Characterization of Major Seals in Zubair Reservoir Leading to Multiple Fluid Contacts: Raudhatain Field, North Kuwait*

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Abstract

The Zubair Formation of Hauterivian – Late Barremian/Early Aptian age is siliciclastic deposit interpreted as a complex unit of initial deltaic origin evolving to estuarine setting with tidal influence. It has been subdivided into three major informal members: lower, middle and upper Zubair. All contain hydrocarbon reservoirs, from where production started in 1955, in the Raudhatain Field, a North Kuwait faulted dome. The structure, shale seals and faults of throw less than 100 feet set the trap.

The Lower Zubair is a transgressive unit unconformably overlying the Ratawi Formation of Late Valanginian age. Deltaic channels and over-bank deposits capped by shales characterize this setting which evolved into shallow marine shoreface calcareous sediments. The Middle Zubair is a highstand deposit within the paralic framework developing a sand-channelized scheme were flooding surfaces cap each sand body, interpreted as of autocyclic origin. The upper member exhibits two distinctive packages: a first lower lowstand sand-dominant estuarine channel system, and a second one transgressive/highstand deposition with high shale-sand ratio content.

The initial interpretation of seals related to the shales bounding the sandstone reservoirs is reviewed here in terms of the integrated study of cores (description, routine core analysis, SCAL), correlations, logs analysis, Repeat Formation Tester (RFT), and production logs. Both the static and dynamic models were also reviewed.

The seals are identified as (1) Shale Seals of homogeneous lithology, bounding reservoirs with very different pressures, correlatable across the field as seen in all the three members, (2) Shale Seals which becomes silty but still maintain its character as a "seal package", recognizable within the Upper and Middle Zubair members, (3) Diagenetic Seals that occurs as calcareous sandstones/sandy limestones reduce the permeability and become tight and sealing reservoirs, identified at the top of upper and lower Zubair, (4) Tar mat occurrences that behave as seals in clean sandstones and allows us to identify three types of fluids which were documented at the uppermost Zubair sand-channel package and at the Middle Zubair. They are regarded as effective in the field, nevertheless continuous monitoring is on going in order to identify its possible damage/breach.

Selected References

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- Zubair Pressures and Seals
- Zubair OWC
- Zubair Tar Mats
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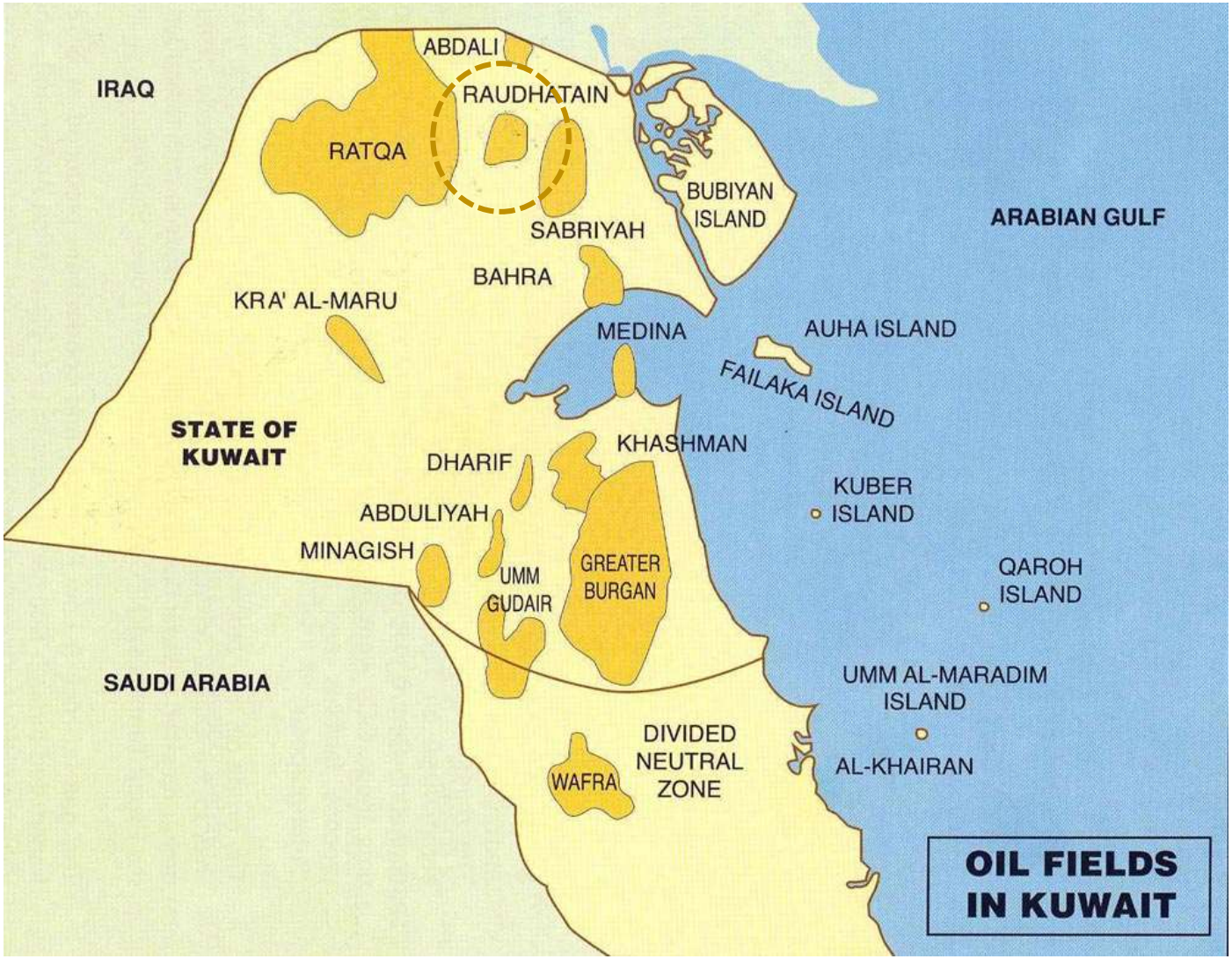
Thanks to the organizers for the invitation to present this paper, especially to Ghaida Al-Sahlan, AAPG_KOC representative.

