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Use of Seismic Attributes and Acoustic Impedance in 3D Reservoir Modelling: An example from a mature Gulf of Suez Carbonate Field (Ras Fanar, Egypt)

Introduction

Discovered in April 1978, Ras Fanar Field in the Gulf of Suez of Egypt has produced approximately 91 MM STB oil from Middle Miocene coralline algal facies which are informally known as the "Nullipore Carbonates" and to a lesser extent the South Gharib Formation. The field lies some 2 Km offshore east of Ras Gharib and produces from a NW-SE trending structural trap bounded by a major fault system to the SW and tilted to the NE.

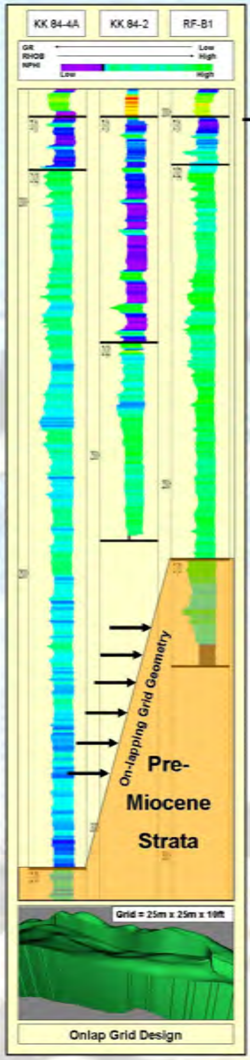
Depositional Setting

The depositional setting of the reservoir comprises a 10-12 Km wide carbonate ramp which extends eastwards from Ras Gharib Field to Ras Fanar Field. In previous interpretations the carbonate Nullipore Facies was interpreted as eroded and subsequently on-lapped by South Gharib sediments along a single unconformity. The proposed geological model allows for both lateral and vertical facies transitions between the Nullipore carbonates and South Gharib evaporitic-siliciclastic-carbonate units. Several phases of upward-shoaling deposition and complexes and patch reefs are exposed as raised "beaches", and are subsequently karstified and reworked into forced regressive beaches and ?washovers deposits. Newly formed lowstand biostrome complexes and patch reefs may have developed locally but sedimentation would have been dominated by evaporates forming in sabkhas/salinas. Periods of erosion coincide with high porosity layers within the reservoir resulting from karstification and solution collapse brecciation. Diagenetic overprinting of the original facies was intense therefore a petrophysical-based modelling procedure was adopted.

3D Modelling Workflow

This paper presents a simple but effective 3D reservoir modelling workflow which used absolute acoustic impedance (AI) data and its relationship to effective porosity as a deterministic 3D modelling parameter ("porosity-facies") rather than the more traditional facies based approach. Simple un-faulted models of AI data and interpolated effective porosity allowed an early assessment and confirmation of the geological significance of the modelling procedure. Implicit in the modelling workflow was the assumption that the 3D distribution of the resulting AAI-conditioned "porosity-facies" could be interpreted using a geological model which conformed to a "modern" sequenced-based approach to reservoir zonation and the model-derived vertical and horizontal "porosity-facies" trends were reflected in the actual evaporitic-carbonate facies transitions seen in the Gulf of Suez today, as well as nearby outcrop analogues (see Figure 1).

Two significant chronostratigraphic surfaces have been used to construct the static reservoir model. The upper surface is a field-wide "Shale Marker". This marker horizon coincides with the boundary between the South Gharib Formation and the overlying Zeit Formation and, is thought to represent a near horizontal chronostratigraphic maximum flooding event. The lower surface corresponds to the basal Miocene unconformity. It displays a topography relief due to intense differential erosion of different sub-cropping siliciclastic and carbonate pre-Miocene Formations during Oligocene to Lower Miocene times.

