Lithology Classification and Prediction in the Abu Sir Field, Nile Delta, Offshore Egypt

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Summary
A full offset elastic seismic inversion was conducted over the Abu Sir Field, Offshore Nile Delta, Egypt in an effort to resolve lithological and gas saturation uncertainties in a Pliocene gas accumulation prior to the drilling of an appraisal well. A significant risk in Pliocene elastic exploration and exploitation in the Nile Delta is the risk of residual gas yielding false “DHI’s.” Complicated hydrocarbon fill and leak models make it difficult to predict with confidence when an observed DHI will be the result of residual gas or commercial saturations of gas. A second risk in Pliocene accumulations is the impact of low net-to-gross thin bed intervals within an overall slope channel levee complex. An accurate assessment of the relative proportion of channel sand vs. thin bed reservoir is important as is an assessment of the net-to-gross of the thin bed package. The inversion project set out to differentiate not only channel sand vs. thin bed reservoir, but also to differentiate varying net-to-gross within the thin bed packages.

The resulting inversion was unable to resolve the question of residual gas saturation, nor to differentiate net-to-gross within thin bed packages, but a simplified lithology classification system based on a “shale,” “thin beds” and “sand” classification was employed and proved highly successful at predicting actually drilled lithologies in the AS-3 appraisal well. This resulting inversion volume was then used as the basis of the geocellular model of the field used for resource estimation.

Introduction
The Abu Sir field lies in approximately 3300 feet of water in the deep water portion of the Nile Delta. The field is a Pliocene amplitude supported “Slope Fan Channel Complex” that was discovered in 2002. Two Gas Water contacts were observed at that time in AS-1X well. In 2003 the AS-2X appraisal well was drilled but the DHI corresponding to the lower sand was found to be a residual gas response. The reservoir interval lies at approximately 3200 feet below mud line. The 2002 seismic was reprocessed in 2007 using Pre Stack Time Migration leading to a significant improvement in the focusing of the reservoir image in the Pliocene.

The AS-3 delineation well was drilled in 2008 to assess the DHI observed at deeper level a western, downthrown fault block. Risk of “Fizz Gas” presence already observed in the AS-2X well was one of the major concerns together with an accurate prediction of the sedimentology since 75% of the estimated recoverable resource was predicted to be located in thin bed reservoir rocks.

Figure 1 illustrates the seismic response observable in the seismic data with strong amplitude anomalies associated with the presence of sands and thin beds filled with gas.

Figure 1: Reservoir Average Amplitude Map

Theory and/or Method
An elastic inversion followed by a lithology classification was conducted by CGGVeritas in partnership with North Alamein Petroleum Company (NALPETCO). Constant interaction between NALPETCO and CGGVeritas was essential during the project in order to maximize the turnaround of the project and to benefit from the expertise of both parties.

- Conditioning of seismic data
A pre-conditioning sequence focused on the inversion time window was designed to make the amplitudes more
compliant with Zoeppritz equation and enhance the seismic quality.

Automatic high density velocity and anisotropy picking was performed to correct for NMO. A special attention was paid to ensure that the far offset were properly flattened and that the velocity used for the NMO correction were geologically consistent. It is well known that the wavelets of far-offset data are stretched after processes such as NMO or migration in such a way that near-offset sections contain more high-frequency energy than far-offset sections. A deterministic stretch model from CMP gathers was calculated and applied to compensate from the NMO stretch and maximize the frequency content of the far offsets. Finally a pass of flattening based on cross correlation methods was performed on the CMP gathers.

To design the angle stacks modeling from wells As1X and AS2X was first performed to know the value of the critical angle at the reservoir level. The amplitude as a function of the angle of incidence is plotted in Figure 2, in blue for the bottom of the reservoir and in red for the top. A severe drop of the amplitude can be observed at the bottom of the reservoir for angles beyond 60 degrees indicating that the theoretical critical angle was reached.

Two objectives were pursued when defining the facies at the well location:
- Defining facies that were in line with the Image log facies
- Defining facies that could be separated using elastic attributes coming from the inversion (P impedance and Poisson ratio)

O Petrophysical Method
A first set of facies was first created by applying cut offs on the VSH and SWE logs. By comparing this set of facies to the image logs discrepancies for the thin beds were observed due to the fact that the thin beds are cm scale, below the resolution of traditional logs.

O Facies estimation from Image log facies.
It was decided to start from the image log itself and to slowly upscale this log by merging the facies classes together in order to improve the separation in the P impedance vs Poisson Ratio domain. The possibility to separate “good” pay thin beds from “poor” pay thin beds was carefully assessed, and it was finally determined that it was not possible to segregate the “thin bed” facies with any degree of predictive power. It was decided to keep a single pay “thin beds” litho facies.