Introduction - Oil Fields in Kuwait

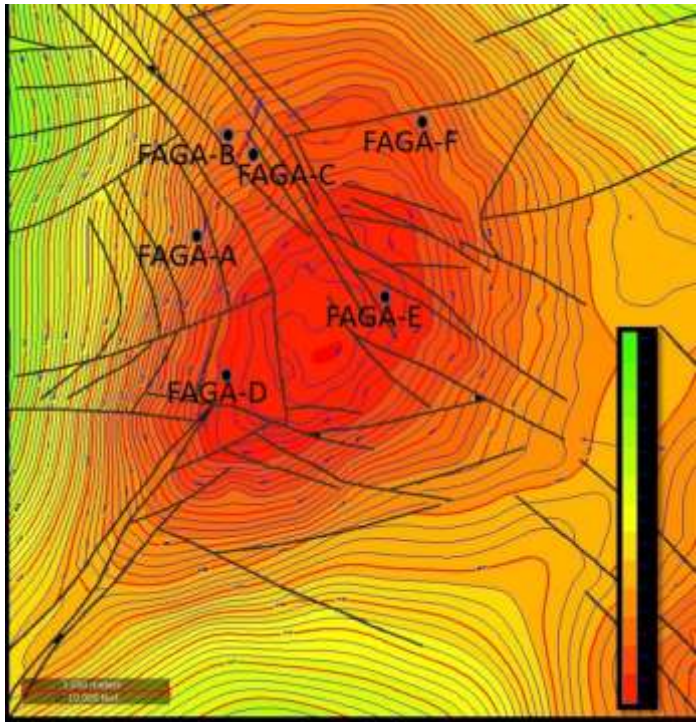


Source of Map: State of Kuwait, Ministry of Oil Web site. http://www.moo.gov.kw/About-Us/Programs/Technical-Affairs/Kuwait-Oil-Field-Map.aspx

