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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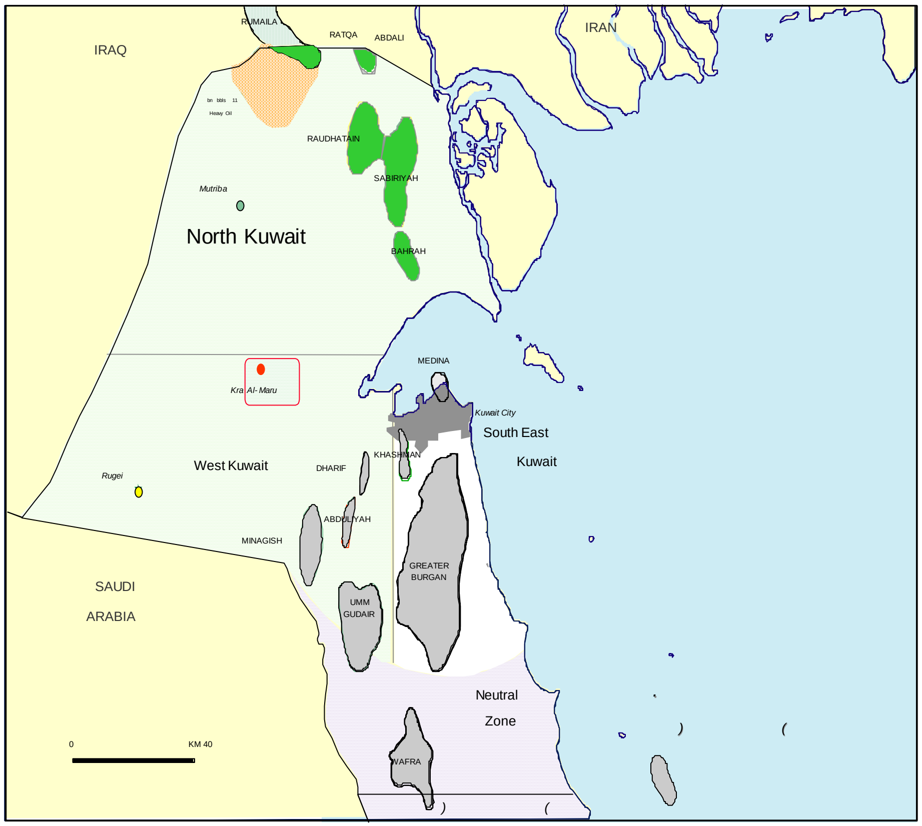
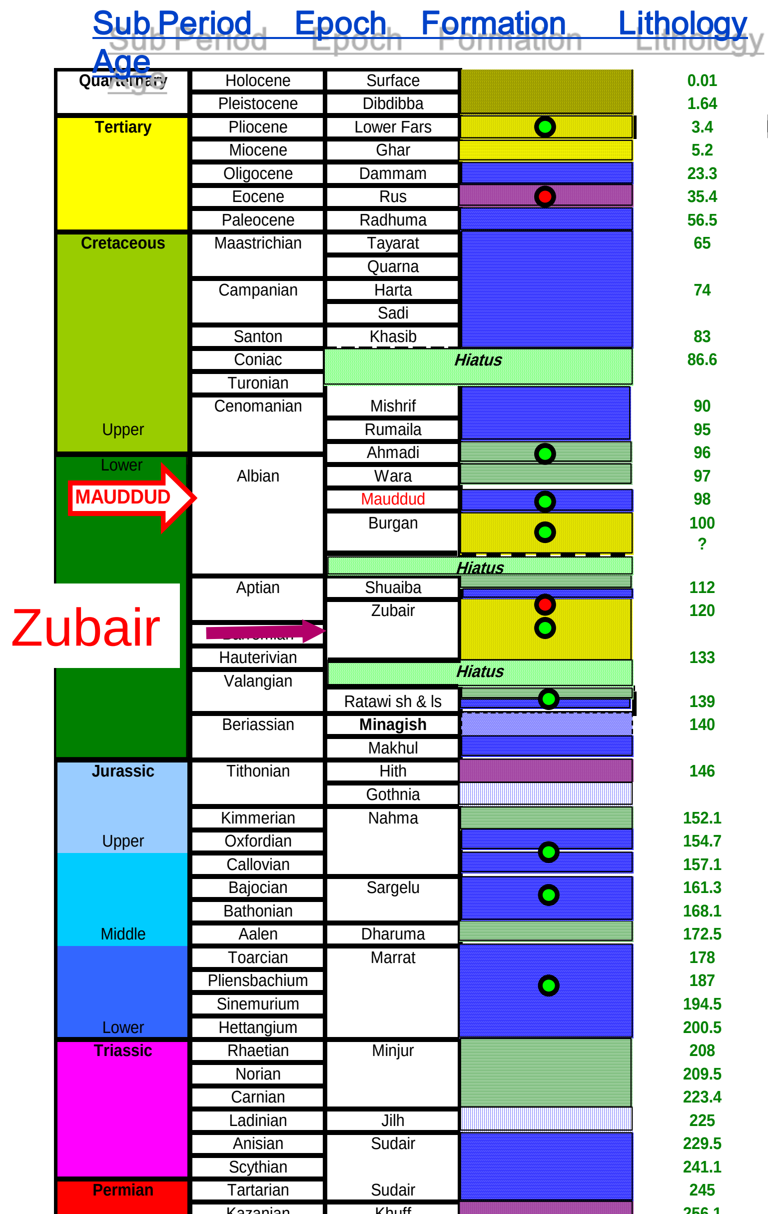
Outline

