PS Challenges in Reservoir Characterization and Original Oil-in-Place Estimation in the Presence of Very Fine Bedding:

An Example from a Mixed Clastic-Carbonate Reservoir from Block 0, Offshore Angola

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Abstract

The Vuko Mesa reservoir is a finely laminated mixed clastic carbonate sequence deposited in a marine shelf environment. Reservoir quality varies rapidly vertically due to the influence of minor transgressive and regressive cycles. Mesa stratigraphic sequences are intercalated with the deposits of fine-grained sandstone and siltstone to very fine-grained and shaly sediments with argillaceous markers. The best producing reservoir intervals are typically 1-2 ft thick in the Mesa reservoir.

The presence of very fine bedding poses a serious challenge to formation evaluation and the estimation of oil volumes and oil recovery. Reservoir units on the order of several inches thick are below the resolution of conventional wireline logs. This leads to difficulties in estimating reservoir properties that are fundamental to oil recovery. Net to gross can be overestimated in this case, along with under-estimation of reservoir porosity and over-estimation of water saturation in the dynamic reservoir model. This problem has recently been addressed by a field cross-functional team of reservoir engineers and earth scientists working to integrate available static and dynamic data.

At the Vuko Mesa Field, core data was reviewed to determine a core-based net to gross ratio. Core data was used to develop new transforms of wireline porosity and permeability processing using the GEOLOG program. Enhanced Vertical Resolution (EVR) processing of the raw wireline field tapes was also conducted in an attempt to obtain net to gross ratios consistent with core-based estimates. These data have been integrated into a new three dimensional reservoir model to improve waterflood management of Vuko field.

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1 Abstract

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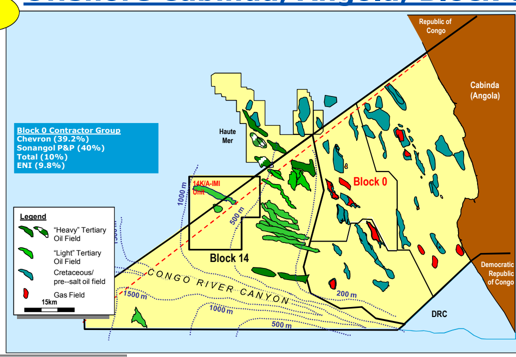
2 Offshore Cabinda, Angola, Block 0



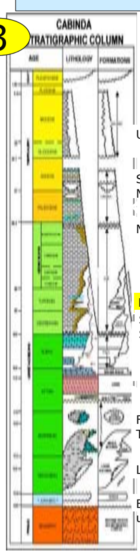
Located in Lower Congo basin which lies in the West Coast of Africa between Republic of Congo and Central Angola.

Three main sequences mark the sequences of tectonic and depositional activity in Cabinda offshore (Lower Congo basin).

1. The Rift: Fault phase, characterized by rapid subsidence, followed by deposition of Lacustrine and Alluvial sediments (Neconmian and Mid-Aptian)
2. Evaporite deposition: The transition period from active rifting to thermal induced crustal subsidence (Aptian).
3. Subsidence stage: Occurred during regional marine deposition and active extension (Albian to Oligocene)

A series of transversal (elliptic) fractures from the mid-Atlantic rifts segmented the continental crust forming sub-basins.
The Congo basin (a sub-basin) extending from Gabon basin to the north of Kwanza basin, is composed of lacustrine silt and shale of the Bucomazi Formation.
Cabinda offshore has two main blocks (Zero and 14) and is operated by Chevron.

3 Cabinda Stratigraphic Column



• Cabinda stratigraphy is composed of Pre-Salt and Post-Salt depositional environments.

• The Pre-salt section, lying over the basement (Mayombe igneous and metamorphic complex), is non-marine deposits consisting of Lucula sands (fluvial channels) and Toca (carbonate reefs). Bucomazi black shale (source rock of both pre- and post-salt) lies above Lucula and Toca.

