

Validating 4D seismic with reservoir surveillance data: A practical example offshore Equatorial Guinea, West Africa

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Summary

This case study describes the impact of integrating time-lapse (4D) seismic data with reservoir surveillance and production data for the Oveng field area of Okume Complex Field, located offshore Equatorial Guinea, West Africa. Aging assets on production decline can greatly benefit from 4D seismic to determine infill drilling locations as well as support reservoir management practices, but only when the seismic data has been validated against multiple other datasets to produce a robust interpretation. This case study describes a multi-disciplinary, collaborative effort towards validating 4D seismic with historical production data along with field surveillance data such as repeat saturation logs, and highlights examples of providing new information for building a more accurate geomodel as well as influencing infill well planning and drilling. The key message is that once all data have been screened and integrated, informed decisions can be made to optimize the value of the asset.

Introduction

Time-lapse seismic data has proven effective in reservoir management and future production planning (Huang et al., 2011; Gainski et al., 2010; Ebaid et al., 2009; Mitchell et al., 2009; Gonzalez-Carballo et al., 2006). It has also proven to be a critical piece of data at the Okume Complex, located approximately 30 km offshore Equatorial Guinea, West Africa, (Figure 1). The producing interval consists of very high-quality, quartz-rich Campanian-aged sandstone deposited within slope-channels in a moderate to weakly confined submarine canyon setting. The complex nature of the deposition coupled with syn-depositional faulting has created a very intricate network of dynamic connections as well as barriers and baffles throughout the reservoir. It has been noted that understanding the baffles and barriers within the reservoir is a prime component in accurately modeling dynamic flow behavior (Beaubouef et al., 2011). The goal of 4D seismic data is to enhance this understanding throughout a producing field by observing pressure- and saturation-induced changes to the recorded seismic signal, however the 4D seismic signal alone can produce non-unique interpretations. By working across disciplines and integrating multiple datasets, a robust interpretation of baffles, barriers, and overall internal dynamic behavior can be achieved with the goal of identifying infill drilling opportunities and enhancing our reservoir management practices.

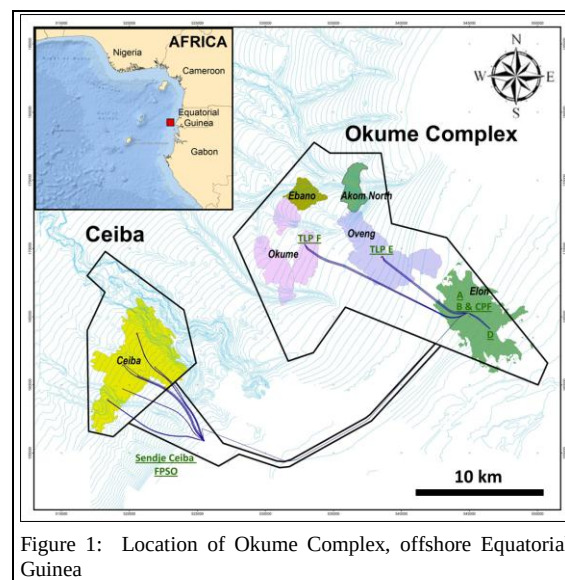


Figure 1: Location of Okume Complex, offshore Equatorial Guinea

Data

Eight exploration and appraisal wells were drilled and logged in the Oveng field area and one conventional core was acquired. This was followed by seven producing wells and five injection wells over two phases of production drilling.

Three seismic surveys were used in this study: A pre-production Western Q-marine survey acquired in 2003 followed by two monitor surveys acquired in 2010 and 2014. Excellent repeatability was obtained throughout both monitor surveys in areas not affected by infrastructure. Moreover, the absence of a geophysically complex overburden coupled with the relatively shallow depth of the reservoir aide in yielding excellent data quality. In addition to careful data acquisition, high-quality seismic processing is paramount for detailed time-lapse interpretation.

