AVO Analysis for Pre-Messinian Exploration Targets: A New Approach to Identify Gas-Bearing Sandstone Reservoirs*

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Abstract

During the last few decades, the Nile Delta basin proved its potential as a world class gas province. The last few years have witnessed a number of multi-trillion cubic feet (TCF) gas discoveries in the deepwater. In the West Delta Deep Marine (WDDM) concession, most of the discoveries have been made in Pliocene deep-marine turbidite reservoirs. Only two dry wells were drilled deeper into pre-Messinian targets (Oligocene–Miocene). Although the pre-Messinian play had higher gas volumes, the risks were higher and was therefore considered less attractive than shallower plays. Recent discoveries in the Oligo–Miocene sequences, coupled with the advanced use of 3D seismic attributes, AVO (Amplitude versus Offset) analysis, and prestack inversion, encouraged us to reconsider the prospectivity of the pre-Messinian section. To mature the current leads and/or define new ones, many seismic attributes can be used to detect the reservoirs successfully. However, the differentiation between gas sand and brine sand is still the main challenge. In terms of AVO response, both gas and brine sands follow class I, and in extreme cases, gas sand will follow class IIp. The ability of Intercept-Gradient to distinguish gas sands, brine sands, and background rock, is dependent on a number of interacting factors such as effective porosity, fluid fill, Vsh, and cap rock elastic properties. Thus, the AVO classification is not the optimum solution to delineate the deep gas sand reservoirs.

In this study, we have invented a new approach, starting from stochastically modeling the different possibilities of the gas and brine sands in the Intercept/Gradient domain. Then, the Intercept and Gradient were rotated and projected in an Extended Elastic Reflectivity (EER) form at a certain angle to represent a fluid stack volume. This fluid projection provides the best separation between the two partially-overlapped clouds; gas sands and brine sands. To maximize the benefit of this volume and to consider the uncertainty of the input data, cumulative distribution functions have been designed for the gas and brine sand probabilities. The probability volumes were tested at a dry well location and tie perfectly to the well results. The gas sand probability volume was then used for deep targets detection and showed promising new leads.

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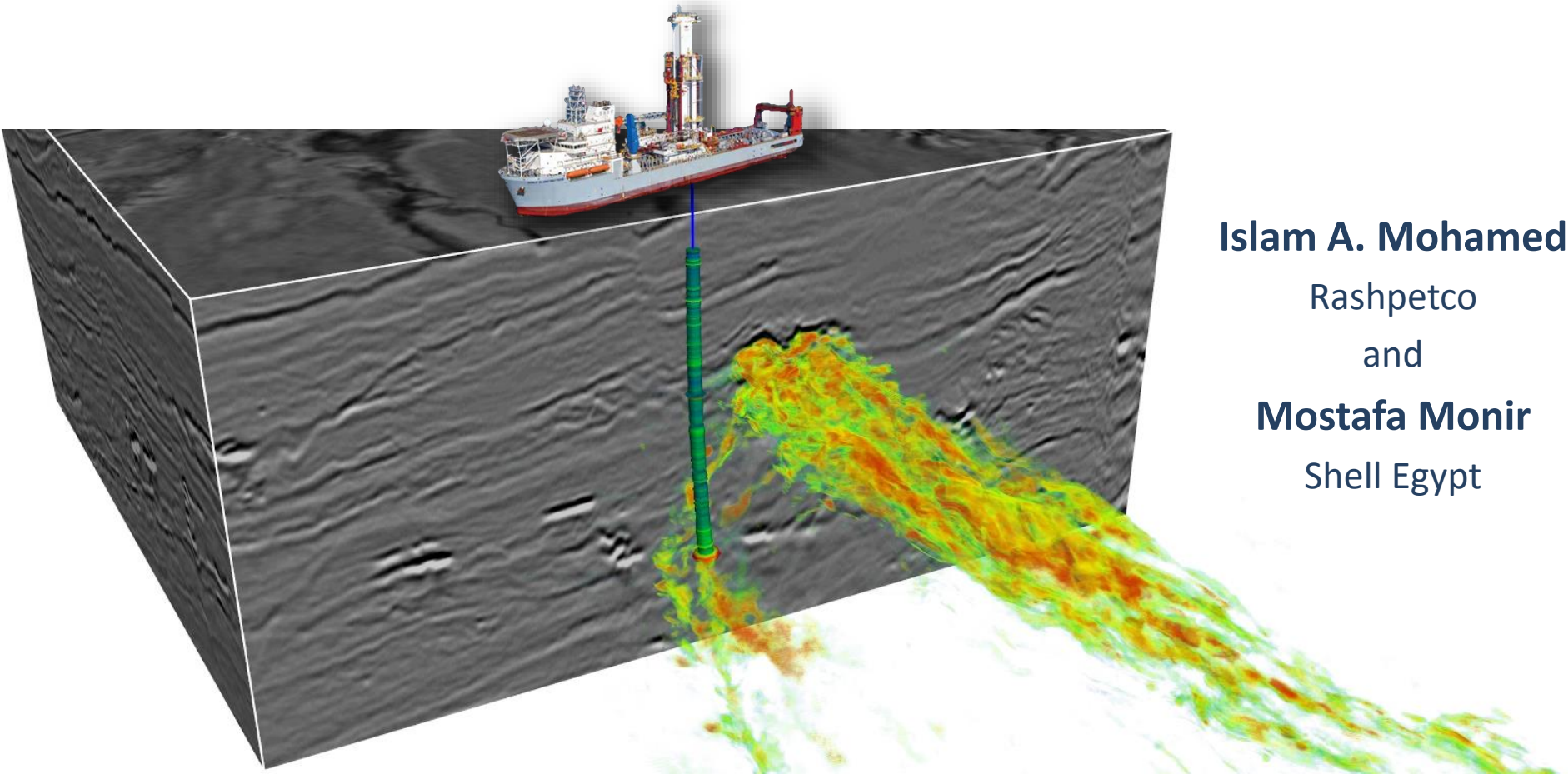
AVO Analysis for Pre-Messinian Exploration Targets; A New Approach to Identify Gas-bearing Sandstone Reservoirs



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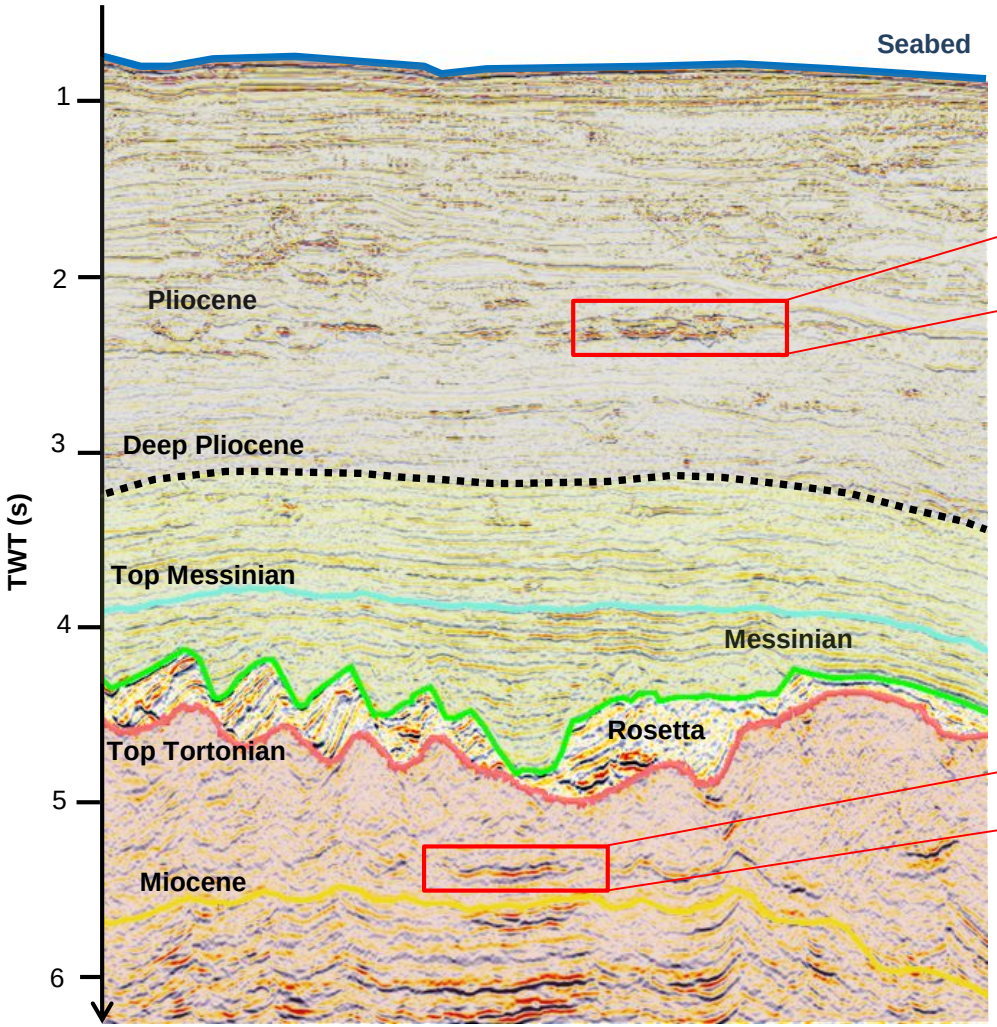
Introduction



Bright Spot = Gas Sand

Bright Spot = ?