Introduction

Raudhatain Oil Field – North Kuwait Zubair Reservoir

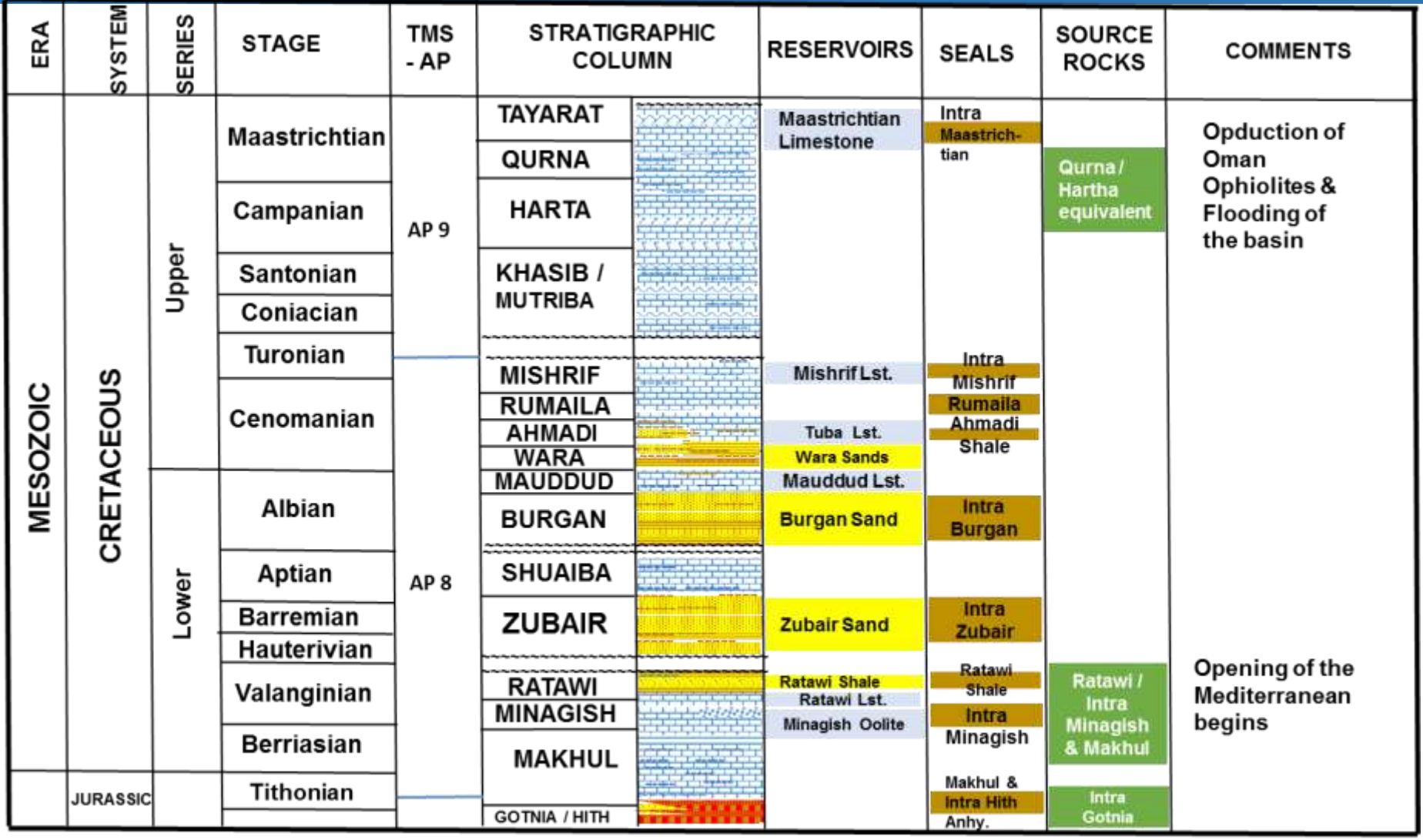
- **Structure: faulted dome**
- **Year of Discovery: 1955**
- **Reservoir: Zubair, Cretaceous**
- **Principal rock type: clastic sediments, total column thickness: 1400 ft., with excellent quality sandstone reservoir.**
- **Environment: Tidal Dominated, Shoreline system.**



- **Average net thickness per layer: 10 – 150 ft.**
- **Porosity range: 15 – 22 %. Permeability range in pay: 25 – 2500mD**

