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Hydrocarbon Charge Risk Assessment using 3D CSEM Inversion Derived Resistivity in a Frontier Basin, Offshore West Greenland

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Summary

Exploration risk assessment in frontier basins is generally based on regional geologic information in combination with prospect scale seismic interpretation and mapping. In a frontier basin offshore West Greenland EnCana Corporation and partners were challenged with prioritizing a drilling program by selecting from a portfolio of fourteen seismically mapped prospects on two exploration blocks. Lacking sufficient geologic information, reliance on unconventional geophysical methods to further the prospects to drillable locations was a necessity.

Resistivity well logging methods measure responses of electromagnetic fields to determine resistivity of the host rock. Modern logging tools resolve resistivity on scales of centimeters vertically and horizontally within metres from the wellbore. Marine controlled source electromagnetic surveying (CSEM) uses similar physical principles but with a stronger electric field source located near the sea floor and with large areal sampling of the electric and magnetic field responses. From these measurements 3D CSEM inversion provides details of subsurface resistivity at scales typical of prospects and oil/gas fields. CSEM derived resistivity information offers additional geologic understanding to better assess pre-drill risk in exploration programs.

This paper summarizes the use of CSEM data acquired and processed by WesternGeco-Geosystem and the 3D CSEM inversion results used by EnCana in the risk assessment of frontier exploration prospects offshore West Greenland. CSEM was used successfully to risk hydrocarbon presence before drilling and allowed prioritization of the "best" drilling candidates from the portfolio.

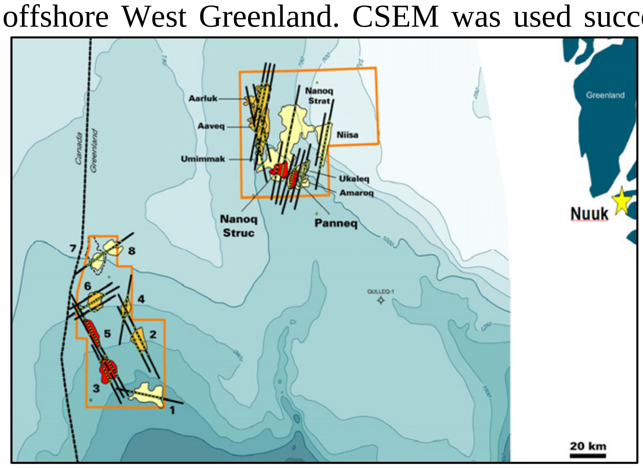

Figure 1: Offshore SW Greenland location map with prospects and 2008 CSEM program.

Introduction

EnCana, as operator of a joint venture with Nunaoil and Cairn Energy, has mapped fourteen exploration prospects in the Atammik and Lady Franklin blocks offshore West Greenland in 350-1800m water depths about 120-200km west of the Greenland capital city Nuuk. The unrisked reserve potential of the prospect portfolio exceeds 7 BBO with mean prospect size of 430 MMBO.

The regional geology of West Greenland and its rifting history put the blocks in a favourable location for deposition of source and reservoir rocks. Oil and gas shows in the area suggest that a working, but as yet unproven, petroleum system offshore West Greenland. Similarity of rifting of the North Sea and of southwest Greenland from Labrador in terms of the conjugate style of the North Atlantic opening, timing, and geometry suggest the West Greenland basins may be geologic analogs to the North Sea basins. EnCana's pre-CSEM assessments recognized lack of "proven" petroleum system and effective hydrocarbon charge is the major unknown factor affecting prospect risk. This paucity of information is typical of frontier exploration and akin to the pre-discovery exploration histories of the North Sea and of numerous other now producing basins.

The joint venture was given the task of prioritizing the portfolio to identify the most favourable drilling candidate for each block. With mapped prospect closures, but no wells on the blocks and the nearest well control 120 km away, the team had little firm geologic information upon which a confident risk assessment could be based. Prior to 2008, the exploration team was unsatisfied with attempts to prioritize the most favourable drilling candidates using interpretations of existing seismic and well data and therefore sought to find additional information and technologies that could assist to progress the exploration program.

Recent developments in CSEM surveying and interpretation were identified as a potential surface-based surveying technology which could assist in prospect risk based ranking. CSEM has been published as a viable exploration method with numerous successful pre-drill predictions of hydrocarbons since the first published marine CSEM survey (Ellingsrud 2002). The method is accepted by many explorers as having surpassed the "proof of concept" stage of the technology development but documented case histories are rare and documented success rate statistics even rarer (Johansen 2008). Cognizant of the large prize at stake, the joint venture jumped at the opportunity to apply CSEM technology to the problem at hand.

