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Imaging Sub-Basalt Sediments Using Marine Electromagnetic Sounding

L. MacGregor, Southampton Oceanography Centre, U.K.

Introduction

The presence of high velocity layers, such as basalt, carbonate or salt, can make the detection and characterisation of sediments lying beneath using conventional seismic techniques a difficult task. In such situations complementary information derived from measurements of electrical resistivity can provide valuable additional constraints on the structure. The electrical resistivity of basalt, carbonate or salt is typically in the range 100-1000 Ωm, whereas the resistivity of the surrounding sedimentary sequences is typically 1-10 Ωm. This marked contrast in resistivity is an ideal target for electromagnetic prospecting techniques.

Method

Several marine electromagnetic techniques have been developed in recent years to address the problem of mapping offshore electrical resistivity structure. One such technique, marine controlled source electromagnetic (CSEM) sounding in the frequency domain, has been successfully applied to the study of oceanic lithosphere (e.g. Young & Cox, 1981; Constable & Cox, 1996) and several combined electromagnetic/seismic studies of active mid-ocean ridges have been performed (e.g. Evans et. al, 1994; MacGregor, Constable & Sinha, 1998; MacGregor, Constable & Sinha 2001). The CSEM method uses a horizontal electric dipole source to transmit a low frequency (from a few tenths to a few tens of Hz) electromagnetic signal to an array of seafloor receivers. These receivers detect and record the electric field at the seafloor. By studying the variation in amplitude and phase of the received signal as the source is towed through the receiver array, the resistivity structure of the sub-surface can be determined. Since the source is 3-dimensional, the response of a given structure depends critically on the source receiver geometry. Careful experimental design to maximise the range of geometries in a survey is therefore necessary to maximise the sensitivity of the resulting data to structures of interest (MacGregor & Sinha, 2000).

The magnetotelluric (MT) method uses measurements of naturally occurring electromagnetic fields to determine the resistivity of the sub-surface. The depth to which the incident EM fields penetrate depends on the frequency of the field and the resistivity of the medium. Thus, by studying the variation in response as a function of frequency, the variation in resistivity as a function of depth may be determined. Traditionally the marine MT method has been used for mapping large-scale (tens to hundreds of km) resistivity variations, since the conductive seawater screened all but the lowest frequency source fields. However recent advances in instrumentation have increased the usable frequency band so that crustal scale variations can now be mapped (Constable et al. 1998). The method has been successfully applied to the study of salt structures in the Gulf of Mexico (Hoverston et al. 2000), and more recently to sub-basalt structures in the North Atlantic (Lewis et al. 2002).

Modelling results

The resolution capabilities of marine electromagnetic sounding in the context of sub-basalt exploration have been investigated by a combination of iterative forward modelling and inversion of synthetic datasets in terms of 1- and 2-dimensional resistivity structures, in order to establish whether sub-basalt sediments can be detected and if so how well their depth of burial, thickness and properties can be determined using marine electromagnetic methods.

Controlled source electromagnetic data are sensitive to shallow resistive structure, but lack sensitivity to the deeper crystalline basement. Magnetotelluric data are notoriously insensitive to thin resistors, however they can constrain the resistivity of the sub-basalt sediments, and the basement beneath. By combining natural and controlled source electromagnetic data, better constraints on the geometry and properties of sub-basalt sediments can be gained than from either data type alone. The natural source data can be collected using the same instruments as are deployed for a controlled source experiment, and can therefore be collected with little extra effort once a controlled source array has been deployed.

Conclusion

Electromagnetic methods can be used to provide valuable information on the structure and properties of the sub-surface in technically demanding environments. These techniques are particularly powerful if combined with the results of other geophysical surveys. For example inclusion of the upper-basalt boundary determined from seismic studies, can improve resolution of deeper structure by the electromagnetic data. Resistivity values from well-logs can also be used to constrain the interpretation and hence improve the resolution achieved. Resolving structure and lithological properties in areas where the target of interest is concealed beneath basalt or salt is likely to require a variety of techniques. However marine electromagnetic sounding can make a significant contribution in the context of sub-basalt imaging.

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