• Presence of marine incursion in Aptian, was marked with deposition of evaporites of Loeme Formation, consisting of halite and potash salts (carnallite, polyhalite and sylvite).

• The Post-Salt tectonic movement was controlled by Loeme salt. The open marine trangression was characterized by the deposition of dolomite and dolomitic sandstones (Mavuma Formation), and later the open marine conditions produced sequences of continental shelf clastic and carbonates (Pinda Formation).

• Mesa reservoir of IABE Formation lies over Vermelha (sandstones) deposited in nearshore / shorface. Mesa and Lago represent a period of gradual sea-level rising. The intervals contain sediments deposited in progradational units characterized by numerous and significant flooding events.

4 Mesa Stratigraphy

• The Mesa Reservoir, of the Upper Cretaceous Iabe Formation, is a shallow marine system composed of mixed clastic-carbonates.

• The lithology is dominated by siltstones and fine- to very fine-grained sandstones.

• Reservoir consists of thinly interbedded dolomitic limestones/sandstones VFG Sandstone, Sandy siltstone and muddy siltstone with calcite cement.

• Deposited in a middle to outer shelf environment with relatively low primaries porosities (3 to 30 %) and permeabilities (.01 to 100 md).

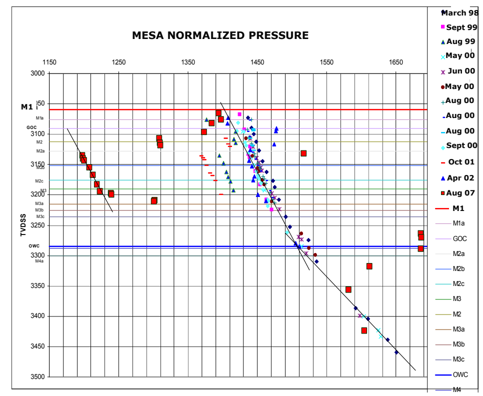
• Best reservoir is the M2 package

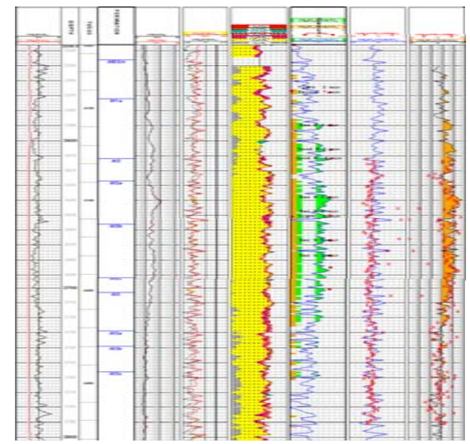
• Difficult to resolve intermediate horizons in the seismic. Overall sediments coarsen upwards within facies, not by a significant increase in the grain size of the coarse elements, but rather by a decrease in the amount of silt plus mud plus carbonate mud, this indicating the occurrence of shoaling.

•Absence of coarser sediment suggests that the area was far from a siliciclastic source.

• Shales of the flooding marine units act as Vertical Seals over the tops of the reservoirs, reducing the Vertical Permeability.
• Other considerations: - diagenesis (dolomitization, cementation)

