Nile Delta Reservoir Case study using a novel broad band pre-stack seismic inversion to rock properties technique, *Michael Smith, Geotrace*

INTRODUCTION

Exploration for hydrocarbons within an onshore concession in the Nile Delta, Egypt has been ongoing for several years. Despite the presence of clean sand reservoirs with a good shale cap rock and four way closures, none of the wells drilled so far have proved to be significant hydrocarbon producers. A pre-stack seismic inversion to rock properties study was therefore carried out to better understand the lithology in the area and highlight potential reservoirs. A novel technique was used to provide the broad bandwidth essential for a successful inversion. This paper details the results of the project.

BACKGROUND

The Nile Delta is an emerging giant gas province with proven reserves of approximately 42 TCF. This resource has more than doubled in size in the last three years, largely as a result of successful deep-water exploration for Pliocene slope-channel systems. Proven reservoirs vary in age from Oligocene and Early Miocene through Pleistocene. Proven source rocks include Jurassic coals and shales and the Lower Miocene condensed Qantara Formation shales. Additional source rocks may be present in condensed intervals of Cretaceous, Oligocene and Eocene age. However in the onshore area of interest, exploration so far has not afforded any significant discoveries.

GEOLOGICAL SETTING

The geological setting is best described by quoting from Boucher *et al* (2004). "Following Tethyan rifting and the opening of the Mediterranean in the Jurassic era, prominent Cretaceous mixed clastic and carbonate shelf edges aggraded vertically along a steep fault-bounded shelf-slope break. This "hinge line" in northern Egypt provides the fundamental control mechanism for Reservoir distribution in Tertiary age strata. In late Eocene times, Northern Egypt was tilted toward the Mediterranean during regional uplift associated with the opening of the Gulf of Suez and Red Sea rifts. Drainage systems shed reservoir quality sediments northward in a series of forced regressions. These regressions culminated in be-heading of the youngest deltas by subaerial erosion during the sea level low-stand associated with the Messinian salinity crisis. Early Pliocene transgressions deposited a thick sealing interval over the low-stand Messinian valley networks." "The steep structural hinge line and faulted continental shelf created a large amount of accommodation space with relatively minor progradation of depositional systems. As a result, the primary play consists of slope-channel fairways in all levels. The Plio-Pleistocene systems are the shallowest targets in the basin that hold the majority of proven reserves. Future large reserve growth is anticipated to come from the pre-Messinian strata."

STUDY RESULTS

Seismic Data Input

In the area of interest, approximately 1,000 square kilometers of 3D seismic data were recently acquired in 2005 and 2006. Although the delta area is difficult operationally, being densely populated and crisscrossed with canals and rivers, the data acquired using a dynamite source were of good quality with good signal to noise. For the study, an area of approximately 100 square kilometers that includes two existing wells was processed through a pre-stack time migration (PSTM) sequence.

Pre-Stack AVO Inversion

The study used a 3-term pre-stack inversion methodology to address the exploration challenges in this area. The methodology is based on application of the Aki and Richards linearized Zoeppritz equation for P-wave reflection amplitude as a function of incidence angle. A conditioning sequence was applied to the input pre-stack time migrated gathers including, critically, a high frequency imaging step (Hamarbatan et al, 2006). This provided a stable wavelet across the gather, and a broad seismic bandwidth both to better measure the curvature in the 3 term equation, and to constrain the earth model.

Rock reflectivities were calculated from the AVO terms and integrated for the rock properties P-wave velocity (V_P), Shear Modulus (μ) and Bulk Density (ρ), with well logs used to constrain the inversion at various stages. These rock properties were combined with a macro earth model, created using well data, high frequency gather velocity analysis and using picked horizons to guide model population, to yield absolute rock and fluid properties. The workflow is detailed in Figure 1 below.