A 3D/4D rock physics inversion was performed on the seismic data with excellent results. Elastic properties were mapped into reservoir properties such as clay volume, porosity, and hydrocarbon saturation, and these inversion products were used to successfully characterize the reservoir at a neighboring field (Marler et al., 2014). The accuracy of these inversion products is calculated at 82%, an 11% increase compared to other methods of seismic pay

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identification (Nicholls et al., 2014). While inversion has proved very successful at predicting static reservoir conditions, this study aims at validating the time-lapse seismic inversion products with non-seismic related reservoir surveillance data to better understand dynamic reservoir behavior.

Geological complexity has been apparent throughout the development and production phases of the Okume Complex, leading to several uncertainties regarding well connectivity. To address these uncertainties, the subsurface team has employed several well surveillance techniques including production trend analysis, pressure interference tests, tracer analysis, capacitance resistance modeling (Parekh et al., 2011), and reservoir saturation logging. This reservoir saturation logging occurred at approximately the same time as the 2014 4D monitor seismic survey, leading to a natural integration opportunity.

Methodology

Initial steps included a multi-disciplinary data screening for accuracy and reliability. Some of the data challenges faced by this study included co-mingled zonal production and infrastructure-related 4D seismic data gaps. This screening ensured that the extensive production, pressure, logging and seismic data for the field was integrated to provide a high quality dataset for further study.

Various models were utilized to relate reservoir surveillance information to the seismic data. Changes in elastic properties of the reservoir due to fluid saturation changes can be confidently modeled using Gassmann's equation (Gassmann, 1951) or modified variants thereof. Additionally, methods are available to model the effect of changing pore pressure on the rock frame and subsequent seismic response (Macbeth 2002, Smith et al 2004). A qualitative compendium can be developed to relate the observed 4D seismic signal to reservoir changes due to production (i.e. saturation and pressure changes), however these basic models are non-unique. For example, an observed softening (decreased impedance) could be caused by a decrease in pore pressure below bubble point such that gas comes out of solution, or could be caused by an increase in pore pressure such that the rock frame becomes more compressible due to weakening grain contacts. Thorough calibration and data integration is the basic methodology used in this study, and is required to move past a qualitative model and make an impactful interpretation of time-lapse seismic data.

To calibrate the 4D seismic signal, a detailed quantitative modeling exercise has described the expected elastic response to production and injection at the wellbore. Figure 2 illustrates forward modeling the change in logged

reservoir saturation from repeat logging as well as the change in reservoir pressure into a change in acoustic impedance (AI). Forward modeling was conducted at several well locations and compared to the change in seismic AI. This difference in AI change was used to provide a calibration point for quantitative interpretation of the observed 4D seismic. This data was then coupled with additional reservoir surveillance data such as pressure trend, salinity, and tracer analysis to develop a more robust interpretation of dynamic reservoir behavior.

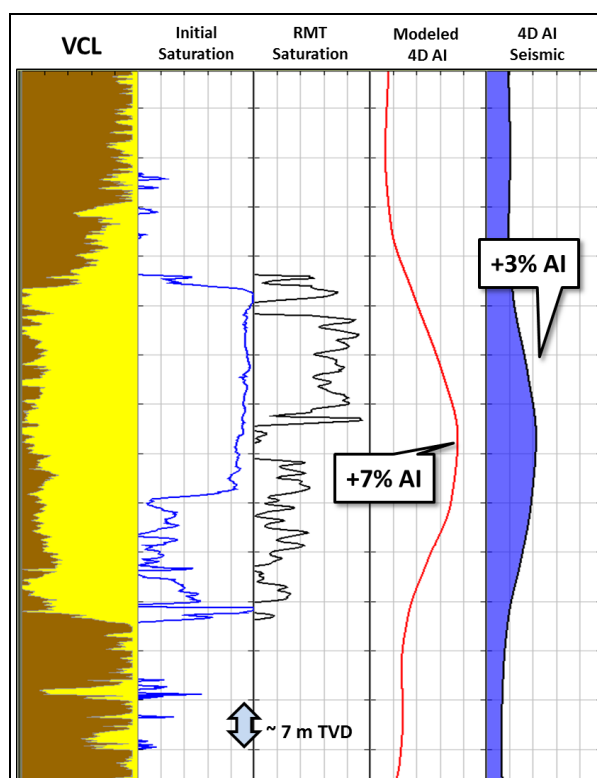


Figure 2: Forward modeling example showing volume of clay, initial logged water saturation, RMT water saturation, the modeled change in acoustic impedance based on the change from initial to RMT water saturation, and the change in acoustic impedance from seismic inversion. Note the 4% difference between the modeled response and seismic response.

