Exploring sub-basalt with EM constrained velocity model

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Abstract

This paper consists of two studies: first a synthetic inversion study and second a study using field data from the Faroe-Shetland basin. In the synthetic study, resistivity measurements from a Well log are used to build a realistic basalt model for an inversion test. Controlled Source Electromagnetic (CSEM) and Magnetotellurics (MT) responses are computed and then inverted to investigate how well the original model can be imaged. The synthetic inversion results shows that both the thickness and extend of the basalt layer can be recovered. In the second study EM (CSEM+MT) field data was inverted. The recovered resistivity model provides adequate information about basalt thickness and the sub-basalt structures, both the sub-basalt sediments and the basement can be resolved. Further the inverted resistivity model is used to update the velocity model for seismic depth imaging using the correlation between sonic log and resistivity log in a nearby well. Subsequent Reverse Time Migration (RTM) was used to depth migrate the seismic data. The resulting seismic image shows clear improvements, it is more focused and important seismic horizons are consistent with the resistivity image, even though the two data types are independent. Further, co-visualization of the depth-migrated seismic image and the resistivity model enhances these ismic interpretation.

Introduction

Potential hydrocarbons can be found in the sub-basalt sediments because basalt can act as a seal for hydrocarbon reservoirs. Sub-basalt imaging is very difficult with seismic because much of the seismic energy is reflected back from the top of basalt due to high impedance contrast. So with reflection seismic, only the top of basalt can be imaged near accurately but not thickness of the basalt sequence nor thepresence or absence of sub-basalt sediments. Electromagnetic (EM) methods are an alternative technique that can overcome this difficulty. EM can recover the resistivity structure of the sub-surface. Basalts are highly resistive in comparison to sediments that make EM methods very suitable for sub-basalt imaging.

Fruhen et al.(2001) and *White et al.*(2003) used long offset first arrivals to determine sub-basalt velocities. These velocity models lack resolution and there is possibility to enhancethis resolution. *Panzner et al.* (2014) explains that for successful depth migration velocity model must have correct travel time for reflection events. *Panzner et al.* (2014) further explains how low frequency EM data can be used to construct velocity models and can help in seismic depth imaging (*Colombo et al.*, 2013). *Herredsvela et al.*, (2012) also described how EM can be used to image sub-basalt sediments.

Here we first show a synthetic inversion study investigating the sub-basalt imaging capabilities of EM methods. Secondly we demonstrate sub-basalt imaging by EM methods using a real dataset the from Faroe-Shetland basin.

Synthetic Example

Reference Well log for this study was taken from Kutch-Saurashtra basin and resistivity values are taken from this Well log to create models. This study is explained in detail by *Borgohain et al.* (2015). CSEM and MT responses were generated and used in EM inversion to see how much this method is viable in sub-basalt mapping. Reference Well log and resistivity values for different sediments and water are given here.

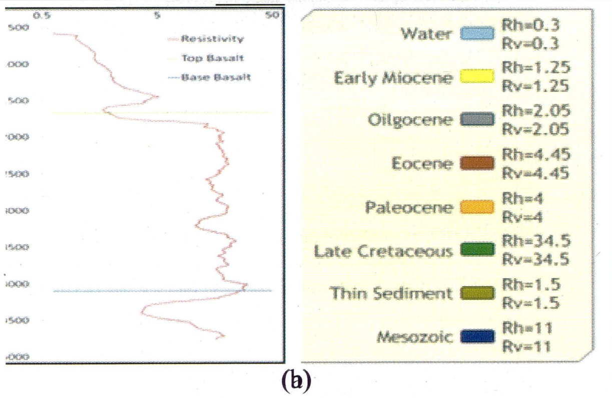

Fig. 1: (a) Reference Well log;1(b) Resistivity values

MT models are created first and their responses are generate for two cases; 1) varying basalt thickness while keeping sediments thickness constant and 2) varying sediment thickness while keeping basalt thickness constant.

MT is more prone to conductors this is the reason to have stronger response for increasing sediment thickness while not so strong in case of increasing basalt thickness. After MT, CSEM is analyzed with 1,000 and 2,000m thick

