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# Pre-Drill Quantitative Analysis of a Sinuous Submarine Channel Prospect, Deepwater West Africa

## Introduction

In a typical reservoir development process, a prospect is confirmed by a discovery well and then assessed with several delineation wells. Engineers perform quantitative evaluations based on deterministic and overly simplistic models to assess the economical value (reserves and recovery calculations) and begin development and facilities planning. Then, a more detailed reservoir characterization study may be undertaken, using reservoir modeling and often resulting in mechanistic screening and production prediction studies.

Deepwater sinuous channels are highly complex depositional systems and require careful consideration for economic analysis and facilities planning, due to the high cost of exploration and development. The objective of this study was to quantify possible reserves and producible hydrocarbons prior to drilling of the first well. The idea was to develop a template for reservoir characterization for this prospect based on depositional element interpretation derived from high quality 3D seismic data. The lack of well data required the use of analog data (outcrop and literature) to characterize the internal geometries of each depositional element as well as their petrophysical properties.

Building a pre-drill model allowed to get a first quantitative look at possible reserves and development scenarios. Once a first well was drilled, the model was updated with actual well data. The turnaround time for more realistic reserve and production estimates could be significantly reduced. This allowed basing all engineering analysis on more realistic models much earlier in the development process, compared to the traditional workflow.

## Depositional Setting

The prospect consists of six sand intervals that are partially separated by shales. Sand interval thickness range from 17-27m, totaling 131m. Each interval is comprised of one or several sinuous submarine channel systems that were deposited in a compressional toe of slope setting. At the time of deposition, bathymetric lows between elongated salt walls that trended parallel to the shelf margin, captured larger leveed channel systems that were prevalent on the up-dip extensional part of the slope. The lower gradient of the shelf-parallel valley axes forced the channel systems to readjust from channel-levee systems to sinuous channel systems. The dominant mode of sand deposition was through lateral accretion, a vertical aggradation component is not recognizable (Kirschner and McGilvery, this volume).

Figure 1 illustrates the depositional processes in the sinuous channel systems: Each sinuous bend consists of a levee (LO_prox) on the outer side of the bend that is built as sediment spills over the outer bank, during turbidite deposition. Away from the channel, the levee deposits grade into low-amplitude, low N/G overbank deposits (LO_undiff). Occasionally, turbidity currents will break the levee, resulting in the deposition of a succession of lobe shaped, interbedded, high N/G splay deposits (SPLAY). High amplitude events (Figure 2) characterize the inner part of the loop. They are interpreted to reflect lateral accretion of inclined sand beds, interbedded with shaly layers (ACC); the succession reflecting waxing and waning of the long-lived turbidity currents thought to deposit this facies. The channel form itself is filled last. It usually appears on the seismic as a low amplitude event. This suggests a shale prone channel abandonment fill (HCF), except for a few areas of high amplitude signatures within the channel form, interpreted as sand-prone channel-fill, the result of bank collapse and subsequent deposition of sands within the channel form (Figure 3).