Introduction

Kuwait General Cretaceous Stratigraphy



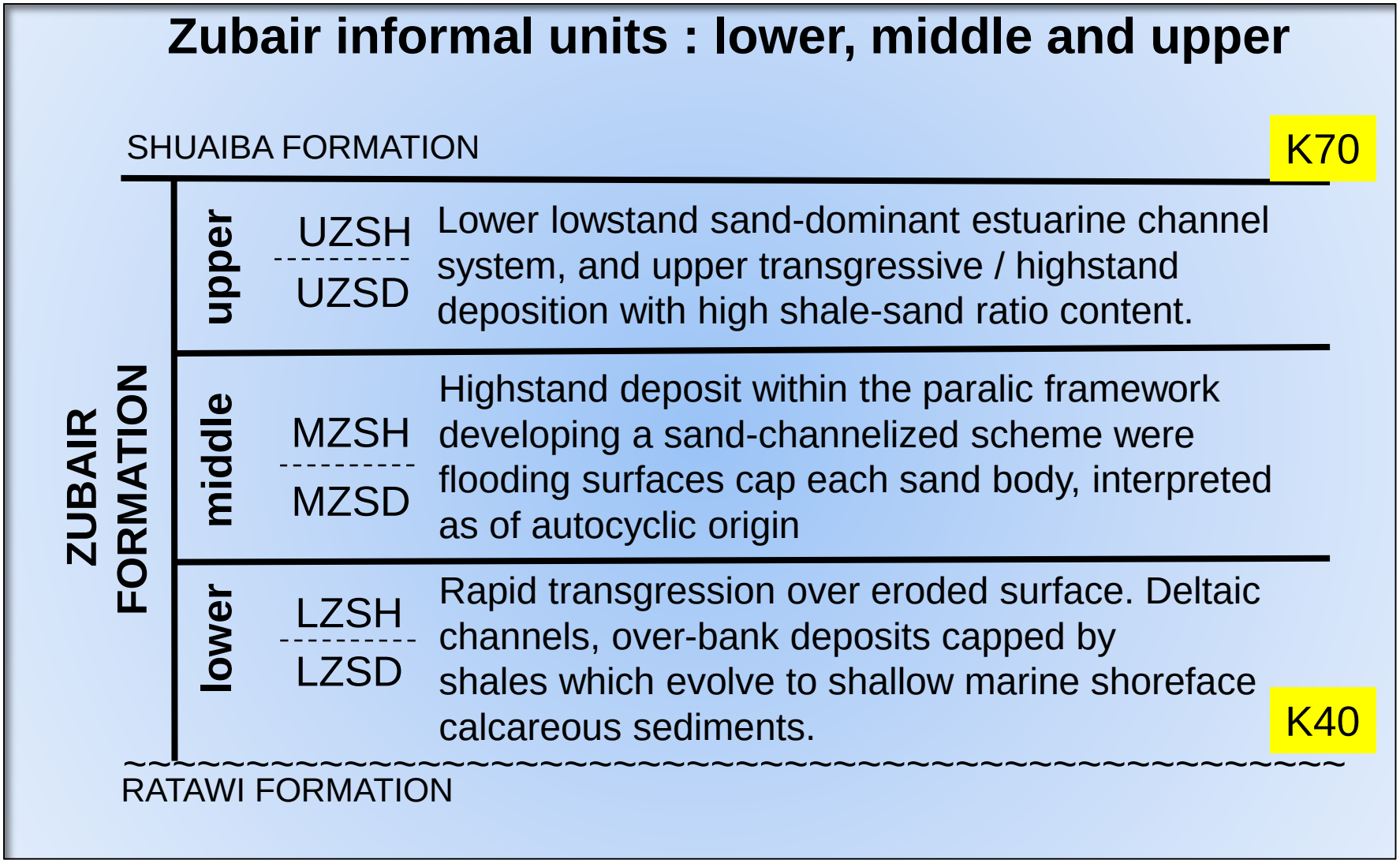
Modified from Stratigraphic Section of Kuwait, KOC Exploration Studies Internal report, 2012

Not to scale

TMS-AP: Tectonostratigraphic Megasequences of the Arabian Plate. After Sharland et al., 2001. GeoArabia Special Pub, 2.

Introduction

Stratigraphy – Zubair Formation



Galea Alvarez, 2015

Introduction
Sequence Stratigraphy - MFS and Coastal Onlap

Comparison of Ages of Maximum Flooding Surfaces, Arabian Plate. Modified from Al - Husseini (2007). The equivalent Coastal Onlaps after Snedden & Liu, 2010

Sharland et al. (2001, 2004*)						Haq et al. (1988)	Haq and Al-Qahtani (2005)	Simmons et al. (2007). Age from Gradstein et al. (2004)		Coastal Onlap - Snedden & Liu, 2010
MFS	Era	Period	Epoch	Stage	Age	Age	Age	Age	Stage	
K90	Mesozoic	Cretaceous	Early	Early Albian	111	107	111	110	Early Albian	
K80				Mid-Aptian	116	?111.0	117	119	Mid-Aptian	Ap4
K70				Early Aptian	120	?111.0	122.5	124.5	Early Aptian	Ap1 – Ap2 – Ap3
K60				Late Barremian	123	114	126	125.5	Late Barremian	Barr 6
K50				Early Barremian	126	116.5	129	129	Early Barremian	Barr 1-4
K40				Late? Hauterivian	129	118	132	134.5	Early Hauterivian	Ha1 – Ha2
K30				Early Valanginian	136	127.5	139	140	Early Valanginian	Va1- Va2
K20				Late Berriasian	138	128.75	141	142	Late Berriasian	
K10				Early Berriasian	143	132.5	144	145	Early Berriasian	

Zubair

Introduction

Sequence Stratigraphy – MFS _ Zubair Formation

MFS K 70	**Early Aptian. At the shale interval of the Shuaiba Z64 (Limestones & Shales). (Cores and logs), on top of UZSH. Planktonic test of possible *Praehedbergella*. The larger foraminifera *Palorbitolina lenticularis*, *Mesorbitolina* sp., *Choffatella decipiens*, *Everticyclammina* sp., and *Melathrokerion valserinensis (Core study)***
MFS K 60	**Late Barremian. UZSH – Z62 Shale: "bloom" of dinoflagellates, and the foraminifera *Choffatella decipiens* (eustatic sea level change). (Core *study*)**
MFS K50	**Early Barremian. FS at LZSH -Z22, with "bloom" of dinoflagellates, Less Pollen & Spores counts, and high palynology diversity (Core) The MZSH - Z28 Shale unit yields dinoflagellates, and high palynologycal diversity, but no other planktonic microfossils were found. Recorded occurrence of the dinoflagellate *Psedoceratium anaphrissum* (Sarjeant), known from early-late Barremian at MZSH. (Core *study*)**
MFS K 40	**Early Hauterivian. We can assume that the LZSD - Z02, with clear marine fossils (Ichnofossils, Polychaetes, bivalve fragments), Oolites and peloids. (Core *study*)**

