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Inversion of Magnetic and Gravity Fields Applied to the Sub-Basalt Imaging Problem

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ABSTRACT

This study investigates the feasibility to use gravity and magnetic inversion to image basalts and sub-basalt structures in sedimentary basins affected by volcanism. A regional 3D model was constructed for the Møre margin, mid-Norway, based on a wealth of seismic and petrophysical information. Resolution of the regional 3D model prevents however detailed imaging of the basalts and sub-basaltic structures. While it is difficult to identify the lateral extend of the volcanic features (at depth of 6 km) in the gravity and magnetic data, as well as in Full Tensor Gravity (FTG) data, the sub-basaltic basement architecture can be identified. The gravity gradients provide valuable information on the vertical and lateral extent below the basalts, despite the small density contrast to the surrounding. Inversion of the gravity and magnetic residuals, after correction for the regional anomalies provided by the 3D model, gives a better insight into the extent and thickness of the basaltic and sub-basaltic layers. Especially, coupled inversion increases the depth resolution, but magnetic and gravity inversion must be weighted differently. Such inversion requires detailed pre-knowledge on the regional structures and shallow sedimentary layers, and can assist other sub-basalt imaging techniques.

Key words: Gravity, magnetic, gradients, inversion, volcanics

INTRODUCTION

We present a study on the use of gravity and magnetic data in sub-basalt imaging. Volcanic passive margin systems are often impeded by volcanic at the continent-ocean-transition (e.g. sea-ward dipping reflectors), and sill intrusions within the basins. In areas, where sills and lavas are interbedded in the sedimentary strata, standard seismic acquisition and processing fails to deliver interpretable images of the sub-basalt sequences. The sub-basaltic sequences hold the promise of large hydrocarbon potential and methods to image beneath them are of high interest (Ziolkowski *et al.*, 2003). Much emphasis has been put on solving the imaging problem during the past years by enhancing seismic methods. However, the fix-all solution has yet not been found.

A useful technique in the presence of seismically problematical lithologies is analysis of potential field data (Smallwood *et al.*, 2001). Gravity modeling can significantly improve the seismic interpretation and help with the structural interpretation in areas obscured by volcanics (Ashcroft *et al.*, 1999).

We present a case study from the Norwegian volcanic margin (Figure 1), which has been strongly affected by volcanism, in particular in the outer part of the Møre and Vøring Basins, where extrusive and intrusive rocks form an important part of the basin fill (Planke *et al.*, 1999). The general structure of the Møre margin has been presented by Osmundsen and Ebbing (2008) and Reynisson *et al.* (2009). These studies provide the complete 3D structure of the mid-Norwegian margin, by integrating a wealth of seismic and well data with potential field data. From these models the regional structure of the margin is well constrained (Figure 1 and 2).

Here, we test the use of gravity and magnetic data to enhance the regional model for the scale of the sub-basalt imaging problem. We discuss the expected amplitudes of anomalies against expected errors, both for conventional gravity and magnetic data, as well as for Full Tensor Gravity (FTG) data.

In the next step, we present an inversion of gravity and magnetic data and discuss some of the problems and advantages in inversion for sub-basalt imaging. Joint inversion of gravity and magnetic data improves the resolution, but a challenge is the weighting of gravity against magnetic data, as well as the focus of the inversion to linear, small-volume structures.

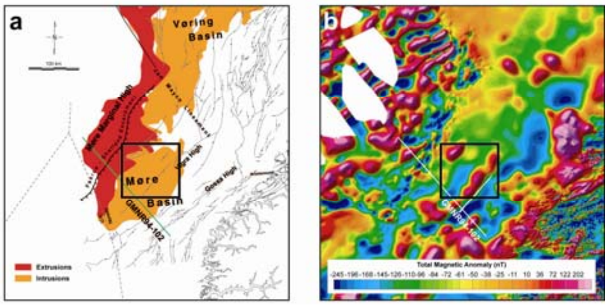

Figure 1. (a) Distribution of volcanic on the Møre margin (modified from Planke et al., 2005). The green line indicates the location of the profile in Figure 2. (b) Magnetic anomaly map of the Møre margin (after Reynisson et al. 2009). Small box indicates area used for inversion.

