Increase Productive Life and Add to In-Place Oil in Mature Reservoirs with Integrated Studies: Zubair Reservoir in Kuwait*

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Abstract

The Zubair reservoir is an Albian siliciclastic reservoir on production for the last six decades. Cumulative production indicates a higher oil recovery factor than expected. An integrated study involving sequence stratigraphy, sedimentology, biostratigraphy, petrophysics and modeling techniques resulted in a better understanding of rock fabric, mineralogical composition, depositional settings and their evolution leading to discovery of more in-place oil and a rejuvenated development plan.

Petrographically, the formation comprises highly mature clastic deposits with variable and heterogeneously distributed argillaceous matter. The fine- to medium-grained sandstones are weakly overprinted by authigenic mineral precipitates. Whole rock and clay-fraction XRD indicate very low expandable clay minerals.

The deposits were rationalized into three levels of comprehensive descriptive and interpretative schemes. The expected geometries, dimensions, internal heterogeneities and reservoir qualities of the various facies associations were upscaled into Gross Depositional Environments (GDE) to increase the confidence and consistency of sedimentological interpretations from openhole logs alone. The palynologically constrained GDE indicate increased importance of deltaic as opposed to previously envisaged shallow marine processes.

Four low-order sequence stratigraphic sequences were identified: A basal transgressive set, a heterogeneous highstand deltaic and more homogeneous channel-dominated lowstand set, which in turn are capped by transgressive deltaic to open marine deposits.
Focused core studies on hot gamma ray intervals showed the presence of conductive heavy minerals in net sands. Intercalation of shale laminations with oil-stained sands contributed to high gamma ray values in some layers. Realistic assessment of net pay in these zones was possible from formation evaluation using resistivity anisotropy tools calibrated to cores.

Identification of arenaceous deltaic sandstones enhanced the net-to-gross ratio in the reservoir intervals. High pressure mercury injection data from SCAL studies confirmed the conclusion. A detailed layering scheme with layer specific modeling techniques, backed by a combination of deterministic sand trend maps and stochastic modeling realized the envisaged model.

An accelerated development with water injection is underway to exploit the discovered reserves. This article describes in detail the studies leading to enhanced value of the asset.
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Outline

Geological Setting
Zubair Reservoir in North Kuwait
Implications from Sedimentology
  - Rock type
  - Facies Association
  - Gross Depositional Environment
  - Rock Fabric
Sequence Stratigraphy
Enhanced Pay
  - Core
  - Special Logs and processing
Modeling
Implications for future development
Summary
GEOLOGICAL SETTING

Sub Period | Epoch | Formation | Lithology | Age
---|---|---|---|---
Quaternary | Holocene | Surface | Dibibba | 0.01
| Pleistocene | Dibibba | 1.64
Tertiary | Pliocene | Lower Fars | Ghar | 3.4
| Miocene | Ghar | 5.2
| Oligocene | Dammam | 23.3
| Eocene | Rus | 35.4
Paleocene | Radhuma | 56.5
Cretaceous | Maastrichian | Layar | 65
| Campanian | Umm Gherma | 74
| Santonian | Lata | 83
| Coniacian | Khasib | 86.6
Upper | Cenomanian | Mishrif | 90
| Albian | Humaima | 95
| Lower | Wara | 97
| Maaddud | Burgan | 98
| Aptian | Shaiba | 100
| Hauterivian | Minagish | 120
| Valangian | Ratawi sh & Is | 133
| Berriasian | Minagish | 139
| Lower | Albian | Makhul | 140
| Jurassic | Tithonian | Makhul | 146
| Upper | Kimmenian | Nahma | 152.1
| Oxfordian | 154.7
| Callovian | 157.1
| Bajocian | 161.3
| Bathonian | 165.1
| Lower | ammonites | 172.5
| Toarcian | Marrat | 178
| Lower | Pliensbachium | 187
| Sinemurium | 194.5
| Lower | Triassic | 200.5
| Rhaetian | Gotha | 208
| Norian | 209.5
| Carnian | 225
| Lower | Ladinian | 229.5
| Ladinian | 233.4
| Lower | Spathian | 241.1
| Lower | Permian | 245
| West | 256.1