Zubair Lithotypes Based on Core Descriptions

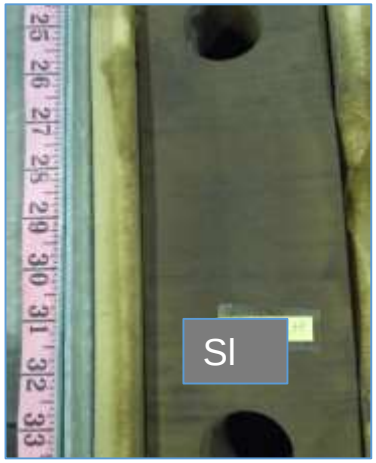
Zubair lithotypes were first described by Kostic & Hoppe, 2010. Associated facies, sedimentary environment interpretations, reservoir quality were described. Some of them are presented here

Sandstones: very good reservoir quality

Sx – Cross-stratified sandstone. The cross-stratification includes simple sandy foresets and mud-draped forms

Sr– Ripple cross laminated sandstone

Sl – Parallel laminated sandstone (Rare burrows)

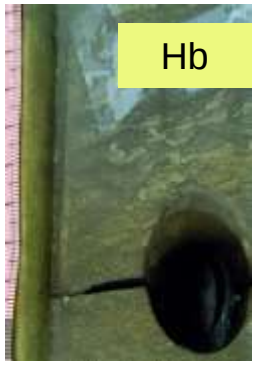


Sm – Massive sandstone. Micro-bioturbation is common

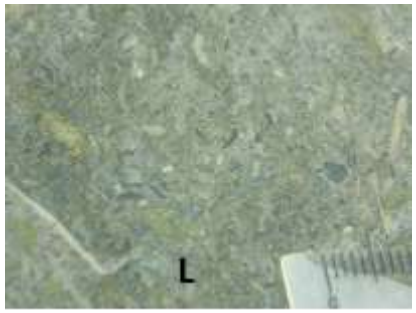
Zubair Lithotypes Based on Core Descriptions

Sandstones and Limestones: poor reservoir quality

Hl – Interlaminated sandstone and shale. Locally contain abundant carbonaceous debris and amber fragments



Hb – Bioturbated heterolithics comprising burrow-mixed sandstone and shale



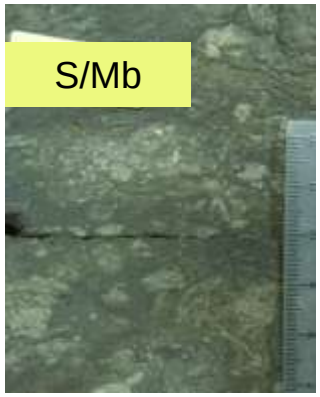
L – Limestone, sandy limestone, dolomitized limestone and dolomite

Reference: Kostic, Boris & Hoppe, Markus. 2010. Sedimentological, petrographical and reservoir quality evaluation of the Zubair Formation (Raudhatain Field, Kuwait) and implications for reservoir modelling. Final Report January 2010, Project for KOC. ResLab Emirates Link ResLab LLC, Badley Ashton & Associates, Millennia Stratigraphic Consultants. Unpublished report.

Zubair Lithotypes Based on Core Descriptions

Sandstones and siltstones: poor reservoir quality

S/Mb – Bioturbated argillaceous siltstones and sandstones with common deposit feeder traces

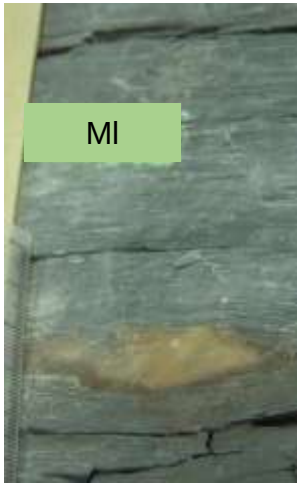


Sb – Mud-rich burrowed sandstones with diverse ichnofauna, including both dwelling and deposit feeder traces. According to amount, variation and density of Ichnofossils, they are identified as Sb1 (Less), Sb2 (Medium), and Sb3 (abundant)