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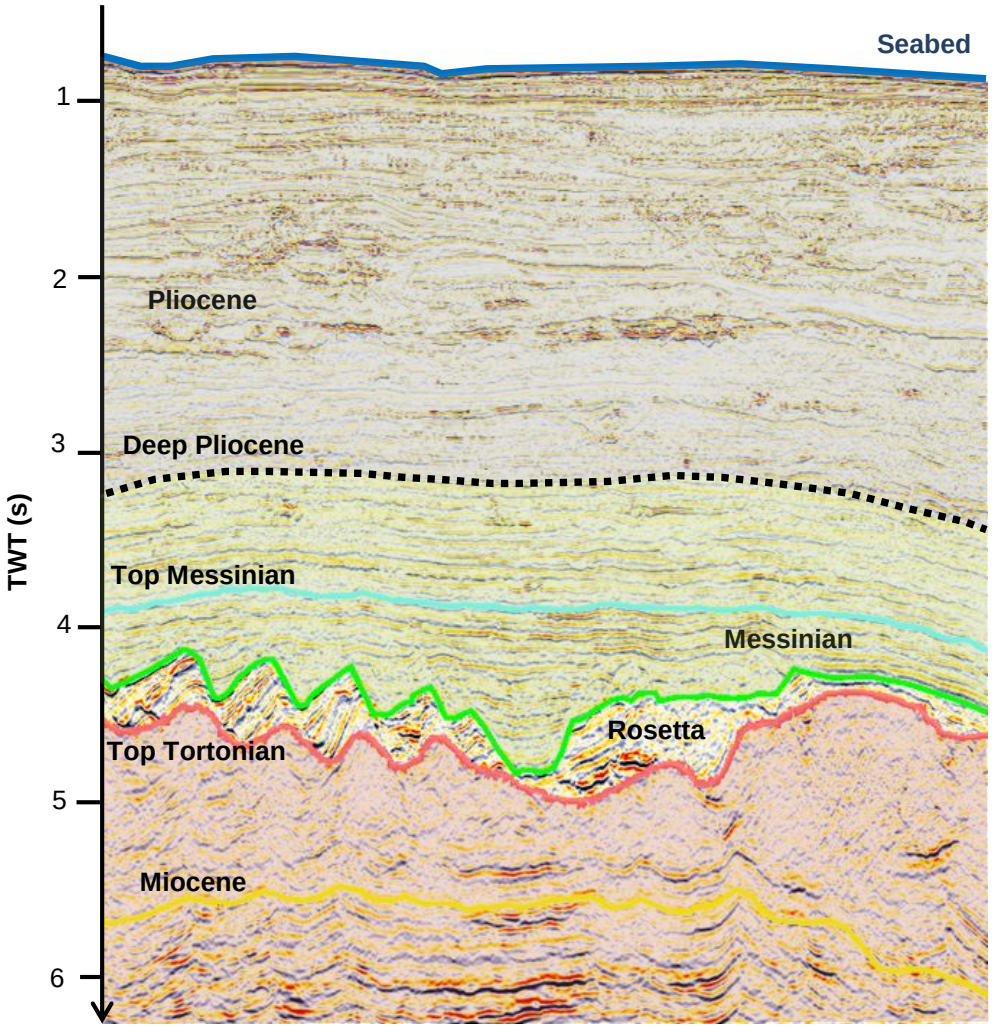
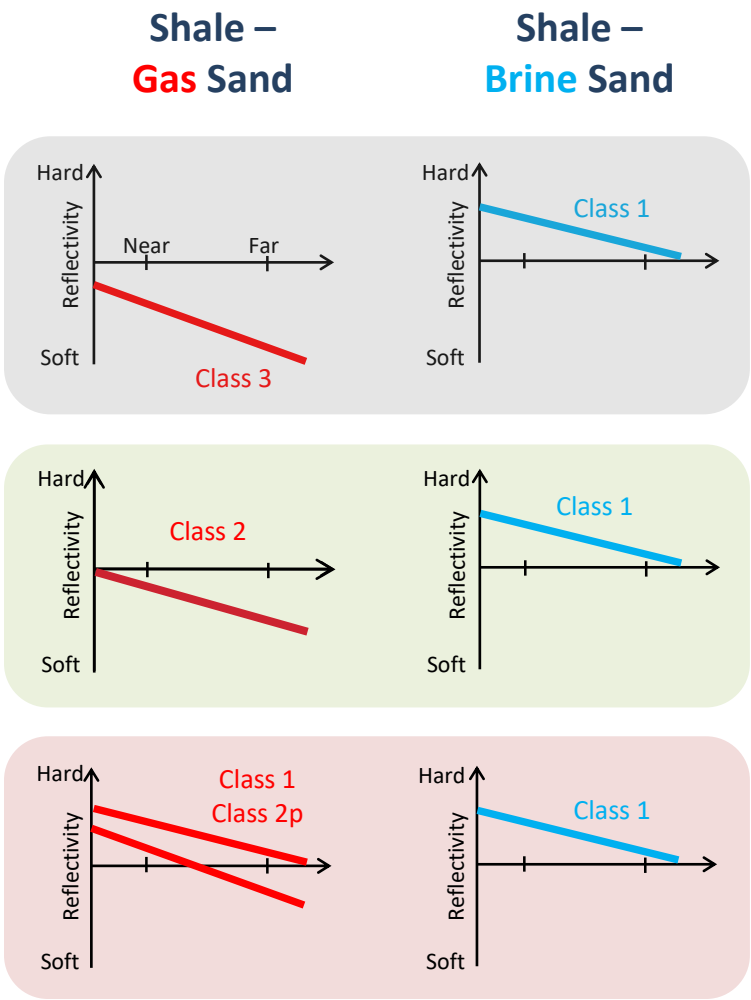
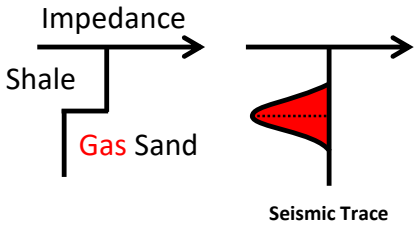
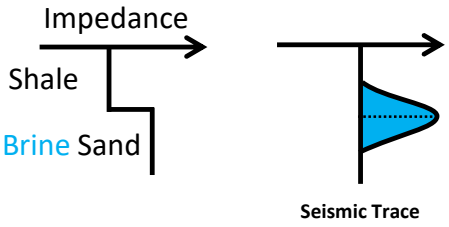
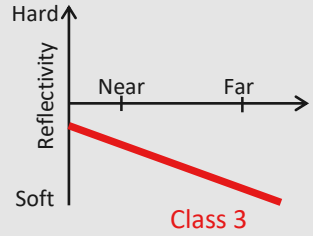
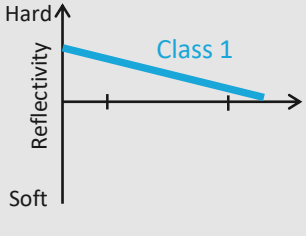
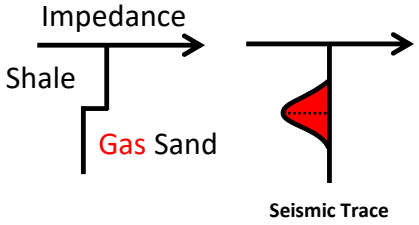
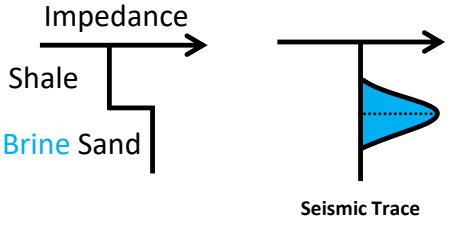
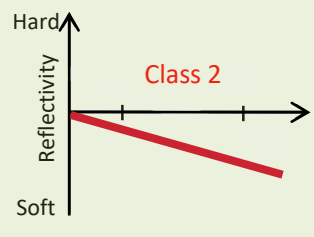
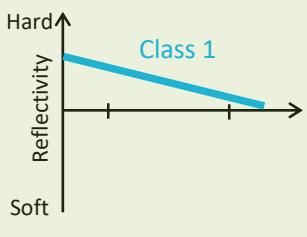
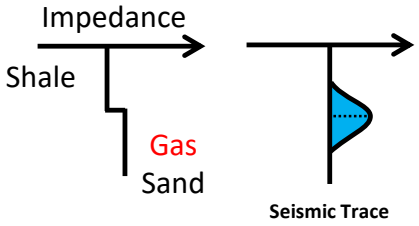
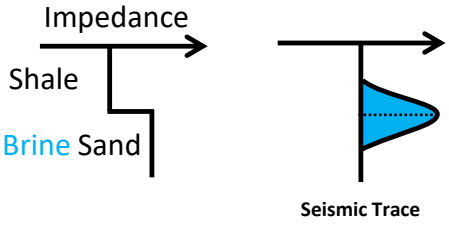
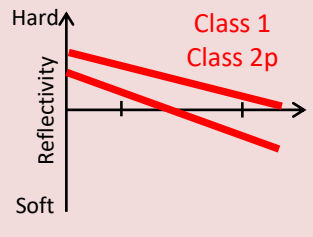
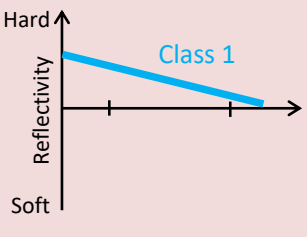
AVO Trends





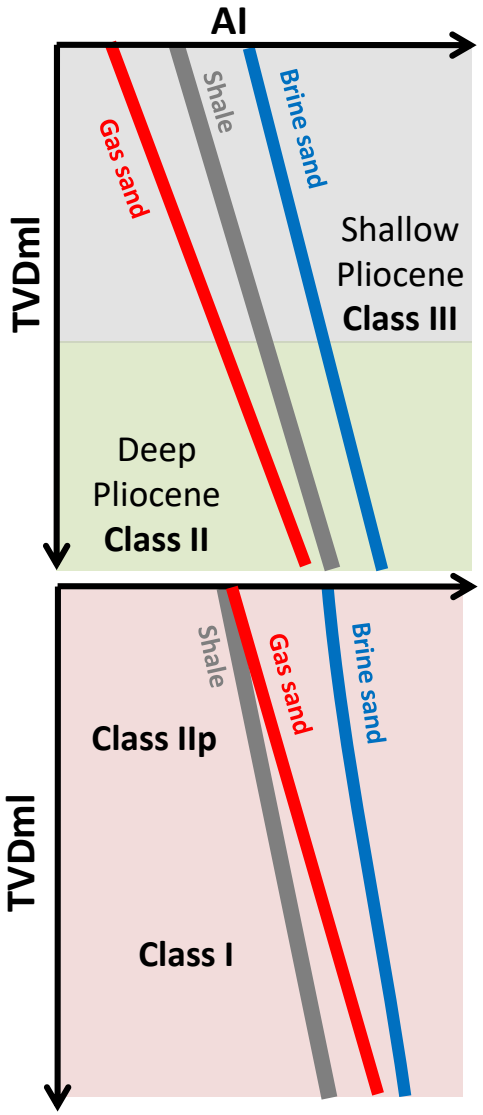
AVO Trends

Shale – Gas Sand	Shale – Brine Sand	Shale – Gas Sand	Shale – Brine Sand
			
			
			