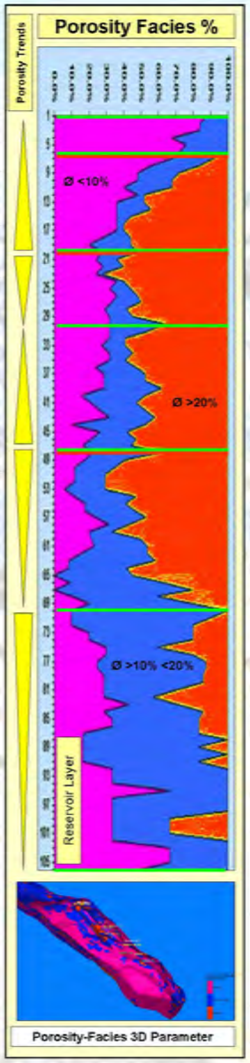


Onlap Grid Design

“Chicken Wire” Anhydrite

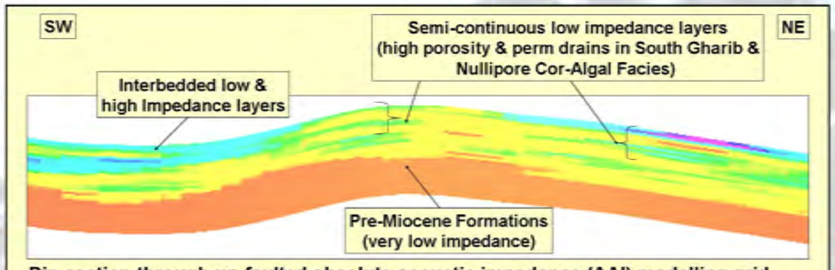
Solution collapse breccias with reddened sediment filled fissures

Secondary dissolution porosity



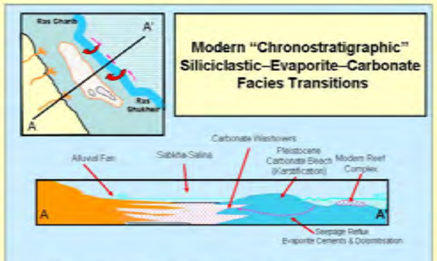
Porosity-Facies 3D Parameter

Subsurface seismic data



Dip section through un-faulted absolute acoustic impedance (AAI) modelling grid

Modern depositional analogue



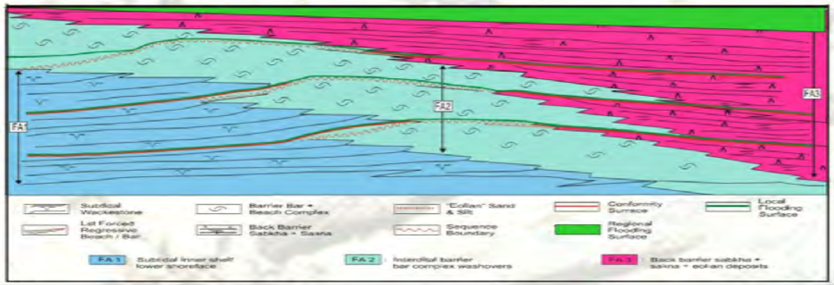
Ras Gharib – Ras Shukheir Sabkha

Gulf of Suez

Elongate reef forming core of emergent beach-dominated island. Beach foreshore comprises coral and fragments of cemented reef-rock accumulated during high storm activity