- 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

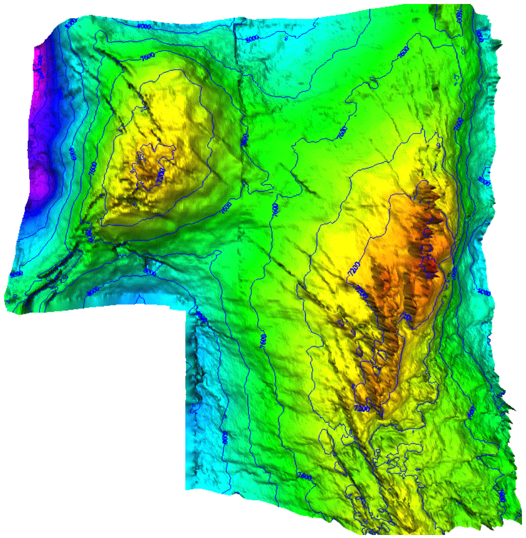
GEOLOGICAL SETTING



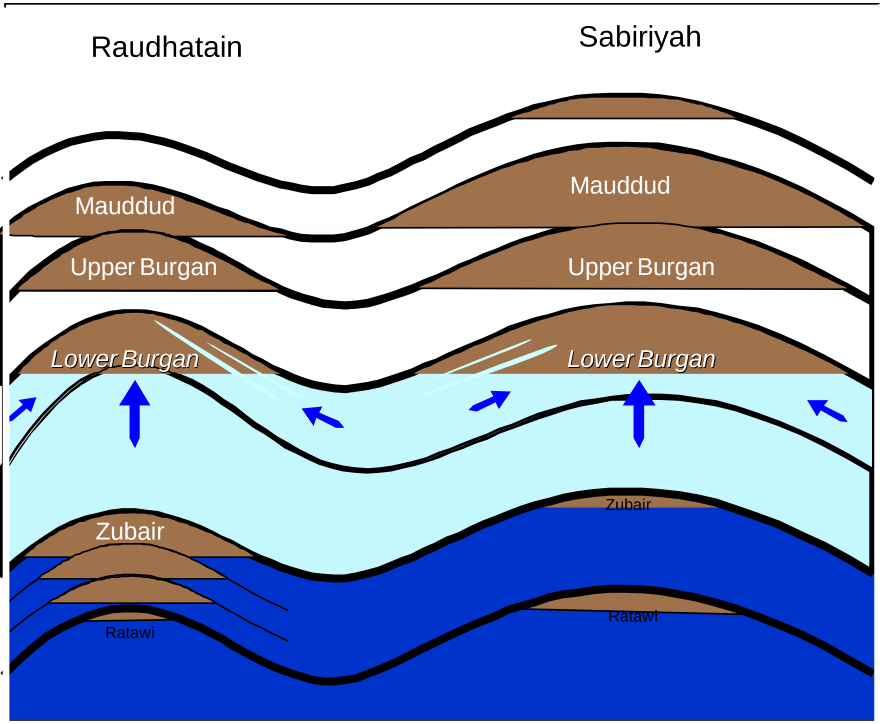


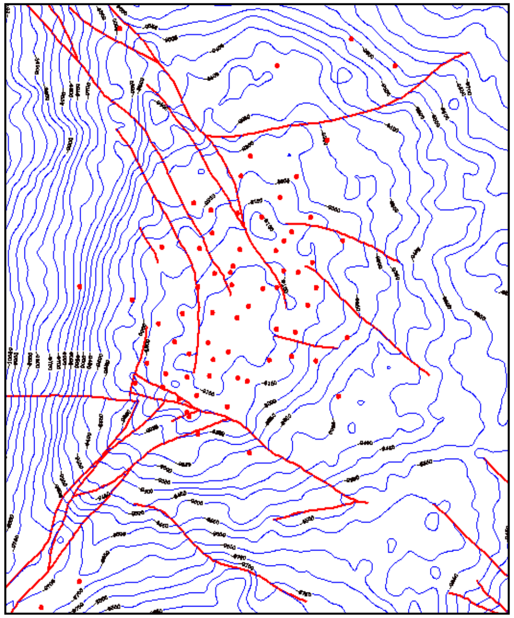
Zubair Reservoir in North Kuwait

Structure

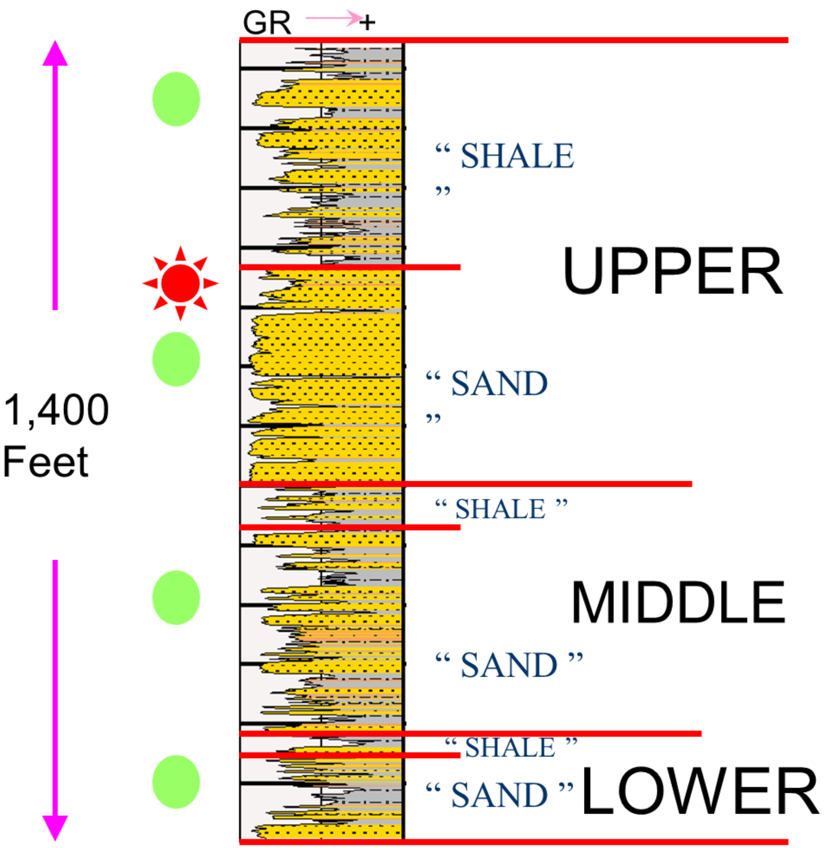


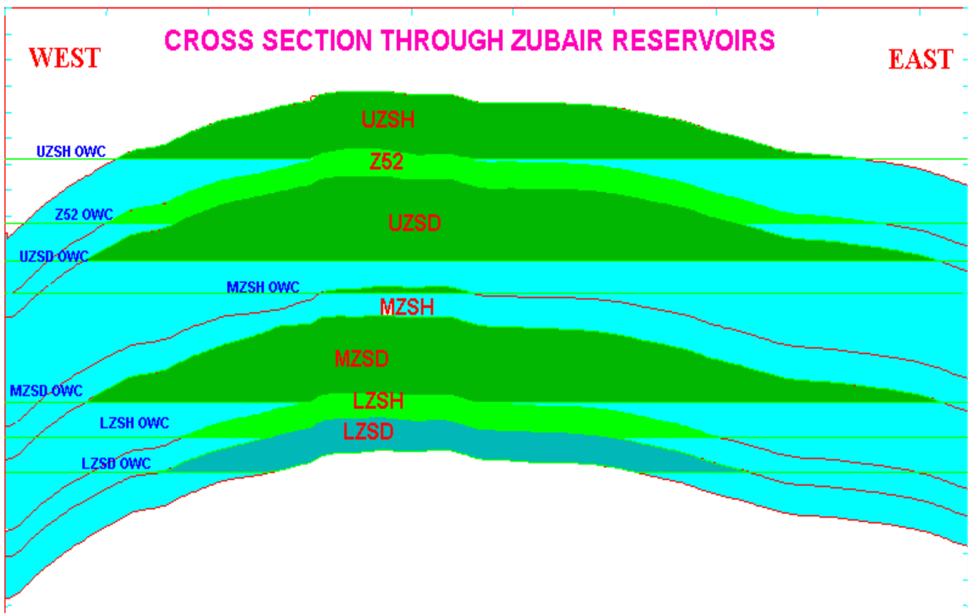
- Bottommost prolific reservoir
- Commercial oil accumulation in Raudhatain Field
- Minor Reservoir in Sabiriyah Field
- RA: Domal anticline with two major fault trends