Zubair Lithotypes Based on Core Descriptions

Mudstones (shales): Seals

Ml – Finely laminated mudstone (shale), locally contains abundant carbonaceous debris and amber fragments

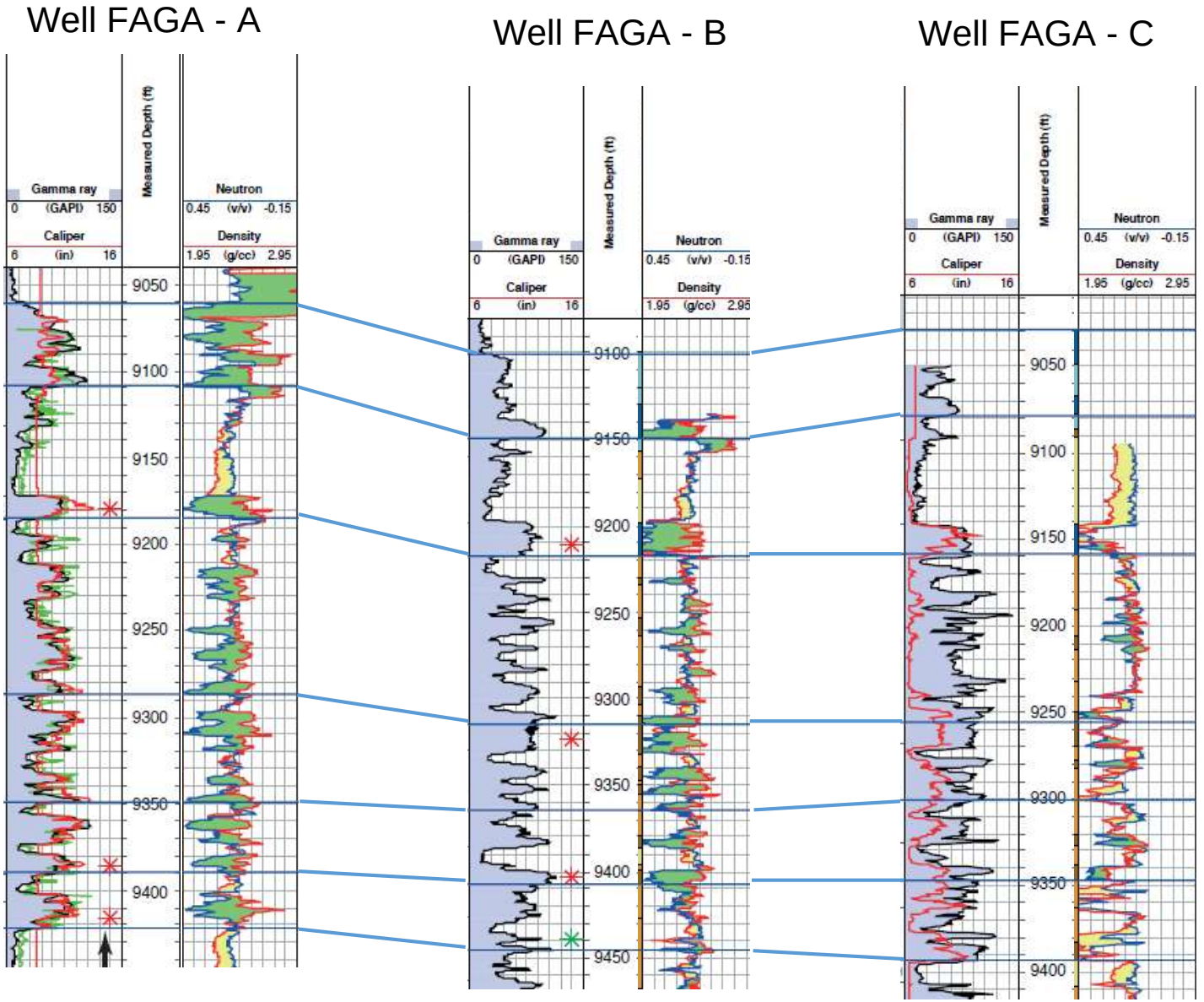


Mb – Bioturbated mudstone (shale)

C – Carbonaceous rich mudstone (shale). Coal

M – Apparently massive mudstone (shale)

Zubair – Seals
Correlation. North West of the Field



Modified from KOC Internal Report 2010

* Barrier to vertical fluid flow. RFT pressure break.