5 Vuko Mesa Vertical compartments

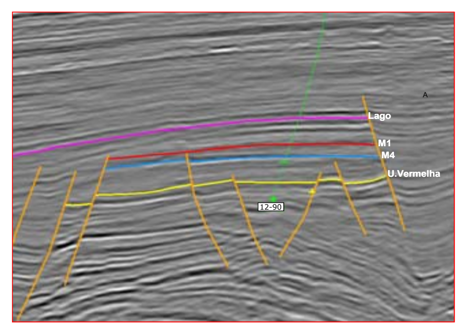




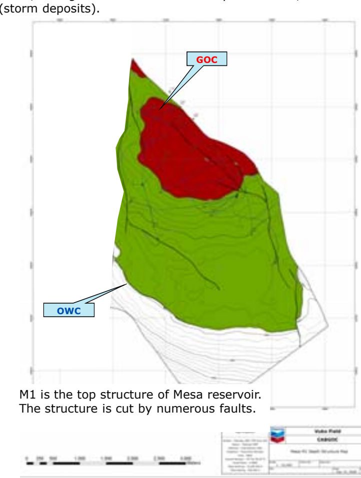
SFT data indicate that there are 3 pressure regimes in Mesa reservoir:
- M2a-M3a low pressure zone, production depleted;
- M1A-M2 high pressure zone, much less production from this zone;
- M3a-M3c higher pressure zone, more pressure support

• Anticlinal horst block, rolling into fault. Sands laterally continuous, with sheet-like distributions (storm deposits).

6 Structure



Seismic Section of Iabe Formation with Mesa reservoir. Anticlinal Horst Fault-block. Interior Faults cause varying dip.



M1 is the top structure of Mesa reservoir.
The structure is cut by numerous faults.

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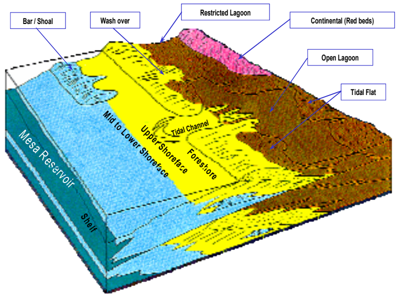
7 Depositional Environment & Facies Interpretation



- Shales of the flooding marine units act as Vertical Seals over the tops of the reservoirs, reducing the Vertical Permeability.
- Depositional environments: distal shelf muds to proximal tidal environments
- Best production is in tidal channel deposits (With better lateral continuity and coarser grain size)
- Poorer production is found in shoreface deposits (Upward coarsening with variable p and k).
- Poorest production is found in flood tidal delta deposits (more fines, internal permeability barriers).

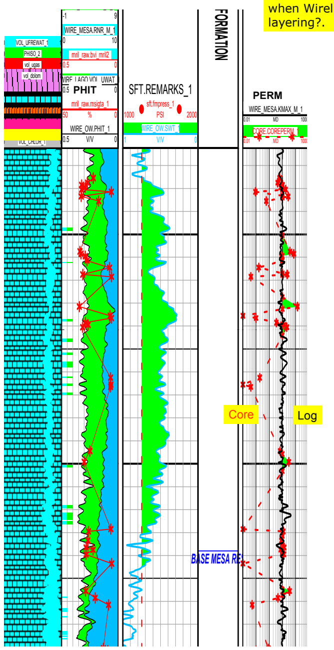
Three lithofacies have been interpreted from core:

1. Facies II : Argillaceous Siltstone, abundant detrital clay. Marginal reservoir quality rock (Patchy Light Staining).
2. **Facies I** : Silty Limestone (Packestone/Wackestone). Non-reservoir.
3. **Facies III** : Very Fine Sandstone/Siltstone. Reservoir quality rock (Ubiquitous Dark Staining)

- The Mesa reservoir is composed of mixed clastics and carbonates deposited in a marine shelf setting.
- Best producing reservoir intervals are typically composed of finely laminated (1-2 ft thick) sandstone/siltstones

8 Vuko Mesa Log Resolution Challenges

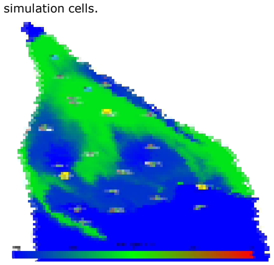
- How do we capture true vertical resolution when Wireline Logs do Not resolve fine scale layering?.