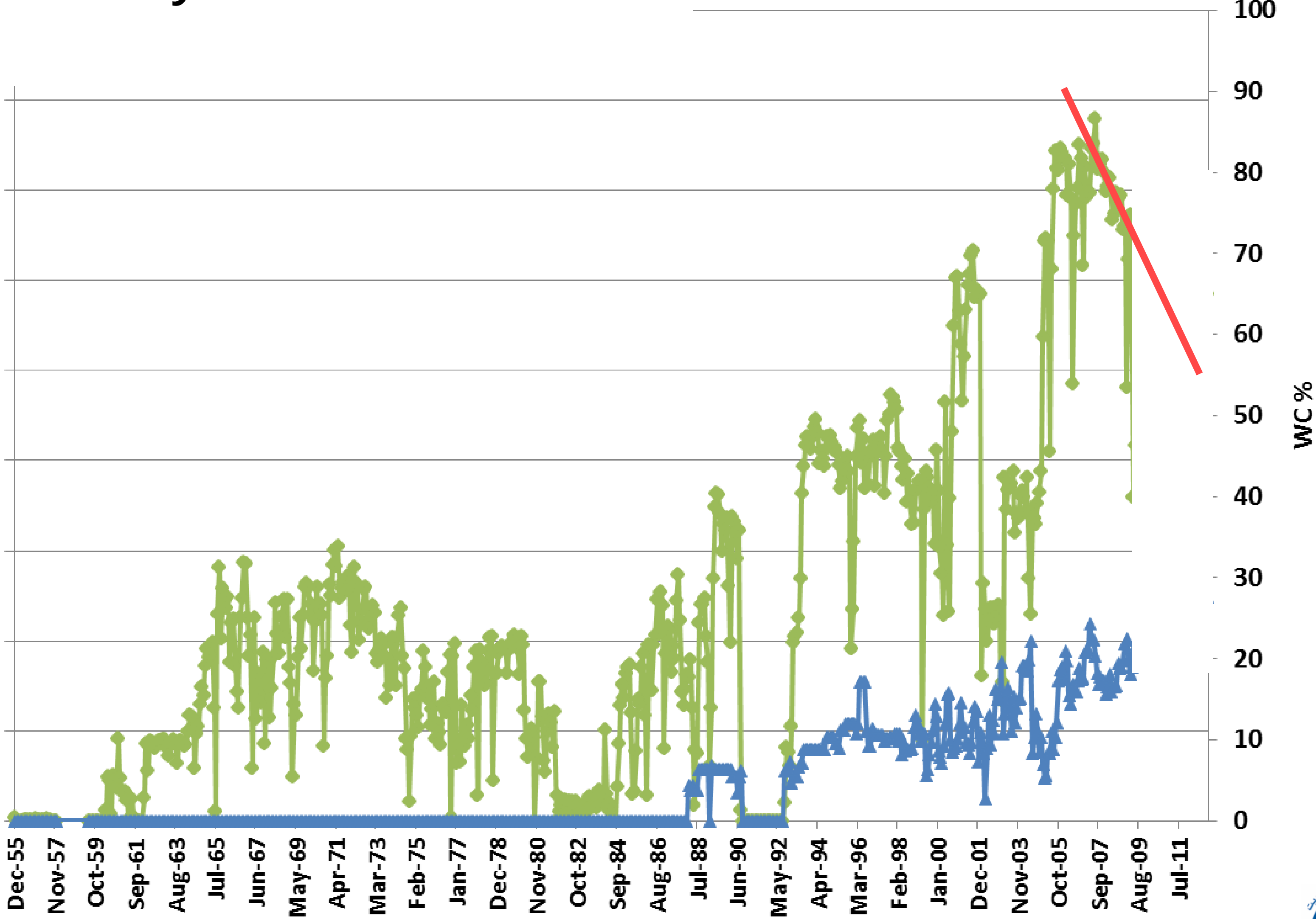
Zubair Reservoir in Raudhatain Field



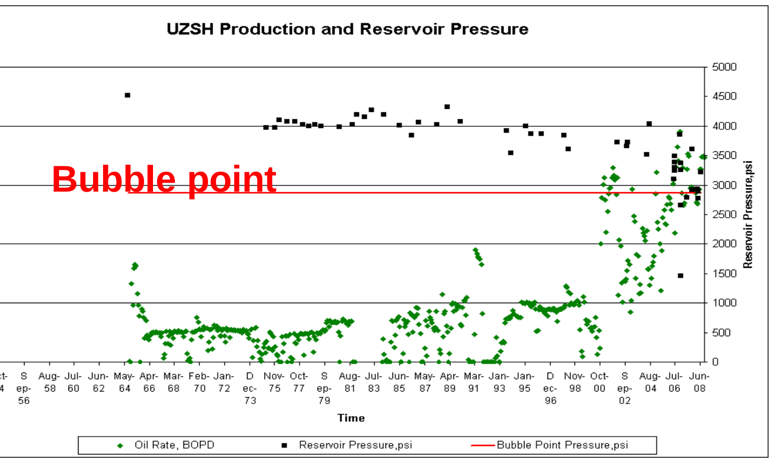


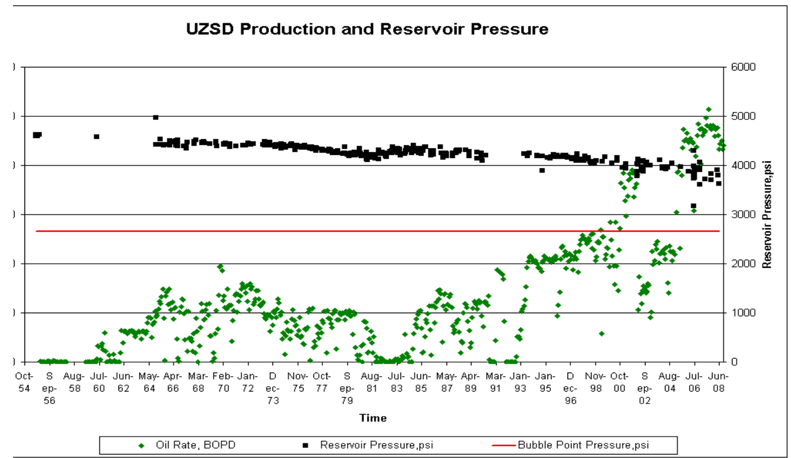
Zubair Production Performance

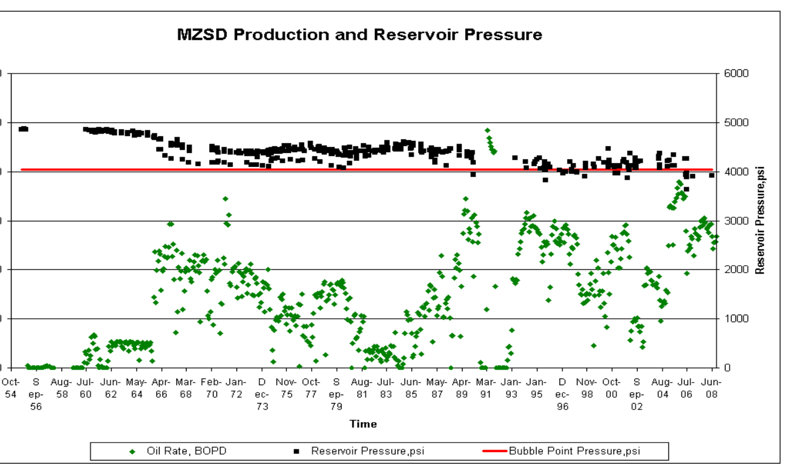
Recovery Factor: 34%

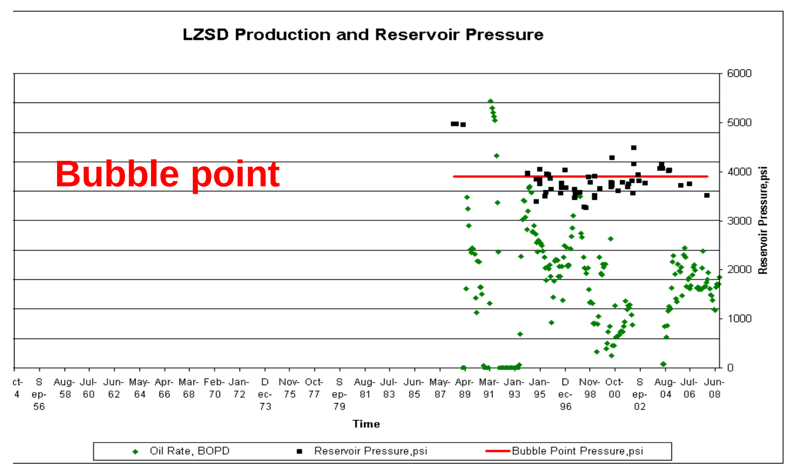


Historical Performance





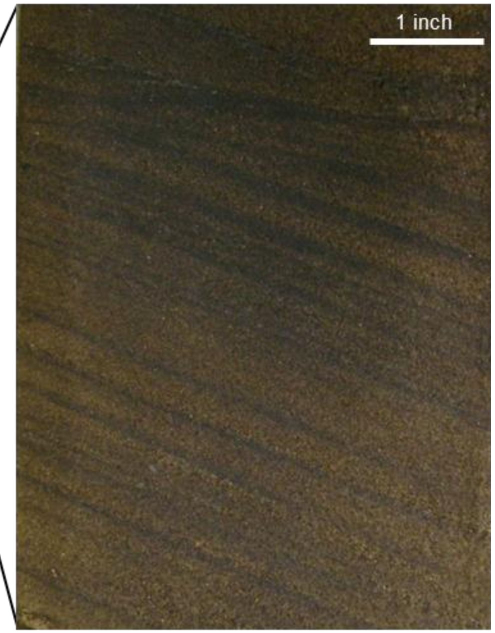




Sedimentological framework – lithotypes

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

Zubair Core-based Lithotypes			Lithology	Grain Size & Sedimentary Structures (Mudrock: Clay, Silt; Sand: Very Fine, Fine, Medium, Coarse, V. Coarse; Conglom.: Granule, Pebble)
Cg		Matrix, rarely clast-supported conglomerates containing mostly angular intraformational (mudstone) clasts.		
Sx		Cross-stratified sandstone. The cross-stratification includes simple sandy foresets and mud-draped forms.		
Sl		Parallel laminated sandstone (rare burrows).		
Sr		Ripple cross-laminated sandstone.		
Sm		Massive (apparently structureless) sandstone, commonly with microbioturbation (cryptic bioturbation).		
Sb (undifferentiated)	Sb1	*Clean*, bioturbated sandstones with simple dwelling burrows (*Thalassinoides*, *Ophiomorpha* and *Palaeophycus*). Rarely preserved primary laminae.		Increase in argillaceous content; Macroburrow diversity and abundance
	Sb2	Intensely burrowed, mud-prone sandstones with a diverse ichnofauna including both dwelling and deposit feeder traces.		
	Sb3	Mud-rich burrowed sandstones with more diverse burrow assemblage including common concentrically-lined forms (*Asterosoma*).		
S/Mb		Bioturbated argillaceous siltstones and sandstones with common deposit feeder traces.		
Sd		Deformed sandstone containing contorted laminae (*ie.* as a result of soft sediment deformation and pedogenesis).		
H (mud-to-sand prone heterolithics undifferentiated)	Hl	Heterolithics comprising interlaminaed sandstone and mudrock. Locally contain abundant carbonaceous debris and amber fragments.		
	Hb	Bioturbated heterolithics comprising burrow-mixed sandstone and mudrock.		
M (undifferentiated)	Mb	Bioturbated mudrock.		
	Ml	Finely-laminated mudrock; locally contain abundant carbonaceous debris and amber fragments.		
M		Apparently massive mudrock.		
C		Coal and/or particularly carbonaceous-rich mudrock.		
L		Limestone, partially dolomitised limestone and dolomite.		



Basic building units for process-based depositional interpretations and reservoir quality-specific rock typing

Facies associations

- 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

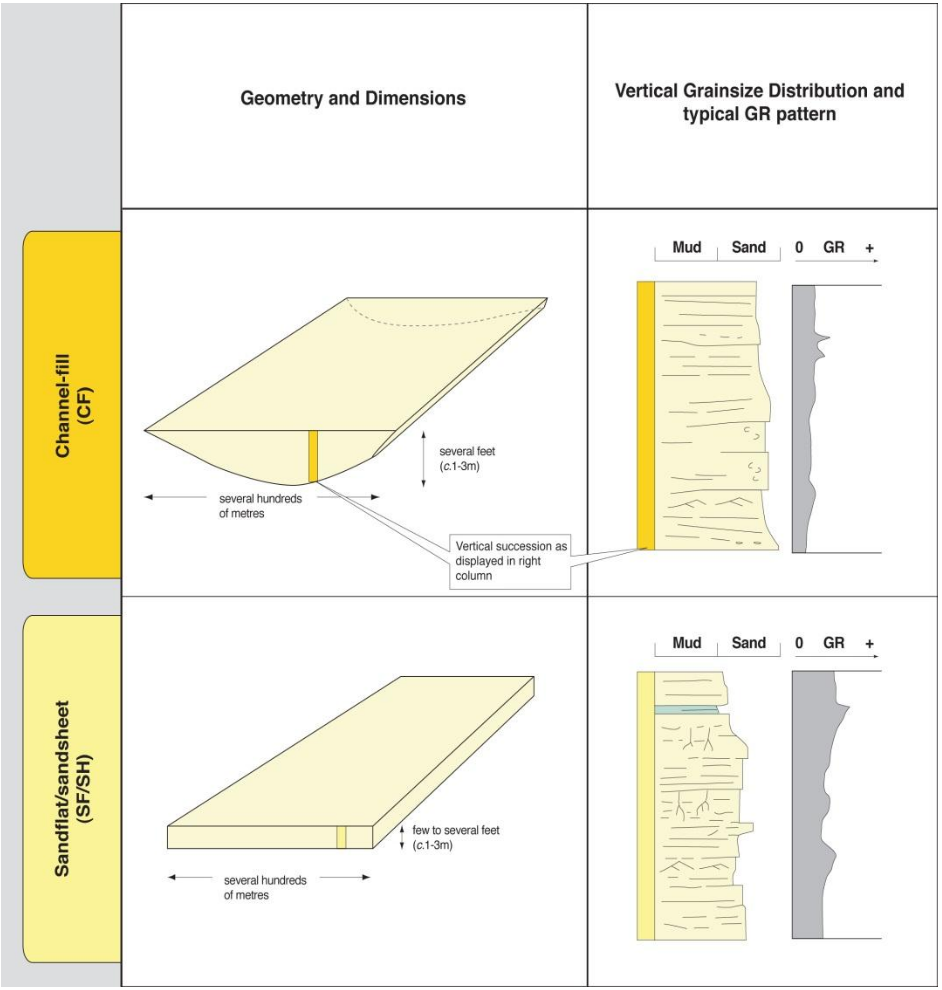
Interdistributary bay/lagoon (ID/L) – interbedded mudrocks and heterolithics with carbonaceous debris and amber.

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



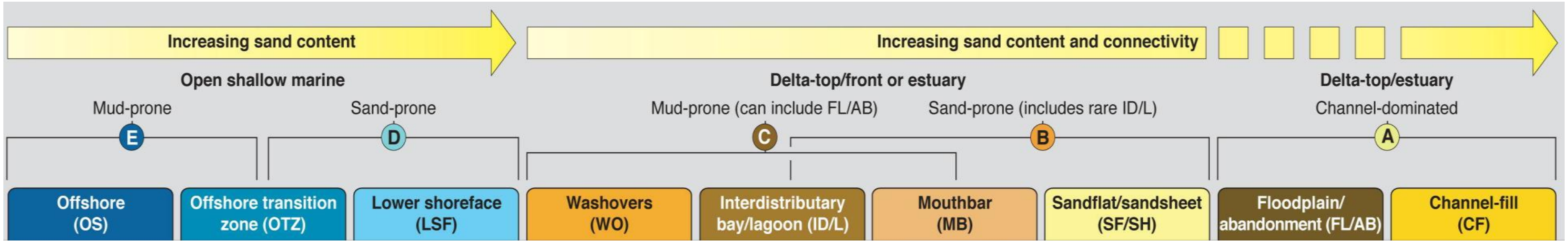
- Individual channel-fills (CF)stack to form multilateral and multi-storey sandbodies (100s to 1000s metres wide, several 10s of feet thick)
- CF: vertical variations in mud content influence permeability architecture (increase at channel tops, decreasing K)
- Sheet deposits more heterogeneous with reservoir quality distribution gamma cut-off of 60API

Differentiation of facies associations in uncored intervals of lower confidence

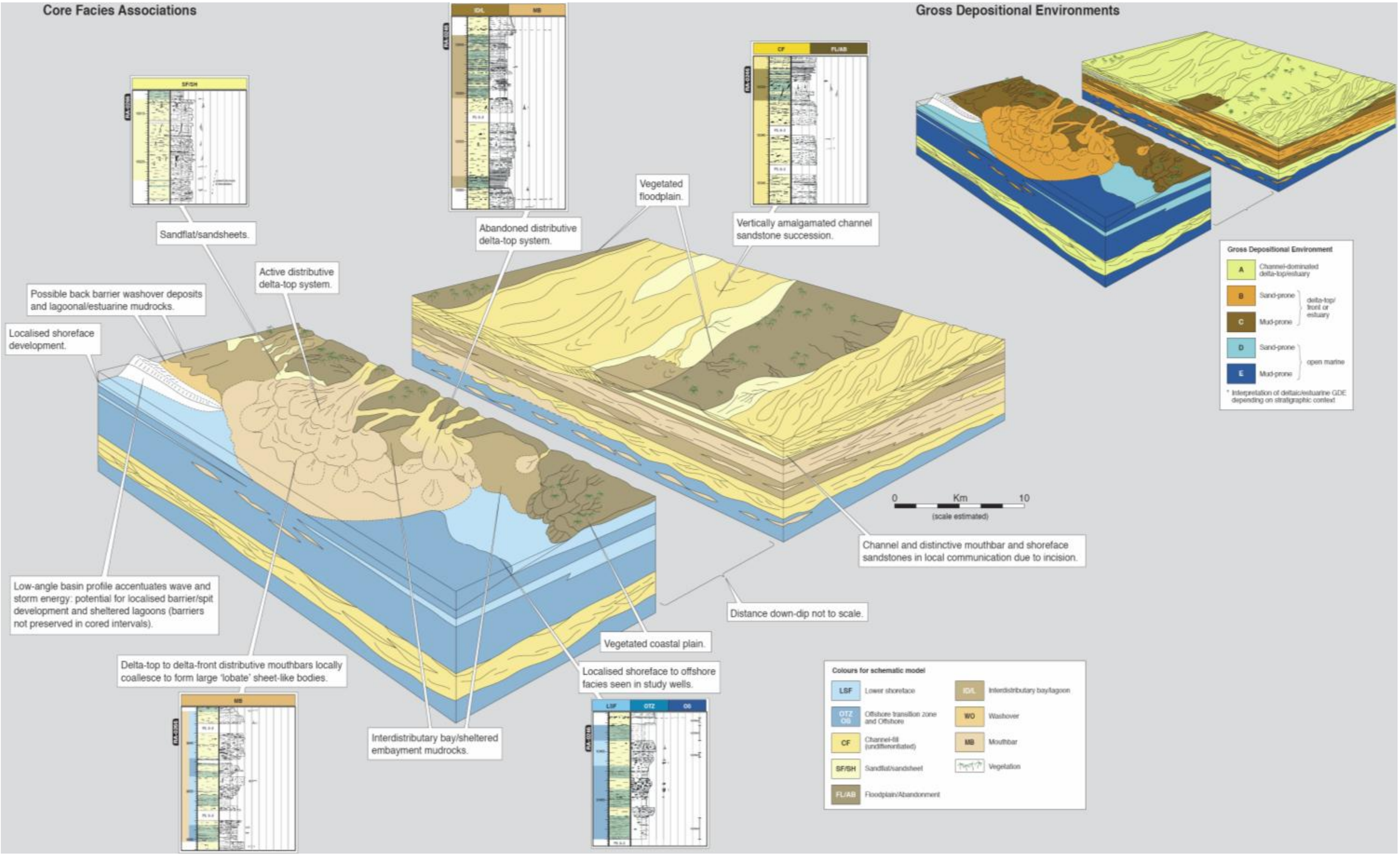
- upscaled into genetically stacked groups to reduce uncertainties in interpretations

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)



