Background velocity model from magnetotelluric resistivity sections: A tool for seismic survey design and synthetic seismic data generation.

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Abstract

We develop a methodology to estimate velocity from magnetotelluric resistivity sections. Using rock physics relations, stochastic formulation and data calibration we can convert resistivity to velocity field. These background velocities models yield a detailed insight into the background velocity, and they are a powerful tool for feasibility studies. We use the velocity field obtained to modeling synthetic seismic data using either acoustic ray-tracing algorithm or acoustic full waveform modeling. Therefore, we can optimize seismic acquisition parameters.

Introduction

Seismic and electromagnetic data give us complementary information. Seismic survey is based in wave equation and depends on density and elastic moduli of the rock. Electromagnetic survey is based on Maxwell Equations which depend on the magnetic permeability, electrical resistivity, and electrical permittivity of the rock. Although the two kinds of data share no common parameter, we can replace the missing link with rock physics, usually, via porosity.

Werthmüller et al. (2013) developed a methodology to estimate resistivities from seismic velocities using porosity as link between them. They use self-similar model and Gassmann equation to determine a range of resistivity models that is consistent with known seismic velocities. Once this transform is calibrated, it could be applied to the whole depth extent of seismic velocities. The purpose of this work takes the opposite directions, but uses the same tools, we intent to determine the range of velocities models that is consistent with known resistivity field.

The result is a transform that can be applied to resistivity field to get background velocities. It can be used for seismic survey parameters design and it provides a good model to generate synthetic seismic data.

The synthetic data can be stacked and integrated with real seismic data. Moreover, it can be used to aid in converting seismic time data to depth. This methodology can be used to help recover information where there is lack of seismic acquisition.

Resistivity to Velocity Transform

There are many different rock-physics models to relate resistivity to porosity and porosity to velocity. Some are based on theoretical assumptions, such as the self-similar model, the Gassmann equation, or the Hashin-Shtrikman (HS) upper and lower bounds. Others are derived empirically, e.g., Archie or the Raymer equation.

Werthmüller et al. shows different velocity to resistivity transforms: the Gassmann equation combined with the self-similar model, the Raymer equation combined with the Hermance model, the Faust equation and the HS bounds. It might be noted that the Gassmann equation / self-similar model relationship had an average behavior, indicating that the is most reasonable relation. In this paper the author points out that the choice of model is not important since it must be calibrated.

Sen et al (1981) develop a theory for dielectric response of water saturated rocks based on a realistic model of the pore space. The author creates, thus, the formulation of the self similar model that relates resistivity to porosity.We use this model to convert resistivity to porosity.

From the porosity and grain/fluid setting we can infer the dry bulk and shear moduli by Krief relations (Krief et al., 1990).

Gassmann (1951) derives equations for fluid substitution in porous, elastic media using dry bulk and shear moduli. Using Gassmann equation, we can calculate the bulk module and then the velocity.

A rock-physics model, as previously established provides a transform from resistivity to velocity. This transform must be calibrated with a set of data, often from well logs, with core samples or internal seismic velocity. Rock properties are a function of many parameters, such as pressure, temperature, wetability, residual oil and water saturations, shaliness, porosity, and permeability. As we are looking for Background model without any hydrocarbons, we can ignore some of these parameters, such as wetability and residual oil and water saturations, except for temperature and pressure, which are functions of depth.

To get a background velocity model from resistivity data, we need to be able to transform for whole data, all depths. The simplest depth trend would be to calibrate the transform at a shallow and a deep part of the section and establish a linear depth trend.

Uncertainty

Conversion between the resistivity and the velocity involves a two-step procedure through a set of equations. Therefore, the conversion is associated with several parameters. These parameters have errors, and must be taken in account.

The parameters themselves are described as uniform distributions of a defined error around our best estimate. To get the probability density function (PDF) of the whole range of possible parameters we use a Markov chain Monte Carlo (MCMC) sampler.

The result of this methodology is the velocity as a PDF for any given set of model parameters, instead of a single deterministic value.

Thus we have a set of velocity field compatible with the input resistivity field.

Example

Our study area is a rift basin. The field is a medium-size probable oil and gas field at a depth of about 2.7 km; the basement depth is approximately 4 km.

It was acquired 10 stations broadband magnetotelluric survey spaced by 1km. The data was processed following steps:

1 .Convert time series to internal software format

2. Reprocess the Fourier coefficients using a robust reprocessing program and possibly data from the reference site.

3. Edit the resulting crosspowers one frequency at a time to verify the viability of the sounding and to reduce or eliminate low quality data.

4. Translate the edited crosspowers into industry standard EDI format for use by interpretation software.

5. Dimensionality study/define strike direction

6. 2D OCCAM Inversion

In the Figure 1 we can see resistivity field obtained by magnetotelluric acquisition. This resistivity data was converted to velocity fields and we compute de velocity models mode (Figure 2) and velocity models with one sigma deviation from model mode (Figure 3).