Using SEG normal polarity; increase of acoustic impedance = peak

AVO Trends Summary

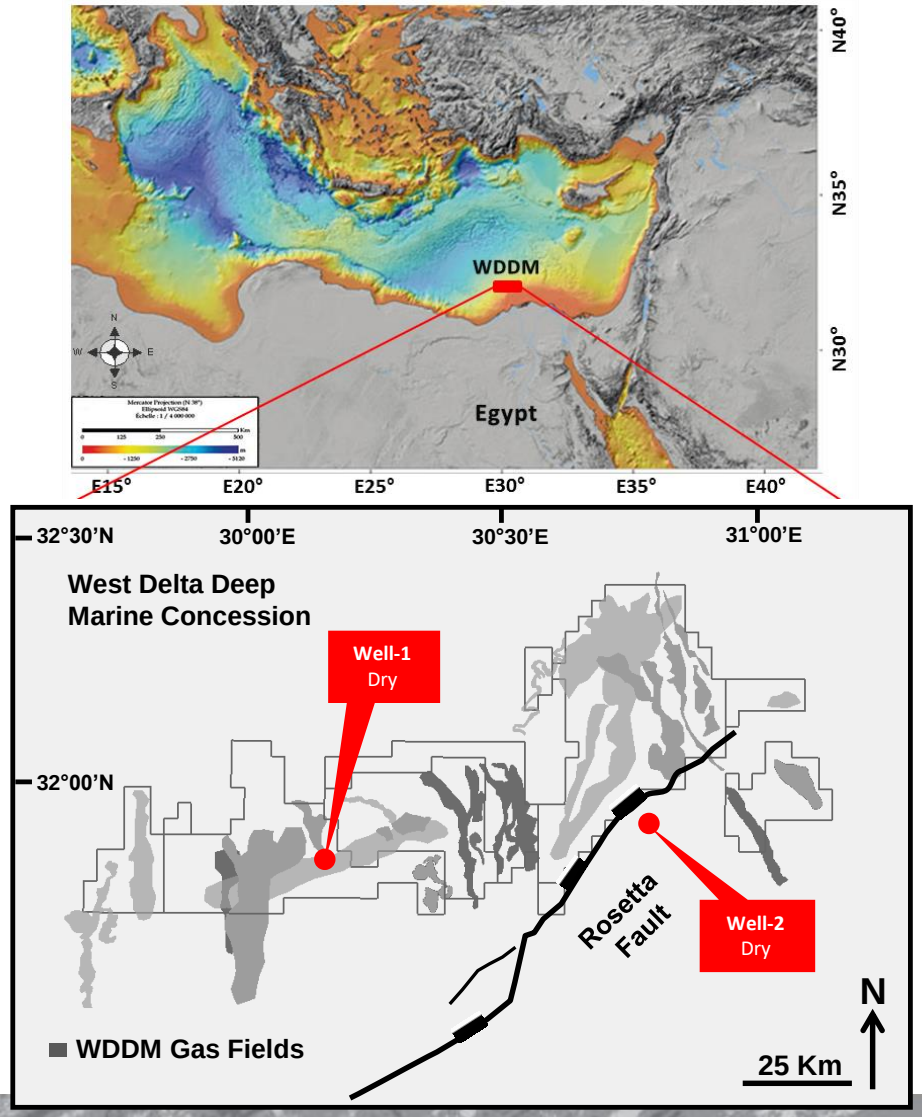
- **Pliocene:**
  - Porosity is the main control on AI and is related directly to depth of burial (compaction)
  - Increasing depth of burial reduces porosity increasing AI
  - Gas sand is softer than the cap shales
- **Miocene:**
  - Porosity is the main control on AI but is not related to depth of burial
  - Gas and brine sands are harder than the cap shales
  - Gas sands display class IIp and I AVO whereas brine sand only displays class I



Area of Study

- Egypt
- Offshore Nile Delta
- 100 Km North of Alexandria
- WDDM development leases area is

  ≈ 1366 Km^2
- Water depth varies from 100 to 1200 m

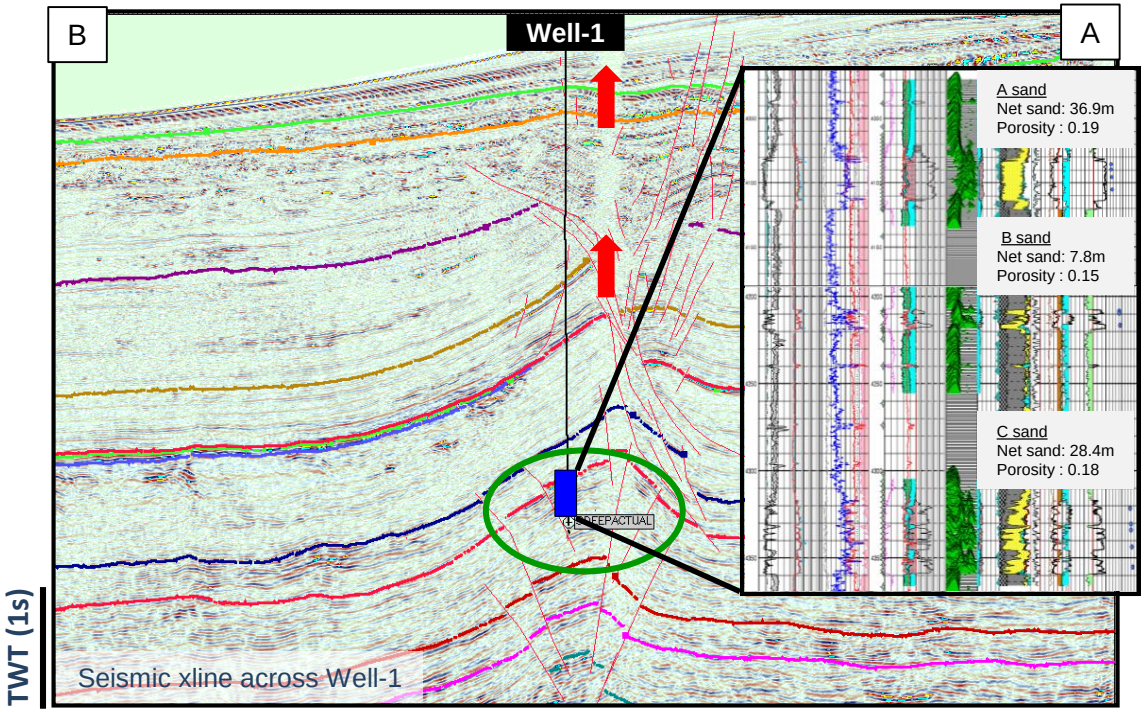


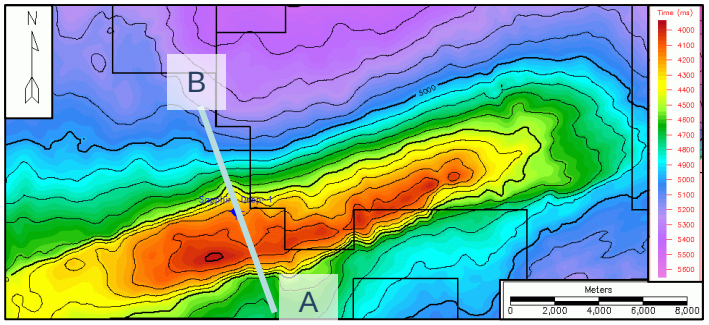
(modified from Mohamed et al., 2014 and Samuel et al., 2003)

Well-1 (Dry Well)

- Drilled in 2004
- Targets:
  - Middle Miocene channels
  - Target channels draped over an anticline (NDOA)
- Results:
  - 3 water-bearing reservoirs
  - 73 m of net sand
  - Porosity ranges:

    15 – 19%

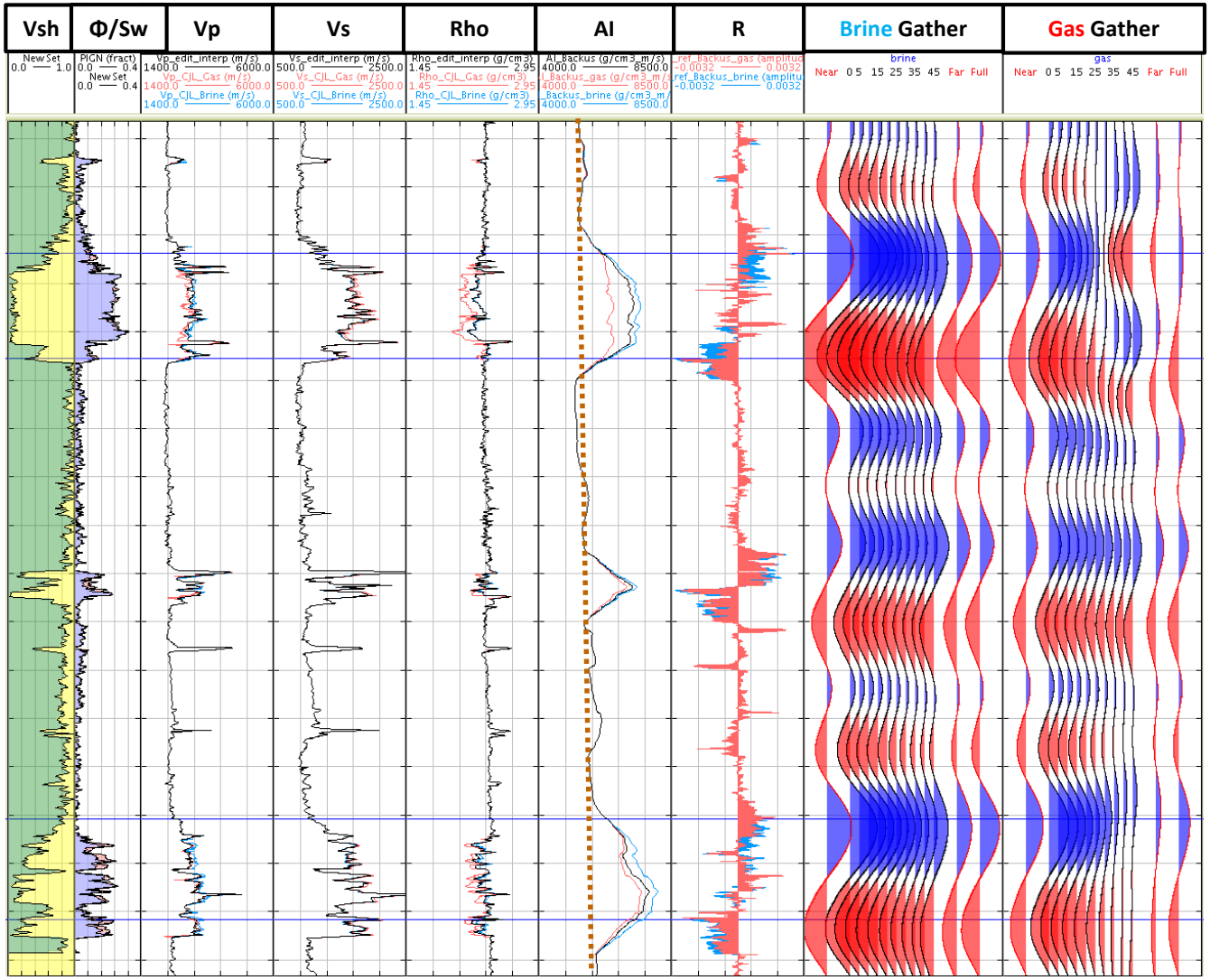




Top Sand B Time Structure Map

- Failure Mechanism: Trap failure (Te)