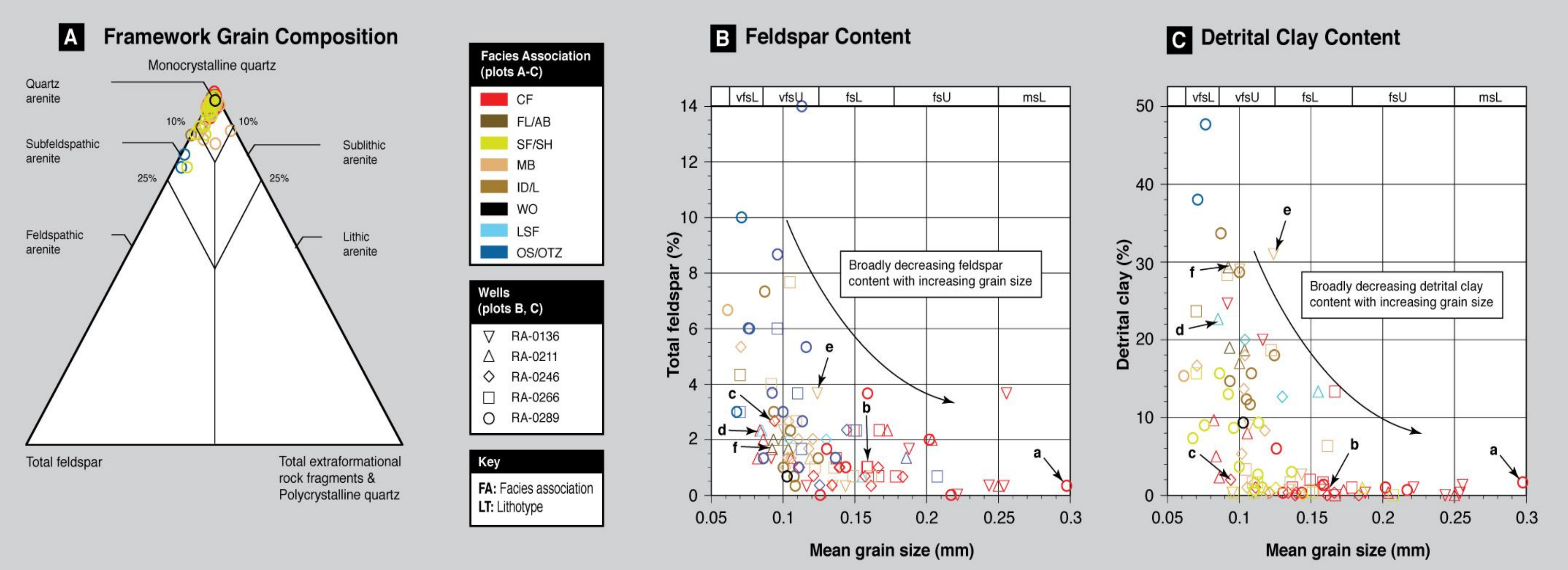
Refined Depositional Model



Present model: increased importance of deltaic inplace of shallow marine shoreface processes; palynological support

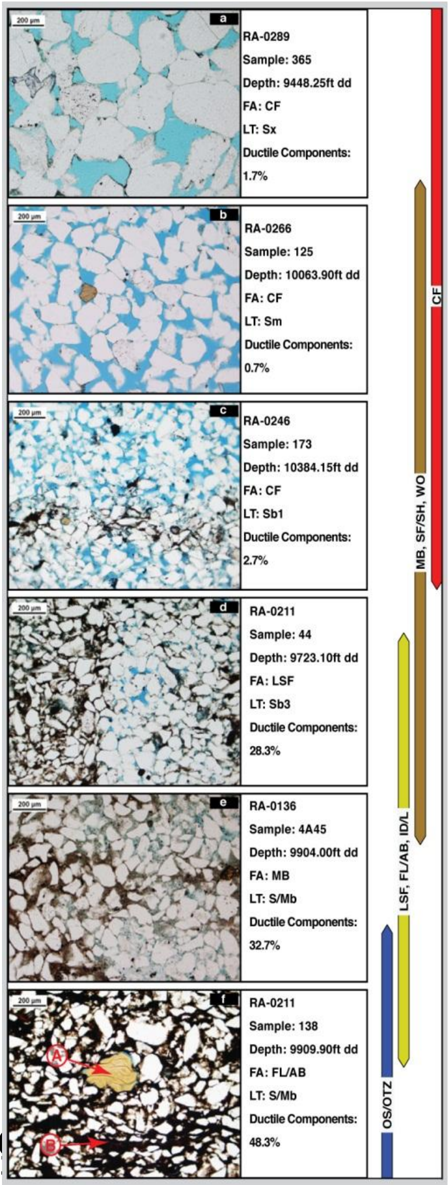
Implications for sandbody geometries and extent

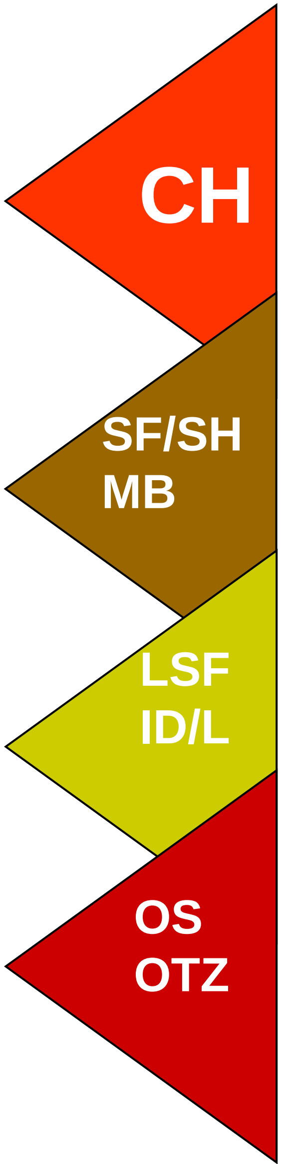
Texture and composition



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

Texture and composition



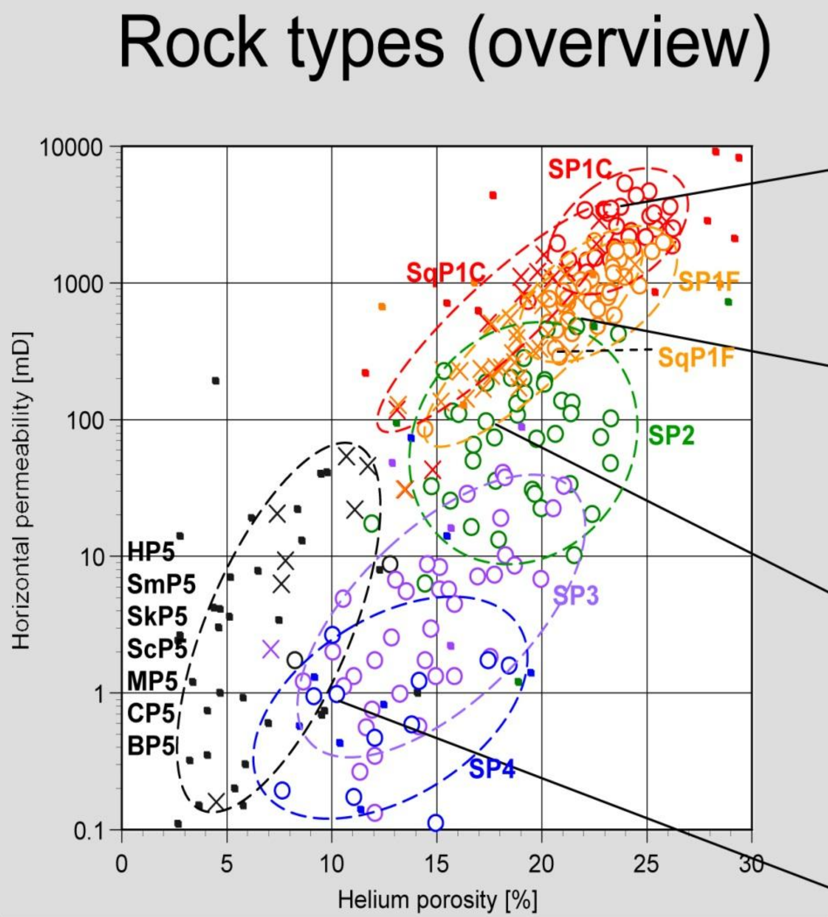


- Cleanest and coarsest (fine to medium-grained)
- Massive to laminated fabrics
- Best reservoir quality

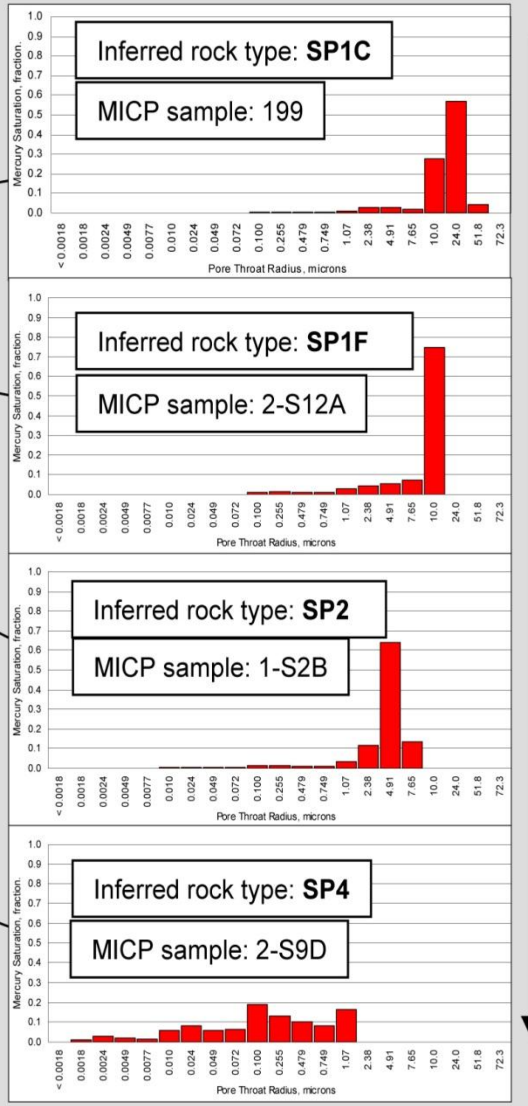
- Wide range in clay content
- Very fine to fine-grained
- Bioturbated fabrics
- Variable reservoir quality ("secondary target")

- Highly argillaceous
- Very fine to fine grained
- Partly bioturbated fabrics
- Poor / non-reservoir

Pore systems and rock types



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

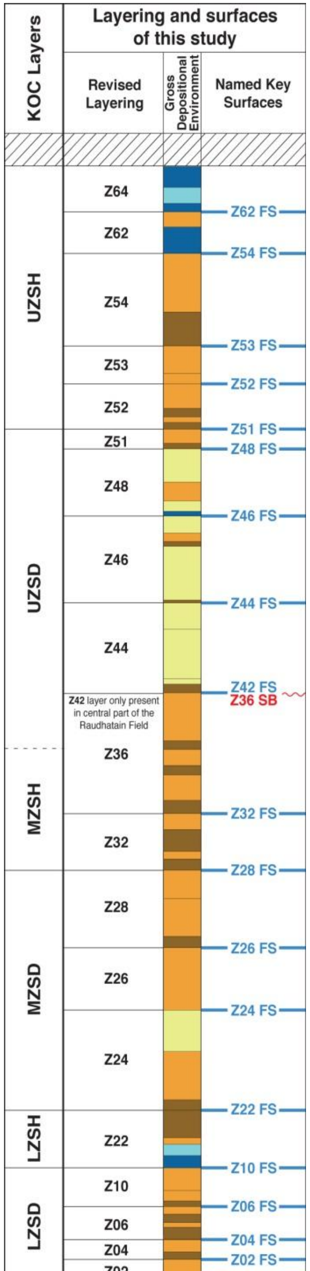


Decreasing pore throat size with increasingly micropore-dominated rock types and decreasing grain size

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



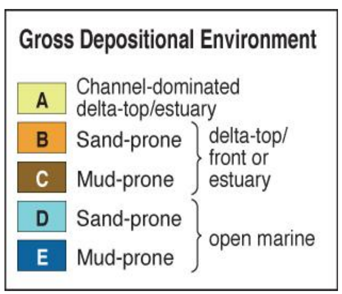
Maximum flooding surface?

