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Feasibility study of joint magnetotelluric/seismic interpretation for sub-basalt imaging

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Introduction

In some specific regions, seismic imaging is difficult, e.g. volcanic terrain because the high-velocity formations scatter and reflect the seismic energy, and therefore mask the underlying structures. In contrast, the magnetotelluric (MT) soundings, which measure the electrical conductivity distribution in the earth, are insensitive to the highly electrically resistive volcanic structures, and are sensitive to the more conductive underlying formations.

We consider the critical case of a sedimentary basin underneath basalt units, the basaltic intrusions being covered with surface marine sediments. When modelling MT data acquired in such a geological context, some difficulty in the interpretation can occur from the presence of the conductive surface sediments, which will decrease the resolution of the sedimentary basin imaging. Also, difficulty can occur from the weak sensitivity of MT to the resistive structures. On the contrary, surface sediments and high-velocity volcanic structures are well constrained in seismic interpretation, whereas it is difficult to detect the low-velocity sedimentary basin making thus seismic and MT methods complementary. Furthermore, there is a correlation between the conductivity structures described by MT data and velocity structures described by seismic data since the main factors affecting the elastic properties and electrical conductivity of a material are the porosity and the connectivity (Kozlovskaya and Hjelt, 2000). In seismics, ocean-bottom seismometers (OBS) perform better than conventional seismic reflection in this geological context, and the imaging of sub-basalt sedimentary structures has been sometimes possible with this method (e.g., Hughes et al., 1998). The MT method is well suited to imaging complex structures (Hautot et al., 2000). Since the MT method is reasonably cheap and large areas can be surveyed in a reasonable time, large data sets can be acquired allowing high-resolution imaging.

Here, MT results and OBS results from a theoretical model are combined. We show that uncertainties on the structures jointly modelled are significantly decreased, improving the imaging resolution.

The geological sample model

In order to test the sensitivity of OBS and MT methods to the geological targets considered, we generated a synthetic model of a representative of this geological context.

In our model, the water depth is 1.5 km, surface sediments are 500 m thick. A sedimentary basin is enclosed into thick basalt units. The structure is two-dimensional (2-D). Marine MT and seismic data are simulated with ocean-bottom magnetotelluric and seismic stations (figure 1).

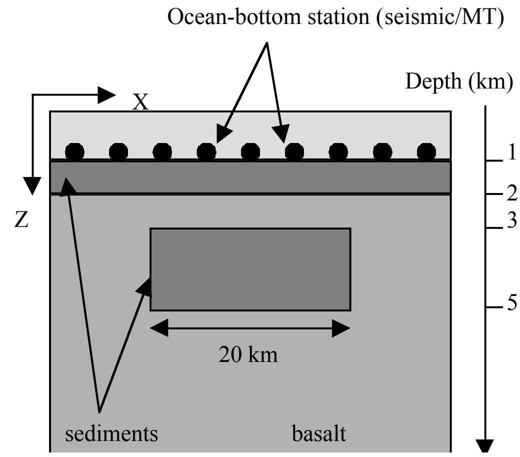

Figure 1: The geological sample model used in the computations.

Electromagnetic modelling

We assigned a conductivity of 3.3 S/m to the ocean, 0.02 S/m to the surface sediments and to the sedimentary basin, and a conductivity of 10^{-3} S/m to the basalt. The MT response of the model is computed on the sea-bottom in a period-range of 0.1 to 2000 seconds. A MT profile is simulated with 9 stations along a distance of 60 km. A random noise of a few percents is added to the synthetic data. In order to analyse the sensitivity of the MT response to the presence of the sedimentary model, the same model has been generated apart from the sedimentary basin. The

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comparison of the MT responses for the two models shown a large effect of the presence of the sedimentary basin for period shorter than 100 seconds.

OBS ray-trace modelling

The velocity model was defined from the geological structures. We assigned a velocity of 1.5 km/s for the ocean, a velocity of 2 km/s for the surface sediments and of 3 km/s for the sedimentary basin, and a gradually increasing velocity of 5 to 6.8 km/s for the basalt intrusions.

We considered the case of one OBS located above the centre of the sedimentary basin. Seismic sources are displayed along the x axis (figure 1). The simulated ray diagram for this model shows clearly reflections from the top of the basalt and from the top of the sedimentary basin. Reflections form the bottom of the sedimentary basin are also visible.

When we considered the case of an OBS at a distance away from the centre of the sedimentary basin, the width of the sedimentary basin is resolved by the transmitted and refracted waves through basalt and Moho which slow down as they propagate in the sediments

Inversion of the data

We performed an inversion of the MT data without any a priori constraints on the conductivity structures in the model, except the dimensions of the whole 2-D structure (60 km wide). The initial model used for the inversion of the MT data generated at the 9 stations was homogeneous (10^{-2} S/m). In the final conductivity distribution, surface sediments and the sedimentary basin are clearly identified. However, the basalt layer between the surface sediments and the basin is not resolved.

Considering the information provided by the OBS data, we performed the same inversion of the MT data, but with some constraints from the initial model. First, we considered that the surface sediment layer thickness is known from the seismic interpretation. The result is clearly better resolution of the basalt layer between the surface sediments and the sedimentary basin.

Second, we considered all the information provided by the OBS data on the surface sediments layer (thickness) and the sedimentary basin (width and the depth of the top). The latter was taken into account in the initial model of the MT inversion by adding to the structure a thin conductive body of the width and at the depth determined by seismic interpretation. The result of this new inversion test is really convincing. All the structures are precisely resolved in the final model, very similar to the model used to generate the synthetic data.

Conclusions

Two problems were considered in this study: in seismic, low-velocity structures are hardly resolved when they are covered with high-velocity structures. In MT, electromagnetic fields are weakly sensitive to highly resistive structures. However, when the two methods are combined for interpretation, we obtained an image of the sedimentary basin within the basalt units with a very good resolution of the geometry of the structures.

Results from this feasibility study are encouraging for an in situ experiment. Specific MT instruments are being developed for that purpose at the University of Brest.

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