
Ultra-deep and Ultra-safe: Combining facies predictions and PPFG well planning for the ultra-deep water Ayame-1X exploration well, Côte d'Ivoire

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1. INTRODUCTION

In May 2017 Ophir Energy announced that the ultra-deep water Ayame-1X exploration well had reached its total depth of 5394m TVDss. The well targeted multiple Cretaceous turbidite channel and fan complexes which were encountered as prognosed. Furthermore, the well drilled and successfully cased the longest riser-less surface section in the region and reached total depth in the subsequent open hole section with a single bit run, again, another basin first. From a pressure perspective the well was drilled safely and the pore pressure and fracture gradient were accurately predicted pre-drill.

Although detailed analysis of the work is still ongoing, we present the workflow that enabled a robust pre-drill pore pressure model to be derived. The pre-drill model utilised lithofacies estimates derived through seismic inversion combined with a thorough assessment of local and regional pressure regimes in order to fully capture and quantify uncertainty. The pre-drill estimates of lithology and pressure were subsequently validated during and after the drilling of the wildcat exploration well.

2. PRE-DRILL PRESSURE MODELLING CHALLENGES

It is generally accepted that pore pressure prediction works best in areas where the sediments are young, rapidly deposited, contain similar clay content and are within low temperature environments much like those of Tertiary deltas. The ultra-deep water blocks of Côte d'Ivoire have additional geological complexities that therefore make pore pressure prediction more challenging. These include: 1) The block of interest contained a 1500(+) sq km 3D seismic survey but without well control; therefore the PPFG work is heavily reliant on analogue data and geological modelling, regional experience and seismic interval velocities. 2) There is a strong variability in the top of overpressure across the shelf and slope regions of West Africa, particularly within the Middle and Late-Cretaceous intervals. 3) Significant lost circulation can occur in the overburden. 4) Very high net-to-gross (N:G). 5) Cretaceous shales are in part cemented and contain variable limestone stringers making any velocity based pore pressure prediction problematic. 6) The Albian interval is known to contain a high TOC source rock shale which creates effects in the wireline data that mimic overpressure. 7) Average geothermal gradients (~37°C/Km) are high.

With all these uncertainties, one of the key solutions to de-risk well design in the ultra- and deep-water blocks is to build a geologically sensible geopressure model. Such models rely on a detailed understanding of lithologies, facies and depositional models e.g. the presence of deep-water turbidites forming slope channel fan complexes, stratigraphic pinch-outs and rotated fault blocks. The pressure model constructed must explain the current occurrence of overpressure, taking into account the local geology and analogous areas (structure, stress, temperature, basin history, sedimentation rates and depositional architecture). Using a model derived from the latter we can then sense check any seismic velocity-based interpretations.

3. WORKFLOW

3.1. Geological pressure modelling

A detailed review of the pressure regime based on several offset wells was undertaken in order to characterise the overpressure distribution, the main mechanism of overpressure generation and how these processes link from the shelf to the deep-water.

3.2. Lithology modelling

A facies-based seismic inversion scheme was applied to the data to determine a range of plausible geological outcomes that fit with prior knowledge of rock types (from adjacent wells and literature review), rock physics relationships, seismic interpretation and pre-stack amplitude data. Tests were performed to investigate ranges of expected N:G, the presence of various lithologies (particularly volcanics and cemented sandstones) and their fit to the underlying seismic amplitude data. Based on the analysis of inversion results and QC products, a final 'most likely' set of facies and elastic property cubes were generated for use in the construction of a geological and rock physics constrained well plan.

3.3. Ayame-1X well planning

The uncertainties around the pore and fracture gradient models were captured by low, expected and high-case scenarios. Additionally, a comparison between the prognosed lithology column for pre-drill and those derived by facies-based seismic inversion was also conducted in order to ensure consistency between models and to optimize the well architecture.