Layers Z51-Z64 – transgressive systems tract (TST)

Flooding/transgressive surface

Layers Z42-Z48 – lowstand systems tract (LST)

Sequence boundary



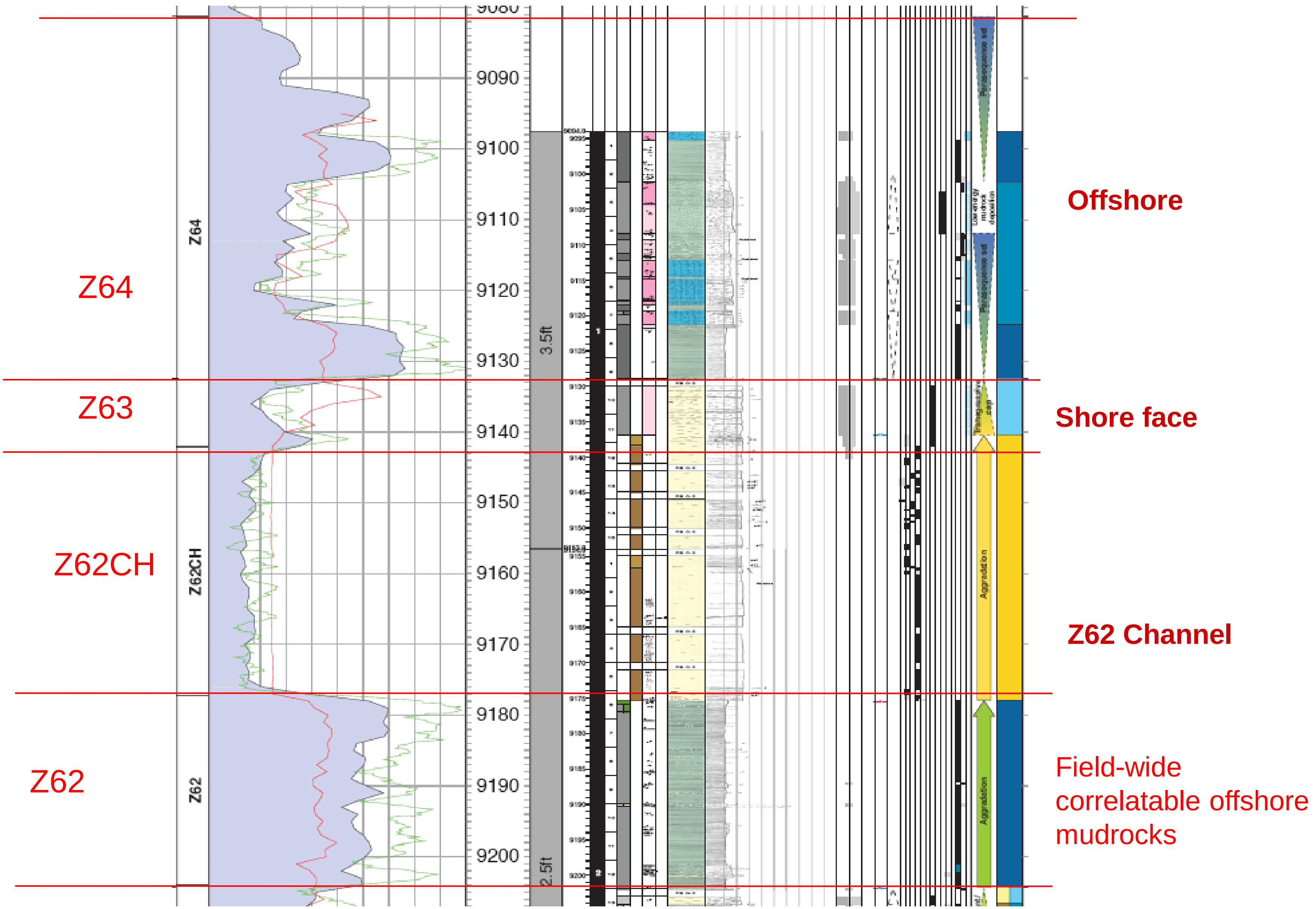
Layers Z22-Z36 – highstand systems tract (HST)

Maximum flooding surface

Layers Z02-Z10 – transgressive systems tract (TST)