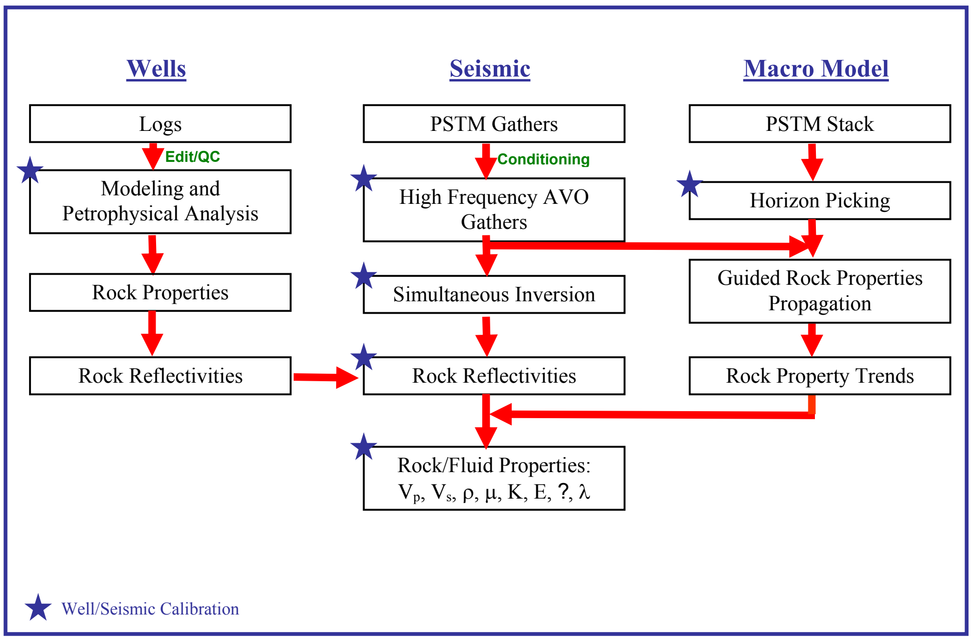

Figure 1 – Pre-Stack Inversion Workflow

In this study the 3D data contains sufficiently long offsets for a stable 3-term solution, giving angles beyond 40 degrees at the Pliocene and Miocene targets. The inversion was carried out on a 100 sq km subset of the 3D seismic. Absolute rock property volumes generated included V_P, V_S, Bulk Density, Shear Modulus, Bulk Modulus, Young's Modulus and Poisson's Ratio.

Interpretation of Rock Property Volumes

The initial inversion volumes of V_P, ρ and μ correlated well with logs from the wells in the study area. Of the rock property volumes generated, Bulk Modulus and Young's Modulus were found to give a good indication of the lithology. Using values observed in well logs as a guide, colour scales were generated as lithology indicators. Different values were observed within the two different geological regimes (Pliocene and Miocene) hence a lithology-indication scale was set up for each regime. Figure 2 shows Young's Modulus through an existing well, with the lithology scales. The black line marks the Pliocene/Miocene unconformable boundary at about 2445ms two-way-time.

Poisson's ratio (ν) can indicate changes in lithology and pore fluid. In terms of lithology, low values are an indicator of sands, since $\nu_{quartz} < \nu_{calcite} < \nu_{clays}$. Figure 3 shows Poisson's Ratio through an existing well, with low values (yellow) correlating well with good quality sands, particularly in the Miocene.