4. DRILLING RESULTS AND INITIAL POST-DRILL ANALYSIS

The pre-drill prognosis proved generally accurate, with the bulk lithologies encountered matching the facies prediction from seismic inversion. Further analysis of the inverted elastic properties shows that they too matched closely to the upscaled well logs. Seismic inversion predicted a top seal above the Santonian reservoir but this was thinner than expected (8 m versus 35 m). Although capable of sealing at the well location, the lateral integrity (continuity) of the seal is now in doubt. The 'back-up' top seals (the 'Ayame Hard Channels') were thicker and although these are acoustically hard channel sands were predicted by the inversion they actually have much better porosity and permeability than expected. A single LOT was conducted in the well, after drilling out the 13-3/8" casing shoe at 4601m TVDss in the Maastrichtian. The formation leaked off at an equivalent mudweight (EMW) of 10.38 ppg compared to the expected pre-drill prediction of 10.36 ppg EMW.

No direct measurements of pore pressure were obtained during drilling or wireline operations; however, post-drill analysis of wireline measurements suggest a pore pressure at top reservoir to total depth of 5394m TVDss of slightly above hydrostatic - 8.65ppg EMW, correlating extremely well with the pre-drill pore pressure prediction. The well was drilled with a maximum mudweight of 9.4ppg and the maximum equivalent circulating density (ECD) was recorded as 9.76 ppg EMW. No losses or influxes were experienced.

5. CONCLUSIONS

Pore pressure and fracture gradient predictions for well planning in data challenged areas such as those in the ultra-deep water blocks of Côte d'Ivoire is inherently difficult. To help reduce uncertainty and provide confidence in pore pressure prediction models an integrated approach combining a well-based offset well study and facies-based seismic inversion was implemented.

The key control on the distribution of pore pressure in shelfal to deep-water areas is largely dependent on the rate of deposition of each facies. Where N:G is low (as in the case of mud-rich fans) thin isolated reservoirs lead to high pore pressures. Where N:G is high as in the case of sand-rich or amalgamated fans, single thick sand reservoirs are present. Using these empirical relationships and a detailed understanding of lithology and facies, improved pore pressure and fracture gradient profiles can be built for well planning purposes. In this case, these models were qualified during drilling.

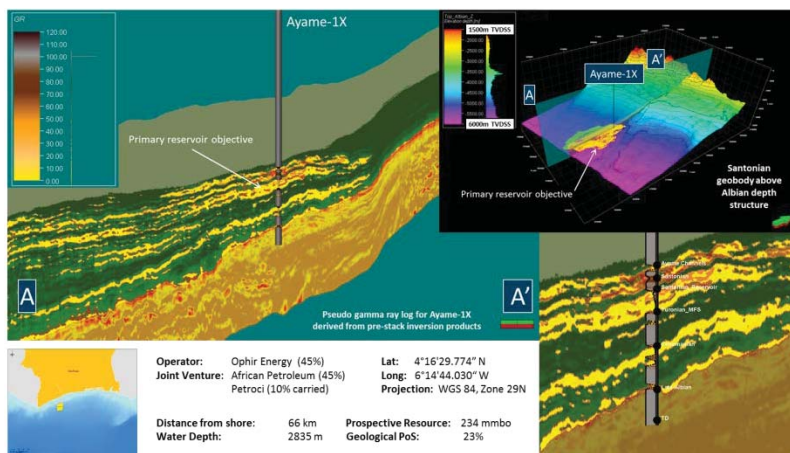


Figure 1.

Bottom LHS: Location map of the Ayame-1X well, offshore Côte d'Ivoire (images courtesy of Ophir Energy).

Top RHS: Facies-based seismic inversion highlighting the sand and shale facies.

Top LHS: Geobody extraction of the primary objective at the Ayame-1X well overlain on the Top Albian depth surface.

Bottom RHS: Zoomed image of the Cretaceous interval highlighting the predicted pre-drill lithologies.