For calibration we use the interval velocity field obtained by smooth gradients inversion of RMS Velocity field from the seismic processed lines that passes over the MT stations. The velocity models mode match interval velocity from seismic lines with 0.70 correlation (Pierce coefficient). We use velocities models mode for acoustic ray trace modeling and acoustic full wave form modeling (Figure 4 and 5)

We can see in ray trace stacked section that the main horizon fits in time the real seismic data with reasonable accuracy (Figure 6 and 7).

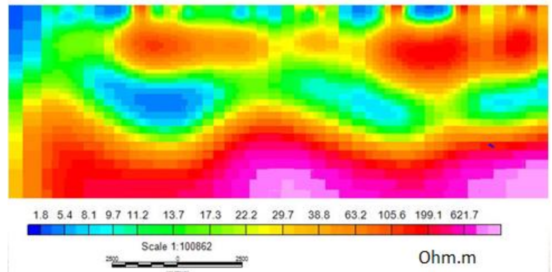

Figure 1: Resistivity field obtained by OCCAM 2D Inversion of magnetotelluric data

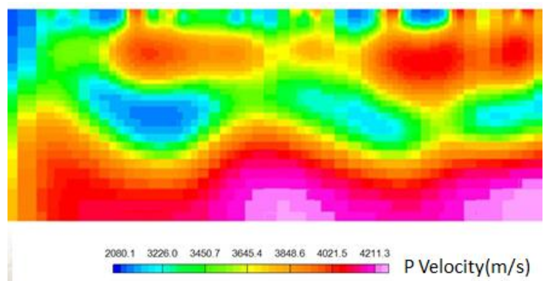

Figure 2: P wave velocity field converted.

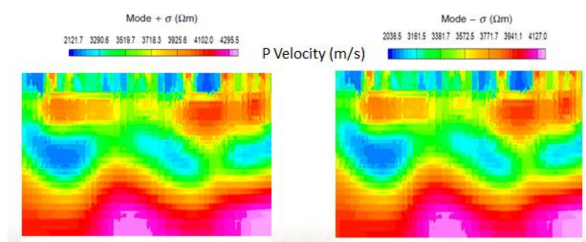

Figure 3: P wave velocity field mode minus one sigma and model mode plus one sigma.

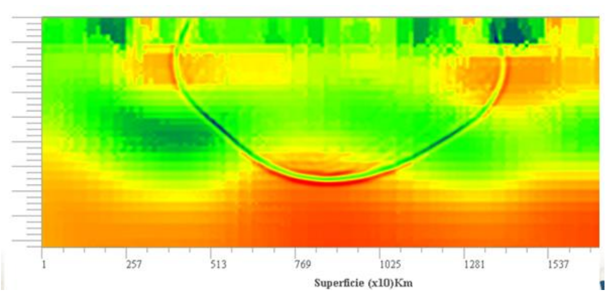

Figure 4: P Wave field propagation on velocity field converted

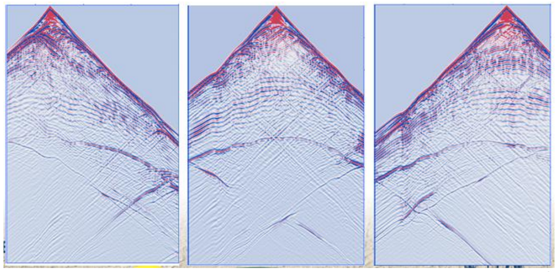

Figure 5: Synthetic seismic data (Shot Domain) obtained by wave field propagation on Figure 4.

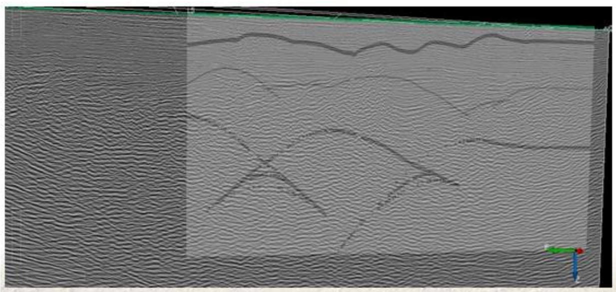

Figure 6: Synthetic stack seismic data over real seismic data.

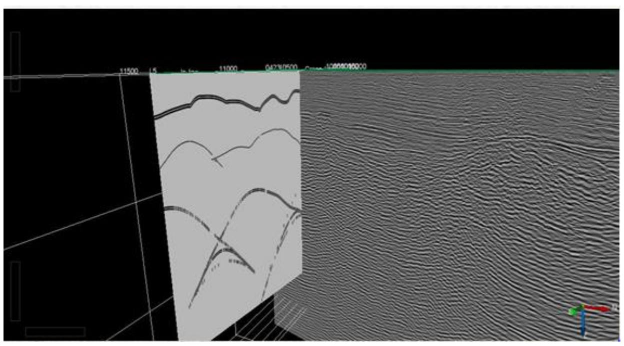

Figure 7: Synthetic stack seismic data crossing real seismic data.

Conclusions

We present a methodology to estimate the range of background velocity models that is consistent with known resistivity field.

The approach uses depth dependent petrophysical relations and uncertainty analysis of the data and the model.

We concluded that magnetotelluric method is capable to provide a good background velocity with low cost, and allows filling the lack of information when you don’t have good quality of seismic data.

Acknowledgments

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