O Final approach
Three litho facies: (Shale, Thin Beds and Sand) and two fluid phases (Wet and Gas Bearing) making a total of five classes were finally used. It was not judged possible to separate the fizz gas in the P impedance (Ip) vs Poisson ratio cross plot. Figure 3 illustrates the litho facies distribution in a P impedance (Ip) vs Poisson ratio cross plot.

- Inversion Generation
CGGVeritas’s 3D simultaneous elastic inversion software jointly inverts any number of angle stack (below the critical angle) to derive estimates of the elastic parameters. This
multi-trace inversion algorithm works within a stratigraphic grid and is parameterized in terms of P-wave velocity, S-wave velocity and density to describe the elastic earth model. This, in combination with the use of the Zoeppritz equation for the modeling, allows the method to take full advantage of wide angle data sets.

The discrimination between sands with residual gas saturation and sands with commercial gas saturation is very difficult with elastic attributes based on the P-velocity. The P-velocity is decreasing very quickly as some gas presence is found in the reservoir.

The Poisson ratio section (Figure 4) illustrates the gas sands as low red values, shaly sands with intermediate green values and the shale with high blue values. It is however clear that both commercial and fizzle gas sands are both responding with the same range of low values. The attribute that would allow a discrimination of the two types of gas is the density, as for a constant porosity the density can be linked to the gas saturation by a linear relationship.

Simultaneous elastic inversion provides cubes of elastic attributes that were interpreted in terms of reservoir lithology and fluid content. In order to quantify uncertainty in seismic lithology prediction, CGGVeritas has developed a supervised Bayesian classification tool, called LithoSL.

The litho-logs defined at the well were used to define different litho-classes in our case water-sand, gas-sand, thin beds with gas, thin beds with water and shale, which must be discriminated from input seismic attributes. Log data points in the training set are displayed in a series of 2-D cross plots of elastic attributes. Cross plot points are color-coded according to litho-class to assess visually the separability of the different classes. Next, a multivariate probability density function (PDF) is fitted to each cluster of points in the training set using a non-parametric modeling technique.

The probability density function (PDF) for the five litho classes were built in the Ip vs Poisson ratio cross plot shown in Figure 5. Clearly observable is the clear separability of the gas sand in yellow and of the water sand in dark blue. The PDF of the shale (in grey), the water thin beds (in light blue) and the gas thin beds (in green) are overlapping which will result in a higher uncertainty associated to the prediction of these litho classes.

After the training phase, the classifier is applied sample-by-sample to the input cubes of inverted attributes. The procedure outputs a probability cube for each litho-class. The calculated litho-probability cubes were then used for uncertainty assessment. The probability density functions initially assume that all the litho classes are equiprobables. According to the geological knowledge of the area an a priori proportion 3D model can be built to increase the weight of a lithoclass compare to the others in some areas.

This will enhance the prediction of facies that have overlapping probability density functions in the P impedance vs Poisson ratio domain.

Spatial information splitting the area into a Distal Belt and a Channel Belt together with vertical information from the GWC were used to model the a priori proportion of each of the litho class. For example Shale were assume to be predominant in the distal belt in comparison to the four other litho classes and below the GWC the a priori proportion of the water sand and water thin beds was raised. In Figure 6 the result of the classification is shown for an inline passing through well AS-2X. A very good match between the litho facies at the well location and the predicted one from the inversion results is observed, however the “fizzle gas” result is not predicted by the inversion.
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Figure 6: Facies Classification Results Through AS-2X Control Well

Figure 7 illustrates the results of the inversion at the AS-3 appraisal well location. This well was drilled after completion of the inversion project. The upper portion of the reservoir package drilled was found to be exclusively “thin bed” facies as predicted in the inversion. The deeper, thick sand, in which it was predicted that the well would find a Gas-Water Contact, was found at the depth and thickness predicted, but was wet. The portion of the sand above the “flat spot” was found to contain residual gas saturation levels whereas below this DHI-predicted GWC the sand was fully water wet indicating that the DHI was indicative of a paleo-GWC.

- A paleo gas water contact separating the base of the “fizz gas” interval in the deeper sand body from the water leg was encountered where the GWC was predicted. Therefore the inversion did not succeed to separate the commercial gas from the residual ‘fizz’ gas.

- The Resulting BTE (Best Technical Estimate / Most Likely) Lithology volume has become the basis of the go-forward facies geomodel for field development planning.

Conclusions

- The well location was re-confirmed by the inversion as being optimal to test the key uncertainties of the field.

- The well results were in very good agreement with the facies predictions from the inversion, especially lack of channel sands in the upper part of the sequence and the presence of a deeper thick sand body.

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