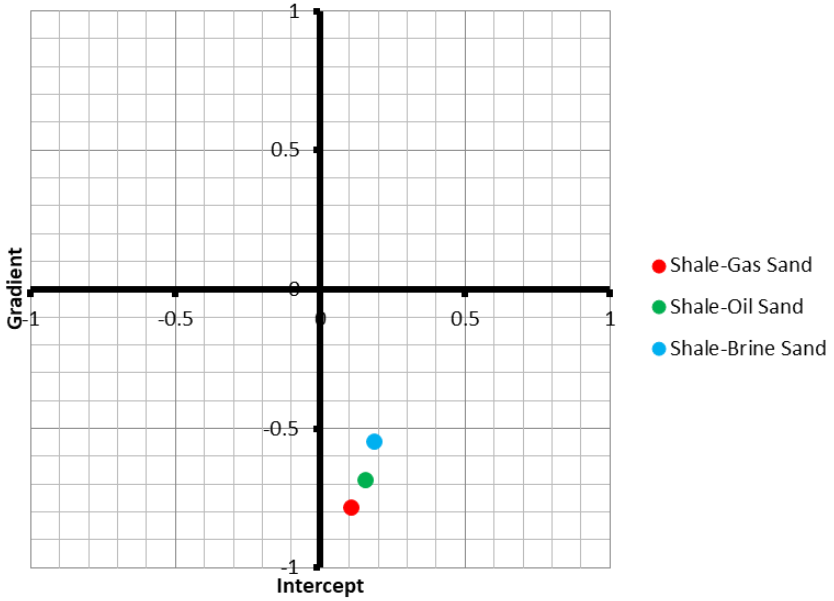
AVO Synthetic Seismograms

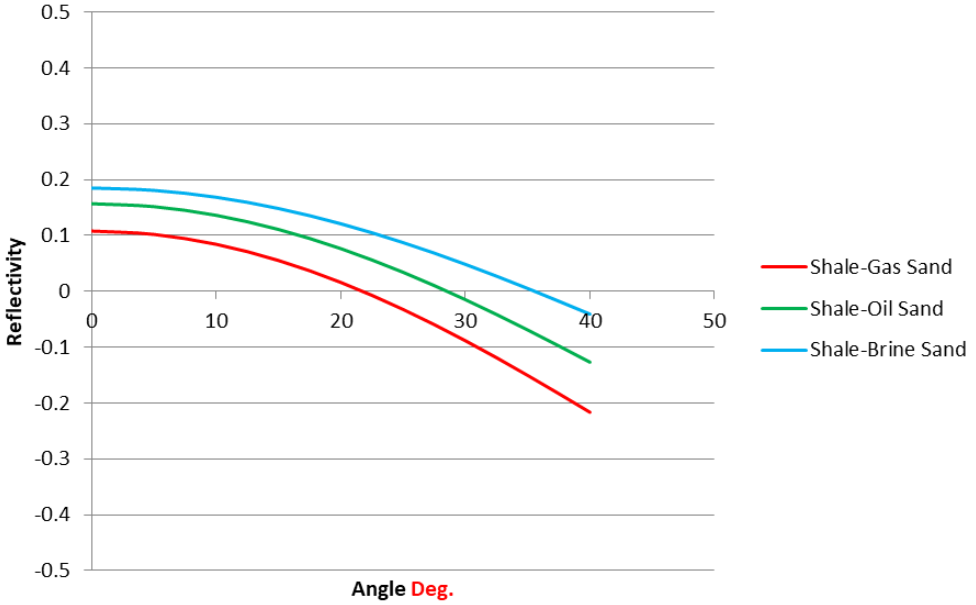


- Brine sand is a bright peak
- Gas sand is Class 2p

- Brine sand is a bright peak
- Gas sand is a dimmer peak

AVO Blocky Model

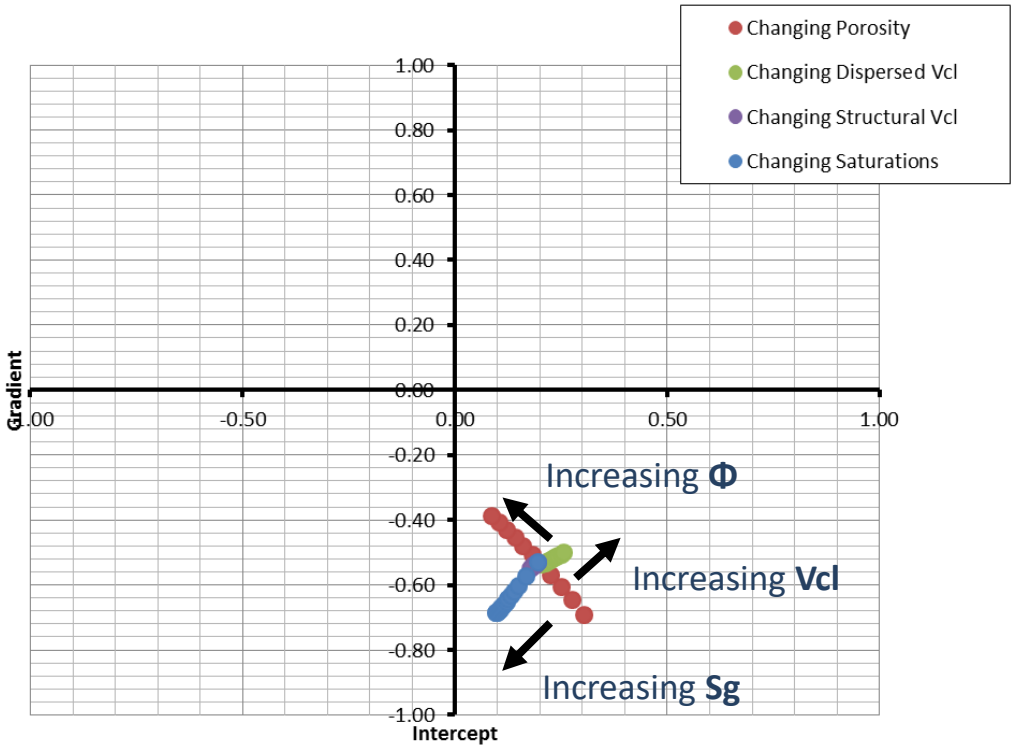




- Three shale-sand interface cases:
  1. Brine sand
  2. Oil sand
  3. Gas sand
- Gas sand shows separation towards class IIp region

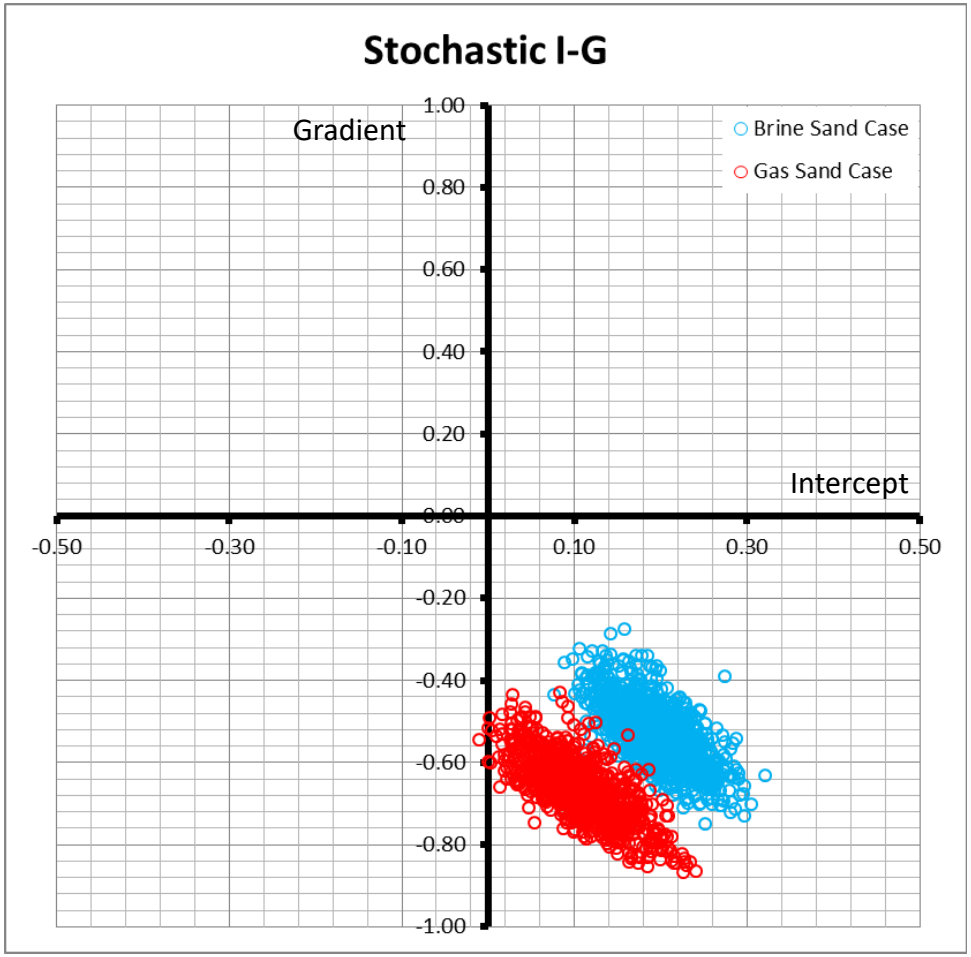
AVO Ranges

- Intercept-Gradient changes with reservoir properties:
    1. Effective Porosity
    2. Dispersed Vcl
    3. Structural Vcl
    4. Fluid fill
- Most important factors are: effective porosity and fluid fill
- Structural clay has a minor effect



AVO Ranges

- Intercept and Gradient were stochastically calculated using Monte-Carlo simulations
- For Brine sand case
  - Substituted to 100% brine
  - Changing Porosity and Vcl
- For Gas sand case
  - Changing Sg, Porosity and Vcl