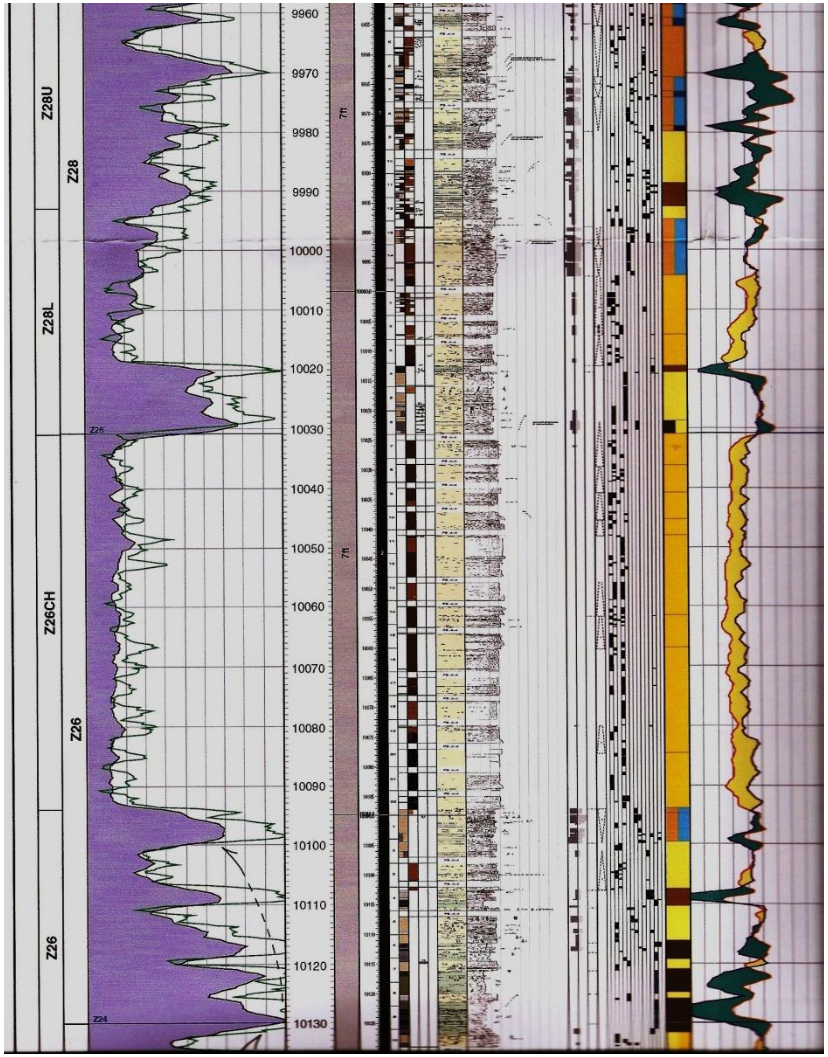
Sequence boundary

GDE from Core

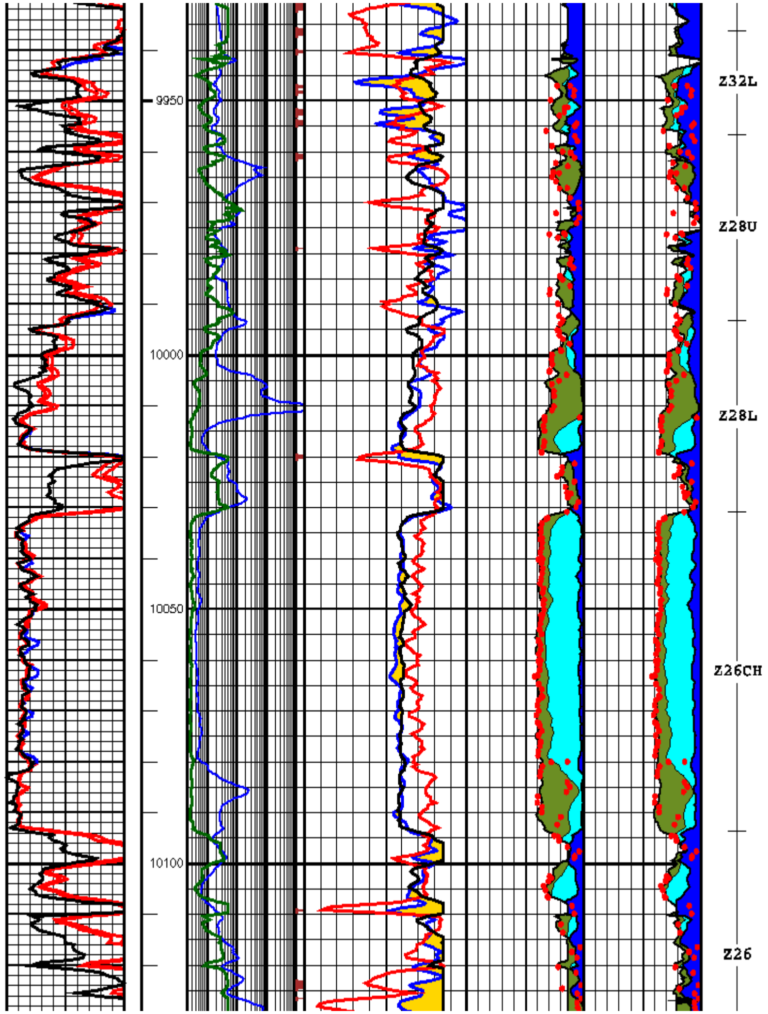


Pay Intervals

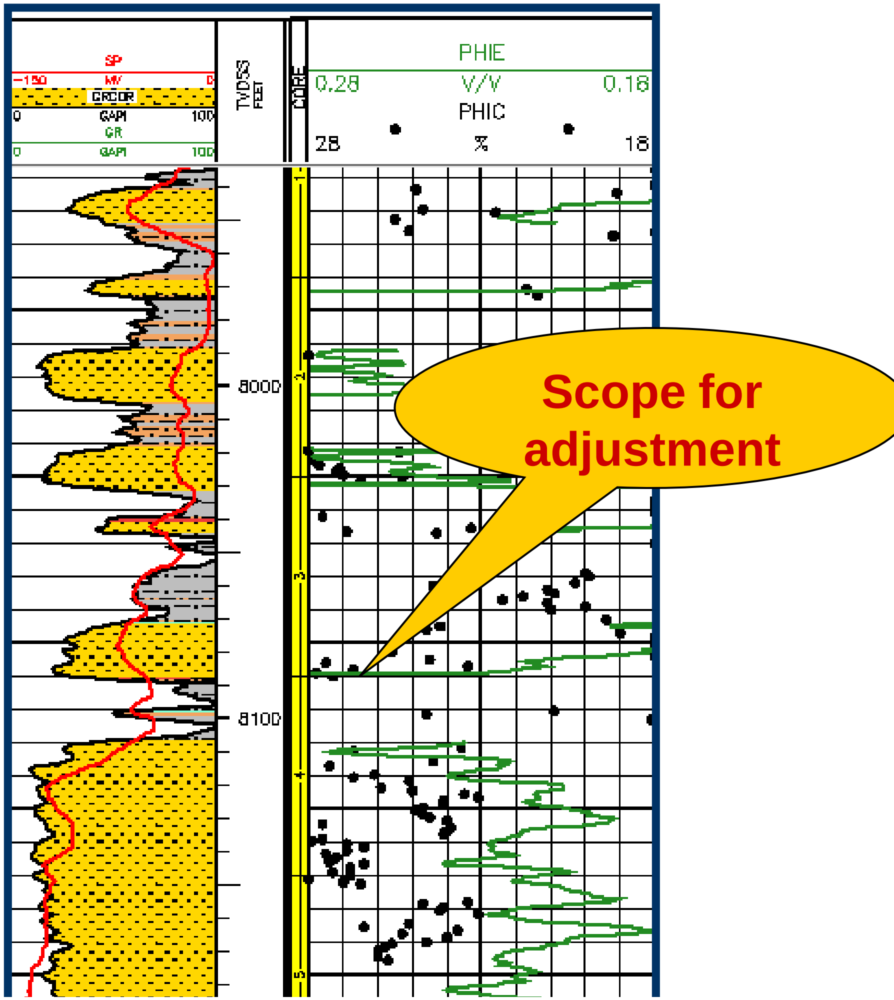
Core Sedimentology



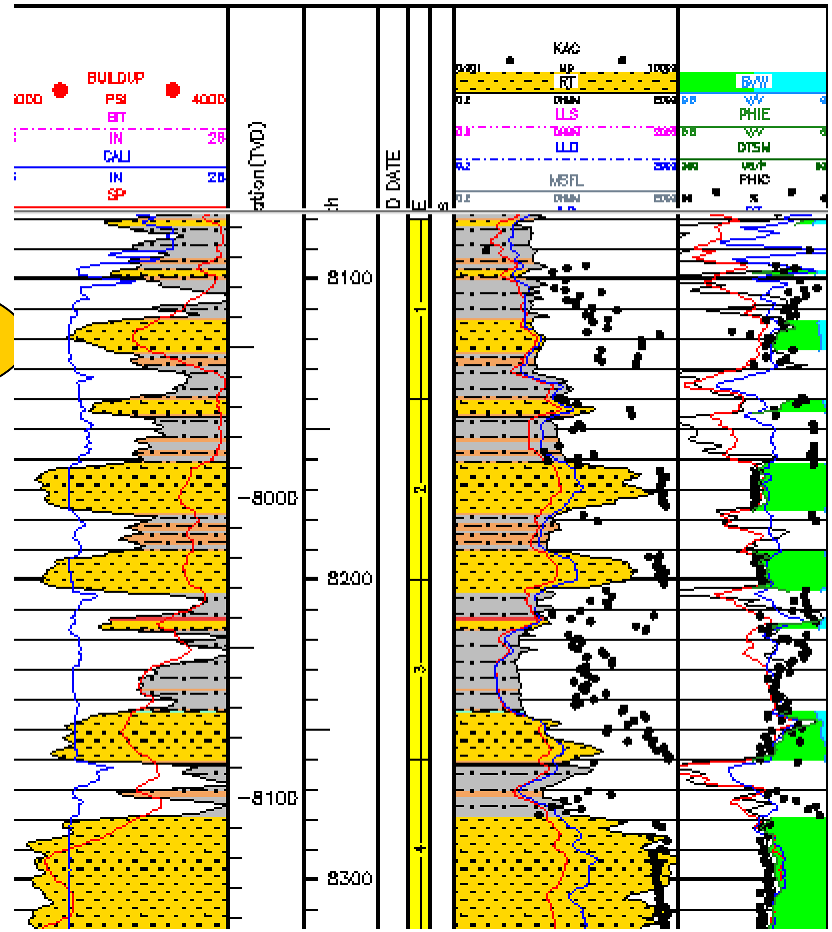
Logs Reprocessed to capture Pay in High Gammaray Intervals



