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Preface Special Issue on Controlled Source Electromagnetics

About a decade ago, Controlled-Source Electromagnetics (CSEM) was perceived by some to offer a step change in hydrocarbon exploration. By now, EM technology is viewed more realistically, and has matured to form a small but stable portion of the exploration industry. Land-based EM techniques continue to be applied, e.g., for mining or geothermal exploration. New developments in sensing technology, the increasing availability of high-performance 3D inversion codes and further integration of EM with other types of data may open up further application areas for land-based EM in hydrocarbon exploration and reservoir monitoring.

On the other hand, EM technology has also been perceived as stagnating to some extent. Therefore, to stimulate discussion and further progress, at EAGE 2014 Rita Streich (Shell), Oliver Ritter (GFZ Potsdam) and Janniche Iren Nordskag (Statoil) organized a workshop titled „CSEM: Where do we stand and where can we go?". This workshop received significant interest and was attended by approximately 100 participants from industry and academia. Overall, 18 oral and 8 poster presentations were given, which formed the basis for this special issue on CSEM. The call for papers was then extended to also include contributions that could not be presented at the workshop.

With this Special Issue, we aim to showcase latest developments in CSEM. To help promote discussion and further progress of EM technology, we had encouraged submission of papers on diverse aspects that all are important for exploiting EM to its full potential. These include new developments on EM hardware and surveying techniques, latest 3D imaging, joint inversion, and multi-disciplinary interpretation approaches, methodological and numerical developments for real data interpretation, innovative applications of EM across the geosciences, not only for various exploration targets, but also for reservoir monitoring. We had also particularly encouraged submission of papers with controversial content, and papers addressing future needs. Out of 25 submitted manuscripts, 13 were eventually accepted for this Special Issue.

A number of papers are concerned with innovative 3D imaging, joint inversion, multi-disciplinary interpretation approaches and, a point which has often been demanded yet is hardly ever fully addressed, the assessment of ambiguities, bias and uncertainties in EM inversion.

Using a seafloor-towed electrical dipole-dipole system in the German North Sea, Gehrmann et al. demonstrate application of a new inversion scheme to study the electrical resistivity structure in comparison with seismic data. They employ trans-dimensional Bayesian inversion to estimate the most likely number of layers needed, together with their uncertainties. Eventually, the constrained CSEM inversion results yield no indication for free gas in the target area.

Moghadas et al. explore systematically how different choices of inversion algorithms, and application of different constraints, impacts inversion results. They demonstrate these effects on 1D inversion of time domain marine CSEM data collected using a seafloor towed streamer system. One of the algorithms tested is a probabilistic inversion. Their 1D approach can be viewed as a robust method of deriving starting models for 2D or 3D inversion. Insights gained from this study on characteristic differences between the various inversion models may well generalize to higher-dimensionional inversion.

Singh and Sharma present another fast-track imaging technique for (airborne) very low frequency (VLF) EM data based on inversion of the apparent current density distribution in the subsurface. Imaging results are compared with other techniques using synthetic and field data.

Wiik et al. introduce seismic information into EM imaging by defining a regularization constraint whose strength and directionality depend on structural roughness and continuity seen in seismic images. In this way, similar model structure is encouraged in a fairly simple, geologically reasonable, computationally tractable manner. Synthetic and real data examples demonstrate that the new regularization results in similar data fit as standard smoothing regularization. When used with appropriate caution, their approach may provide more easily interpretable images.

There is a notion that EM results are not only influenced by the choice of processing, inversion and interpretation techniques, but also depend strongly on the human interpreter. Tseng et al. explore this aspect by running a blind test of state-of-the-art interpretation workflows. A part of the SEAM data set is given to a group of interpreters, with accompanying information as would typically be available for real EM surveys. The interpreters then delineate the subsurface, demonstrating how resistivity images and confidence in the interpretation are gradually built up by using 1D, 2.5D and 3D interpretation in sequence. The final results provide an honest account of present-day EM capabilities, showing that, if good efforts are made to avoid over-interpretation, there is reason for optimism regarding the quality of EM images.