- Figure on the left shows the problem of resolving porosity and permeability in the Vuko Mesa. The presence of very fine bedding poses a serious challenge to formation evaluation, and to the estimation of oil volumes and oil recovery.
- Core plugs (red) have high frequency cycles that are not captured in this conventional log processing.
- Note that there are portions of the well that have low permeability and are not effective and are not identified by the log. The log-based estimates of Net/Gross can be overly optimistic.
- Wireline log resolution is limited by the physics of the recording instrumentation.
- High Resolution processing of the RHOB log was attempted using Halliburton's EVR process. The Enhanced Vertical Resolution process uses data from multiple passes of the density log

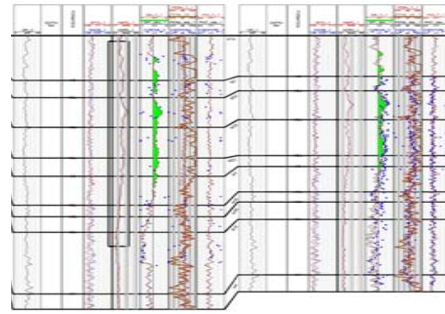
9 Reservoir Simulation Challenges

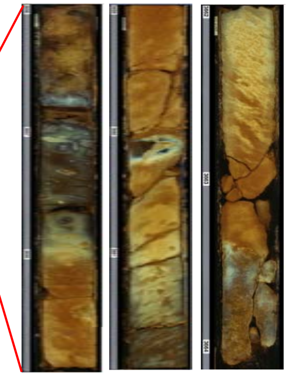
- Uncertainties in the static reservoir properties (P, K) must be dealt with when predicting reservoir performance and planning future wells.
- Large adjustments to the static model were required to calibrate and history match previous models of the reservoir.
- Net to Gross was overestimated in conventional models, since effective and non-effective portions of the reservoir are "blended" together by the logs used to populate simulation cells and by large scale-up of the model.
- Total pore volume in the model needed to be reduced, since pore volume from non-effective rocks were merged with effective rocks and included previously.
- Water saturation needed to be reduced in previous models, since non-effective rocks were included in the simulation cells.



: Oil Saturation in the S4A from reservoir simulation model. Green represents high oil saturation.

10 Determine Cutoff from Core Study

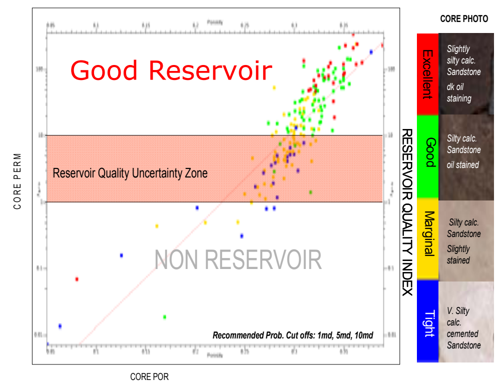




Probabilistic Net Reservoir Cut off Analysis

Net Reservoir cut off analysis suggests that a reservoir quality uncertainty zone exists between K cut offs of 1-10mD.

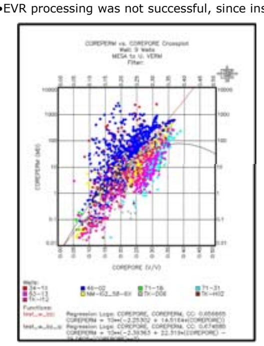
Thus K cut offs: >1mD, 5mD and 10 mD have been employed to generate high, mid, and low RNR facies scenarios.

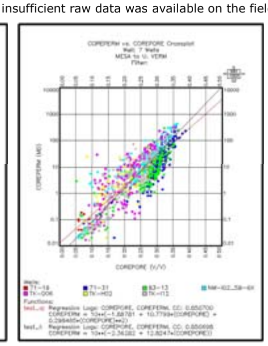


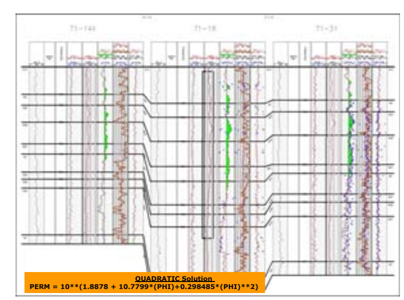
- Colors (dark brown and yellow) are dependent on the degree of oil staining and abundance of clay.