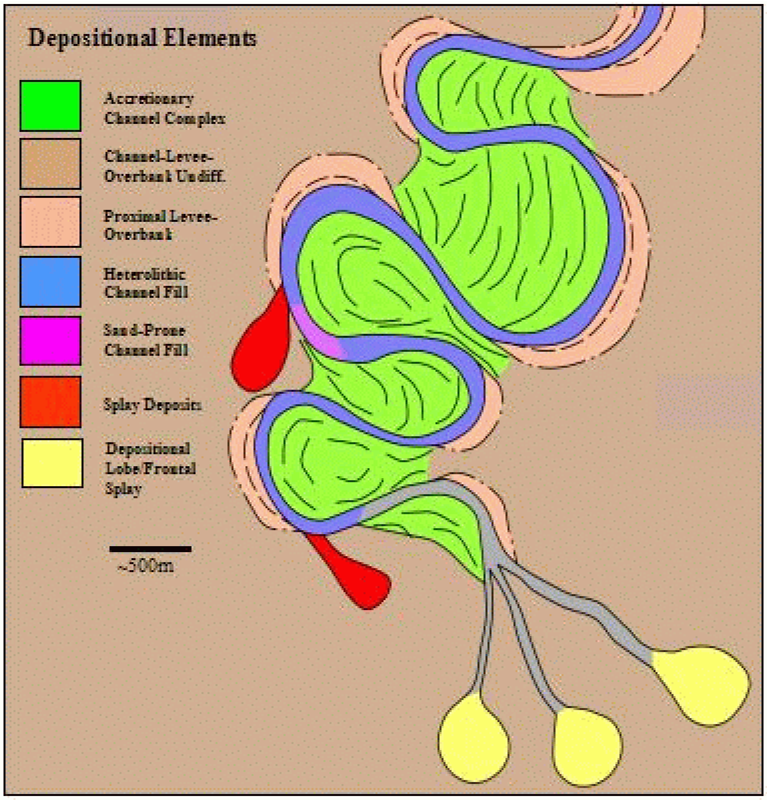

**Figure 1: Depositional elements of sinuous submarine channel system.**

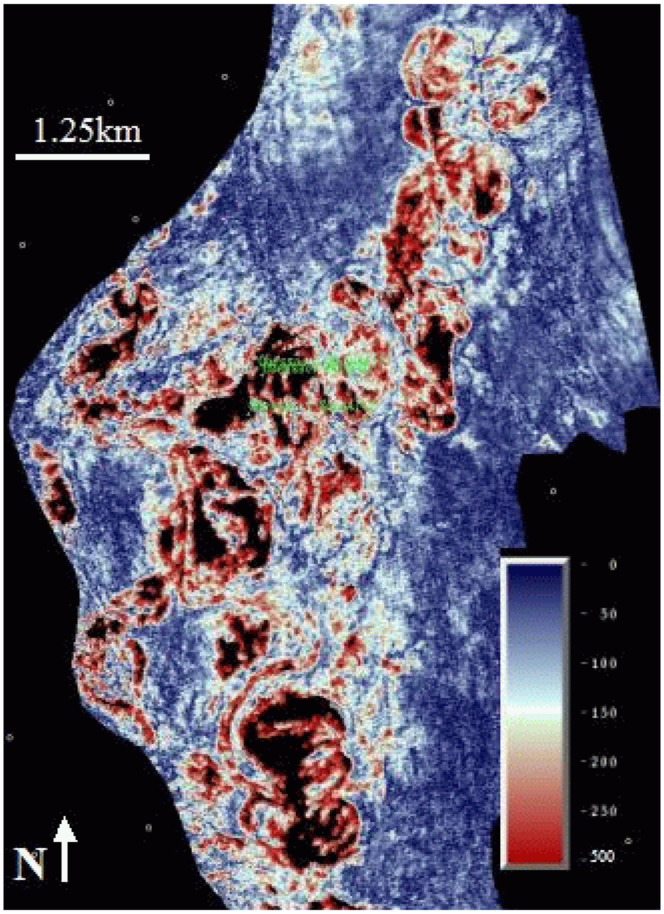

**Figure 2: Seismic amplitude. Red & Black is highest and corresponds to high quality sand.**

## Modeling Process

A fine-scale 3D reservoir modeling grid was built, using seismically derived faults and marker surfaces (both for sand intervals and deterministic shales). Cell sizes were 30x30x0.5 m, totaling ~33 million cells. Shales were not introduced in the fine-scale model to avoid undesired "edge" effects during the upscaling. These edge effects would have resulted in high poroperm elements, "rimmed" with a medium poroperm edge when placed within or next to a low poroperm element (e.g., where ACC borders the levee-overbank deposits).

Proprietary AVO class analysis shows that AVO responses are directly correlatable with sand quality. For each of the six reservoir zones, a depositional elements and AVO class map were interpreted and loaded into the 3D modeling zones. Figure 4 displays the AVO class indicators, which were combined with the depositional elements (Figure 3). This results in a break-up of each depositional element into several elements of different sand quality (Figure 5). For each depositional sub-element, a pseudo well was introduced to characterize the variation in porosity, permeability and water saturation, as derived from analog fields (e.g., Joiner et al., 1999).