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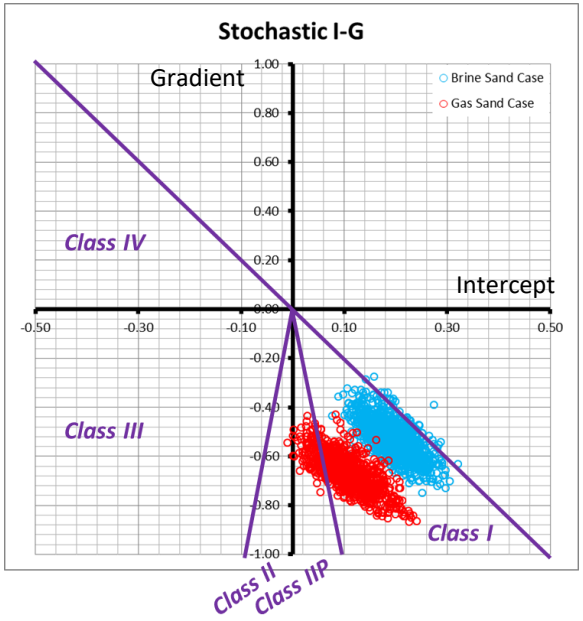
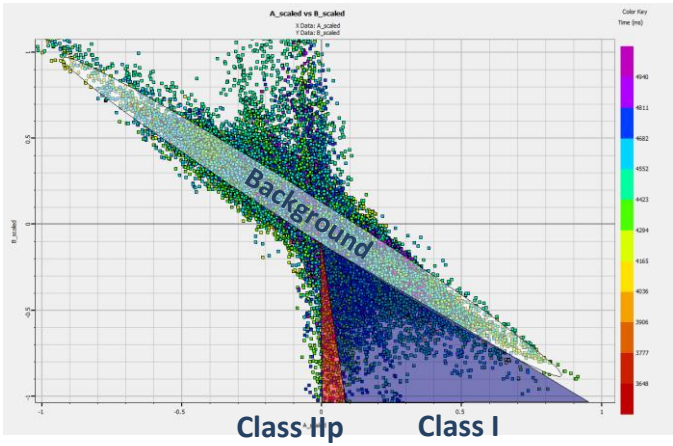
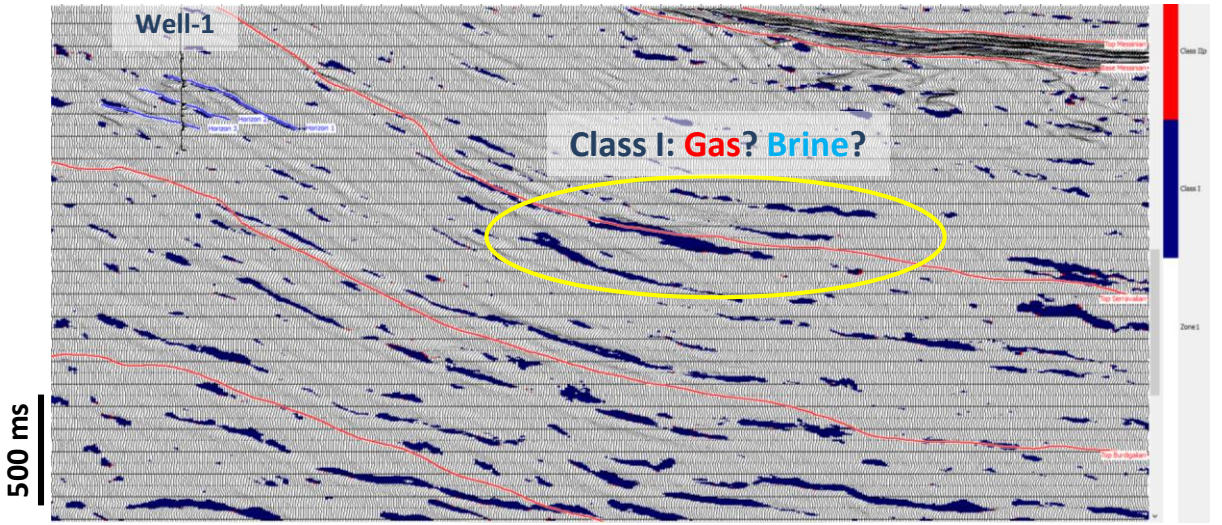
AVO Classification



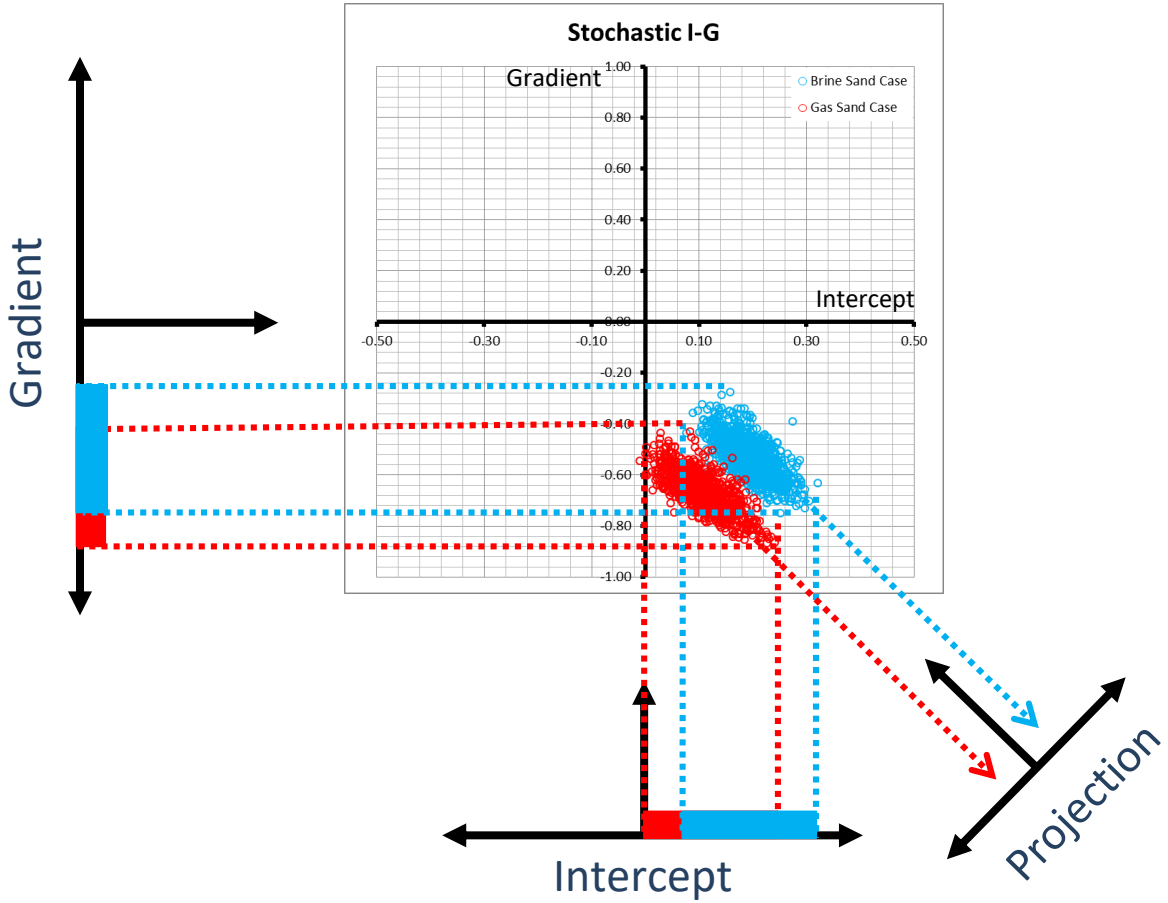


Actual seismic Intercept-Gradient data



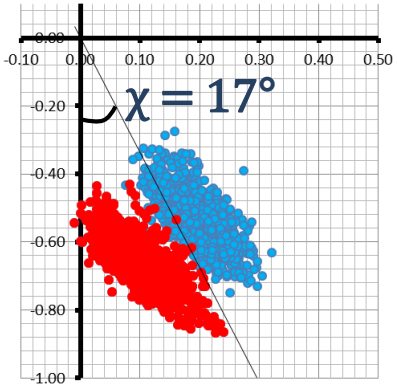
AVO Classification Can Be Used to Identify the Sands, Not the Fluids