Method

On fine scales in a wellbore, petrophysical well log analysis is the conventional tool used to identify resistive geologic strata which may contain hydrocarbons. The well logs measure electrical responses in a wellbore. Marine CSEM surveying uses similar physical principles but with stronger electric field sources towed above the sea floor and with electric (**E**) and magnetic (**H**) field measurements made at the sea floor over broad areas. Data processing conditions the **E** and **H** field measurements for input into 3D CSEM inversion. 3D inversion iteratively models using Maxwell's equations, the CSEM survey design and a starting model to output a resistivity rock model that best models the **E**/**H** data observations. It is capable of identifying resistive subsurface anomalies (vertically and spatially) the size of oil/gas fields.

Potential pitfalls in CSEM interpretation result from assumptions that resistivity equates to hydrocarbon pay. Geologic complexity in stratigraphy with unpredictable carbonates, evaporates, volcanics and diagenesis pose real challenges to reliability of interpretation of CSEM derived resistivity. Fortunately, the Greenland survey area has relatively "simple" geology based on clastic rift fill. Complications from "simple" geology were manageable as these were generally known volcanics of Paleocene age (geologically, seismically and magnetically identifiable) separated from Cretaceous exploration objectives.

WesternGeco-Geosystem designed and acquired a CSEM survey (shown in Figure 1) using all geological information and seismically mapped surfaces including the mapped Paleocene volcanics. The survey objective was to resolve subsurface resistivity of potential Cretaceous reservoirs to depths more than 3500m below sea floor over each of the prospects and with vertical resolution of 50m.

Hydrocarbon-filled strata are typically resistive, relative to brine saturated strata, on the order of 1-3 orders of magnitude. Well logs in the area indicated reasonably uniform resistive clastic sedimentary section from sea floor to target reservoir averaging 1.5 Ohm-m, from target to basement averaging 4 Ohm-m, and basement at 60 Ohm-m. Depths to targets for all prospects varied from 1500m to 3800m below sea floor. Other than the Paleocene volcanics, no resistive lithologic units are seen in the geologic data.

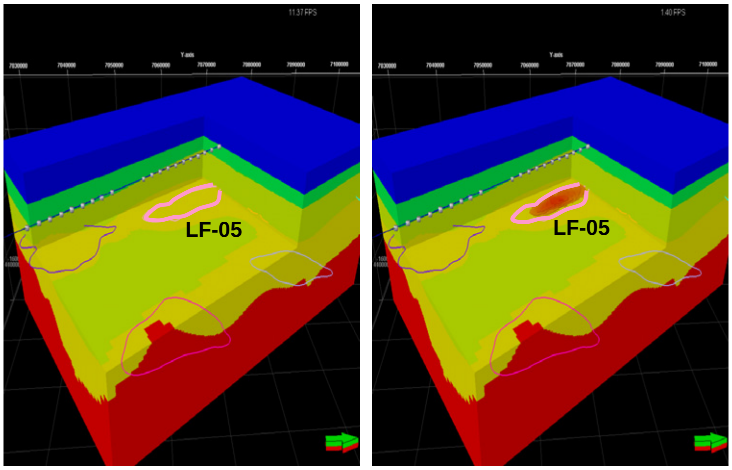

Figure 2: CSEM inversion starting model (left) and final inversion volume (right) for LF-05

Starting structural models for the inversions (Figure 2) were created from seismic interpretations and well log resistivity verified by profiles of marine magneto-telluric (MMT) data inversions and by pseudo-section analysis of the CSEM data. 3D CSEM inversion by WesternGeco-Geosystem used the method of R. Mackie to create 3D resistivity volumes. Although requiring considerable computer run time and interpreter input the 3D inversion results were geologically consistent, numerically stable and within interpretational allowances. Inversion iterations and RMS convergence factored into confidence indicators used to assess reliability of the inversion results.

The resistivity volumes were visualized in Petrel for ease of interpretation using all of the geologic, seismic, gravity/magnetic and MMT data for each prospect. The prospects demonstrating resistive character were scrutinized intensively to validate each prospect's inversion results. The final 3D CSEM inversion showed remarkable insensitivity to the starting model. Reasonable geologically based variations introduced to the starting model resulted in convergence to similar resistivity solutions. This increased confidence in the geologic validity of the interpretations.