Zubair

IRAQ
IRAN
SAUDI ARABIA
WAFRA
BAHRAH
Raugei
Mutriba
ABDALI
Kuwait City
MEDINA

0 KM
0 100 200
North Kuwait
West Kuwait
South East Kuwait
Kuwait City
Kuwait
Zubair Reservoir in North Kuwait

- Bottommost prolific reservoir
- Commercial oil accumulation in Raudhatain Field
- Minor Reservoir in Sabiriyah Field
- RA: Domal anticline with two major fault trends
Zubair Reservoir in Raudhatain Field

1,400 Feet

- UPPER
  - "SHALE"
  - "SAND"

- MIDDLE
  - "SHALE"
  - "SAND"

- LOWER
  - "SHALE"
  - "SAND"
Zubair Production Performance

Recovery Factor: 34%
Historical Performance

UZSH Production and Reservoir Pressure

Bubble point

MZSD Production and Reservoir Pressure

LZSD Production and Reservoir Pressure

Bubble point
Sedimentological framework – lithotypes

Three levels of comprehensive descriptive and interpretative schemes: Sub-bed/bed-scale lithotypes

Basic building units for process-based depositional interpretations and reservoir quality-specific rock typing
Bed stack-scale, genetic facies associations: Geometrical information

**Channel-fill (CF)** – stacked, weakly upward-fining, low/high-angle cross-bedded sandstones.

**Floodplain/abandonment (FL/AB)** – mudrocks and heterolithics, rare argillaceous sandstones..

**Mouthbar (MB)** – locally upward-coarsening, argillaceous to clean horizontally bedded sandstones.

**Sandflat/sandsheet (SF/SH)** – stacked, trendless, laminated/rippled sandstones and heterolithics..

**Washovers (WO)** – sharp-based and topped, flat laminated sandstone

**Interdistributary bay/lagoon (ID/L)** – interbedded mudrocks and heterolithics with carbonaceous debris and amber.

**Lower shoreface (LSF)** – bioturbated sandstones with diverse marine trace fossil assemblage.

**Offshore transition zone (OTZ)** – heterolithics and argillaceous sandstones.

**Offshore (OS)** – laminated to massive mudrocks. Locally shell-rich horizons. Paucity of bioturbation.
Facies associations – geometry/dimensions and internal heterogeneities

- Individual channel-fills (CF) stack to form multilateral and multi-storey sandbodies (100s to 1000s metres wide, several 10s of feet thick)

- CF: vertical variations in mud content influence permeability architecture (increase at channel tops, decreasing K)

- Sheet deposits more heterogeneous with reservoir quality distribution gamma cut-off of 60API

Differentiation of facies associations in uncored intervals of lower confidence
  - upscaled into genetically stacked groups to reduce uncertainties in interpretations
Gross Depositional Environments

- GDEs represent genetically grouped facies associations
  - more confidence and consistency from openhole logs alone
- 5 GDEs ranging from
  - Proximal channel-dominated delta-top/estuary (GDE A)
  - Sand-prone delta-top/front or estuary (GDE B)
  - Mud-prone delta-top/front or estuary (GDE C)
  - Sand-prone open marine (GDE D)
  - Mud-prone open marine (GDE E)
Present model: increased importance of deltaic in-place of shallow marine shoreface processes; palynological support

Implications for sandbody geometries and extent
Texture and composition

- Highly mature sandstones (mostly quartz arenites and wackes)
- Wide range in detrital clay content – inverse relationship with grain size
Texture and composition

- Cleanest and coarsest (fine to medium-grained)
- Massive to laminated fabrics
- Best reservoir quality
- Wide range in clay content
- Very fine to fine-grained
- Bioturbated fabrics
- Variable reservoir quality (“secondary target”)
- Highly argillaceous
- Very fine to fine grained
- Partly bioturbated fabrics
- Poor / non-reservoir
Pore systems and rock types

Decreasing pore throat size with increasingly micropore-dominated rock types and decreasing grain size.

