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CSEM Survey over the Frigg Gas Field, North Sea

M.P. Hamilton* (Electromagnetic Geoservices), G. Mikkelsen (Total E&P Norge), R. Poujardieu (Electromagnetic Geoservices) & A. Price (Total E&P)

SUMMARY

A Controlled-Source Electromagnetic (CSEM) survey was conducted over the produced Frigg gas field aiming to locate any remaining stranded gas. This is an innovative application for CSEM, which has traditionally been used for exploration or in particular prospect ranking. A survey such as this contains some additional challenges such as pipeline effects that may not normally be present in exploration CSEM surveys. For a survey of this nature, the collection of CSEM data in a grid fashion with all receivers recording azimuthal data has a clear advantage over 2D acquisition. This paper provides an introduction and overview for this project and its unique application of CSEM, and discusses some of the challenges faced.

Introduction

A Controlled-Source Electromagnetic (CSEM) survey was conducted over the Frigg gas field, located in the North Sea in license blocks PL024 (Norway) and P118 (United Kingdom), during September 2009.

The Frigg field is located in the North Sea, within the Viking graben, approximately 1850 m below the seabed. The field was produced continuously for 27 years, and was shut down in 2004. The survey was conducted with the intention of locating and mapping any remaining stranded gas in the reservoir, making this study rather unique for CSEM, which has to date been predominantly used as an exploration tool or for prospect evaluation and ranking (e.g. Yuan et al., 2009). Since the Frigg field has been produced, there is substantial information on the geology of the field and surroundings. A lobate submarine fan deposit of sand that was compacted forms the reservoir, with the seal being formed by middle Eocene open marine shales. The sands that constitute the Frigg reservoir are known to be clean, with a good porosity and a high permeability (Heritier et al., 1979).

Much of the infrastructure that was used for the production of the field is being, or has already been removed. At the time of the survey, the primary concern for data quality was the effect of the pipelines in the area on the CSEM data. This paper provides an introduction and overview for this project and its unique application of CSEM, and discusses some of the challenges faced.

Acquisition

The seabed in the survey area is relatively flat with an average value a little over 100 m, and a localised high of about 70 m water depth located in the centre of the survey.

Using a high capacity EM survey vessel, a total of 106 receivers were deployed in a single deployment along 10 lines in a dense grid survey configuration (Figure 1). The grid was planned to be as regular as possible, while taking into account operational constraints such as the location of pipelines, for which a buffer zone of 150 m was used for safety reasons.

Prior to the survey acquisition 3D feasibility modelling was conducted to assess the viability of the project. The results from this feasibility modelling were used to aid in survey design, such as optimizing the receiver layout and defining the transmitter waveform (Mittet and Schaug-Pettersen, 2008). The horizontal electric dipole source transmitted a composite pulse with a base frequency of 0.2 Hz and a maximum current of 1250 A. The frequencies that were processed are 0.2 Hz, 0.4 Hz, 0.6 Hz, 1 Hz, and 1.2 Hz.

All receivers measured the horizontal electric and magnetic fields in two orthogonal directions. Importantly, ALL receivers were recording during the towing of ALL transmission lines, producing a fully 3D CSEM dataset, with significant azimuthal data coverage.

Survey considerations and challenges

As would be the case with any producing or produced field, one of the main concerns was the infrastructure present in the area. In the case of this survey, a lot of the infrastructure had already been removed however, there were still a substantial amount of pipelines present on the seafloor (Figure 1). Although the pipelines are no longer in use and there is no cathodic protection current on any of them, it was expected that there would be some effect seen on the data.

An additional challenge for this survey is that since this is a produced field, the anomaly that would be present due to remaining reserves was likely to be relatively small. It was therefore clear from the outset that advanced inversion techniques and perhaps post survey modelling would be an essential part of the project.

