changes in resistivity. Logging data (VSP, electrical logging, lithology) are used to check the existence of such interfaces.

Constrained inversion of MT data is based on the existence of such horizontal interfaces on which velocity and resistivity (and density) changes significantly. Practically the geometry of the model (number and thickness of the layers) is fixed and MT data inversion focuses on lateral changes of resistivity within fixed layers.

Constrained (controlada) inversion



Resistivity of sedimentary rocks

Sedimentary rock is a multiphase system. The simplest model is a two-phase rock. Mineral grains that have a very high resistivity (semiconductors) comprise the bulk of the rock, while the pore space is occupied by a second phase that has a low resistivity.

Even if the second phase **is volumetrically small, it can significantly influence** the overall resistivity of the rock. This is a common occurrence with, for example, **saline aqueous fluids** occupying the space between the grains.

Other conducting phases can be present and include **clay, sulfide or graphite**.

Electrical conductivity of sedimentary rocks

(1) Clay content

(2) Effective porosity

(3) Fluid saturation

(4) Electrical conductivity of pore fluid

Electrical resistivity allows us to obtain geological (lithological) information independent from other geophysical methods.

What is magnetotellurics used for ?

(1) Regional-scale studies of the Earth crust and upper mantle;

(2) Oil and gas exploration and reservoir characterization;

(3) Geothermal, hydrological studies and aquifer/aquitard characterization;

(4) Mineral exploration;

(5) Ecological and environmental studies.

Where is application of magnetotellurics for hydrocarbon prospecting effective?

Where seismic faces problems…

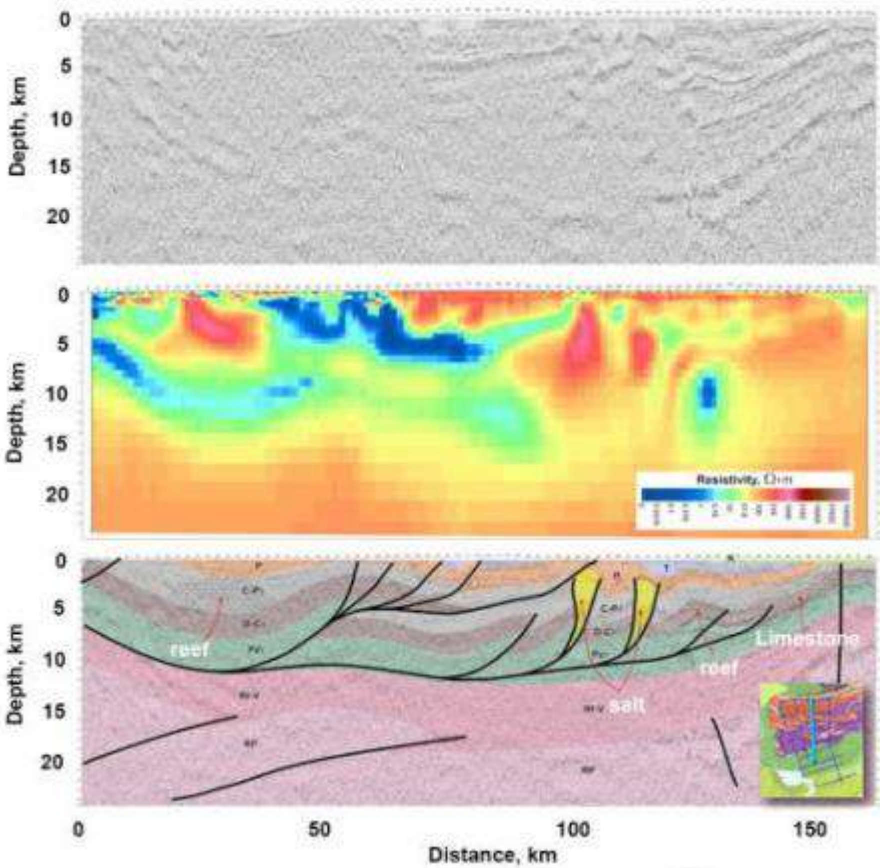
1. Geological provinces with seismic rigid boundaries or/and velocity inversion in the upper part of cross-section (basalt traps: Eastern Siberia, Parana, Deccan).