11 Log Processing to Equalize Wells and improve Resolution

- The objective was to obtain a good correlation for P, SW and K and tie to core data, improve vertical log resolution as much as physically possible.
- Multi-well core data from Vuko, Kungulo Takula and Numbi were input to permeability modeling.
- EVR processing was not successful, since insufficient raw data was available on the field tapes from the density logs.







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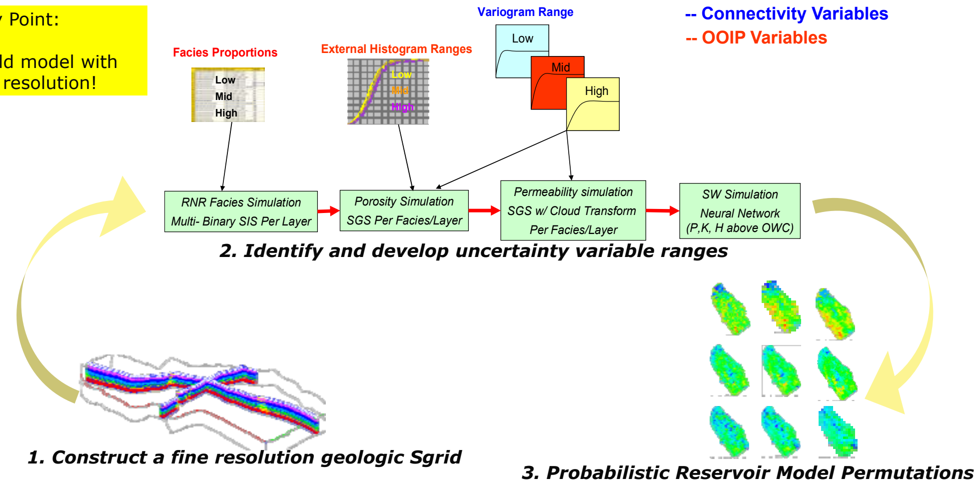
12 High Resolution Reservoir Characterization

Key Point:

Build model with log resolution!



Key static subsurface uncertainties associated with Mesa reservoirs in Block 0 have been identified and can be summarized into two questions:

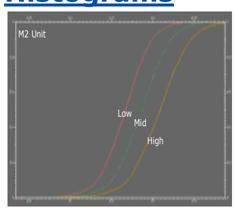
- *how much oil is there*? (Original Oil in Place)
- *how easily recoverable is it*? (Reservoir Connectivity).

Thus the following static model variables have been selected:

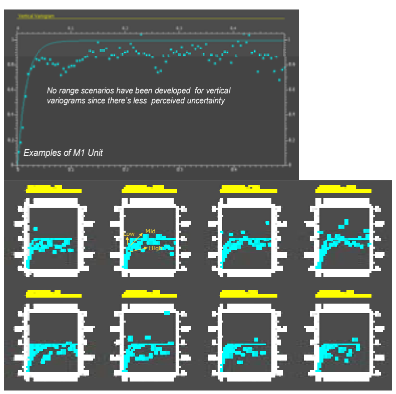
OOIP Variables
- **External Histograms (for porosity)**
- **RNR Facies Proportions (RNR cutoff)**