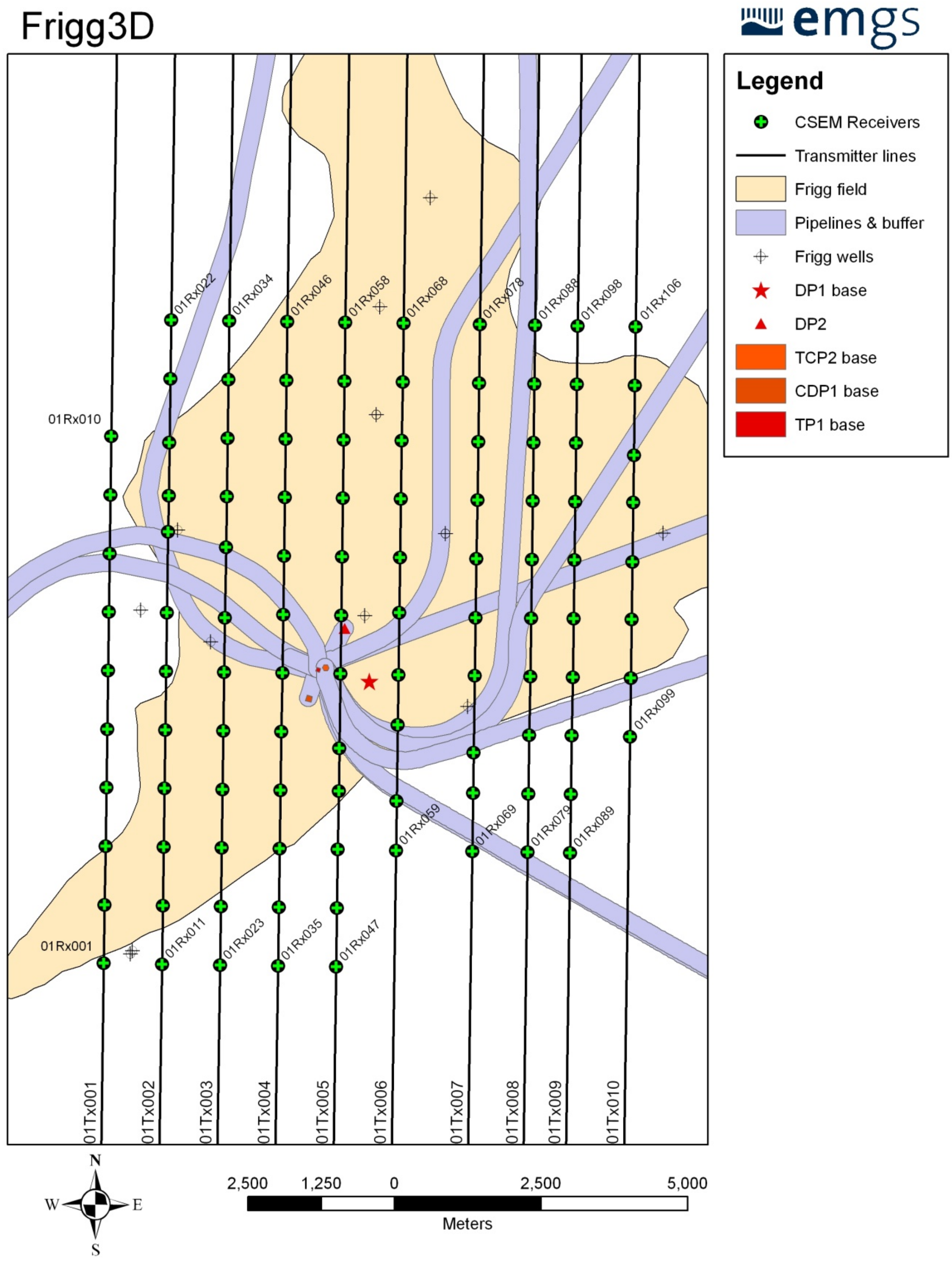

Figure 1 The planned survey layout map for the acquisition of the FRIGG3D dataset. The dense grid was planned to be as regular as possible taking into consideration operational constraints. The line spacing is 990 m and the receiver spacing along the lines is 1000 m where possible.

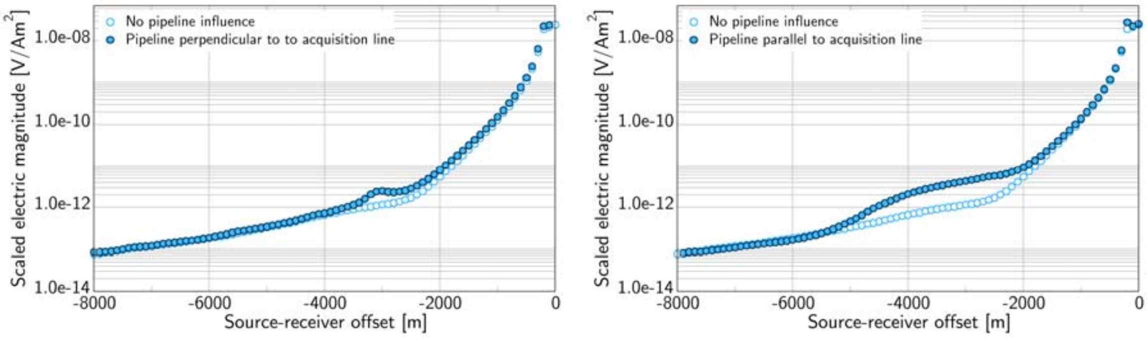

Figure 2 Magnitude versus offset data (Ex, 1.2 Hz) for two receivers that display the effects of pipelines (dark blue points), plotted against data that are not influenced by pipelines (light blue points). The perpendicular pipeline crossing "notch" is observed at -3km offset (left figure), while the pipeline is parallel to the acquisition line from 0 to -5 km offset in the figure on the right.