2. Salt tectonics basins (e.g. Mexican Gulf, Precaspian depression, Central Iran, etc).

3. Fold belts (e.g. Taimyr, Zagros, Subandino basins, NW Colombia, etc).

4. Sedimentary basins covered by thick permafrost (e.g. Eastern Siberia, Alaska, Northern Canada and Arctic Seas Shelf).

Constrained inversion and joint geological interpretation of Taimyr Fold belt

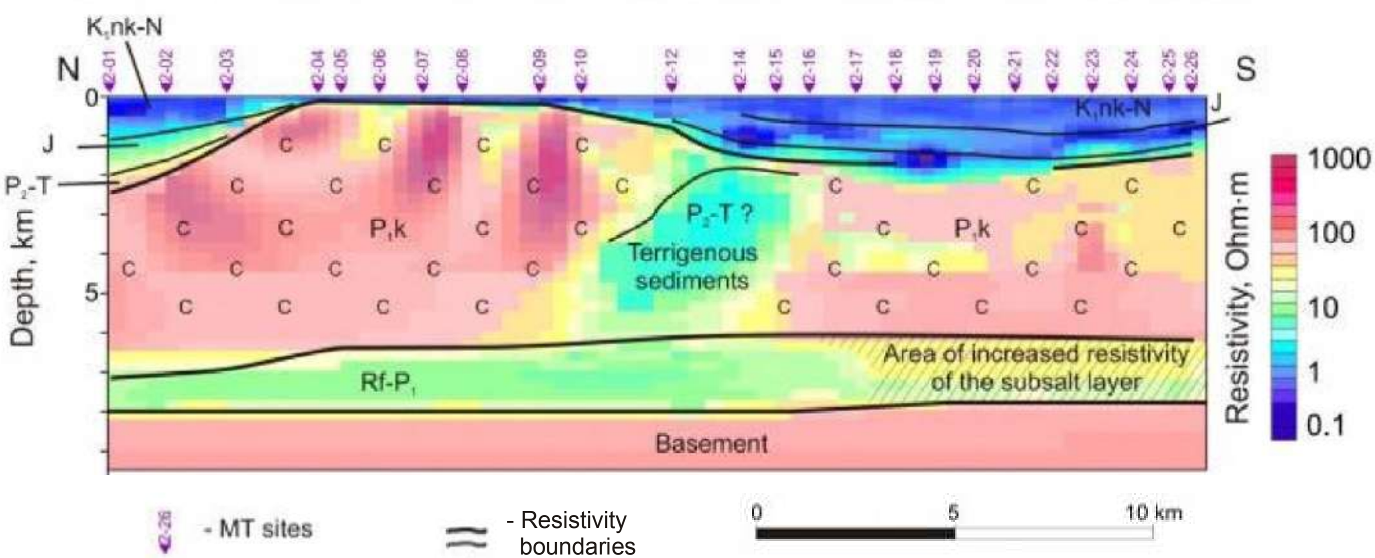


Palshin et al., 2017

