Understanding formation anisotropy within a false bright spot anomaly response.

A case history from Mediterranean Sea

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Outline

- Nile Delta: The plio-pleistocene play (introduction)
  - Exploration overview.
  - Play Concept & geological background
  - Achievements and status of the art

- Formation anisotropy
  - Definition
  - Impact on rock media and logs.
  - Why should we care of?

- The case studied
  - Scope of work and executive summary
  - Log reconstruction and interpretation.
  - Anisotropy & high pore pressure, effects on well results.

- Lesson learnt and conclusions
Nile Delta: The Plio-Pleistocene play

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Nile Delta: The plays

Proven Plays
1. Plio-Pleistocene
2. Messinian
3. Serravallian and Tortonian
4. Oligocene

Courtesy Eni exploration stories
Nile Delta: The Plio-Pleistocene play

Channels sub play
Active growth faults sub play
Buried growth faults sub play
Plio-Pleistocene discoveries

Nile Delta

Mediterranean Sea

Reserves

63%
3%
34%
100 Kms
50 mi
Plio-Pleistocene Play: Most of the play above the DHI floor

GOOD DHI AREA
All significant gas accumulation expected to have DHI

TRANSITION ZONE
Some gas accumulation expected to have DHI

NO DHI AREA
All gas accumulation expected NOT to have DHI

Seal Presence
Seal Efficency
Indicative DHI floor

Courtesy Eni exploration stories

courtesy eni exploration stories
Nile Delta, Plio-Pleistocene Play: Record of achievement

Technical rate of success > 90%
Commercial rate of success 75%

Big Discoveries West Delta Channels

Source: IHS and ENI database

Big Discoveries
South West Cretaceous Hinge
Pre-Messinian
29 exploratory wells
12 tcf discovered

Plio-Pleistocene
130 exploratory wells
> 35 tcf discovered

North East Levantin Salt Basin
Pre-Messinian
29 exploratory wells
12 tcf discovered

Oligocene
Plio-Pleistocene play: a successful start

Courtesy Eni exploration stories
Nile Delta, Plio-Pleistocene play: Amplitude adsorption effect

Secondary target
- Thick sand HC bearing
- No DHI supported
- The largest pool in the field

Well TD

Courtesy Eni exploration stories
Nile Delta, Plio-Pleistocene play: Where is the dry well?

A DHI based approach cannot distinguish between high and low hydrocarbon saturation.
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What is a Bright Spot?

- Bright spots in seismic are usually the first type of direct HC indicators and it could be associated with HC traps, but bright-spot anomalies may turn out not to be a HC due to many reasons.

What Causes a Bright Spot?

- Low impedance gas sand
- Sands or shale in overpressure
- Highly cemented sands
- Low-porosity heterolithic sands
- Coal beds & top of salt diapers
- Formation Anisotropy
Anisotropy in rock media

★ What is anisotropy by definition?
   The difference in reading/value of a foreseen property when measured in different directions.

★ Anisotropy may be classified as;
   - Wave velocity
   - Electrical conductivity
   - Permeability
   - Permittivity
   - Thermal conductivity
   - Rock strength or elasticity

Isotropic

Measured properties are the same

Anisotropic

Measured properties are different
A major difficulty in seismic processing consists in the determination of an anisotropic velocity model. Failure to account for anisotropy in seismic may lead to error in:

- Velocity Analysis
- NMO (Normal Moveout)
- DMO (Dip Moveout)
- Migration and Seismic image quality
- Time-to-depth
- AVO analysis
- HFM (hydraulic fracturing modeling)

Elastic Anisotropy: Why Should we Care?
Elastic Anisotropy: Effect on Normal Moveout (NMO) correction

Principle of NMO correction:
Reflections are aligned using the correct velocity, such that the event are horizontally. Then all the separated traces are stacked (summed).
Example of NMO correction: True velocity 2500 m/s – 10% Anisotropy

Hyperbolic fitting

the resulting velocity is higher than the true NMO velocity

consequent

MISPOSITIONING (depth domain)

Isotropic Velocity 2597 m/s

Effect due to the conventional isotropic approach

Courtesy Anisotropy estimation by Sonic Scanner – M. Ferla

Courtesy Eni exploration stories
Example of NMO correction: True velocity 2500 m/s – 10% Anisotropy

$V = 2500\, \text{m/s}$

Anisotropic Moveout Correction

Non-Hyperbolic fitting

Isotropic Velocity 2597 m/s

 Courtesy Anisotropy estimation by Sonic Scanner – M. Ferla

Courtesy Eni exploration stories
Thomson parameter: definition

The five Thomsen parameters for transversely anisotropic media are given by:

<table>
<thead>
<tr>
<th>Thomson parameter</th>
<th>definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>( V_{P0} )</td>
<td>compressional velocity at zero relative dip</td>
</tr>
<tr>
<td>( V_{S0} )</td>
<td>shear velocity at zero relative dip</td>
</tr>
<tr>
<td>( \delta )</td>
<td>small-offset NMO factor</td>
</tr>
<tr>
<td>( \epsilon )</td>
<td>P-wave anisotropy</td>
</tr>
<tr>
<td>( \gamma )</td>
<td>S-wave anisotropy</td>
</tr>
</tbody>
</table>

In terms of the five independent TI elastic stiffness coefficients, the Thomsen parameters are defined as (Thomsen, 1986):

\[
V_{P0} = \sqrt{\frac{C_{33}}{\rho}} \quad \text{Compressional waveform}
\]

\[
V_{S0} = \sqrt{\frac{C_{55}}{\rho}} \quad \text{Shear waveforms}
\]

\[
\epsilon = \frac{C_{11} - C_{33}}{2C_{33}} \quad \text{From Core or Annie Approximation}
\]

\[
\delta = \frac{(C_{13} + C_{55})^2 - (C_{33} - C_{55})^2}{2C_{33}(C_{33} - C_{55})} \quad \text{Shear and Stoneley}
\]

\[
\gamma = \frac{C_{66} - C_{55}}{2C_{55}}
\]
Most updated Sonic device (Sch)

S-Scanner, sequentially fires six sources:

- one far monopole high-frequency (used for compressional and shear generation)
- one far monopole low-frequency (used for Stoneley generation)
- two orthogonally-polarized dipole sources (used to generate the borehole flexural mode)
- two monopoles located just above and below the receiver array (commonly used for cement bond evaluation)
Electrical Anisotropy

- Homogeneous and thick sand are normally isotropic, however, many reservoir rocks exhibit resistivity anisotropy due to several factors such as depositional changes, or thin sand-shale laminations, HC saturation (Oil).

- Shale are almost always electrically anisotropic due to compaction and dewatering of mud creating a preferential axis of orientation of the clay platelets.
Electrical Anisotropy: Tri-axial resistivity

Co-located coils

Resistivity tensor

\[
\begin{pmatrix}
V_{xx} & V_{xy} & V_{xz} \\
V_{yx} & V_{yy} & V_{yz} \\
V_{zx} & V_{zy} & V_{zz}
\end{pmatrix}
\]

1D inversion

Courtesy of Schlumberger
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Nile Delta, Plio-Pleistocene Play: The case studied

Case studied (Pre-Drill)
- Pliocene targets (bright spot) - Nearby DHI discovery area
- 4way deep close structure - Normal Pore Pressure
- Buried grow fault sub play - Extremely high ROS (>95%)
- Attractive seismic amplitude anomalous (> 40 Km2)
- 3D OBC Acquisition - Processing -

Discovery area
- Proved commercial HC (4way dip closure)
- Only conventional logs
- No Bottom Hole cores
- No multi-azimuthal WVSP (zero off-set only)
- No advanced sonic log (DSI only)

Resources
- Nile Delta: 63%
- Mediterranean: 3%
- Nile River: 34%
Mainly Silty and shaly rather than sands evidenced by LWD indicated low chance of having good reservoir facies among target section.

Low resistivity pay is well known and proved in Nile Delta (on and off-shore) Plio-Plistocene section.

Low resistivity appearance = in contradiction with seismic interpretation (unless considering a low
Work flow and scope of work

Full set of logs were acquired to justify or disapprove the presence of HC with the seismic response/interpretation

- **Advanced Sonic Tool**
  - Vp, Vs, Elastic Modeling
- **Spectroscopy Tool (Th, K, U)**
  - Shale analysis
- **Laterolog/3 axial Resistivity**
  - Rv, Rh analysis
- **Resistivity Image**
  - Dips, Thin Layer Analysis
- **Nuclear Porosity Tools**
  - Lithological, petrophysical
- **Pressure/Sampling Tool**
  - Fluid and pore pressure assessment

Prospect → Logs → Quality Control

- **Reason of failure**
- **Lesson Learnt**
- **Elastic Modelling**
- **X-Plots Log analogy**
QC Logs

- Correct overly logged curves in the repeat section with logged curves in the main log
- Correct calibrations
- Correct coherency plot for the first arrival (compressional slowness) and second arrival (shear slowness)
Case Well with two offset wells – Neutron Log

Analogy approach with discovery well data set was applied for better understanding what could be the reason of failure/mismatch with seismic interpretation

Neutron = 58 pu

Neutron = 52 pu

Neutron = 50 pu

Frequency Neutron Log porosity comparison showed a significant difference in NEUTRON porosity between Case Well and two nearby wells (+ 6 % = higher BW volume)
Density Log Response - difference between Case Well and two nearby wells
(- 0.1 g/cm³ = different clay type)

Density = 2.02 g/cm³

Density = 2.18 g/cm³

Density = 2.12 g/cm³
DT compressional slowness - the significant difference in DTco between Case Well and two nearby wells > 20 us/ft, reasons ???