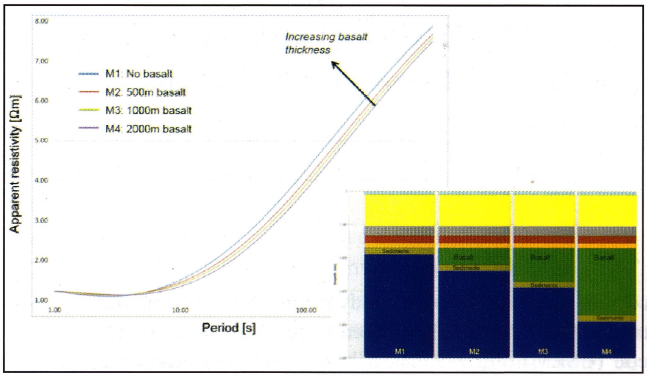

Fig. 2: MT models and responses for varying basalt thickness

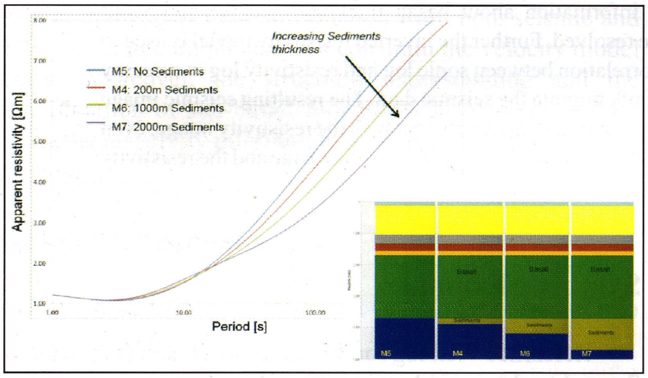

Fig. 3: MT models and responses for varying sediment thickness

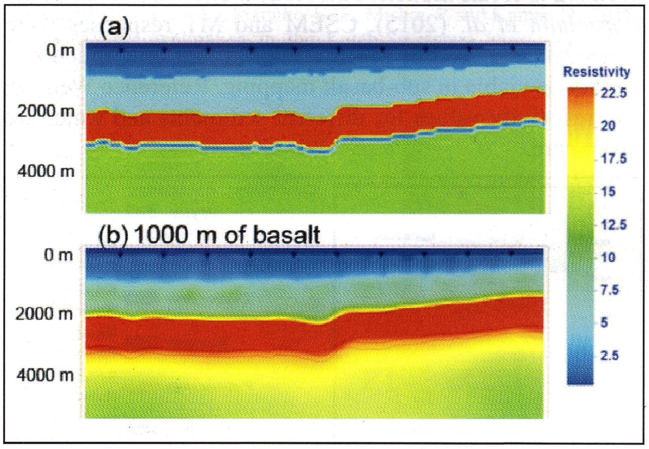

Fig. 4: (a) 1,000m thick basalt model; b) CSEM inversion

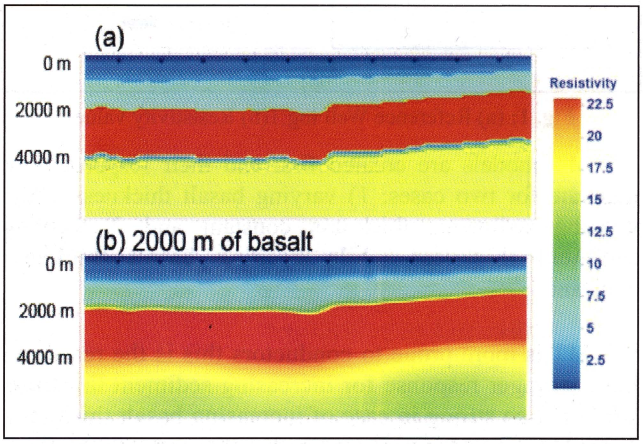

Fig. 5: a) 2,000m thick basalt model; b) CSEM inversion

basalt models. CSEM responses are used to get inversion images.

For CSEM inversion, it is assumed that top of basalt can be imaged with seismic accurately and flooded basalt model is used in inversion. It is visible in the images that CSEM can determine the thickness of basalt and also sediments underneath.

Field data from Faroe-Shetland basin

The CSEM and MT survey was acquired during autumn 2012.We utilize only a part of the survey data constituting a long, regional2Dline. The 2D line ranges from the East Faroe High in the NW over the Corona Basin and the Corona Ridge to the Flett Sub-Basin in the SE. Both the Brugdan (6104/21-1) well and the Rose bank (213/27-1) well are situated along this line. The survey layout is shown in Figure 6.

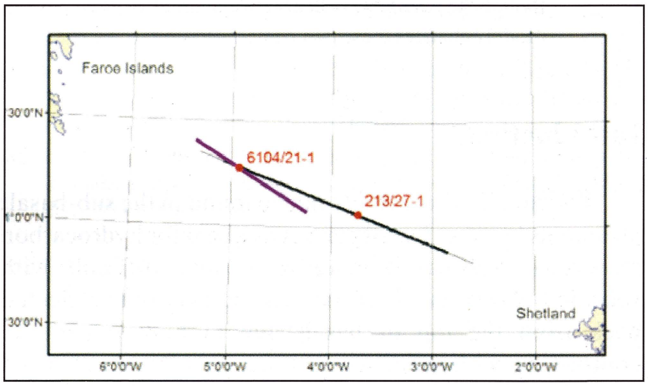

Fig. 6: Survey map showing the location of the EM line (black), seismic line (magenta) and location of both Wells (red).