Constrained inversion: imaging subsalt sediments

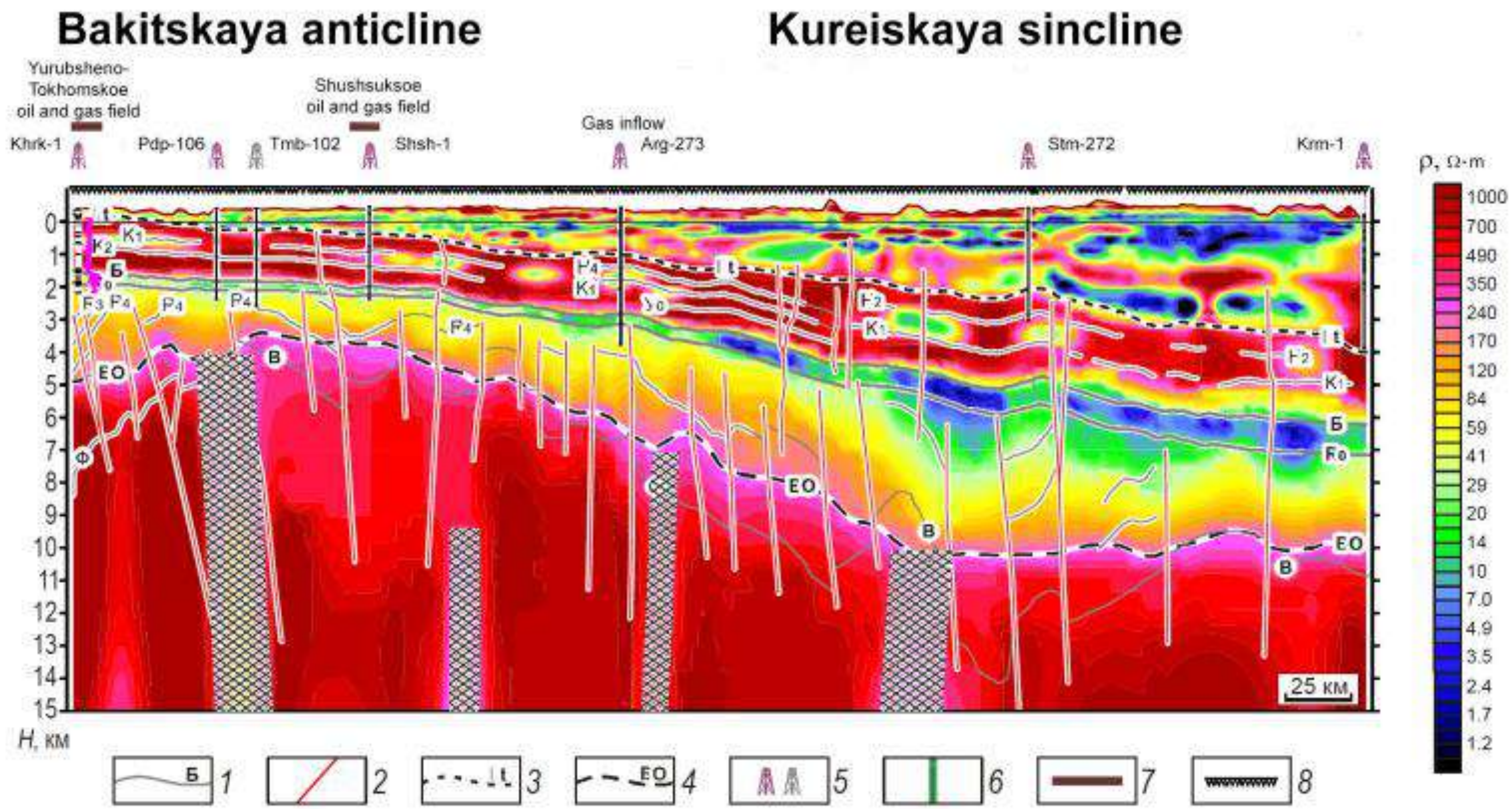
A low resistive canopy was revealed inside the salt dome body. Most likely it corresponds to terrigenous rocks of the Upper Permian-Triassic age with good prospect for hydrocarbons.

Subsalt Pz carbonate formations porosity was estimated and low resistive zones were suggested as having good hydrocarbon prospects.