Each resistivity anomaly was subjectively assessed based on geologic characteristics, and interpretational consistency and quantitatively assessed using inversion stability, starting model sensitivity and final RMS convergence quantifier. The first pass assessments of COS elements were made on this subjective basis however ongoing refinement of the assessment is investigating the use of the CSEM inversion parameters in a quantitative approach. It remains to be determined if the final quantitative method using subjectively defined criteria in a formula is any less subjective than an outright subjective assessment. Integration of the interpretations of seismic and potential field data is also moving forward to create a multi-parameter rock model consistent with geophysical observations and geologic information.

Examples

CSEM inversion results clearly defined resistive bodies on eight of the prospects. Resistivity imaging (Figure 3) of known isolated Paleocene age volcanics that were not included in the starting models helped to confirm the inversions were robust and geologically meaningful. This instilled a level of confidence in the resulting rock model. The observed geometry of the resistivity anomalies and conformability with structural closure added confirmation. Prospect LF-05 shows all of the required prospect characteristics: conformability with the target reservoir interval, resistivity increases upwards from 10-35 Ohm-m (orange to red grid tiles) and a flat base (hydrocarbon contact?). These characteristics are consistent with an oil-filled reservoir. Alternative interpretations produced models less consistent with the CSEM data than the oil-filled interpretation.

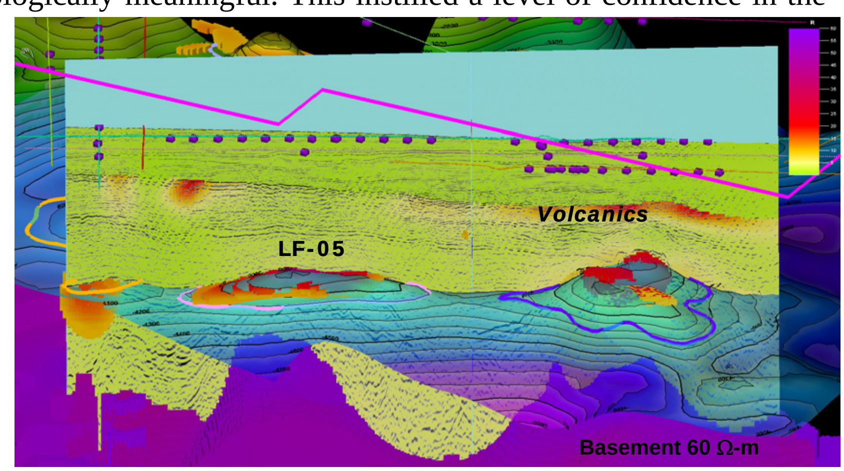

Figure 3 3D perspective view of LF-05 co-rendered structural contours, resistivity grid (tiles >10 Ohm-m), and seismic (resistivity background)

Pre-CSEM risk assessments were unable to high-grade prospects because seismic and well data could only address geometric and general geological aspects of the potential reservoirs. Seismic, gravity, magnetic and well data were lacking on any aspects of predicting presence of reservoir fluids. When dealing with one risk element, such as charge risk in the context of this paper, with limited data and no firm positive or negative information it is a common risk assessment practice to assign that element a 50% COS, same as a coin toss. CSEM was able to provide new information affecting charge risk assessment in a convincing and positive way.

With the use of CSEM in the charge risk analysis and resulting revision of the exploration COS and risked reserve potential, the most favourable prospects were indentified for selection and further analysis as potential well locations. The primary exploration team objective, prospect ranking for drilling, was a success that can be attributed to the use of CSEM and 3D inversion.

Conclusions

3D CSEM inversion is demonstrated as a viable technique to estimate bulk resistivity of the subsurface. The resistivity values generated appear to be a robust inversion solution to the CSEM data and are deemed reliable resistivity factors upon which the exploration team assessed exploration charge risk. The prospect portfolio was successfully high graded and most prospective drilling candidates defined according to criteria consistent with geological principles, geophysical mapping and the CSEM 3D inversion results. Offshore West Greenland is typical of the prospect prioritization challenges faced in many frontier basin exploration programs and in these cases CSEM/3D inversion is a useful technology for exploration risk assessment.

Acknowledgements

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