Using variograms derived from analog fields and outcrop studies, porosity was modeled stochastically, using the Sequential Gaussian Simulation technique (Figure 6). Permeability and water saturation were obtained through correlation functions with porosity. Porosity, permeability and water saturation were then upscaled into a coarse-scale grid with cell sizes of 60x60x2 m, totaling ~2 million cells. The coarse-scale grid cell dimensions allowed for the model to be run efficiently in a finite-difference flow simulator, while minimizing the upscaling. Yet, the cells were still small enough to allow appropriate representation of the smaller heterogeneities. Figure 7 shows the upscaled porosity, still assuming a N/G of 1.0.

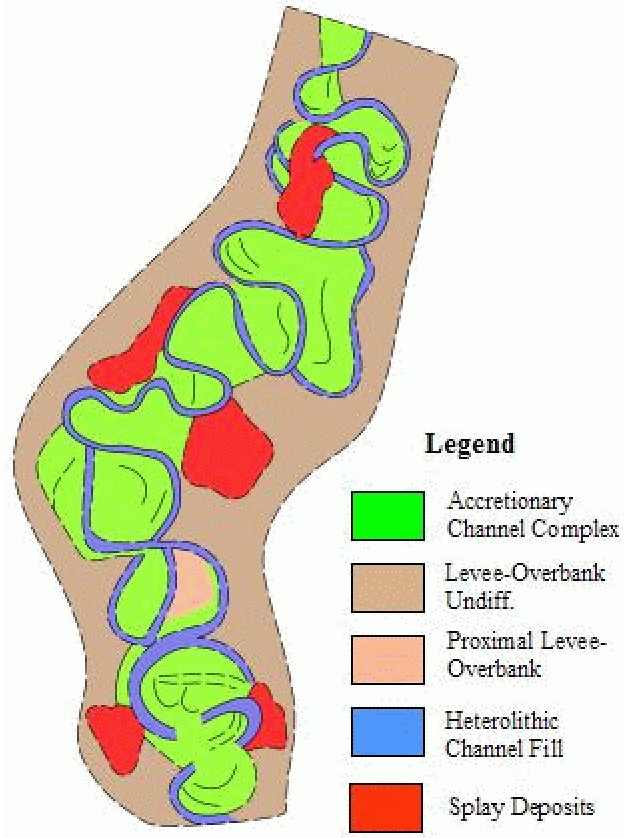

**Figure 3: Depositional elements interpreted from seismic amplitude (schematic).**

**Figure 4: Polygons based on AVO response, indicating reservoir quality in terms of porosity and NTG. green=high, yellow=medium, red=lowest quality.**

In the next step, shale objects were modeled stochastically inside the depositional sub-elements. This allowed modeling different shale geometries and N/G ratios for each of the depositional sub-elements. Figure 8 shows the porosity model with the shales set to 0% porosity. Figure 9 depicts an E-W cross-section, illustrating the varying shale geometries and N/G ratios for different depositional sub-elements.

## Evaluation

The entire reservoir consisted of ~392,000 active simulation cells. Extensive streamline simulation using different well patterns allowed us to quickly pre-select appropriate well locations to make sure the key compartments (structurally and stratigraphically) were drained appropriately. Once pre-selected, the well locations were then used in a more sophisticated black-oil finite-difference simulation to better understand mechanistic flow behavior, design actual development well placement scenarios, and obtain more realistic reserve/recovery estimates.