We carried out CSEM and MT data inversionusing a Gauss-Newton type joint inversion scheme with a finite element forward modeling operator (Key and Ovall, 2011). No constraints were applied in the inversion, so the imaging result shown in Figure 7 is purely data driven. Hoversten et al. (2013) carried out an EM imaging study using the same data and got very similar results.

Further the inverted resistivity model was used to update velocity model for subsequent seismic depth migration, since it is nearly impossible to build a sub-basalt velocity model

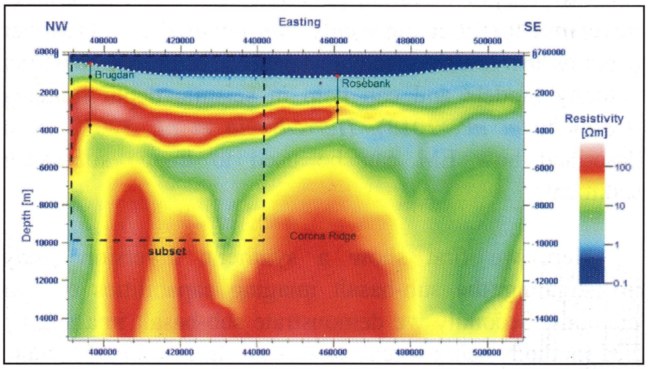

Fig. 7: Resistivity model from isotropic CSEM & MT joint inversion. (after Panzner et al., 2014)

using traditional move out based velocity analysis work flows (*Panzner et al.*, 2014).

The 2D seismic line used (FLA_06) is part of the Faroes Large Aperture Research Experiment (FLARE) (*Fruehn et al.*, 1998). The seismic line has an angleof 10 degrees to the CSEM & MT line, and crosses the Brugdanwell (6104/21-1) location as shown in the survey layout in Figure 6.For the depth imaging only the direct reflection data with offsets up to 6 km are only used.

The correlation between resistivity log and acoustic velocity log in the Brugdan well (6104/21-1) was used to derive an empirical relation (Figure 8), which was then used to update the velocity model only below the top basalt reflector. The velocities in the supra-basalt sediments are well defined by the reflection seismic data.

Panzner et al. (2014) tried to use traditional move out based methods to derive a velocity model but it turned out to be impossible to estimate the sub-basalt velocity structure. Therefore they simply flooded the entire model below the top basalt reflector with a constant velocity which was estimated based on the first arrival times of the refracted waves in the basalt layer.

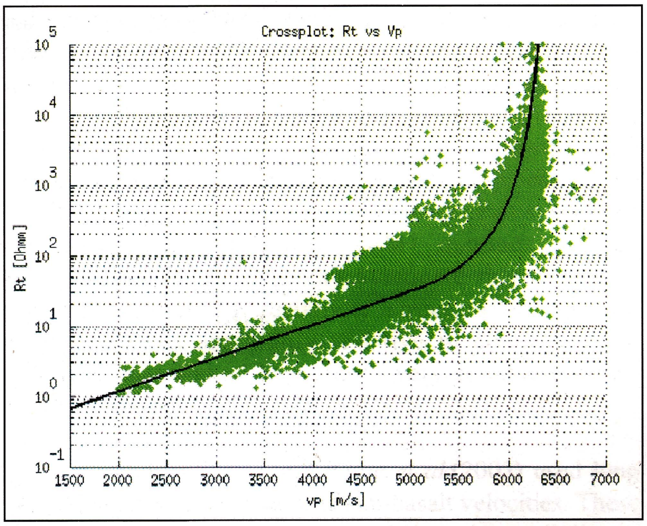

Fig. 8: Cross-plot of sonic velocity and resistivity from the Brugdan well (after Panzner et al., 2014)

To improve the seismic depth imaging *Panzner et al.* (2014) used the correlation between resistivity and velocity derived based on Well data (Figure 8) to convert the resistivity model into a velocity model. The subsequent depth migration using a RTM algorithm (*Weibull and Arntsen*, 2013) lead to significant imaging improvements (Figure 9 and Figure 10). The migrated image is more focused and important seismic horizons such as the top basement reflector are consistent with the resistivity image, even though the two datatypes are independent. Further, co-visualization of the depth-migrated seismic image and the resistivity model enhances the seismic interpretation.