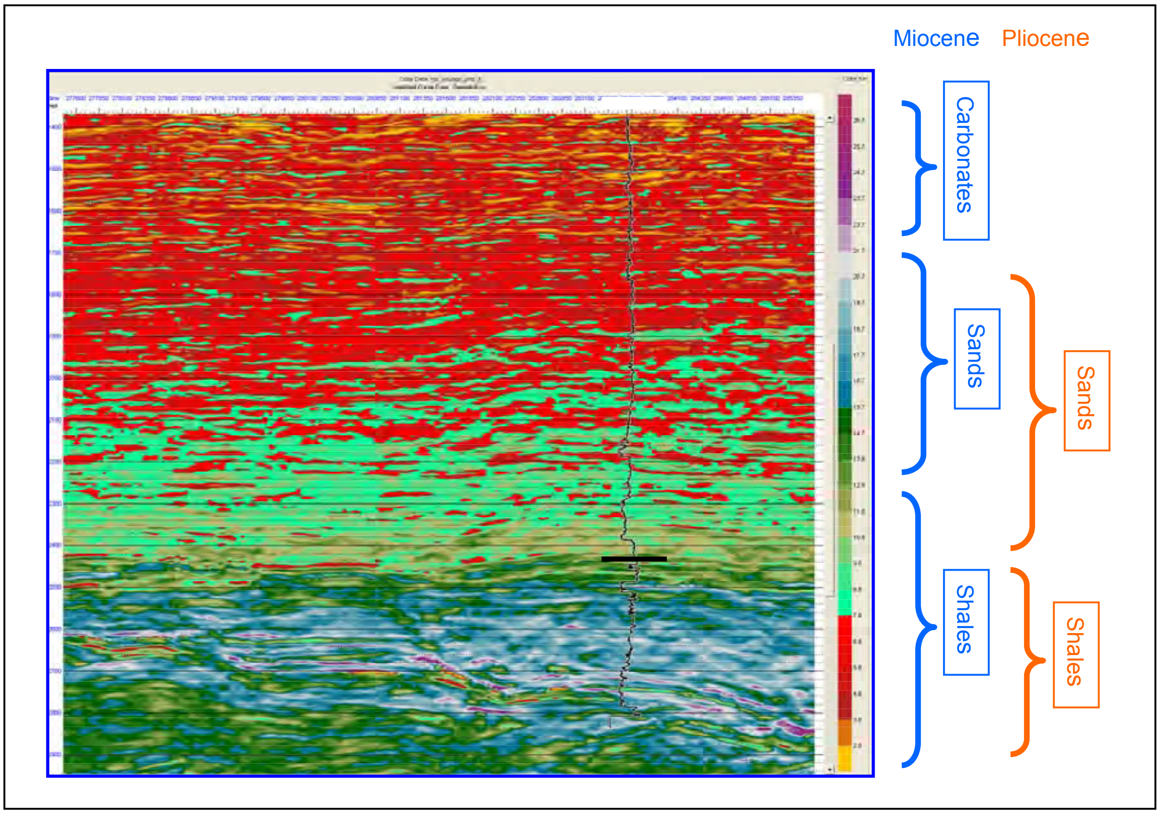

Figure 2 – Young's Modulus as a lithology indicator through existing well location (gamma log overlain). Lithology indications refer to the colour bar.

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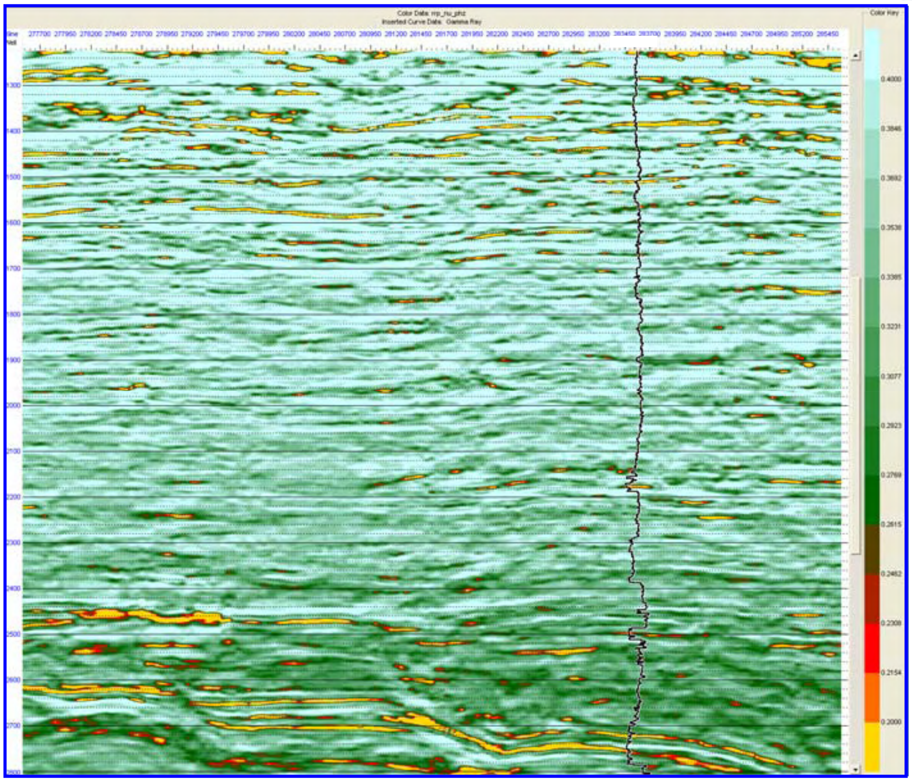