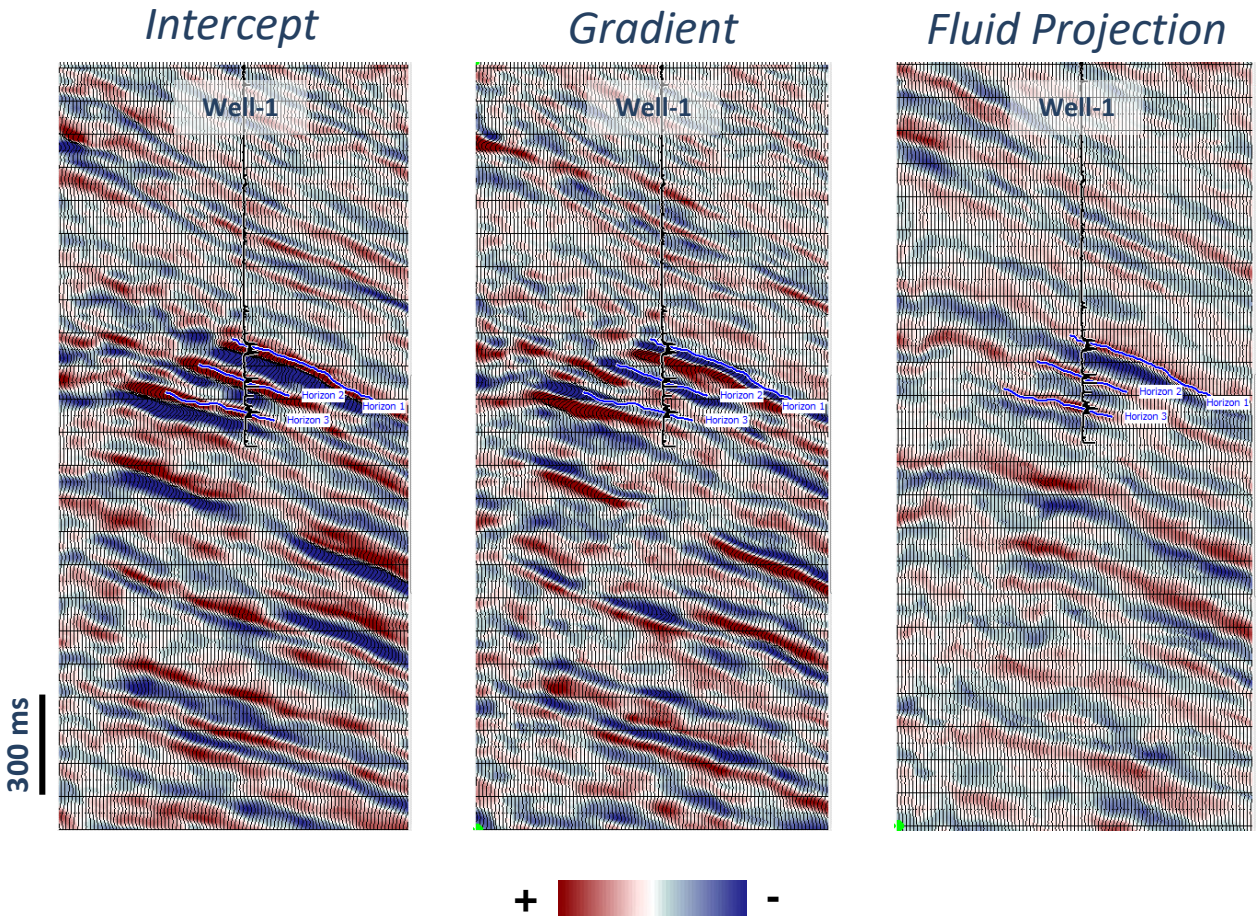
Fluid Projection



$$EER\chi_{me}=I\cos\chi_{me}+G\sin\chi_{me}$$

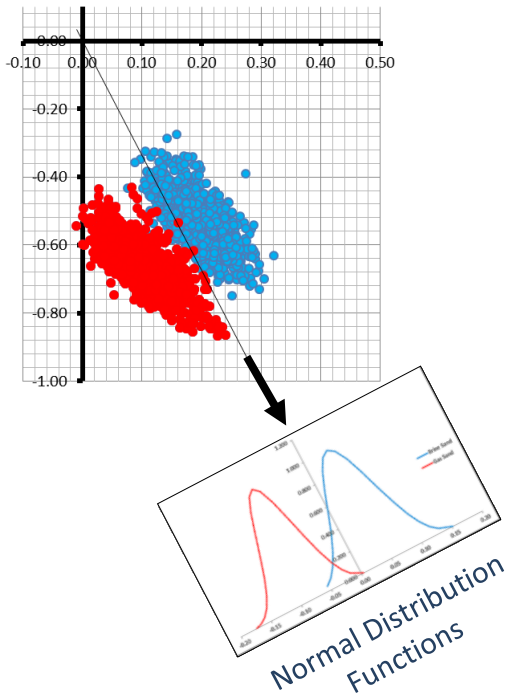
Fluid Projection

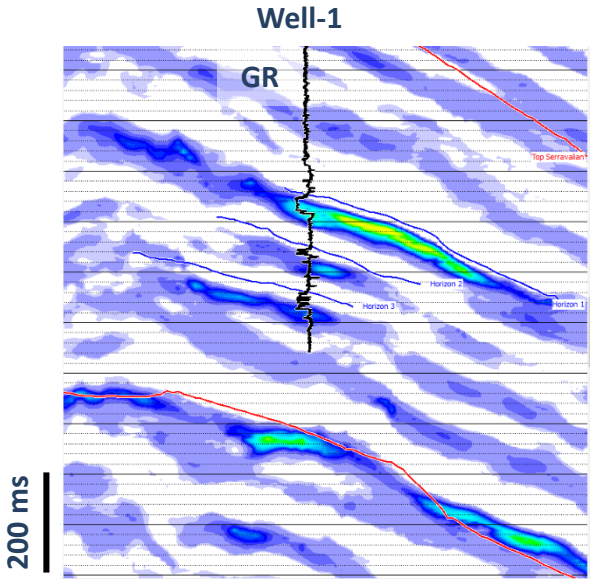




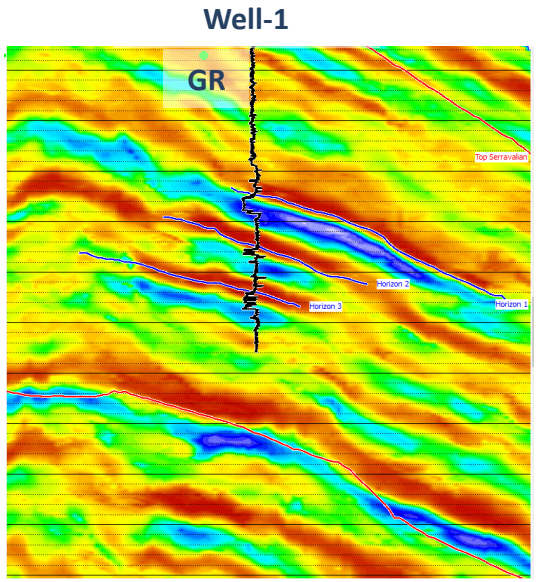
Using SEG normal polarity; increase of acoustic impedance = peak

Normal Distribution Function





Gas sand probability using normal distribution function

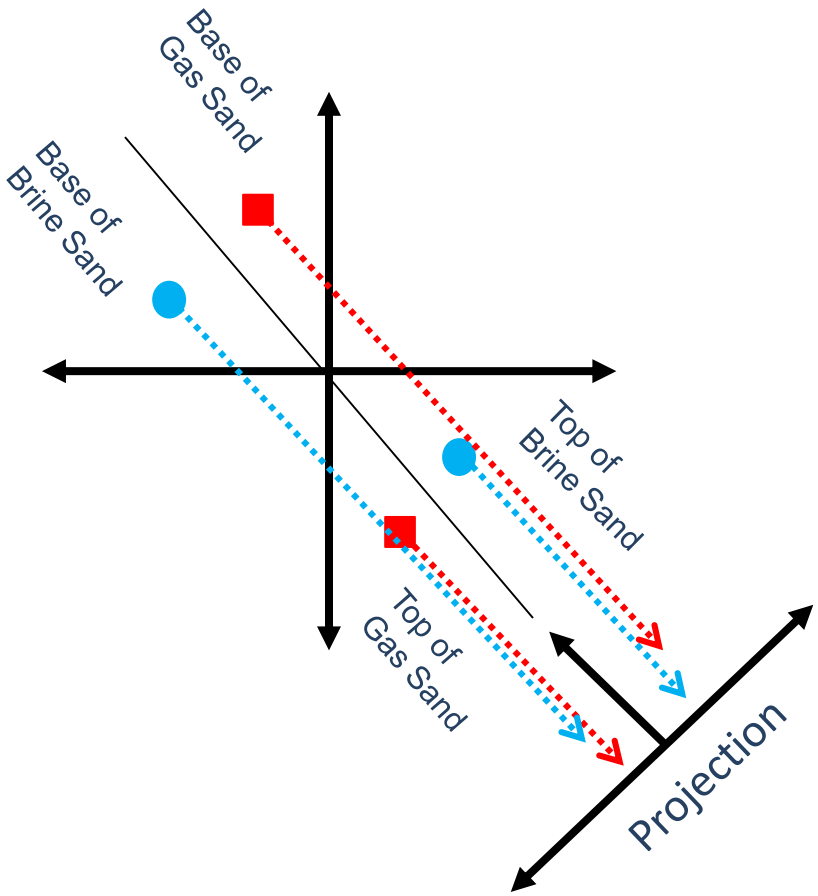


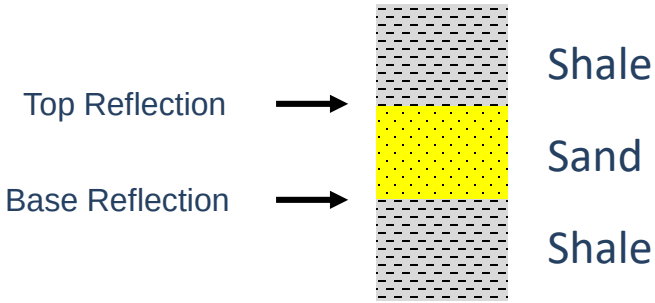
Brine sand probability using normal distribution function

0 1
Probability

- Normal Distribution Functions had been constructed to measure the gas/brine sand probabilities
- The output volumes range: 0 – 1

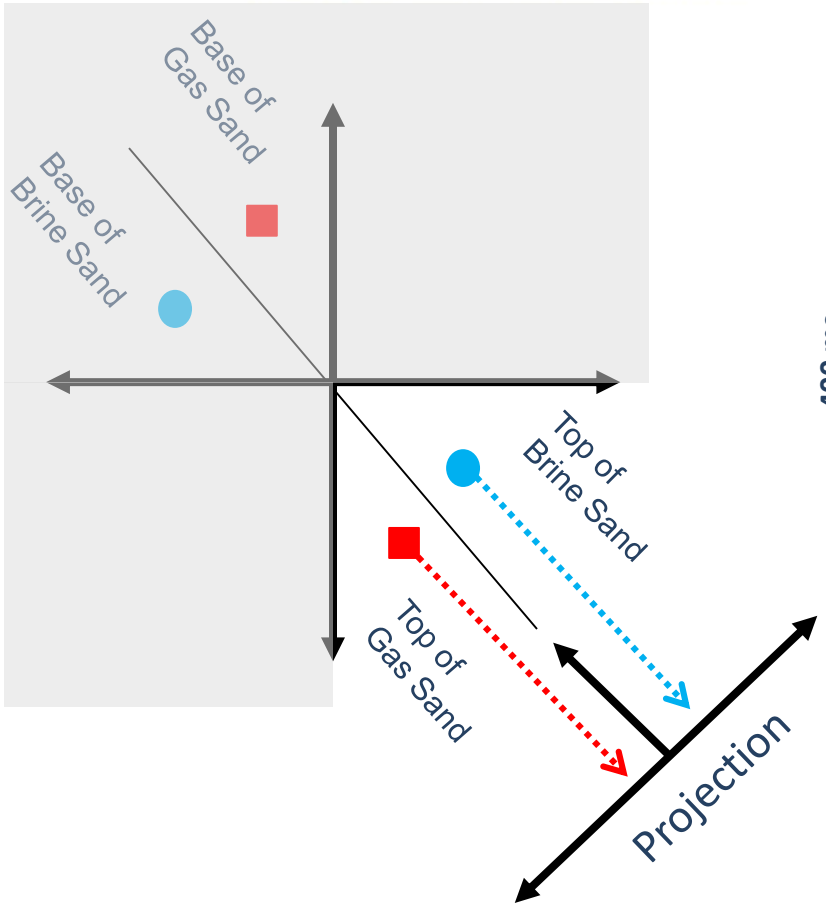
Misclassification Problem

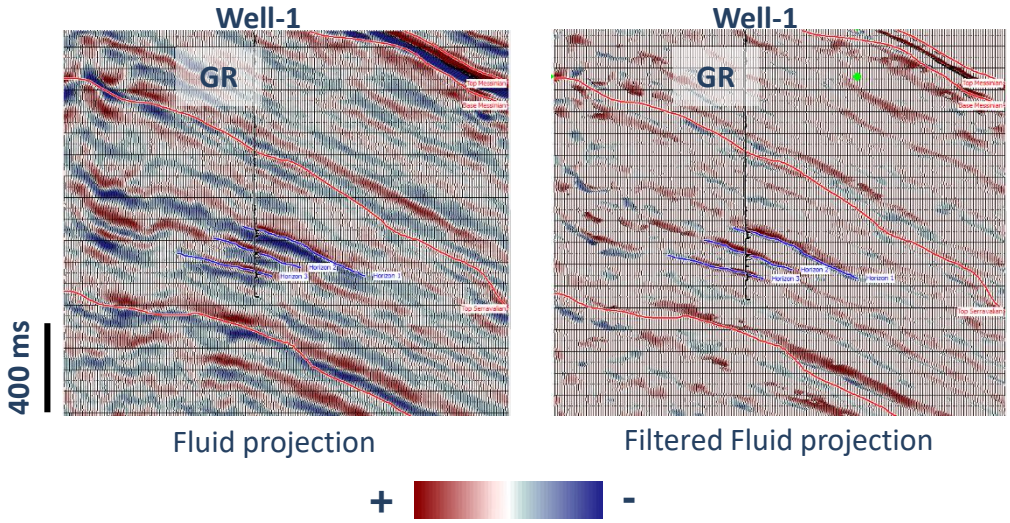


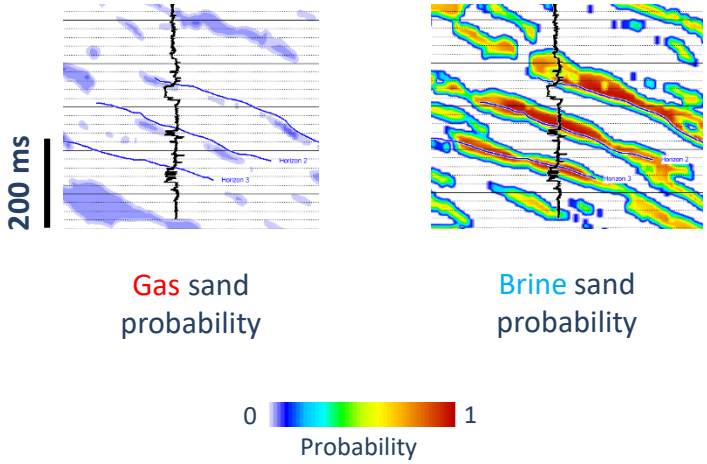


- Top of the gas sand can be plotted at the same location of the base of brine sand