Analysis and Discussion

The following example highlights the use of calibrated 4D seismic in reservoir management. The X injector in Figure 3 was completed in 2010 intending to support updip production wells. However, injection water tracer has not been observed at the producers, and a pressure connection

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was not obvious with existing data. An initial look at the 4D full stack seismic data displayed a large signal outboard of the injector and isolated from the production wells (Figure 3A). This observation was interpreted as injection into an isolated compartment. The 4D signal also highlighted several faults in the area which appear to be baffles or barriers to fluid flow, information which was then used in dynamic reservoir modeling. Once the 3D/4D rock physics inversion was completed and the elastic responses calibrated to production information, a more quantitative interpretation of the 4D signal was possible.

While both increasing and decreasing AI signals were observed in the vicinity of the injector, increasing AI interpreted as water replacing oil above the oil-water contact (OWC) and decreasing AI interpreted as increased pore pressure below the OWC, a narrow channelized feature displaying a water-replacing-oil signal was observed leading in the direction of producer Y (Figure 3B).

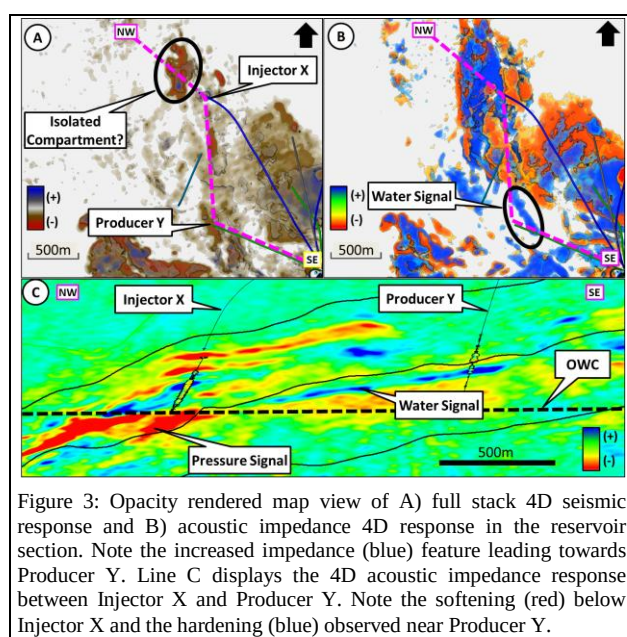


Figure 3: Opacity rendered map view of A) full stack 4D seismic response and B) acoustic impedance 4D response in the reservoir section. Note the increased impedance (blue) feature leading towards Producer Y. Line C displays the 4D acoustic impedance response between Injector X and Producer Y. Note the softening (red) below Injector X and the hardening (blue) observed near Producer Y.

Through the aforementioned calibration, the increase in AI corresponds to ~40% increase in water saturation. The confinement of water flood coupled with the placement and interpreted transmissibility of faults were updated within the reservoir model, leading to a more accurate representation of the subsurface. However, further data integration was needed to fully explain this injector-producer pair.

A water signal was observed on the 4D AI leading from the vicinity of injector X towards producer Y, yet an injection water tracer connection has not been established. Produced water salinity data from producer Y shows a higher salinity value than other producers in the field area being supported by injection. A closer inspection of the 4D AI data shows that the water signal observed at producer Y does not connect directly to injector X, but appears to connect to the softening (interpreted as increased pore pressure) which occurs below injector X in the water-leg. This is interpreted as injector X supporting producer Y via an aquifer connection, which agrees with the salinity data. To further understand connectivity, the team initiated a pressure interference study by shutting in injector X. The test confirmed a pressure connection and validated the team's interpretation. With this in mind, injector X was returned to injection to continue to support producer Y.