## Summary & Conclusions

A combined deterministic and stochastic approach, strongly constrained by 3D seismic data was taken to build a 3D geologic reservoir model of a deepwater prospect. All petrophysical data and object dimensions were derived from analog fields or outcrop analog data. The model building process was quick (~ 6 weeks) and allowed us to gain familiarity with both, the modeling of this particular prospect, and current reservoir modeling techniques. While

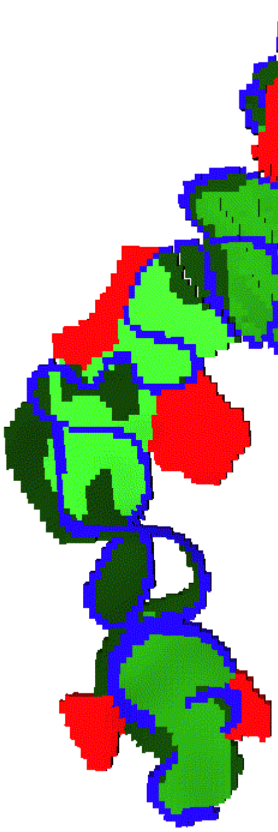

**Figure 5: Modified depositional environment by AVO class. Bright Green=highest quality.(see Legend in Figure 3).**

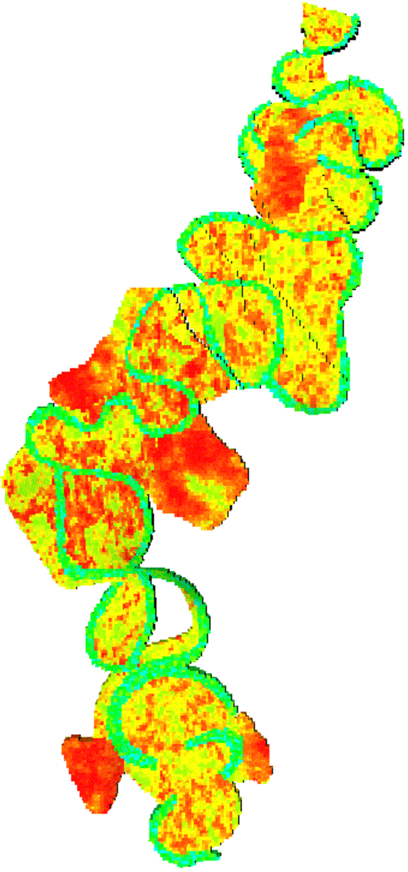

**Figure 6: Fine scale porosity [0-0.35], assuming NTG=1.0. Hot colors are high values.**

much of the data was realistic yet incorrect (taken from analogs), this early model allowed our development engineers to get an early start in sophisticated and detailed engineering analysis processes. Once the first well was drilled this model could be quickly updated with actual (realistic and "correct") data.

We believe that we have derived significant value from this process and have applied a similar approach to a second project in the vicinity and will continue to apply it to other, similar projects. In general, this effort is part of a strategy to push quantitative analysis and 3D geological reservoir modeling "further upstream", making this technology not just a development technology tool, but insert it into the exploration and early evaluation processes.

## Acknowledgements

We would like to thank our co-workers, Mac McGilvery, Ron Martinussen, Lisa Purnell, Ron Thompson, Elliot Hough, Ami Patel, and Andy Reinhardt for their assistance with various elements of this study or their critical insights to ensure technical consistency. Furthermore, we would like to thank the management of ConocoPhillips and partners (Sonangol, Norsk Hydro, Shell, Petrobras) for permission to publish this paper.

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**Figure 7: Upscaled porosity [0-0.35], assuming NTG=1.0. (see Legend in Figure 3).**