Filtered Fluid Projection

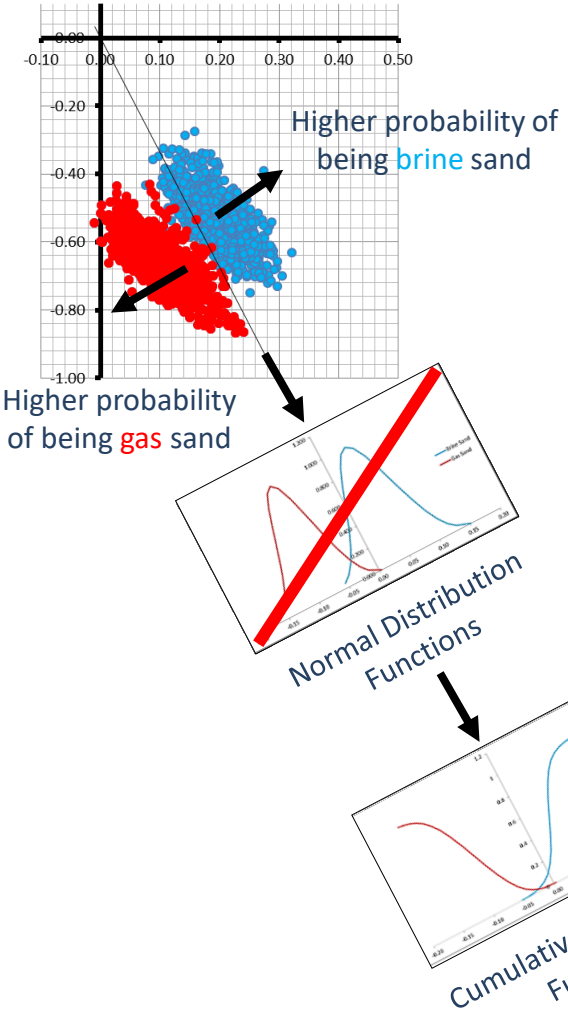


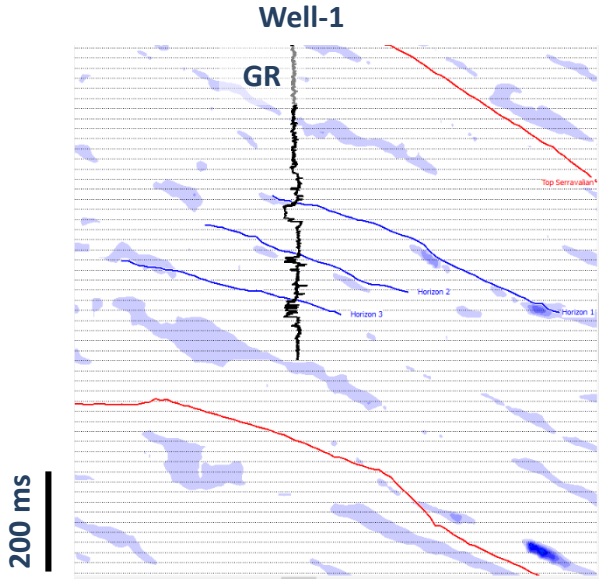




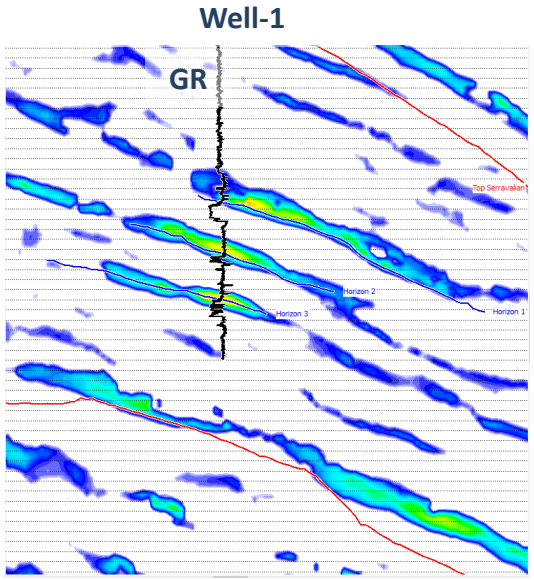
- Filtering Intercept and Gradient

Cumulative Distribution Function

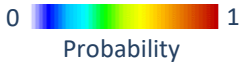




Gas sand probability using cumulative distribution function

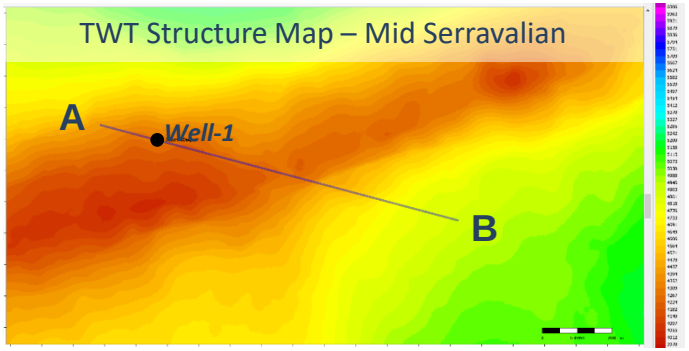


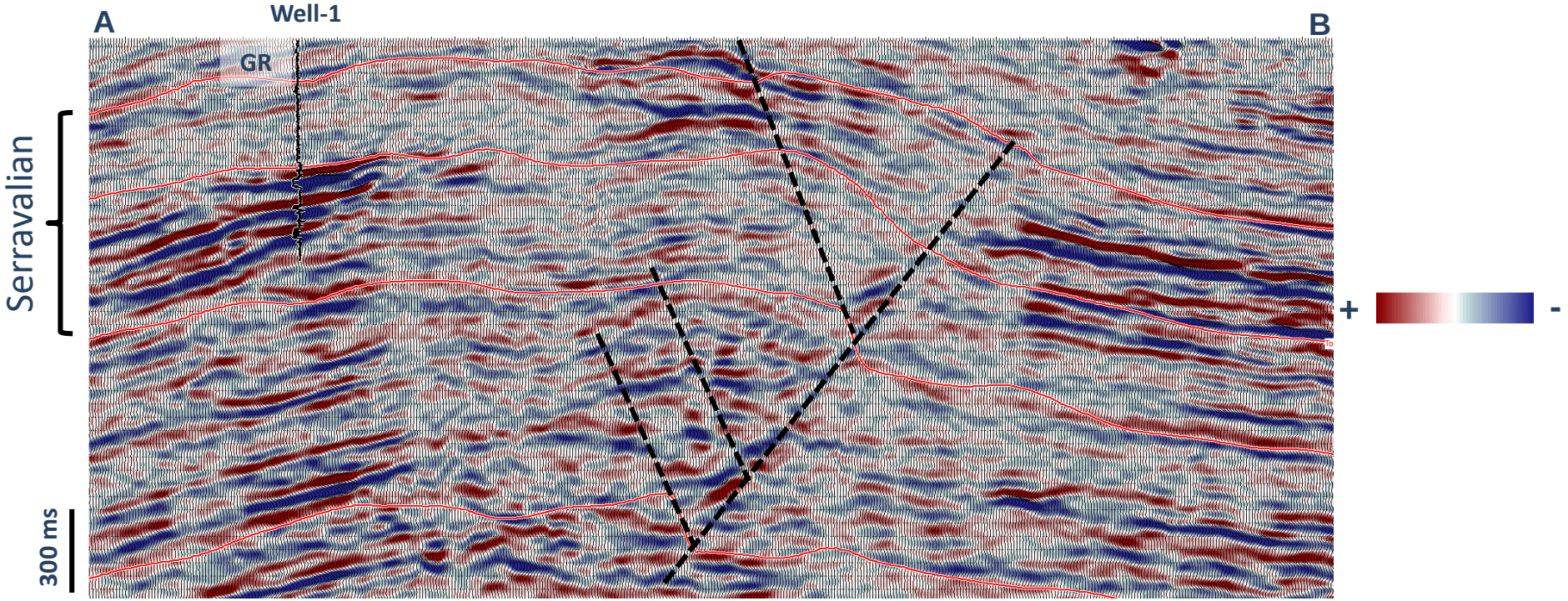
Brine sand probability using cumulative distribution function



Results

- Seismic full-stack:
  - Passing through the Nile Delta Offshore Anticline (NDOA)