METHOD AND RESULTS

Magnetic and gravity data are conventionally used to model regional 3D structures. The model in Figure 2 presents a cross-section through the Møre margin. The deep structure of the model is constrained by a wealth of seismic data, while well data constrain the upper sedimentary layers (Reynisson et al. 2009). However, at the depths of the top basement (8-14 km), the sediments get compacted and their density increases, leading consequently to a small density contrast to the underlying basement (e.g. Ebbing et al., 2009). In theory, gravity gradients are more sensitive to small-scale and shallow structures (Smit et al., 2005). Between the low-magnetic sediments and the magnetic basement and volcanic layers a high contrast exists, which could help to image the thickness of the volcanic layers and underlying sedimentary thickness.

Potential field signature of basalt/sub-basalt structure

The depth to the top of the volcanic layers is reasonably well constrained from seismic data (~6 km depth). But our analysis showed that the lateral distribution of the sills and basalt flows could not be linked consistently with any gravity or magnetic signal in the study area. The sub-basaltic basement structure of the synthetic model is difficult to resolve from the magnetic and gravity anomalies. The gravity gradient data give a much better image of the sub-basaltic basin. Figure 2 shows how well the horizontal gravity gradient relates to the basement undulations in the study area. Unfortunately, no measured gradient data are available on the Møre margin and therefore, no systematic analysis of real data can be provided.

With synthetic data, however, it can be shown that the deep volcanic layers have only a minor effect on the signals, which is in the order of the theoretical noise level for the different data sets. Detailed analysis of the energy content for different frequencies shows virtually identical results for models including volcanic as for models without volcanic. Shallower basalt flows have much greater impact on the gravity and magnetic fields. The impact is on a wide frequency range as the large-scale basaltic plate has a long wavelength signal but the small scale geometric undulations and edges have short-wavelength effect. The gravity anomalies are more sensitive to the large-scale variations but the magnetic and gravity gradients are more responsive to the small-scale structures (Reynisson et al., 2009).

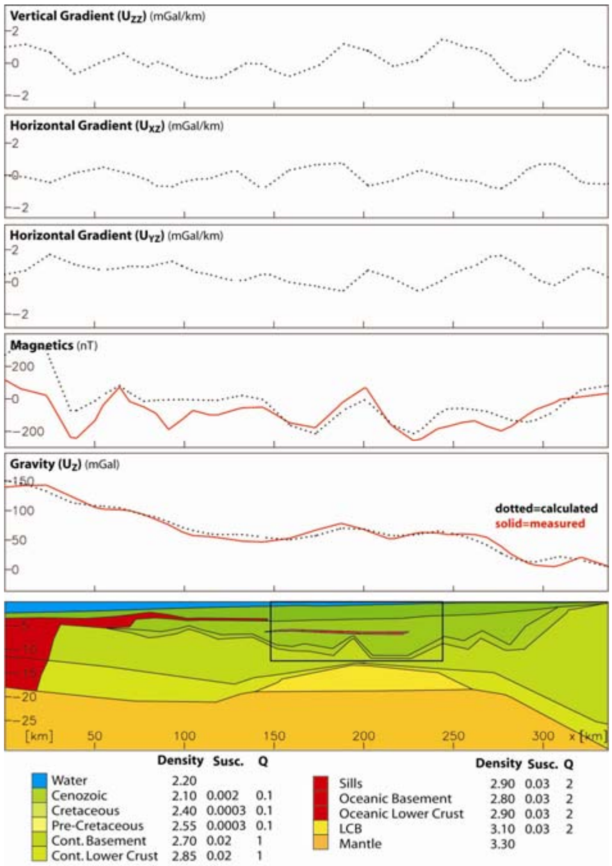

Figure 2. A profile view from the Møre margin from the regional 3D density and magnetic model (see location on Figure 1). Measured potential field signature is indicated by red lines and the calculated fields from the model are presented by black dotted lines. Gravity gradients were calculated from the model, but no measured data are available. Black box shows the area where the inversion has been applied.

Inversion

While the gravity and magnetic data cannot be used for a direct imaging and identification of the sub-basalt structures, we want to explore the potential application of inversion to gain insights into the volcanic thickness and sub-basaltic sedimentary sequence. The high contrasts in magnetisation makes magnetic inversion feasible, but the ambiguity in inversion makes it difficult to distinguish the top sills and top basement structures. Here, we use the information on the top sills as an upper bound for the inversion and also provide a lower bound located close to the top basement from the regional model.