Reservoir Connectivity Variables
- **Variogram Length (short, mid, long)**

12 Porosity External Histograms

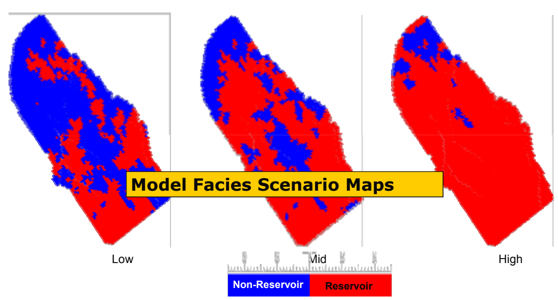


13 Variograms

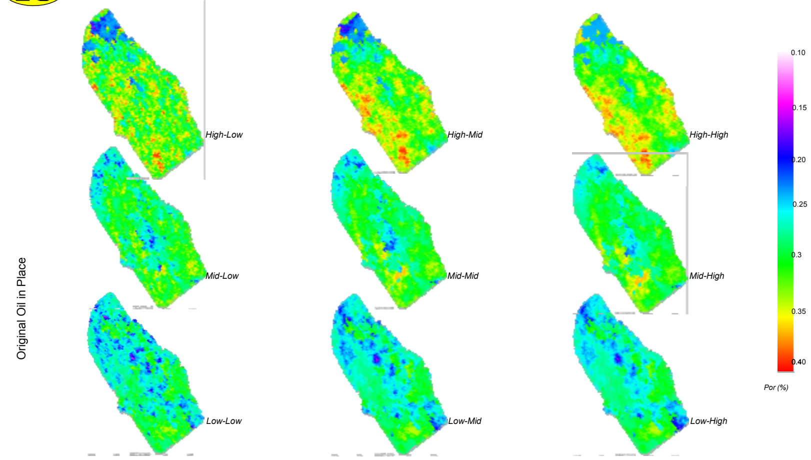


14 RNR Facies Scenarios

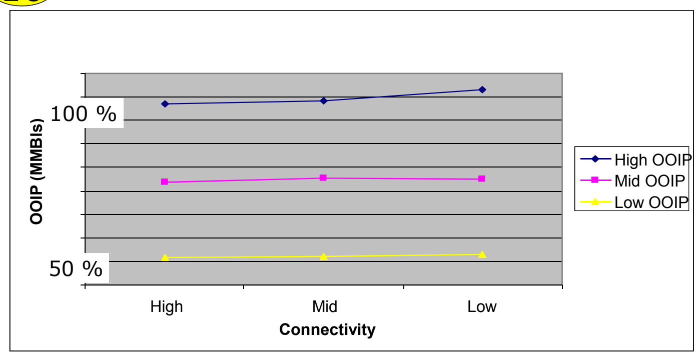
M1 UNIT	LOW			MID			HIGH		
	Target	Simulated	Delta	Target	Simulated	Delta	Target	Simulated	Delta
RESERVOIR	0.15	0.15	0	0.41	0.41	0	0.96	0.95	0.0117
NON RESERVOIR	0.85	0.85	0	0.59	0.59	0	0.04	0.05	-0.0117



15 Alternate Earth Models for Vuko Mesa



16 Oil Volumes for Alternate Models



Different model building parameters, such as Net to Gross, have a dramatic impact on the barrels of original oil in place (OOIP) for the Vuko Mesa reservoir.

17 Completed Work

- A family of reservoir models have been constructed for the Vuko Mesa field that are consistent with the available log, core, seismic and stratigraphic concepts. Resolution of the model is the same as that of wireline logs.
- Wireline logs for the field have been normalized, tied to wells, and the highest resolution logs possible have been used to build the current reservoir model. EVR processing was attempted, but was unsuccessful.
- Family of current models are "centered" around the current log data. However, we recognize that the current wireline logs are still limited by resolution, and additional work is required to investigate this effect on the dynamic (oil recovery) model.

18 Next Steps

- History-match of the current family of earth models is now underway. This will provide information about the range of parameters that provide a reasonable history match. It is anticipated that the low-side of models will provide the best match, given the over-estimation of NTG caused by the "averaging" of wireline logs.
- Net to gross corrections need to be applied to the current model, by comparing NTG in the cores and logs.
- A series of small models (or sectors) will be constructed at core resolution, and their recovery compared to the current family of models at log resolution, and the coarser resolution of the dynamic simulator.
- It is very important to maintain the proper dynamic behavior of this layered reservoir to obtain credible performance estimates for new injector and producer wells. **This is a critical step in recovering the most reserves from Vuko Mesa.**