Continued time-lapse seismic acquisition has also proven useful in evaluating future infill drilling opportunities. A location of interest was identified after the 2010 monitor survey indicated an apparent isolated compartment (Figure 4A and 4B). A minor 4D AI softening was observed, but was near background amplitude level and considered insignificant. This compartment was interpreted to be stratigraphically sealed from the adjacent producing interval, and lies between an injector-producer pair. However, the 2014 monitor survey displayed greater 4D signal at the location of interest, and compartment connectivity was called into question (Figure 4C).

The 4D rock physics inversion products coupled with reservoir surveillance data were instrumental in describing this dynamic behavior. Two plausible interpretations could explain the observed 4D signal in the prospective area; depletion from a nearby producer causing gas out of solution and reservoir compaction or increased pore pressure overlying a water signal due to nearby injection. Reservoir surveillance data shows a pressure as well as tracer connection between the straddling injector-producer pair, and confirms that no significant amount of gas has been produced. Based on this integration, the prospective area is interpreted to be experiencing basal sweep as well as increased pore pressure due to injection. Based on our modeling, this increase in AI corresponds to a ~30% water saturation increase. The decrease in AI observed in the updip portion of the prospective area corresponds to 400 psi increase based on modeling, which directionally agrees with reservoir pressure information from the nearby injector.

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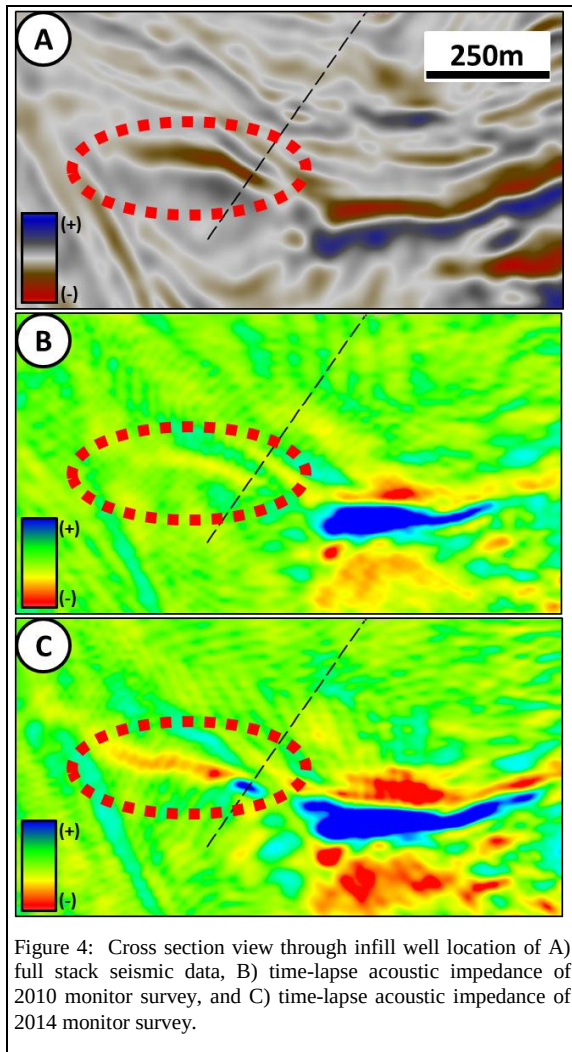


Figure 4: Cross section view through infill well location of A) full stack seismic data, B) time-lapse acoustic impedance of 2010 monitor survey, and C) time-lapse acoustic impedance of 2014 monitor survey.

Conclusions

Time-lapse seismic data has proven very successful in aiding interpretation of reservoir behavior under producing conditions. Careful acquisition and processing of 4D seismic coupled with calibration to production and surveillance data is paramount for making an informed, quantitative interpretation of the time-lapse data. This study showed the successful integration of seismic, reservoir saturation logging, salinity data, pressure trends, and tracer analysis to develop a robust dynamic reservoir interpretation. By understanding and integrating multiple datasets, impactful decisions can be made with respect to reservoir management as well as infill drilling.

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EDITED REFERENCES

Note: This reference list is a copyedited version of the reference list submitted by the author. Reference lists for the 2016 SEG Technical Program Expanded Abstracts have been copyedited so that references provided with the online metadata for each paper will achieve a high degree of linking to cited sources that appear on the Web.

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