Figure 3 – Poisson's Ratio as a potential indictor of good quality sands through existing well location (gamma log overlain)

Combination of Rock Properties

Identification of rock and fluid characteristics is often facilitated by analyzing combinations of rock properties. This can be achieved by cross-plotting. In this study the combination of low Poisson's ratio with low density was selected as the best indicator representing good quality sands with the highest probability of oil/gas pay. Treating the Pliocene and Miocene separately due to their different ranges of values, geobodies of low Poisson's Ratio and low density were selected and plotted using 3D visualization techniques. Figure 4 shows the selected geobodies within the Miocene in a subset of the inversion area.

CONCLUSIONS

Interpretation of rock properties from a pre-stack AVO inversion study has shown to aid exploration in a currently non-productive area by providing increased understanding of the lithology and highlighting potential reservoir targets.

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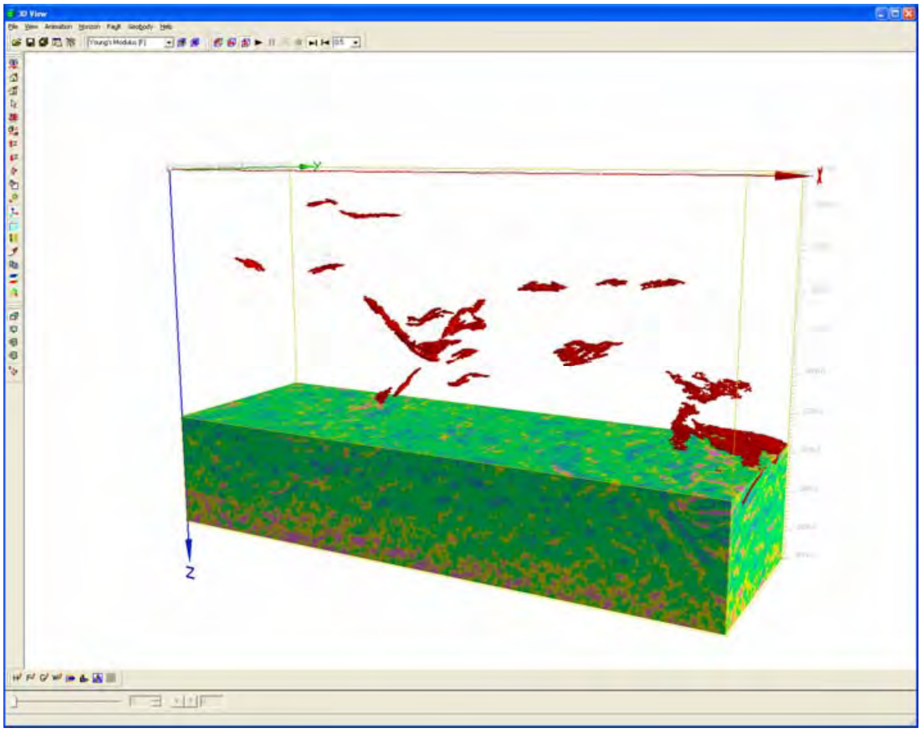

Figure 4 – 3D Miocene Geobodies generated from Poisson's Ratio vs. Density Crossplot with Young's Modulus Background