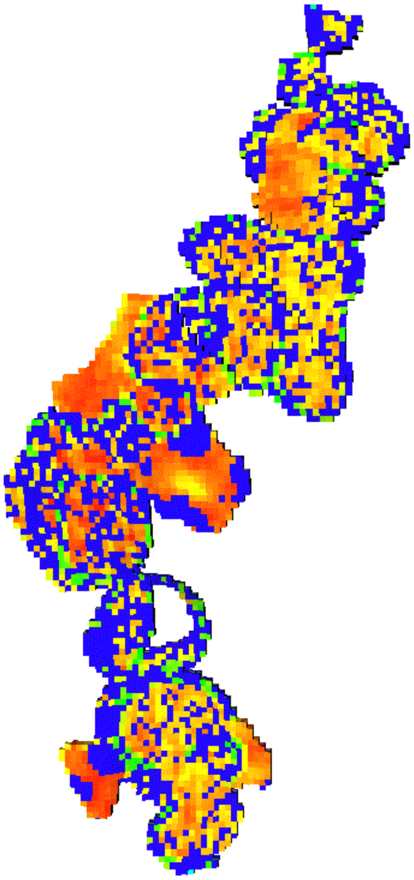

**Figure 8: Upscaled porosity [0-0.35]. NTG varies depending on AVO response. Blue=shale, green=low porosity, red/yellow=high porosity.**

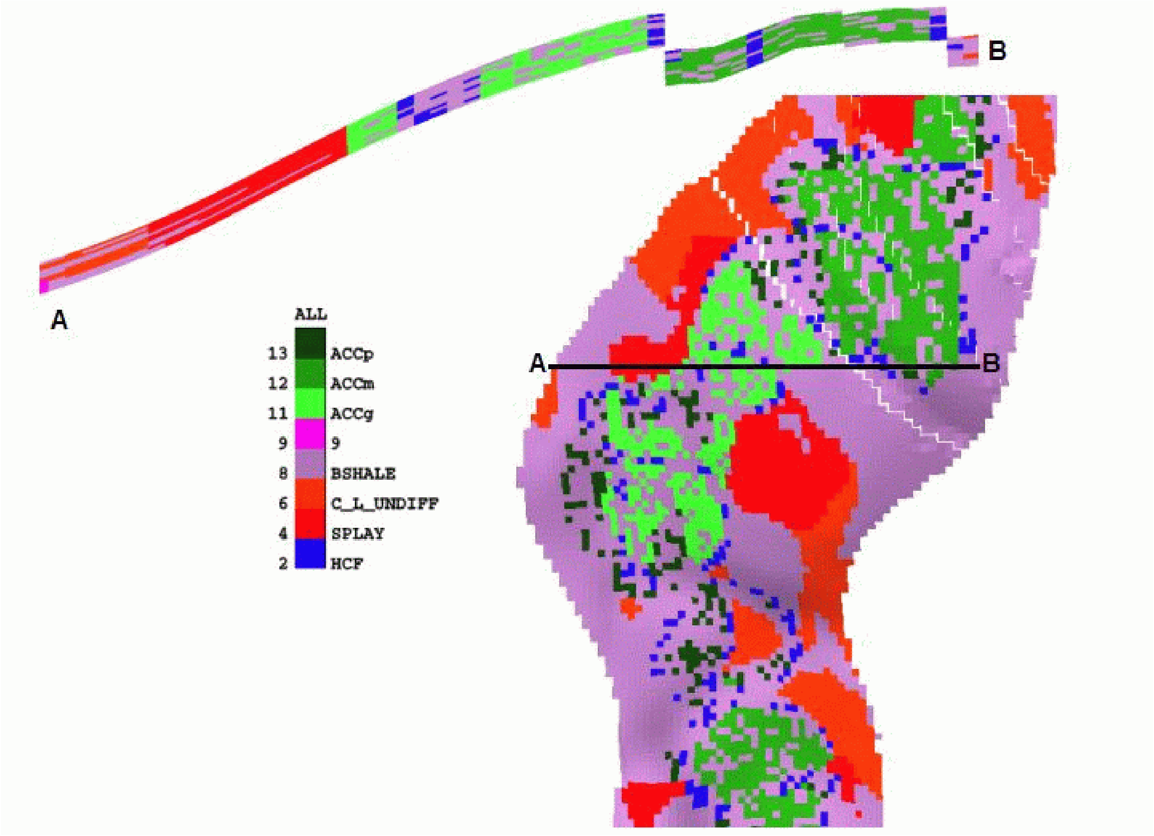

**Figure 9: E-W cross-section showing different elements with different shale contents.**