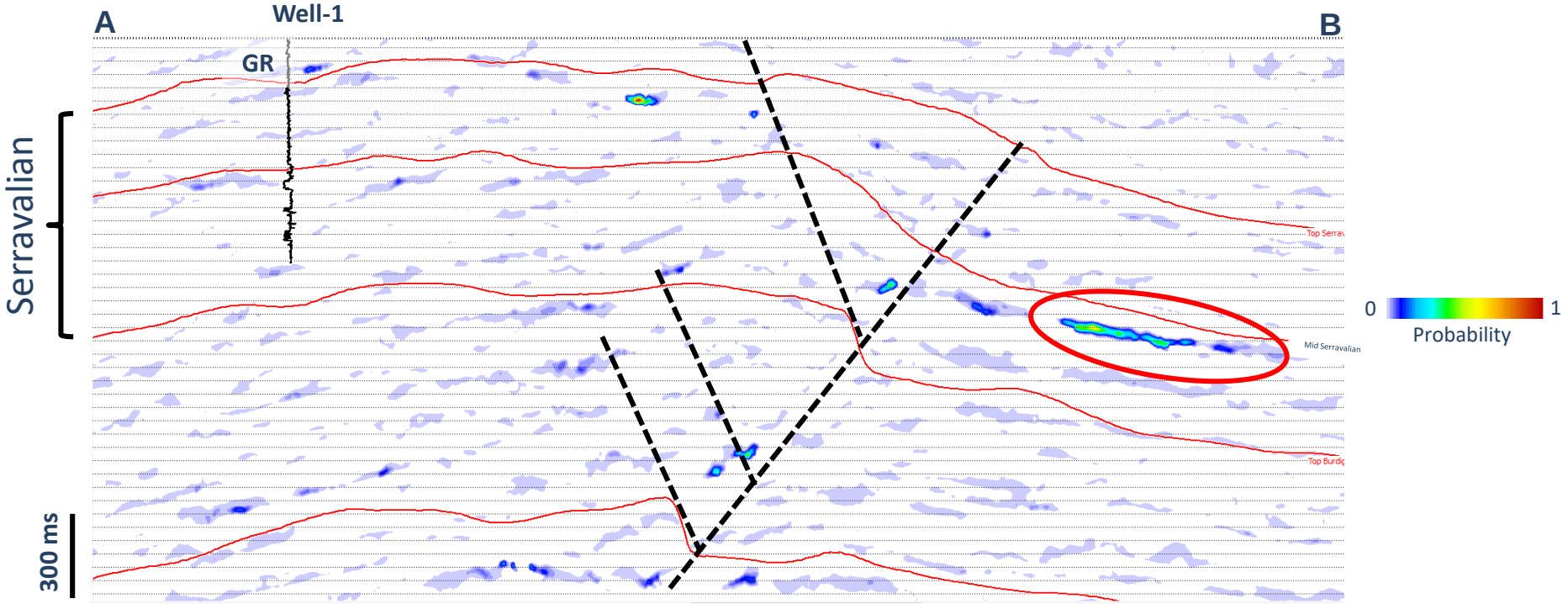




Seismic Full Stack

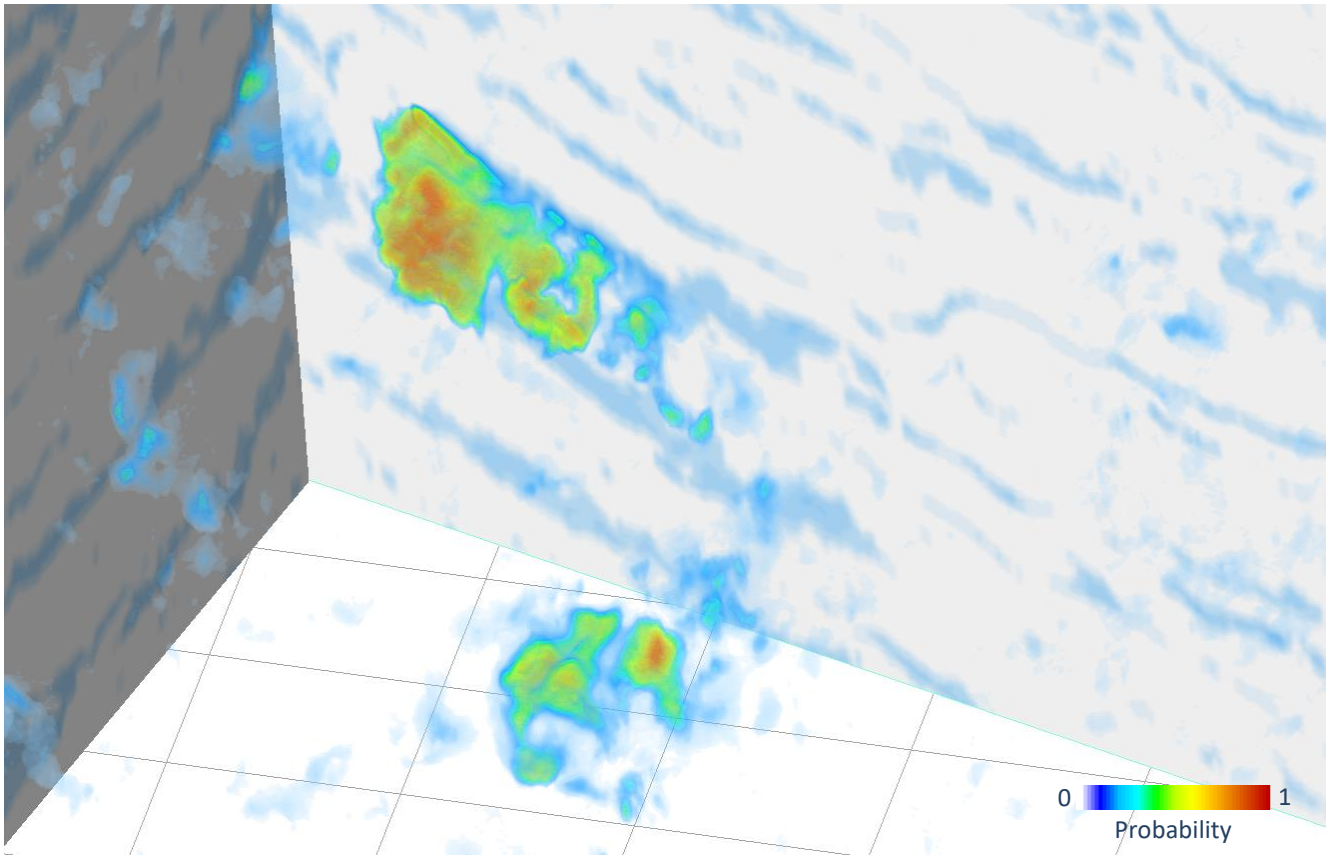
Results

- Gas Sand Probability:
  - Consistent with Well-1 results
  - Shows potential gas prospects

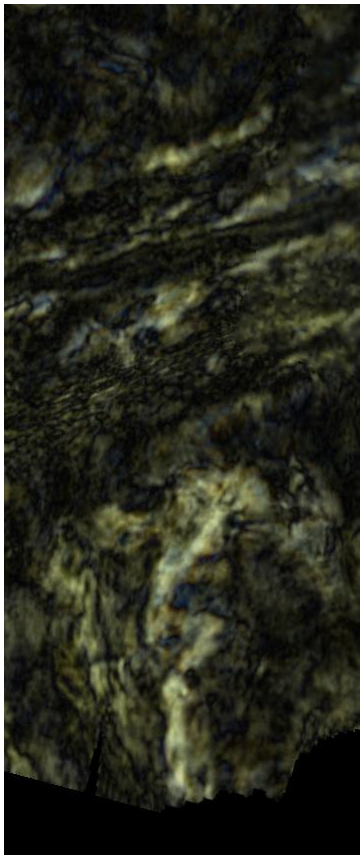


Results

Gas Sand Probability

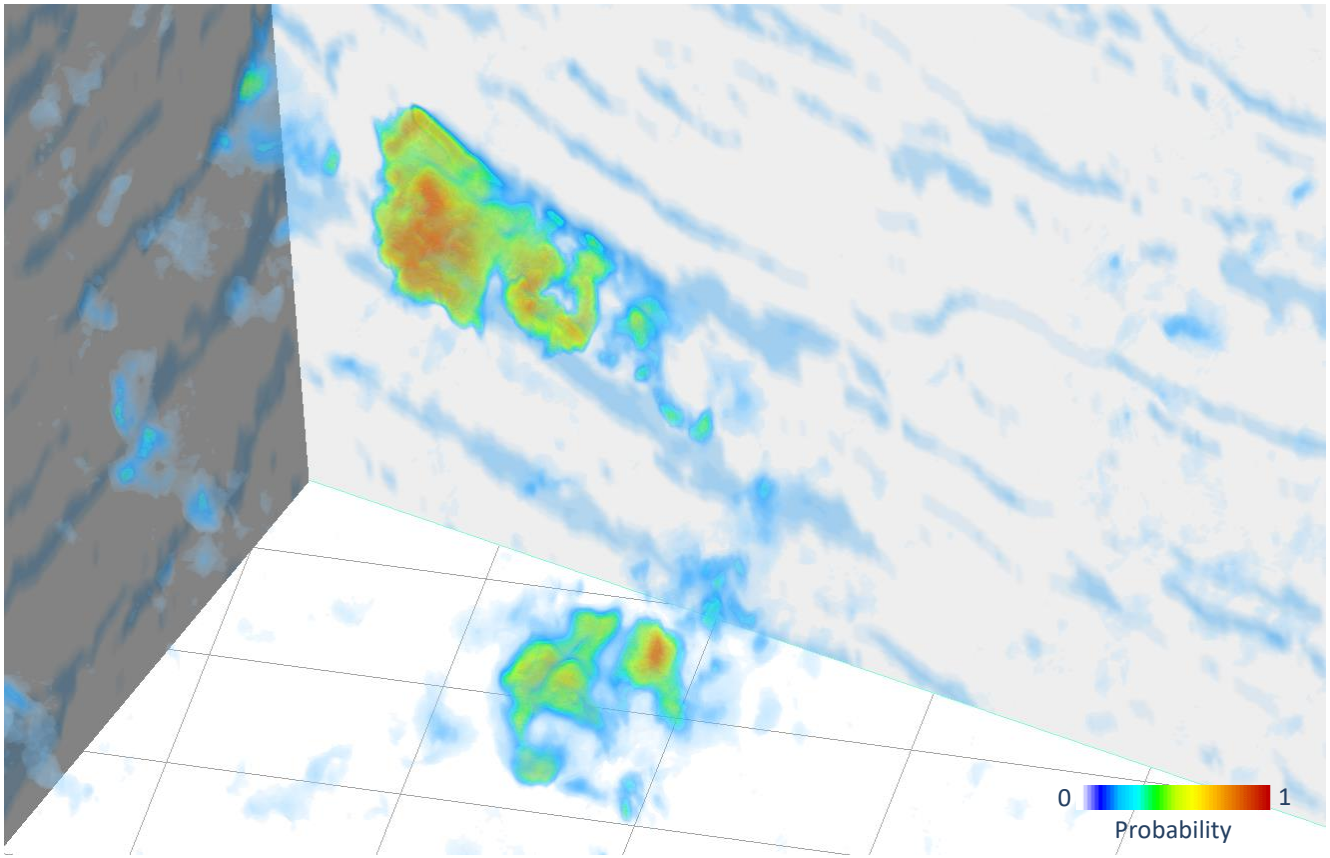


Spectral Decomposition

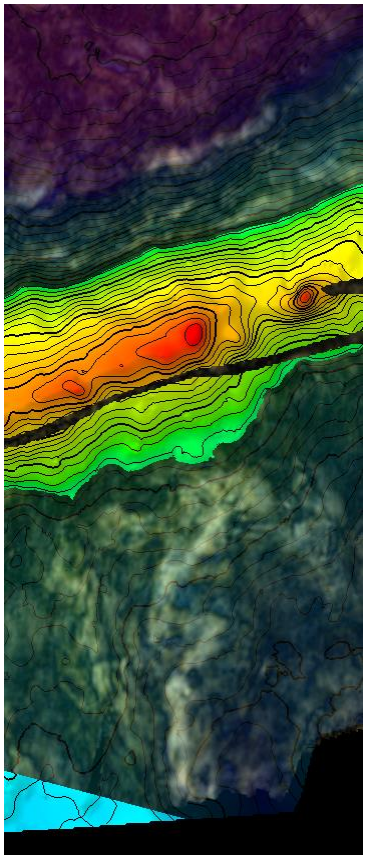


Results

Gas Sand Probability



Spectral Decomposition
+ Structure Map



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Conclusions

- Shallow Pliocene prospects are DHI supported, while Miocene prospects are a bit complicated.
- AVO classification can be used only to delineate the sand reservoirs.
- Fluid projection is the most effective and reliable way of highlighting gas prospects.
- Cumulative Distribution Function (CDF) is a very useful tool measure the gas sand probabilities.

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Thank You