Whereas there commonly is much focus on EM data modelling, inversion and interpretation, the quality of EM data crucially depends on the transmitting and recording hardware. Literature on hardware is scarce, probably to a large part for confidentiality reasons. This Special Issue contains two papers that describe recent hardware developments, illustrating present-day technology. Wang et al present the concept of two novel marine CSEM transmitters with two horizontal orthogonal electrical dipoles which can land on the sea floor. An application for gas hydrate exploration in the South China Sea is presented for which the two transmitters were successfully deployed.

As a companion development, Chen et al. describe their marine controlled-source electromagnetic receiver. By the design choices made, this instrument is also optimized for hydrate exploration. The receiver is equipped with an arm-folding mechanism for easy deployment and recovery, and features low power consumption, thus enabling continuous recording for long times at high sample rates. Beside the description of their own receiver, the authors have also included a useful comparison of state-of-the-art seafloor instruments into their paper.

Several of the papers in this issue focus on new techniques for forward modelling and inversion algorithms, dealing simultaneously with new numerical approaches and with challenging EM application cases that necessitate these new numerical developments. In this way, attempts are made to widen the range of applicability of EM methods on land, and to develop EM towards a monitoring tool for a range of geotechnical installations such as CO2 storage or enhanced oil recovery.

Börner et al. demonstrate the power of finite elements to model complex geological structures in 3D. They simulate fluid replacement in a reservoir using a multi-method set-up of DC- geoelectrics, controlled source EM, and borehole transient EM and discuss the resolution potential of the various methods.

Joint 3D inversion of multiple electromagnetic data sets is the focus of a paper by Meqbel and Ritter. A key issue in combining disparate data is the weights given to each part of the data set. The new algorithm for combining magnetotellurics, controlled source EM, and DC resistivity data presented here specifically addresses this point. A new weighting scheme is introduced, which weights individual components of the total data gradient after each model update to determine a balanced contribution of all data sets to the joint inverse model.

Tietze et al. investigate the applicability of controlled-source EM for enhanced oil recovery in a German oil field by simulating injected brines replacing resistive oil within the reservoir. From synthetic studies, they conclude that most promising results should be obtained by observation of the vertical electric field in combination with combined vertical-horizontal dipoles as sources. They then begin testing their hypotheses in a real borehole-to-surface controlled source EM field survey in Northern Germany. Within that survey, the steel casing of an abandoned borehole is used as an EM source. Their inversion results obtained from the well casing source highlight the progress toward dealing with the abundant well casings that must be expected in any future EM monitoring application.

Several other papers also address challenges associated with well casings. Tang et al. describe an approach for modelling current injection into a steel casing. They use a method-of-moments approach for approximately calculating currents induced into a casing embedded in a simple subsurface, where currents are either injected into the casing directly or induced by a nearby CSEM source. EM fields due to the casing are then fed into a finite-element code as secondary sources to calculate casing effects in a 3D medium. This permits assessing casing effects without having to resort to computationally demanding numerical schemes with very fine discretization of the well casing and its vicinity.

Hoversten et al. investigate the potential economic value of EM in a reservoir monitoring context. They develop a financial model to assess the economic value of better volume calculations in stimulated reservoirs, and conclude that even small improvements of volume estimates can lead to very significant net present values for typical lifespans of producing oilfields. They then discuss the technical feasibility of monitoring hydraulic fracturing, using a realistic model of a hydro-frac system that includes the fracture, fracking fluid and injection well. Fine-scale finite-difference modelling is applied to represent the steel cased well accurately. For several scenarios considered with different conductively enhanced proppants, indications are found that the fracture should indeed be detectable, and field trials are encouraged.

Vilamajó et al. describe an actual land controlled-source EM field experiment in which a vertical electric dipole source is deployed at the depth of their target reservoir, underneath the bottom of a well casing. They describe the processing of their data, and qualitatively explain the enormous influence of the well casing on the data. Although rigorous inversions of these data have yet to be done, the study represents a step towards ground-truthing and better understanding well casing effects.

Guest Editors for the SI

Oliver Ritter and Rita Streich