Porosity/Pay Improvement Opportunities



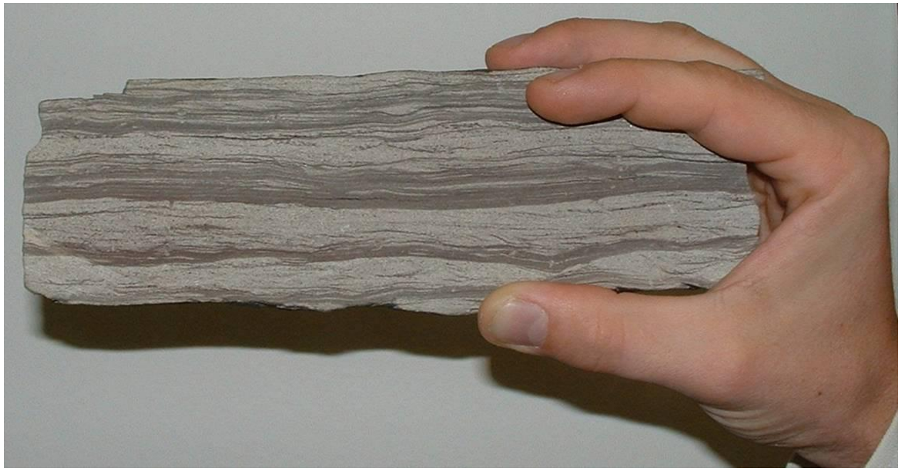
Core Vs Old Log

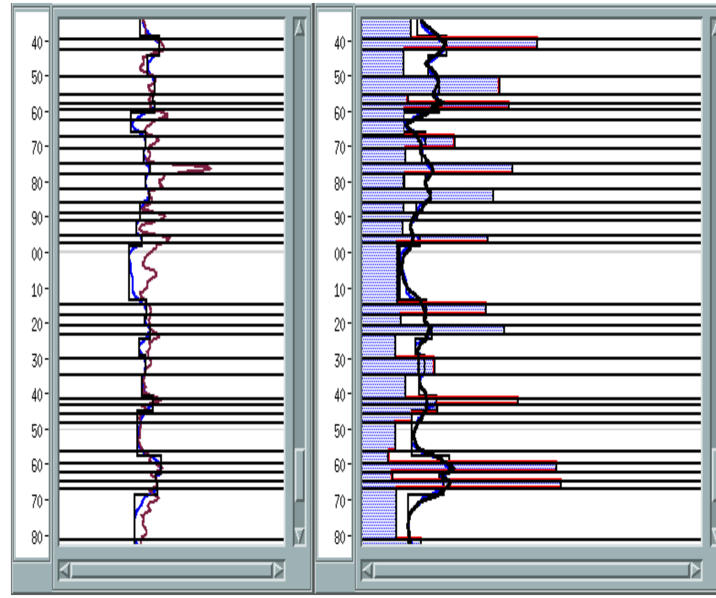


Pay in Shaly Intervals

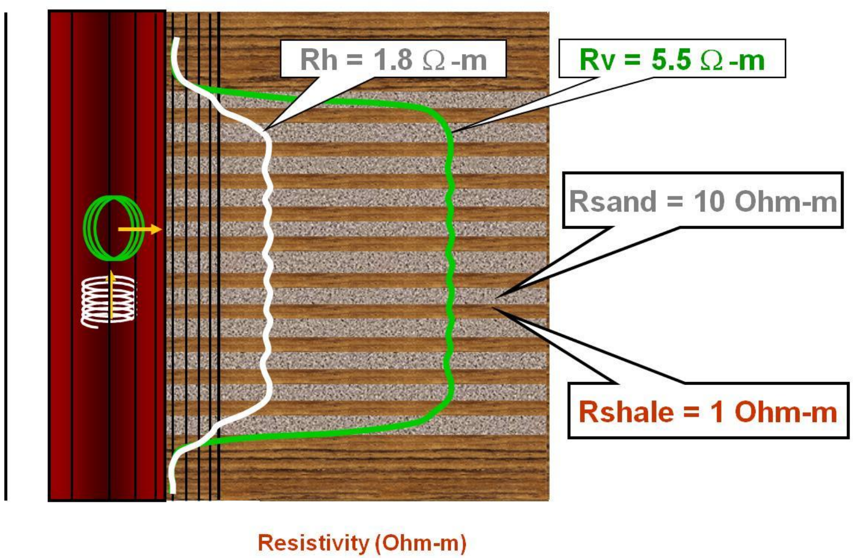
Resistivity Anisotropy

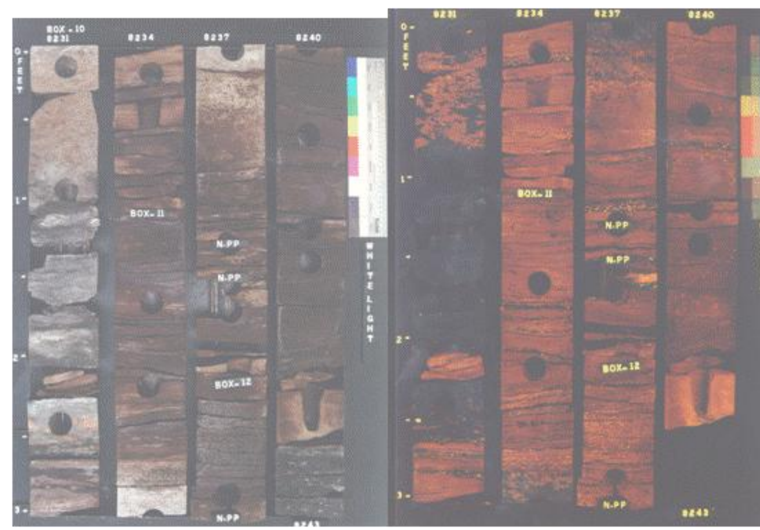
Image based Modeling





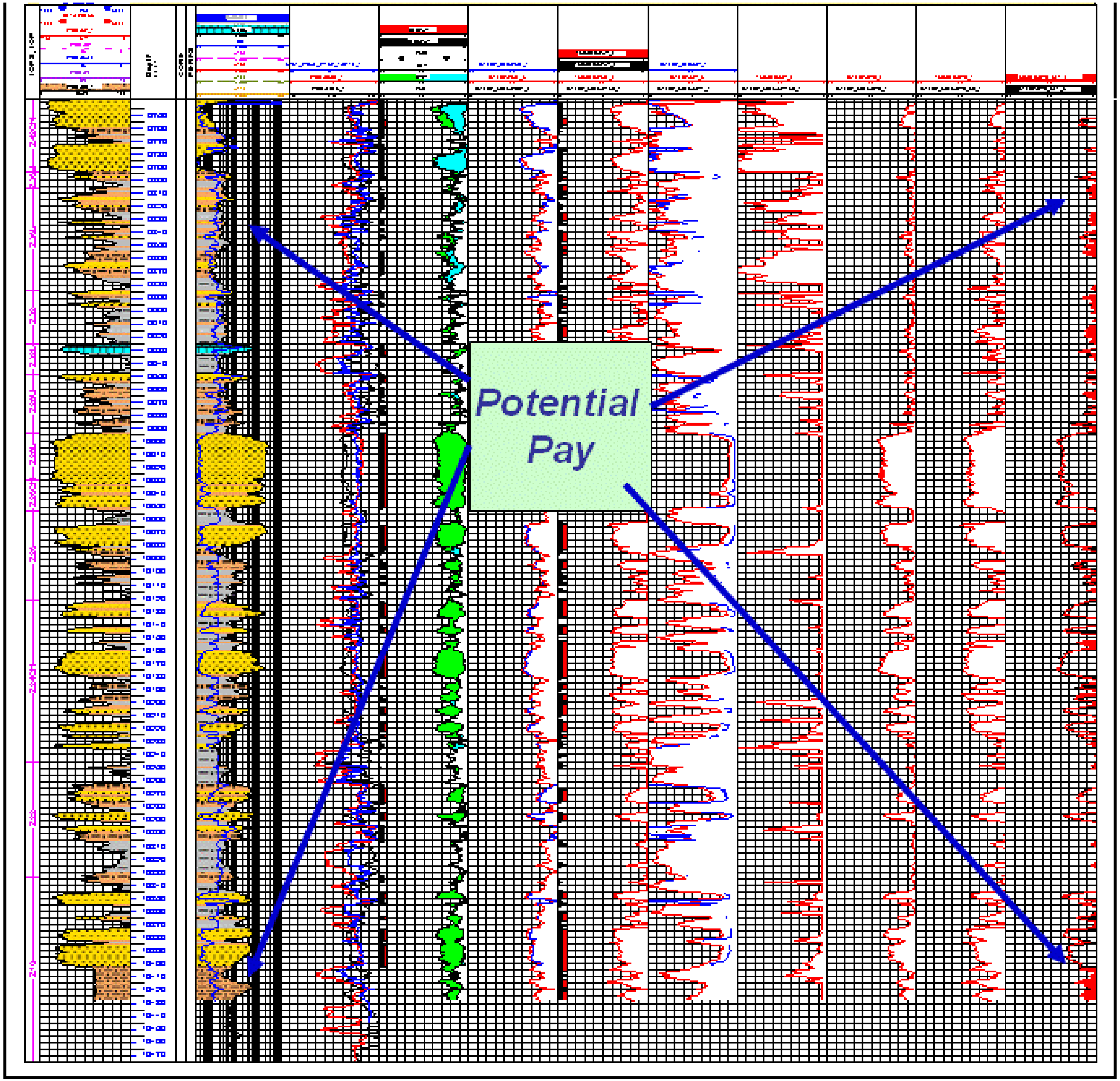
Sand-Shale Resistivity Model



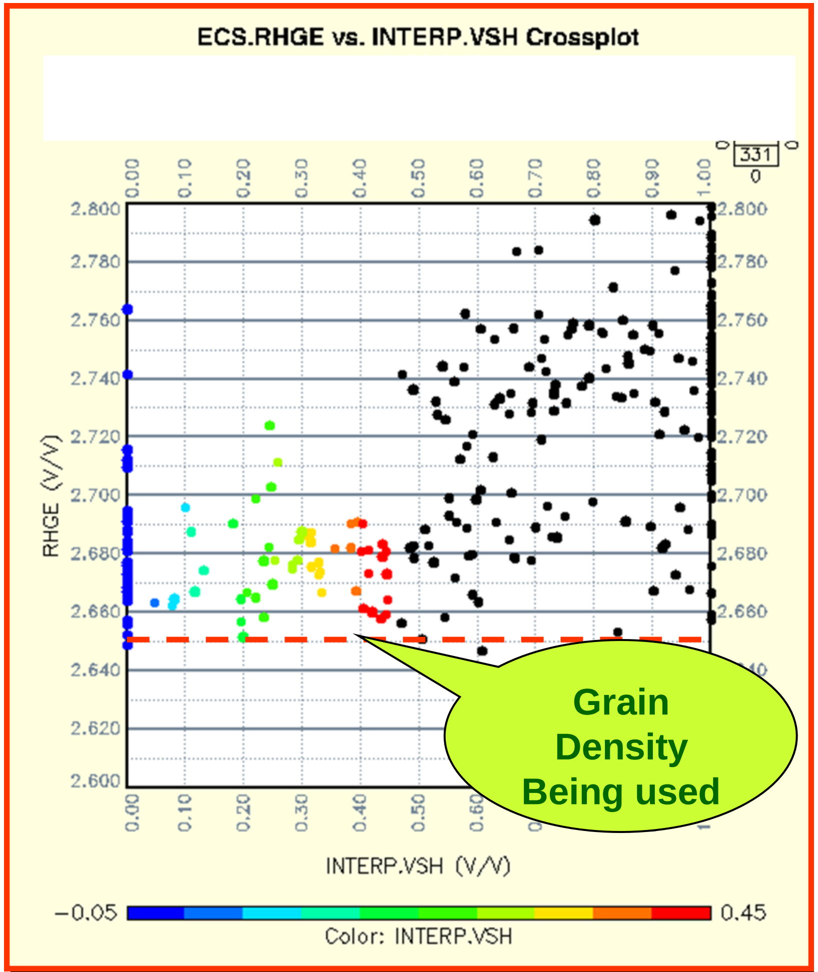


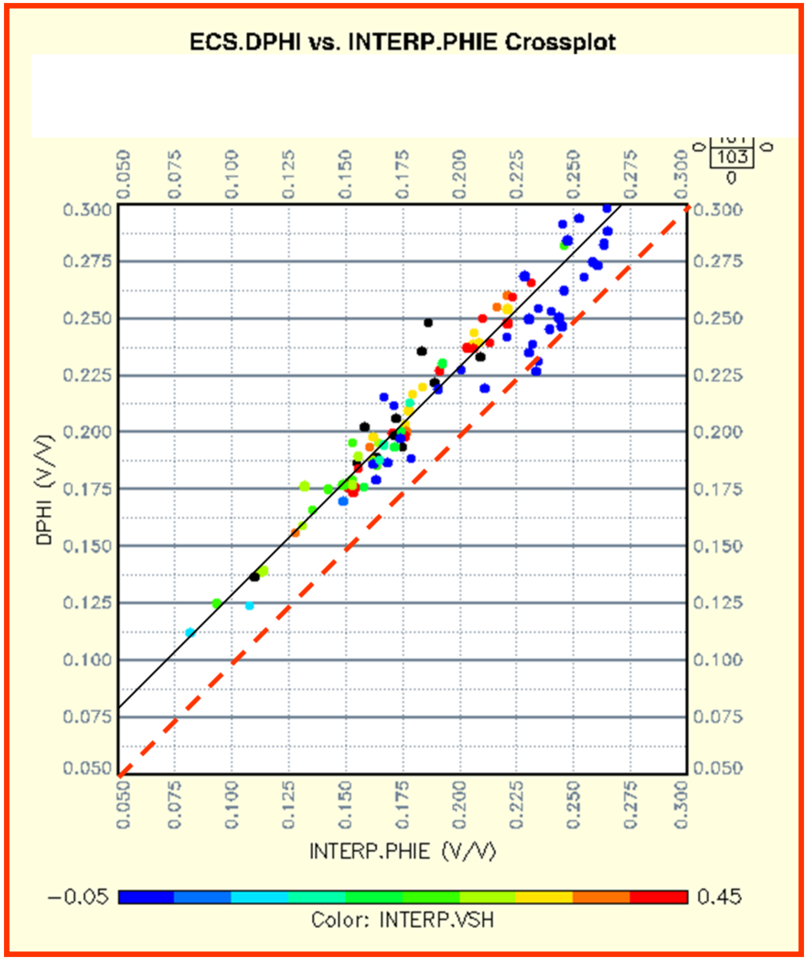
Core

Identified Pay from Resistivity Anisotropy



Matrix density and Porosity from Elemental Analysis

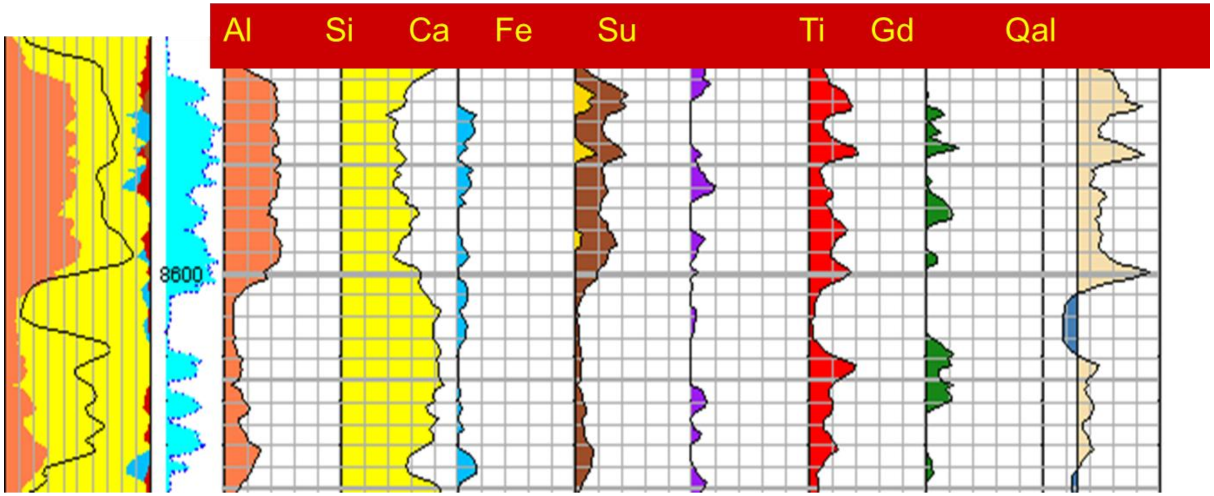




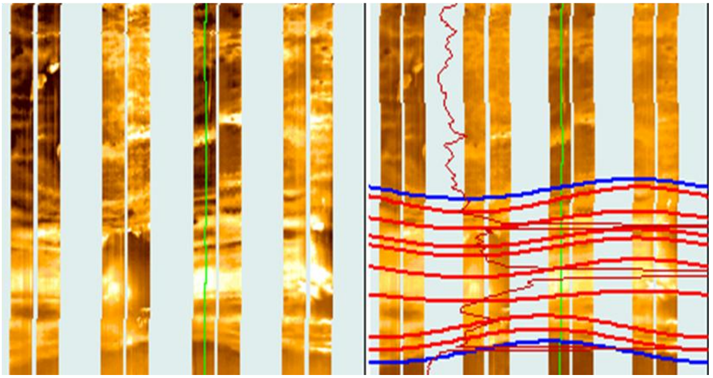
Matrix density from Elemental Analysis Is more than 2.65: Matrix density used In Porosity calculation Is 2.65

Elemental Density porosity is consistently higher: Possible increase in porosity by 2.5 pu

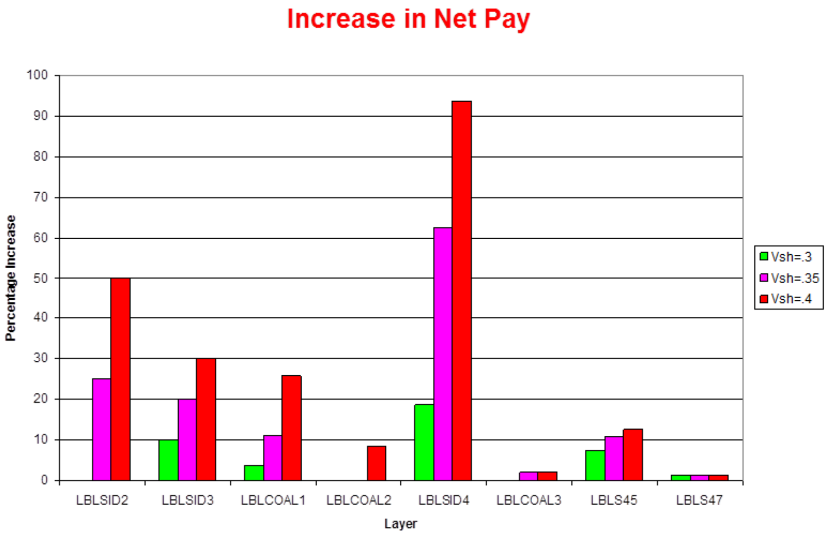
Pay Improvement from Imagelog and Elemental Analysis