Inversion of potential field data to image homogenous planar structures is challenging. At the edges of the structures, the response can be very good, but it will be less pronounced over the inner part of the structure. This limitation causes poor resolution of the central part using inversion (Williams, 2008).

The sill complexes in the Møre basin have a thickness of < 500m and have a regional extension. To be able to retrieve the horizontal distribution, the length scale has to be increased towards the horizontal vs. the vertical direction. Further sensitivity tests showed that also the inversion is sensitive to the lateral extent and the length scale in N-S and E-W directions.

Figure 3 shows the lateral extent of the sills from inversion of gravity and magnetic data. Magnetic inversion focuses on the shallowest parts of the sills, while the gravity inversion tends to distribute the solutions over a too large area.

In the next step, the inversion of the gravity and magnetic is correlated. Coupling of the two data can provide a better definition of structural features and improve the inherent lack of depth resolution (Fregoso and Gallardo, 2009). The weighted correlation between the two inversions leads to a more focused inversion result. However, an equal-based weight tends to be too much dominated by the magnetic inversion.

CONCLUSIONS

Analysis of gravity and magnetic data holds the potential to assist in imaging sub-basalt imaging. However, even with the increase in FTG technology, estimates of the thickness of sills and sub-sills structures are challenging, due to the (1) small volume of sills, (2) emplacement in depth where density contrast between sediments and top basement is small, (3) planar extension of sills. FTG data enhance structural changes, but the effect of the basaltic layers has an amplitude close to the inherited noise level. Weighted inversion of magnetic and gravity can improve sub-basaltic imaging, but the inversion requires detailed pre-knowledge. The regional model must be well constrained and the weighting of the gravity and magnetic inversion requires further testing. Sub-basalt imaging remains challenging, and the integration of other available geophysical methods (i.e., electromagnetic methods) is important to further enhance sub-basaltic images.

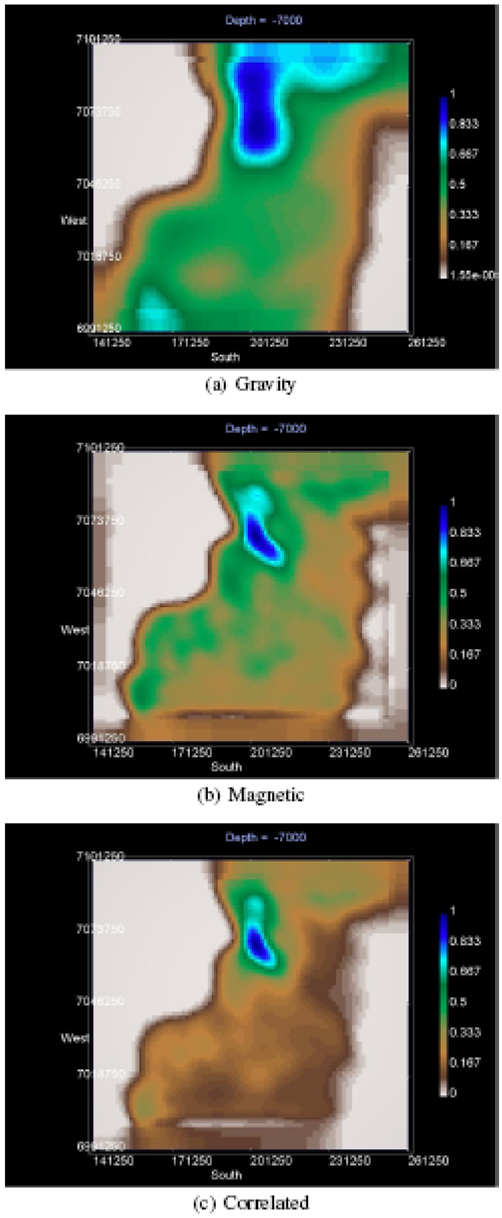

Figure 3. Inversion result of (a) gravity data, (b) magnetic data, and (c) correlated inversion. The results show a depth slice in 7 km depth, close to the top sills.

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