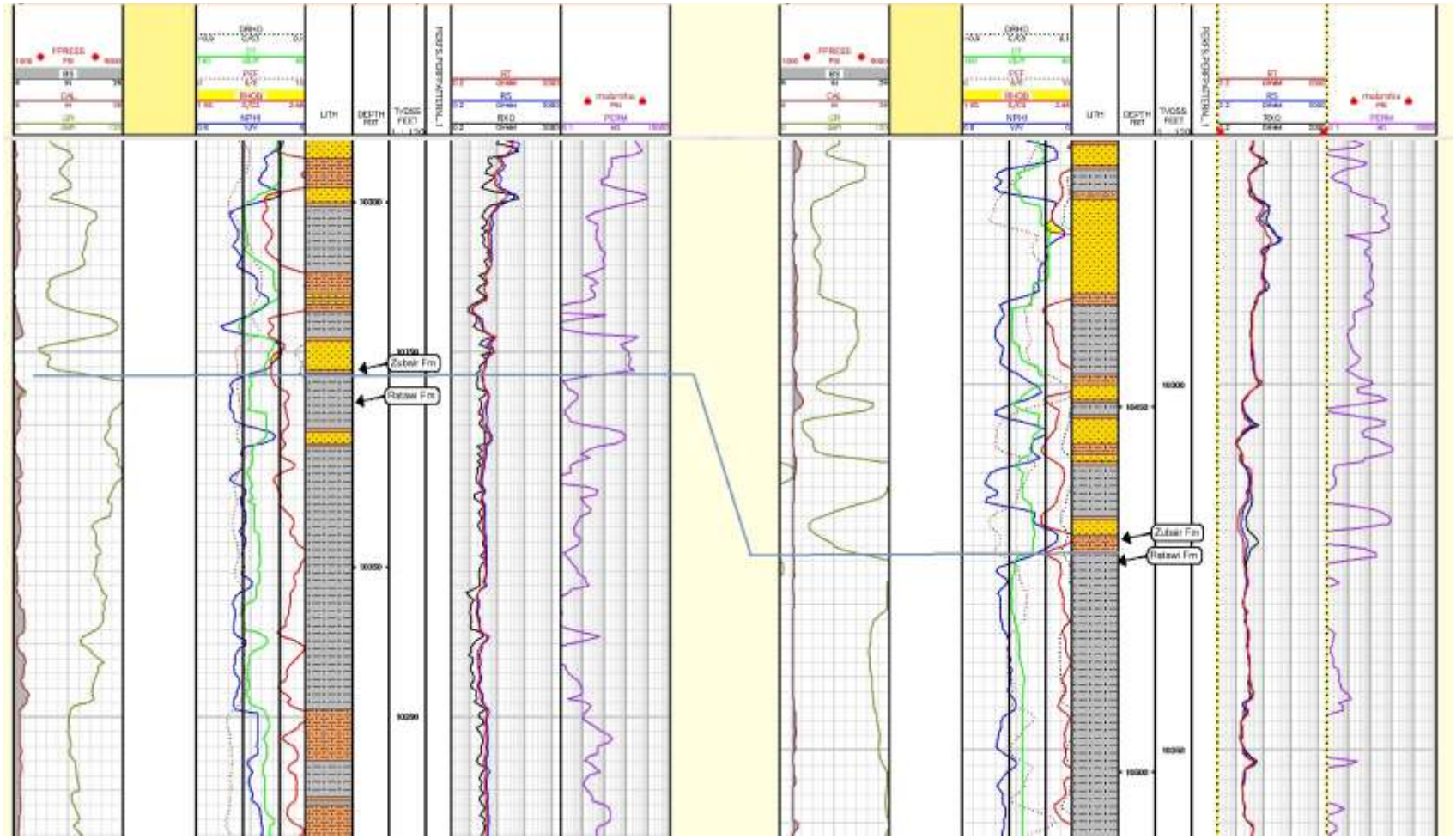
* Baffle to vertical fluid flow. RFT pressure break

Lower Zubair - Seals

Zubair – Ratawi Boundary. West of the Field

Well FAGA - A (NW)

Well FAGA - D (SW)