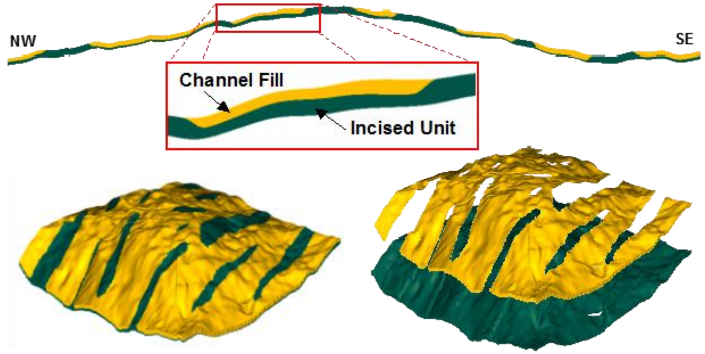
Pay increase related to quality of Sand



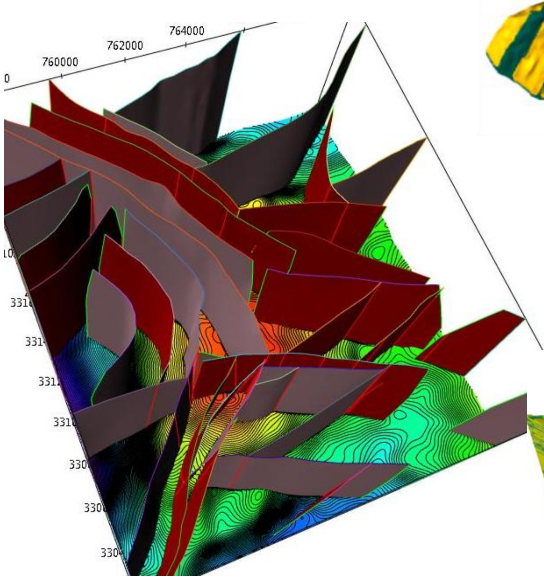
Interval 8618 – 8621 feet



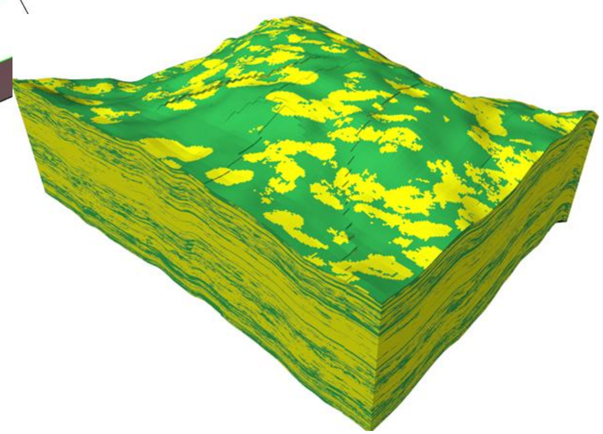
Static Model



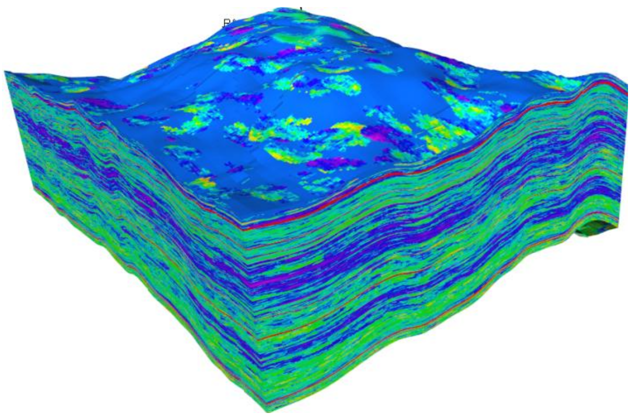
Channel Models



Fault planes



Facies Model



Porosity

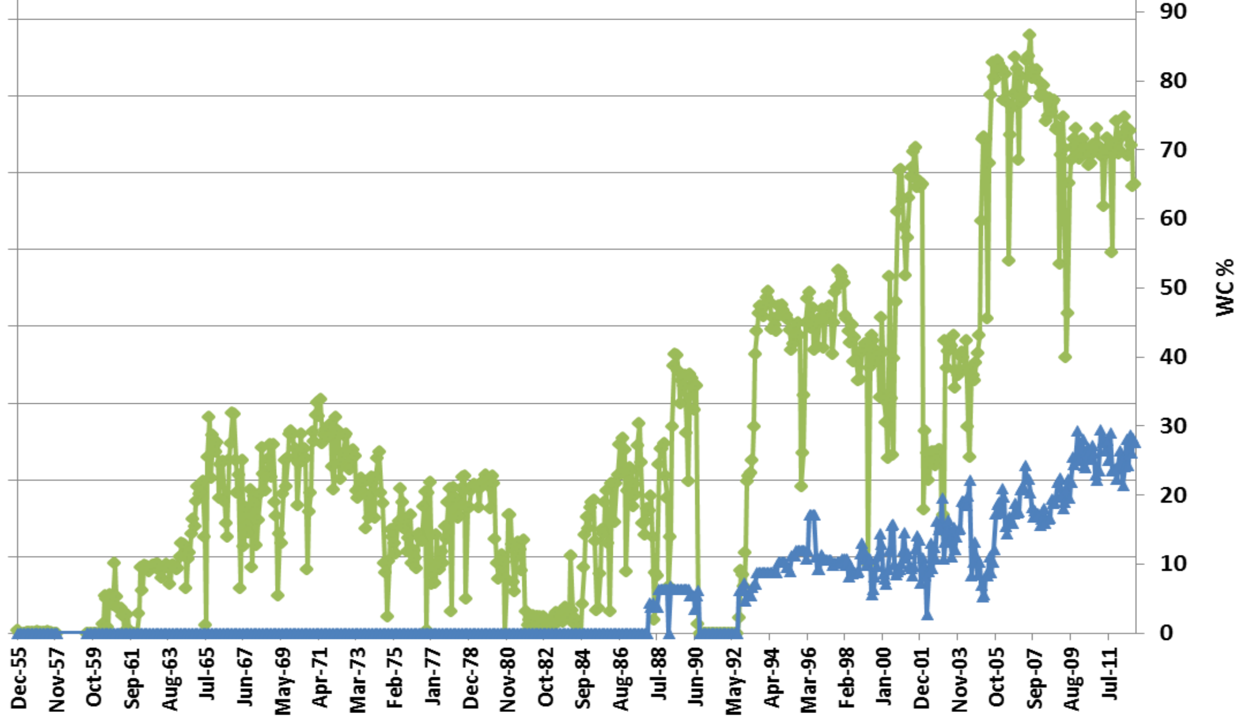
Static and Dynamic Models

- 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

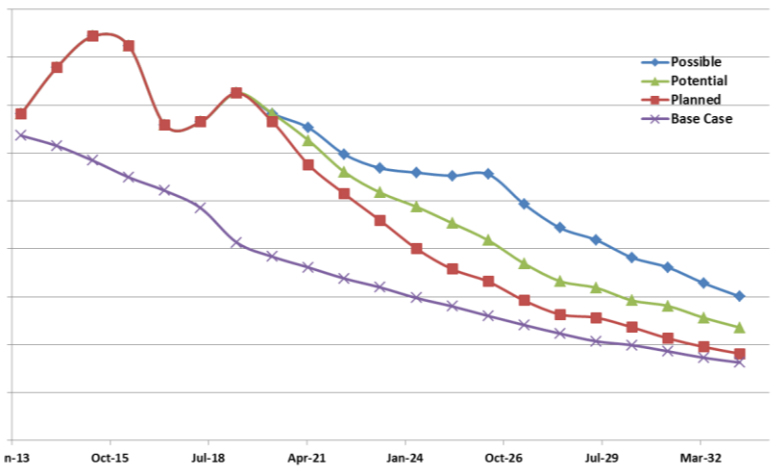
Impact of the study

- 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

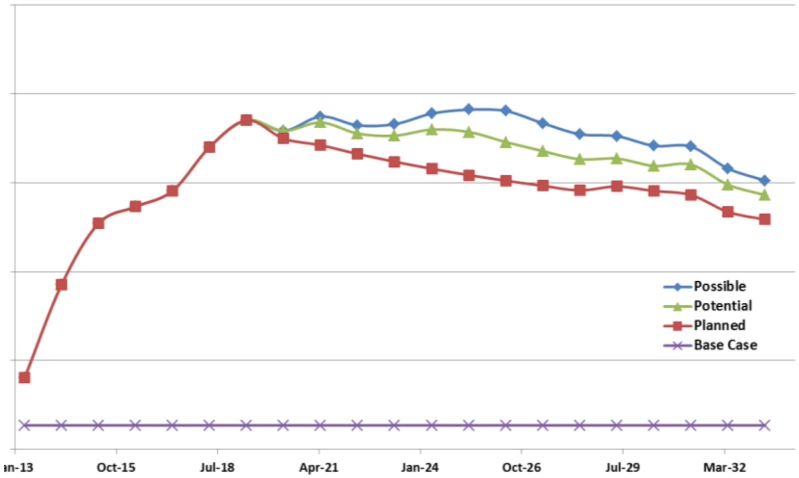
Oil Production



Forecast



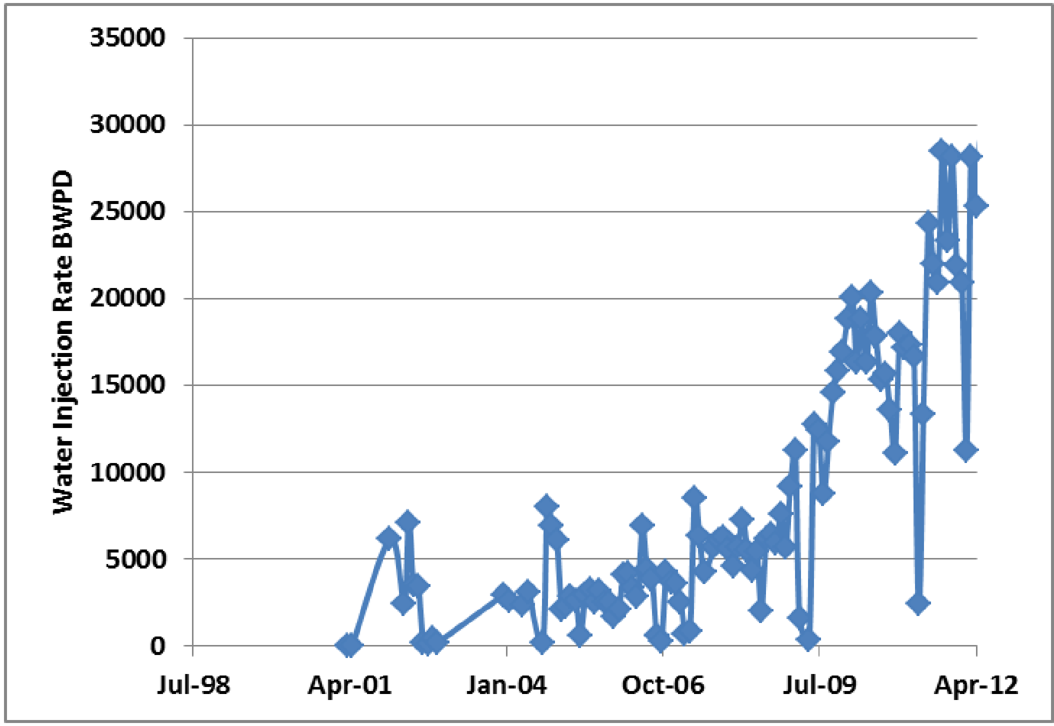
Oil Production



Water Injection

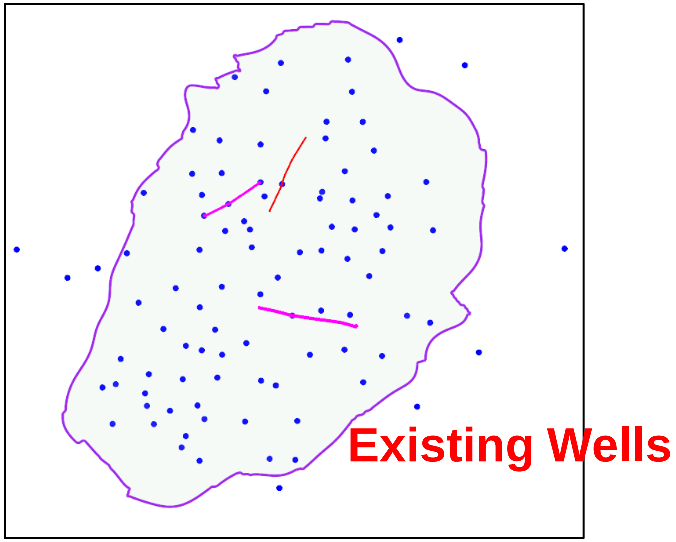
Zubair Injection Performance

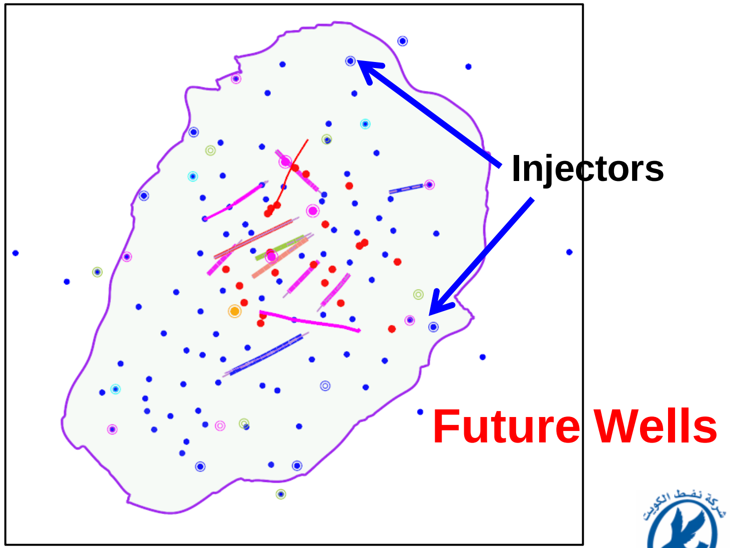
- Peripheral injection in 3 Zones
- Low Injectivity in MZSD and LZSD
- Good injection in thick channels UZSD
- Currently injecting in 4 wells
- Planning to inject in 23 wells
  - High pressure in future wells



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.

Acknowledgements

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- FD (North Kuwait).