**Overpressure zone**

- **Case Well**: DTCO = 165 μs/ft
- **Well B**: DTCO = 140 μs/ft
- **Well A**: DTCO = 145 μs/ft
Cross plots Density vs. Neutron

- **Case Well**
  - SHma=58 pu
  - 2.02 g/cm³

- **Well B**
  - SHma=50 pu
  - 2.18 g/cm³

- **Well A**
  - SHma=52 pu
  - 2.12 g/cm³

- **Only shale displayed**

- Case Well Shale distribution **more grouped** and not **dispersed** like in wells A and B
- Different shale type which indicates clay variation
- Case well shale matrix significantly different comparing with nearby wells (2.02 vs 2.18 g/cm³)
Answer from Advanced Sonic: Overpressure and Gas

Vp/Vs vs DTCO plot for the three wells
- Gas Indications for Nearby Wells
- Likely, overpressure indication for Case Well
Case Well with two offset wells – Gamma Ray Spectroscopy log

Spectral GR Cross-plots

- Case well: Montmorillonite (high clay bound water, very unconsolidated formations)

- Well A & B Illite and Kaolinite predominant (less bound water)

- Clay type confirm overpressure model in the case well.
Answer from 3D-Induction: Overpressure

Abnormal low resistivities
(clue to overpressure)

The 3D resistivity indicates
No pay = manly shale with minor gas bearing sand at the bottom drilled section
Case Well with two offset wells – Pore Pressure Profile

**PP measured by MDT**

**PP rump by PPFG**

**PP rise by observing Gas – MW behavior**

**PP rump by PPFG**

- Overpressure + 14.3 ppg
Case Studied: Drilling results

Sandstone with fizz water (c1,c2,c3 gas component)

Main target
Approximately 35 m of Shale/Siltstone (Wet) high pressure regime significantly different from proved HC area

2 m Sand body HC bearing (c1,c2,c3 gas component)

FE, Pressure and Sampling showed that bright spot was not influenced by HC

Further Anisotropy and Elastic modeling were carried out for better understanding the seismic reflection
TIV in the case well - Thomsen Parameters

TIV Anisotropy was quantified by estimating the three Thomsen parameters

- Epsilon describes the difference between the vertical and horizontal p-wave velocities
- Gamma describes the difference between the horizontally and vertically propagating shear wave velocities
- Delta controls how the anisotropy changes from the slow to fast directions.
The case well: Acoustic and Electrical relationship

Electrical anisotropy ratio in the range of 1.8

- Rv and Rh in shale are on the lower side compared to reference values from the offshore Nile delta.
- Trend digression; indicate overpressure

Acoustic and electrical anisotropy relationship

- Acoustic anisotropy: Linear Log Vertical vs Horizontal shear velocities
- Electrical anisotropy: Logarithmic Log Vertical vs Horizontal resistivity
- In case of Shear Anisotropy, Electrical Anisotropy could be also suspected
Synthetic Gather: Offset Wells A & B

- Amplitudes brightening at reservoir in wells A and B
- Significant amplitude increase with offset (gas sand)
- Low PR and low ratio Vp/Vs are also linked to gas bearing sands

\[ \nu = \frac{V_c^2 - 2V_s^2}{2(V_c^2 - V_S^2)} \]

Poisson Ratio
- No increase amplitude with offset = change litho but not gas presence
- Very high PR due to overpressure
- Low amplitude highlighted @1.75 s refers to encountered thin gas bearing sand

Not coherent with seismic section

Thin gas layer

Isotropic

Anisotropic
Fault leaking failure

Charging failure

Vertical leaking failure

Trap failure due to leaking faults. The deepest sand body found gas bearing in the 4 way dip closure. In overpressure regime faults can easily be leaking.

High pressure avoided that the gas entered in the system.

High capillary pressure in the siltstone avoid the gas trapping.

The very high pressure anomaly play a role in the seismic wave propagation and AVO analysis.

During the basin evolution the pore pressure exceeds the formation fracture pressure, and the trap failed.
Work flow (Eni’s experience)

Input

Probabilistic Inversion

Output

(for subsequent PSDM workflow)

Courtesy Anisotropy estimation by Sonic Scanner – M. Ferla
Conclusion and lesson learnt

Although the extremely high ROS of finding gas in Plio-Pleistocene boosting the gas reserves in Mediterranean, bright spot anomalies can hide unpleasant surprise even in well known DHI areas.

The case well pointed out the importance of considering variation in rocks physics in the seismic model for a better pre-drill risk assessment purpose especially if anomalous pore pressure are foreseen.

Anisotropy is an important aspect in seismic, and need a better understanding and estimation through a comprehensive and advanced logging measurements and integration of Walkaway VSP and Core when possible/available.

Under certain condition (Multiwell or relative dips from well bore and formation from 0 to 40°) an advanced sonic device can be used for a probabilistic inversion approach in order to reconstruct 5 independent Thomson parameter as input for further PSDM workflow and anisotropy assessment at field/prospect scale.
Questions……

Thank You!