Conventional core analysis data coded by petrography-based rock types. Although significant overlap exists due to sample heterogeneity (e.g. bioturbated fabrics at the plug scale), the different rock types correspond to specific ranges of reservoir quality.

Key:
- Primary controls on pore system
- Additional diagenetic controls on pore system (quartz, carbonates, pyrite, kaolinite)
- Low-confidence CCA data point
Sequence stratigraphy and Layering Scheme

Layers Z51-Z64 – transgressive systems tract (TST)

Layers Z42-Z48 – lowstand systems tract (LST)

Layers Z22-Z36 – highstand systems tract (HST)

Layers Z02-Z10 – transgressive systems tract (TST)
GDE from Core

Offshore

Shore face

Z62 Channel

Field-wide correlatable offshore mudrocks
Pay Intervals

Core Sedimentology

Logs Reprocessed to capture Pay in High Gammaray Intervals
Scope for adjustment

Core Vs Old Log  Pay in Shaly Intervals

Porosity/Pay Improvement Opportunities
Resistivity Anisotropy

Image based Modeling

Sand-Shale Resistivity Model

\[ R_h = 1.8 \, \Omega \cdot m \]
\[ R_v = 5.5 \, \Omega \cdot m \]
\[ R_{sand} = 10 \, \Omega \cdot m \]
\[ R_{shale} = 1 \, \Omega \cdot m \]

Core
Identified Pay from Resistivity Anisotropy
Matrix density from Elemental Analysis is more than 2.65: Matrix density used in Porosity calculation is 2.65

Elemental Density porosity is consistently higher: Possible increase in porosity by 2.5 pu
Pay Improvement from Imagelog and Elemental Analysis

Interval 8618 – 8621 feet

Pay increase related to quality of Sand

Increase in Net Pay
Static Model

Fault planes

Channel Models

Facies Model

Porosity
Static and Dynamic Models

- A coarse simulation grid of 150mX150m and 67 layers
  - refined to 50mX50m and 593 layer geological model.
  - Geological model with 46.4 million cells was split into 19 Grid models for efficient modeling.
  - Proportional and Top and bottom conformal gridding.

- Wells
  - Blocked wells, shifted and scaled logs to match grids
  - Data Analysis: Histograms, Variograms

- Vertical facies trend analysis

- Facies Model: Object Modeling using trends and volume fractions: Honor Sedimentological observations

- Stochastic petrophysical modeling

- Volumetrics: Multiple scenerios
Impact of the study

- Better reservoir characterization
- Increase in STOIIP
  - 30% more
- Optimized well locations
- Bypassed oil areas
  - North blocks developed by PAD
  - Trapped oil in Fault compartments towards south
- Horizontal/Multilateral to boost production
- Target laminated/thin sands
- Increase oil rate and extend plateau period
Oil Production

Forecast

Oil Production

Water Injection
Zubair Injection Performance

- Peripheral injection in 3 Zones
- Low Injectivity in MZSD and LZSD
- Good injection in thick channels UZSD
- Currently injecting in 4 wells
- Planning to inject in 23 wells
- High pressure in future wells
Implications for future development

- Limited production from thick sand bodies: Water swept, Tarmat
- Multiple reservoirs: Zubair unswept oil shrunk towards crest, surface inaccessibility
- Most remaining reserves in thin Sands
  - Horizontal and High angle wells
  - Sidetrack existing wells as they water out
- Reservoirs near bubble point
  - Injectivity issues in thin channels and shoreface sands
  - Reservoir Compartments
Summary

- Production performance of 5 decades: very high recovery
- Integrated study involving sequence stratigraphy, sedimentology, biostratigraphy, petrophysics and modeling technique resulted in a better understanding of reservoir
- Four low-order sequence stratigraphic sequences
- Palynologically constrained GDE: increased importance of deltaic as opposed to previously envisaged shallow marine processes.
- Focused core studies on hot gammaray intervals showed the presence of conductive heavy minerals in net sands
  - Reprocessed logs: New pay and higher porosity
- Integrated model: Increased inplace oil by 30% and consequent reserves
- Accelerated development plan with water injection is underway to exploit the discovered reserves.
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