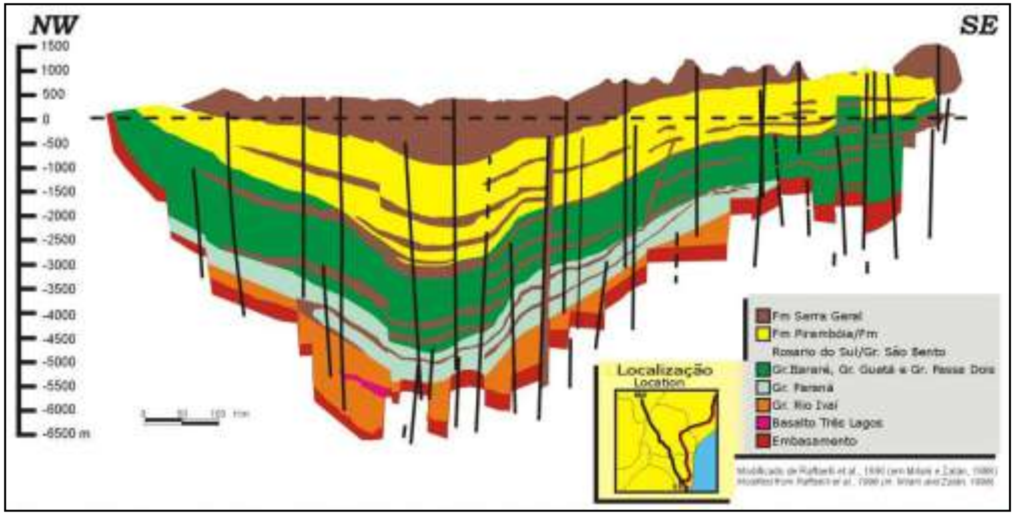
Aleksanova et al., 2009

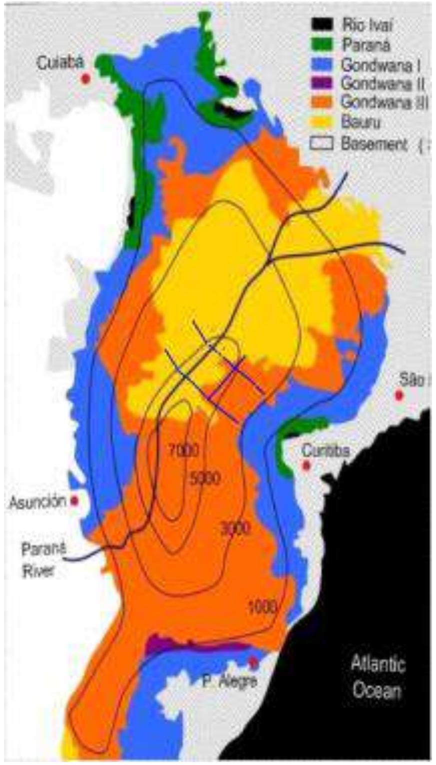
Eastern Siberia
Joint interpretation

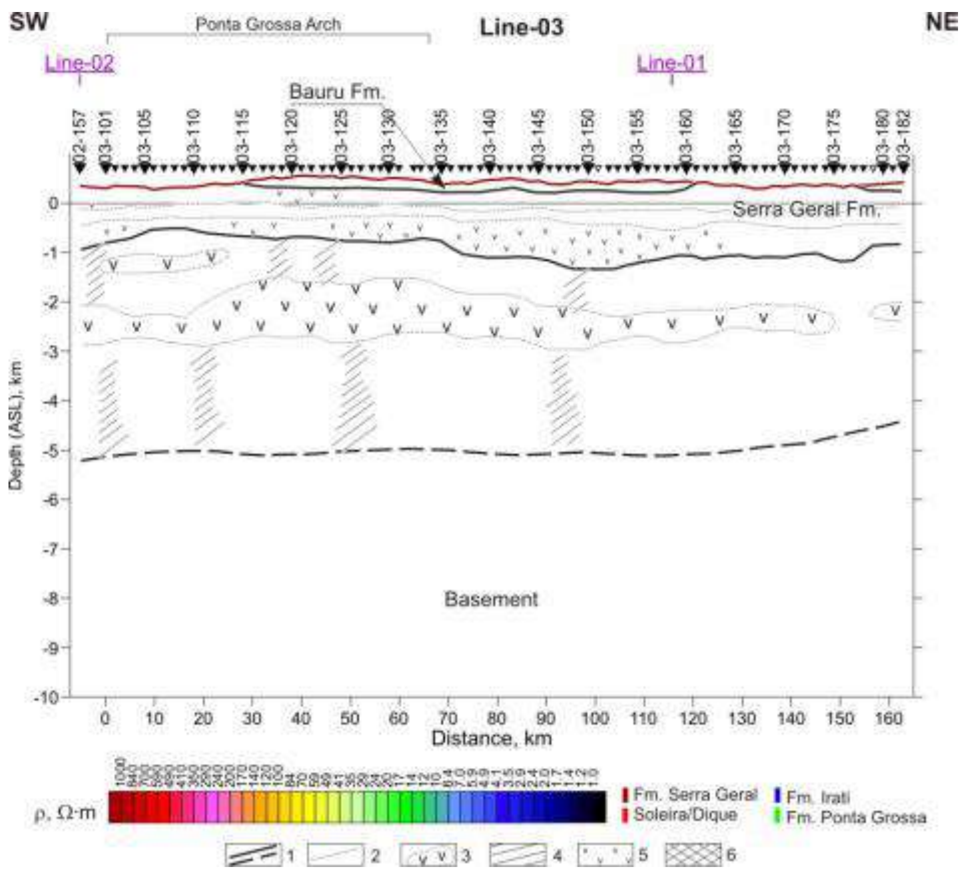


1 – seismic horizons; 2 – faults; 3 – top of carbonates from seismic data and drilling; 4 – high resistive basement; 5 – drilling holes; 6 – intrusive rocks; 7 – oil and gas fields; 8 – MT sites