Data processing

The initial assessment of the data, involving scanning through magnitude versus offset (MVO) and phase versus offset (PVO) plots as well as attribute cubes, indicated that there were effects present in the data related to pipelines, as was expected prior to acquisition. The severity and nature of these effects is pipeline dependent, with some pipelines producing little to no discernable effect on the data, while others have a clearly identifiable and significant affect. Additionally, the effect that is observed on the data related to a given pipeline is dependent on the acquisition orientation in relation to it. If the acquisition line is perpendicular to the pipeline, the effect of the pipeline may be observed as a localised "notch" on the MVO plots (Figure 2, left). If however, the acquisition line is parallel and in close proximity to the pipeline the MVO response is raised in magnitude along offsets where the source is next to the pipeline (Figure 2, right).

As a result of these pipeline effects it is necessary to mask (exclude from further analysis) data that are affected, as it would skew any attribute analysis or inversion result. If this survey were acquired as a series of 2D lines, this would result in a very limited dataset remaining for further work, however, due to the significant additional data acquired with grid acquisition the remaining data and coverage remains substantial (e.g. Figure 3).

Since this survey was acquired in shallow (~100m) water depths, the CSEM responses contain a strong airwave component. Up-down separation processing (Amundsen et al. 2006) was applied to the dataset to reduce the airwave contribution and gain a first impression and understanding of the dataset prior to inversion.

Inversion and current work

The strategy for the inversion of this dataset was to gradually increase the amount of data and constraints being used and to move from 1 dimensional, to 2.5 dimensional, through to 3 dimensional inversion. The first main goal was to develop a good starting model for 3D unconstrained inversion, which used these lower dimensional CSEM inversion results, well resistivity information, as well as seismic horizons. Current work includes constrained 2.5D and 3D inversion and will likely be linked with post-inversion modelling.

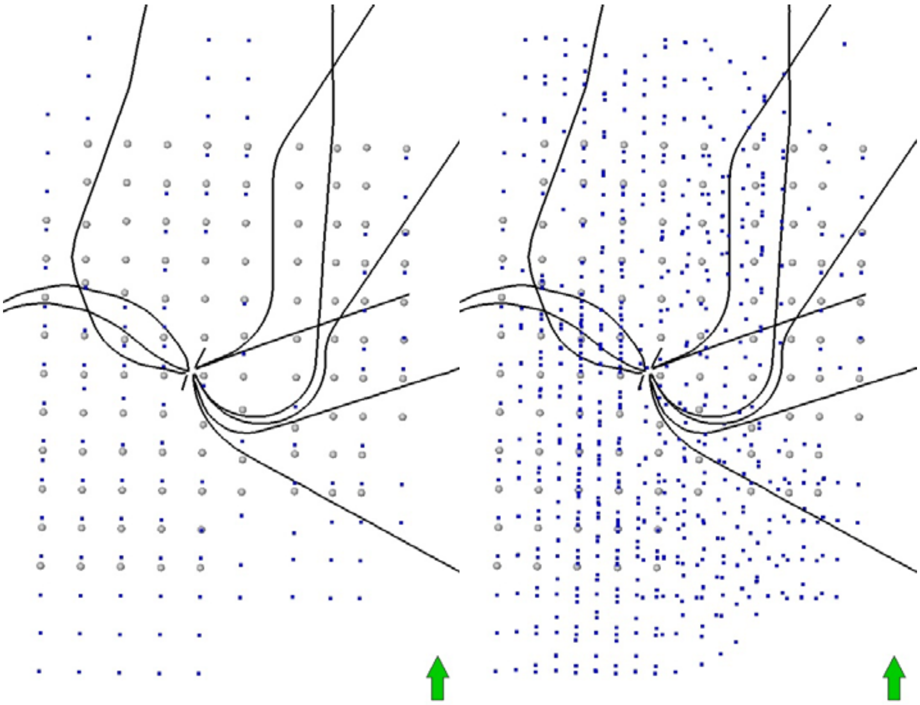

Figure 3 Two displays of remaining (after masking of pipeline-affected data) 0.6Hz electric field data point's (blue) in common midpoint (CMP) position at 5500 m offset. Pipelines are indicated as black lines, and receivers as grey circles. On the left is displayed the data points that would remain if using only inline data, as would be collected with a survey of separate 2D lines. On the right is displayed the data points remaining using both inline and azimuthal data (from all lines), as is collected for the Frigg acquisition. The added data coverage that is delivered by grid acquisition is obvious.

Summary and conclusions

The FRIGG3D survey over the produced Frigg gas field to locate any remaining stranded gas is an interesting new application for CSEM, which has traditionally been used for exploration or in particular prospect ranking. A survey such as this contains some additional challenges such as pipeline effects that may not normally be present in exploration CSEM surveys. The collection of these data in a grid fashion with all receivers recording azimuthal data has a clear advantage over 2D acquisition in terms of data coverage, particularly for a survey of this nature.

Acknowledgements

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