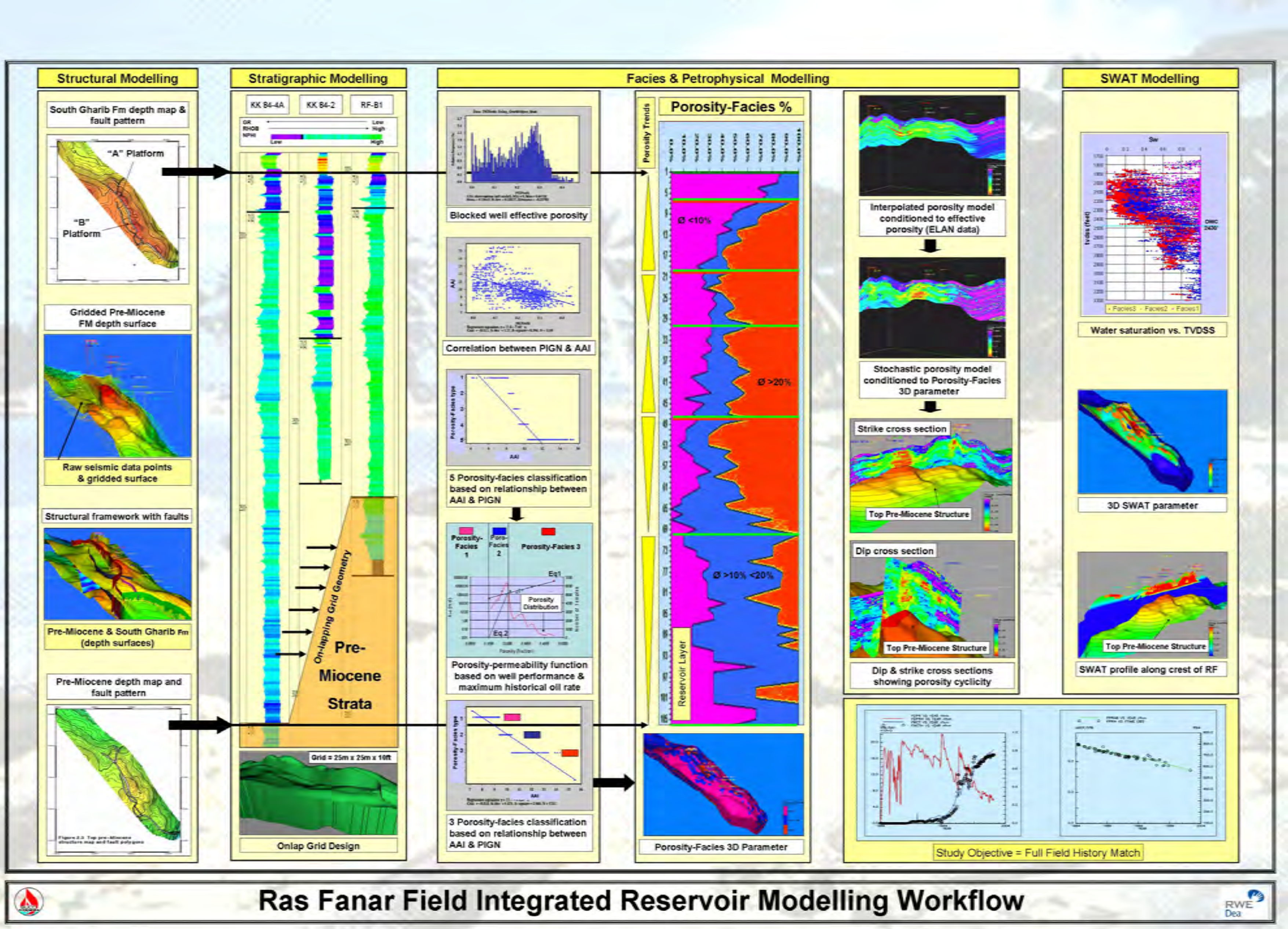
Caribbean

Conceptual sequenced-based depositional model



Ras Fanar Field Integrated Reservoir Modelling Workflow: Figure 1

RWE Dea



Ras Fanar Field Integrated Reservoir Modelling Workflow

Structural Modelling

South Gharib Fm depth map & fault pattern

Gridded Pre-Miocene FM depth surface

Raw seismic data points & gridded surface

Structural framework with faults

Pre-Miocene & South Gharib Fm (depth surfaces)

Pre-Miocene depth map and fault pattern

Stratigraphic Modelling

Onlap Grid Design

Facies & Petrophysical Modelling

Blocked well effective porosity

Correlation between PIGN & AAI

5 Porosity-facies classification based on relationship between AAI & PIGN

Porosity-permeability function based on well performance & maximum historical oil rate

3 Porosity-facies classification based on relationship between AAI & PIGN

Porosity-Facies %

Porosity-Facies 3D Parameter

Interpolated porosity model conditioned to effective porosity (ELAN data)

Stochastic porosity model conditioned to Porosity-Facies 3D parameter

Strike cross section

Dip cross section

Dip & strike cross sections showing porosity cyclicity

SWAT Modelling

Water saturation vs. TVDSS

3D SWAT parameter

SWAT profile along crest of RF

Study Objective = Full Field History Match

Stratigraphic grid construction was based on a simple correlation concept whereby the carbonate facies on lapped onto the pre-Miocene topography and remained parallel to the upper bounding surface, the Shale Marker. Proportional and down-lapping stratigraphic grids were also produced as correlation sensitivities during grid design but these models produced geologically in-consistent results. The static model grid was generated using a grid size of 25x25m and 10' layers.

The best reservoir quality carbonates, dolomitic limestones and dolomites, had high porosity and low absolute acoustic impedance. This relationship is shown on Figure 2. Using the equation for a straight line the impedance values corresponding to 6%, 21%, 31% and 40% porosity were calculated corresponding to average absolute acoustic impedance values of 10.4, 9.4, 8.8 and 8.2 respectively. A 5-fold porosity-facies parameter was defined such that:

Porosity_facies 1= Porosity <6%
Porosity_facies 2= Porosity >6% and <21%
Porosity_facies 3= Porosity >21% and <31%
Porosity_facies 4= Porosity >31% and <40%
Porosity_facies 5= Porosity >40%

During reservoir simulation the 5-fold porosity-facies classification proved to be too complex and a history match was achieved with two basic relationships, one for rock less that 20% porosity and one for rock greater than 20%. A final 3-fold porosity-facies parameter resulted

Porosity_facies 1= Porosity <10% (below cut-off)
Porosity_facies 2= Porosity >10% and <20%
Porosity_facies 3= Porosity >20%

Porosity-permeability transforms for each porosity-facies were conditioned to production data (well productivity and maximum oil rates) with the following relationships:

Eq1 - $k = 102.49*\exp(12.808*Ø)$ $= Ø > 20\%$

Eq2 - $k = 7.530E\text{-}08*\exp(118.0* Ø)$ $= Ø >10\% < 20\%$

The method used to model water saturation was to create Sw v height above FWL functions for the different porosity_facies (see Figure 2). The transition zone could be modelled satisfactorily using this approach, and the equations are listed below:

Porosity_facies 3
SWAT = Ln (Height)* -.1725 + 1 with an irreducible Sw = 0.2

Porosity_facies 2
SWAT = Ln (Height)* -.20 + 1.4 with an irreducible Sw = 0.29

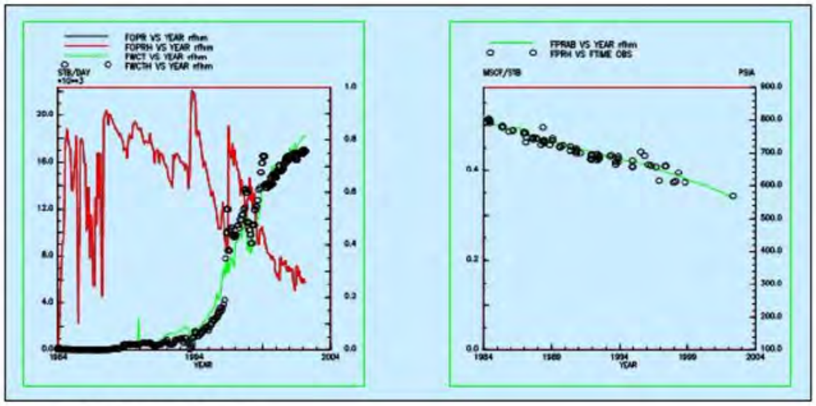
Conclusions

The up-scaled simulation model successfully history matched to field performance using acceptable variations within the geological framework of the original static model. Individual well oil rate and water-cut matches were also good and the pressure matches were excellent (see Figure 3).

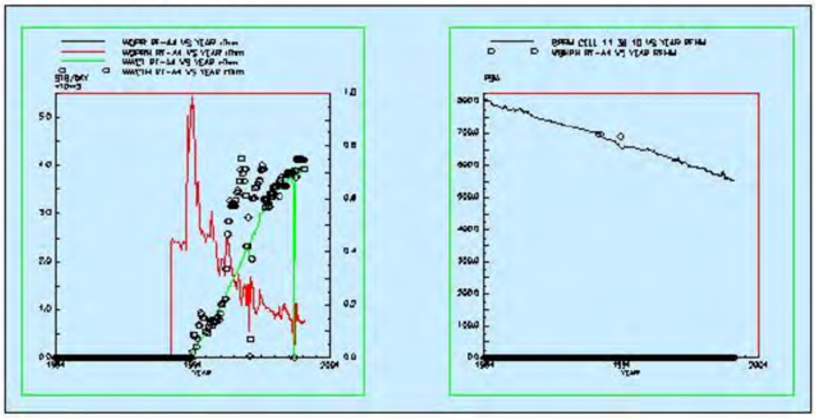
This study has shown that 3D seismic attribute and AI data can be effectively used to deterministically constrain static and up-scaled 3D reservoir models of pre-evaporitic reservoir sequences in the Gulf of Suez.

The joint venture partnership producing Ras Fanar is now in a position optimise OPEX and effectively manage (new wells and re-completions) the late stage field development of this mature asset.

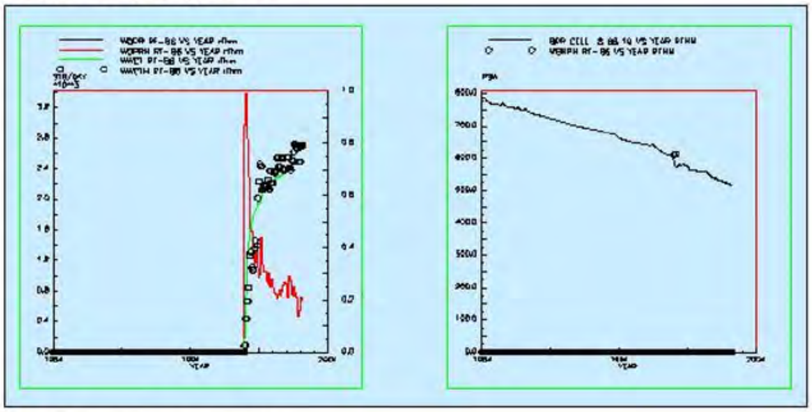
Figure 3: History Matching



Full Field History Match



Well RF-B6 History Match



Well RF-A4 History Match

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