Hypothetical geological cross-section of Parana Basin



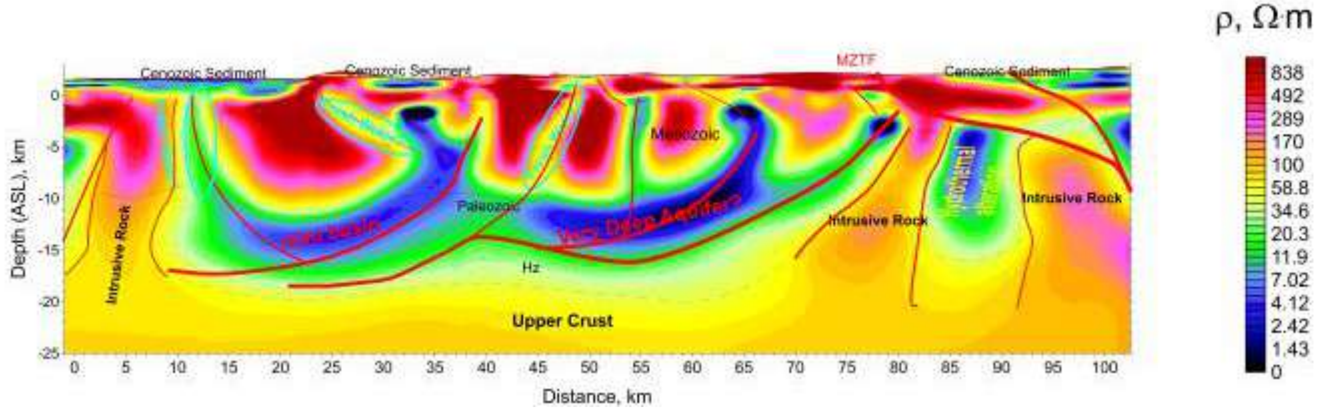


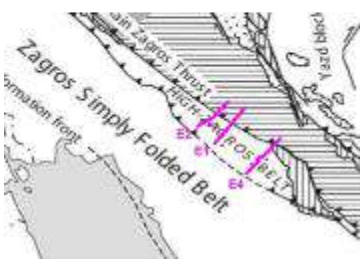


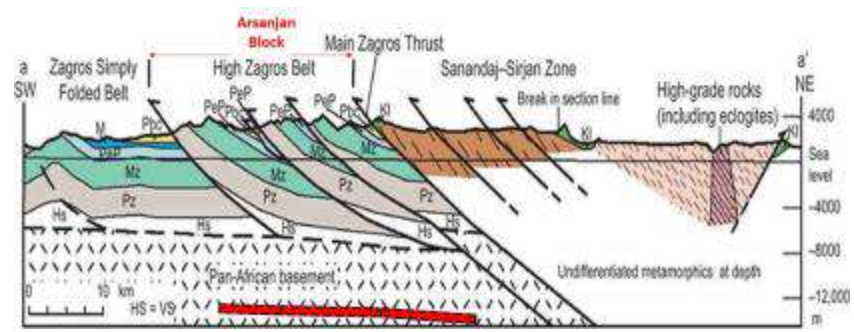
1 – the main geological boundaries; 2 – axillary geological boundaries; 3 – zones with significant contribution of intrusive rocks; 4 – zones of contact alteration of the rocks; 5 – zones with significant contribution of intrusive rocks within Serra Geral Fm.; 6 – conductive zone in the upper crust (suture zones?).

Main Zagros Thrust Belt

E4







Magnetotellurics: advantages and shortcomings

The broad band span of depths

Sensitive to lithology

Could be used for characterization of reservoirs and sealing

Effective tool for outlining fault zones

Relatively low cost and environmentally friendly exploration technology

Could not detect geological boundaries with accuracy compatible with seismic methods

Low spatial resolution, which decreases with depth

Vulnerable to industrial EM noises

Conclusions

Magnetotelluric is an effective technology for hydrocarbon prospecting in geological provinces with seismic rigid boundaries or/ and velocity inversion in the upper part of a cross-section, salt tectonics basins, fold belts and sedimentary basins covered by thick permafrost.

At initial stages of geophysical research it could be used separately along regional profiles.

At exploration stage magnetotellurics could be used together with seismic survey as essential complimentary technology.

Constrained and/or joint inversion followed by geological joint interpretation of all available data (seismic and logging data) enables reducing uncertainty of geological interpretation.