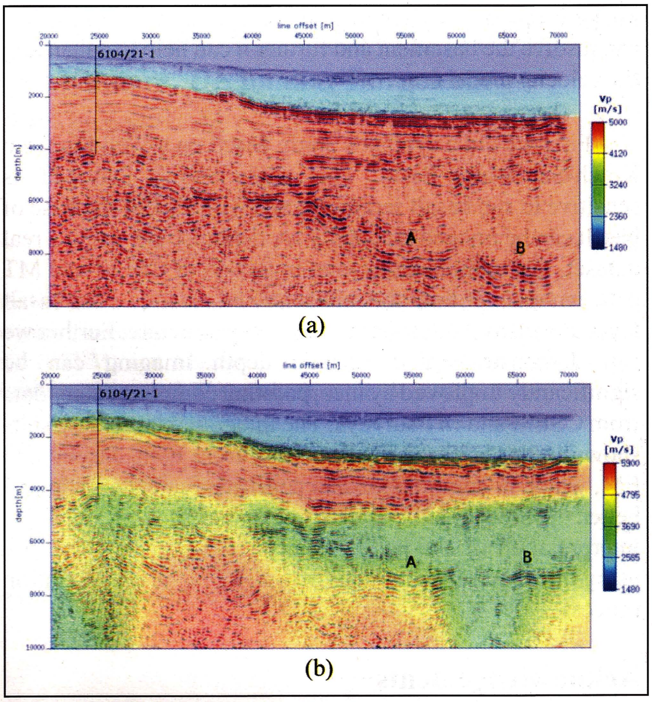

Fig. 9: (a) RTM image for the flooded velocity model and(b) RTM image for the EM based velocity model. The velocity models are overlaid.(after Panzner et al., 2014)

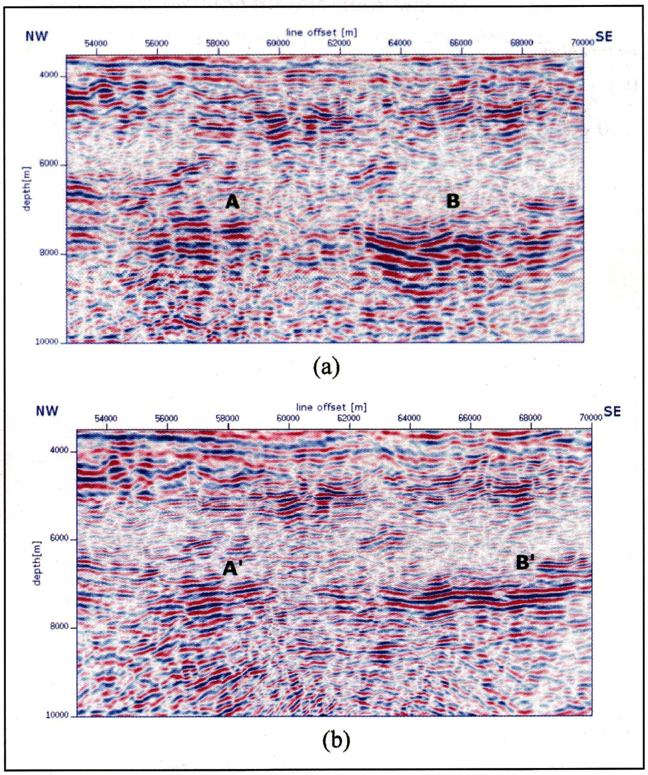

Fig. 10: Detailed view of the RTM images for the flooded velocity model (a) and the EM based velocity model (b) (after Panzner et al., 2014)

Discussion and conclusion

Basement in many basins are quite deeper and are mostly granitic. Granitic basements are generally highly resistive, because of the depth of basement it's difficult for seismic to image it properly. Whereas joint inversion of CSEM & MT can resolve the basement and further it can help in enhancing the velocity models.

First we did a synthetic study based on a Well log from Kutch-Saurashtra basin. This study shows that MT is sensitive to sub basalt sediments and with CSEM the base of basalt can be imaged. Secondly we demonstrate, using a real dataset, that simultaneous joint inversion of CSEM and MT data can recover both the thickness and extend of the basalt layer as well as the sub-basalt resistivity structure. Further we can demonstrate that seismic depth imaging can be significantly improved by incorporating complementary data from CSEM and MT surveys. The integrated imaging results shown in this paper use information from both seismic and EM, which in combination can constrain the velocity model better. Moreover, the structural understanding and the interpretation of sub-basalt reflector scan be supported by using the resistivity information directly in the interpretation process.

Acknowledgements

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