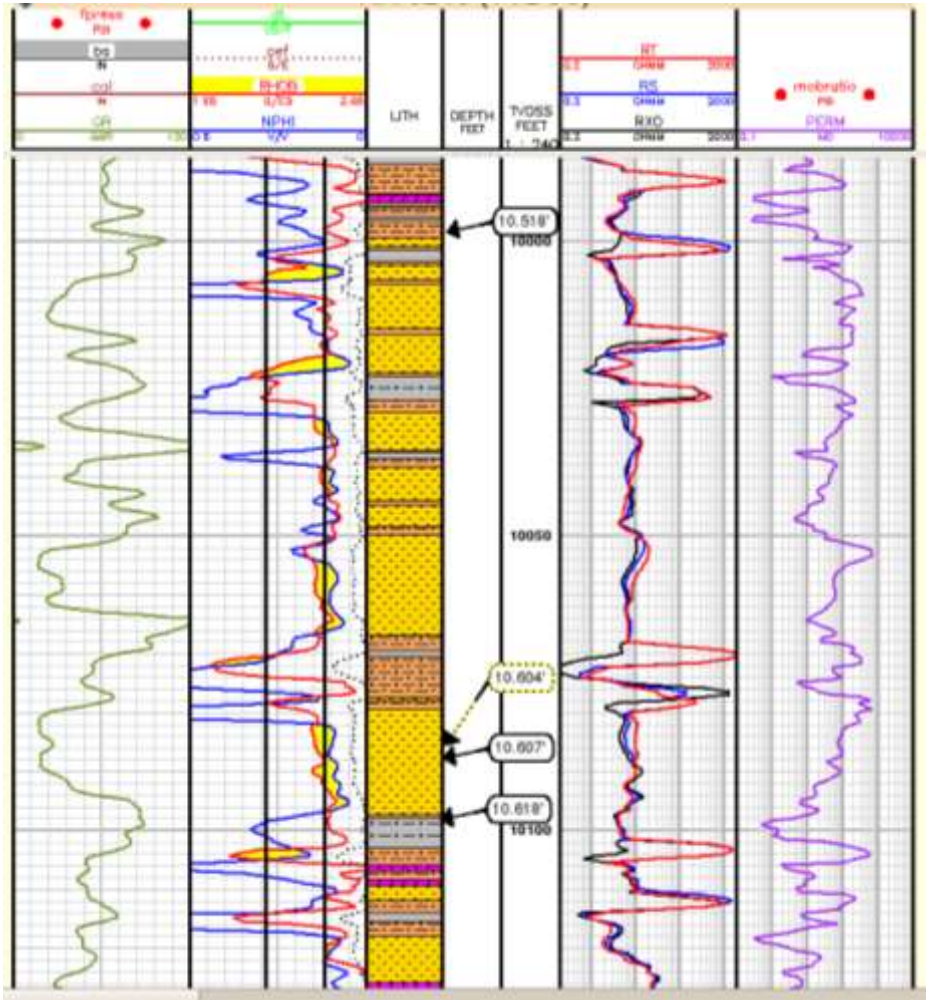


Modified from KOC Internal Report 2015

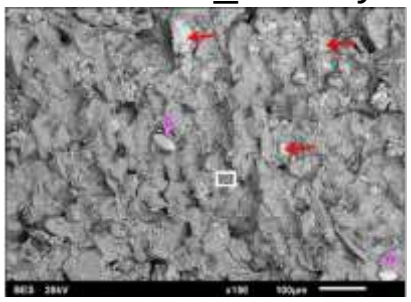
Lower Zubair - Seals

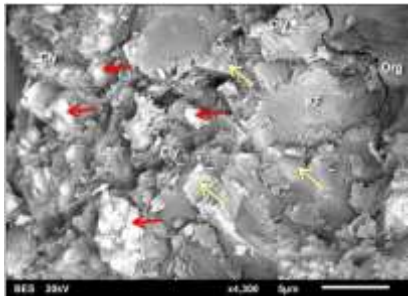
Zubair – SEM: Diagenetic, lithological changes and shale type

Well FAGA - E (Center of the Field)

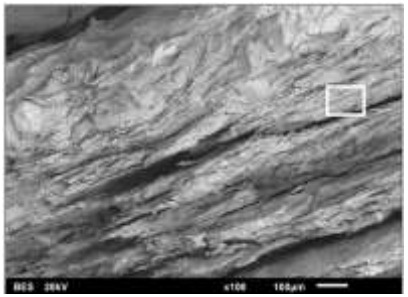


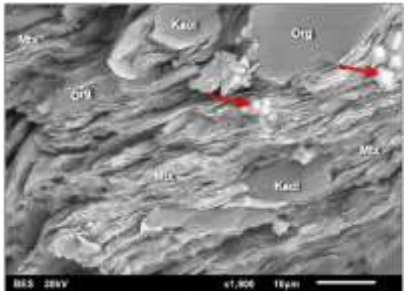
10518’ – LZ_Z10 layer: calcareous cement



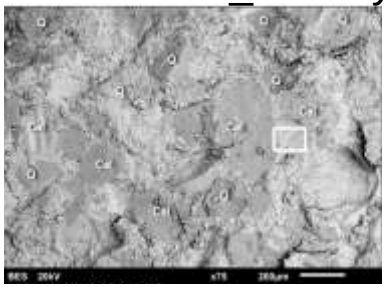


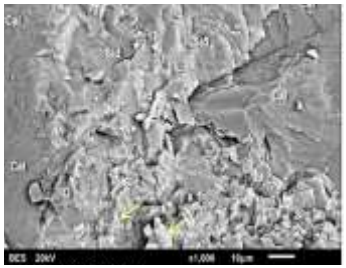
10607’ – LZ_Z04 layer: coarsening upward sh





10618’ – LZ_Z02 layer: shale

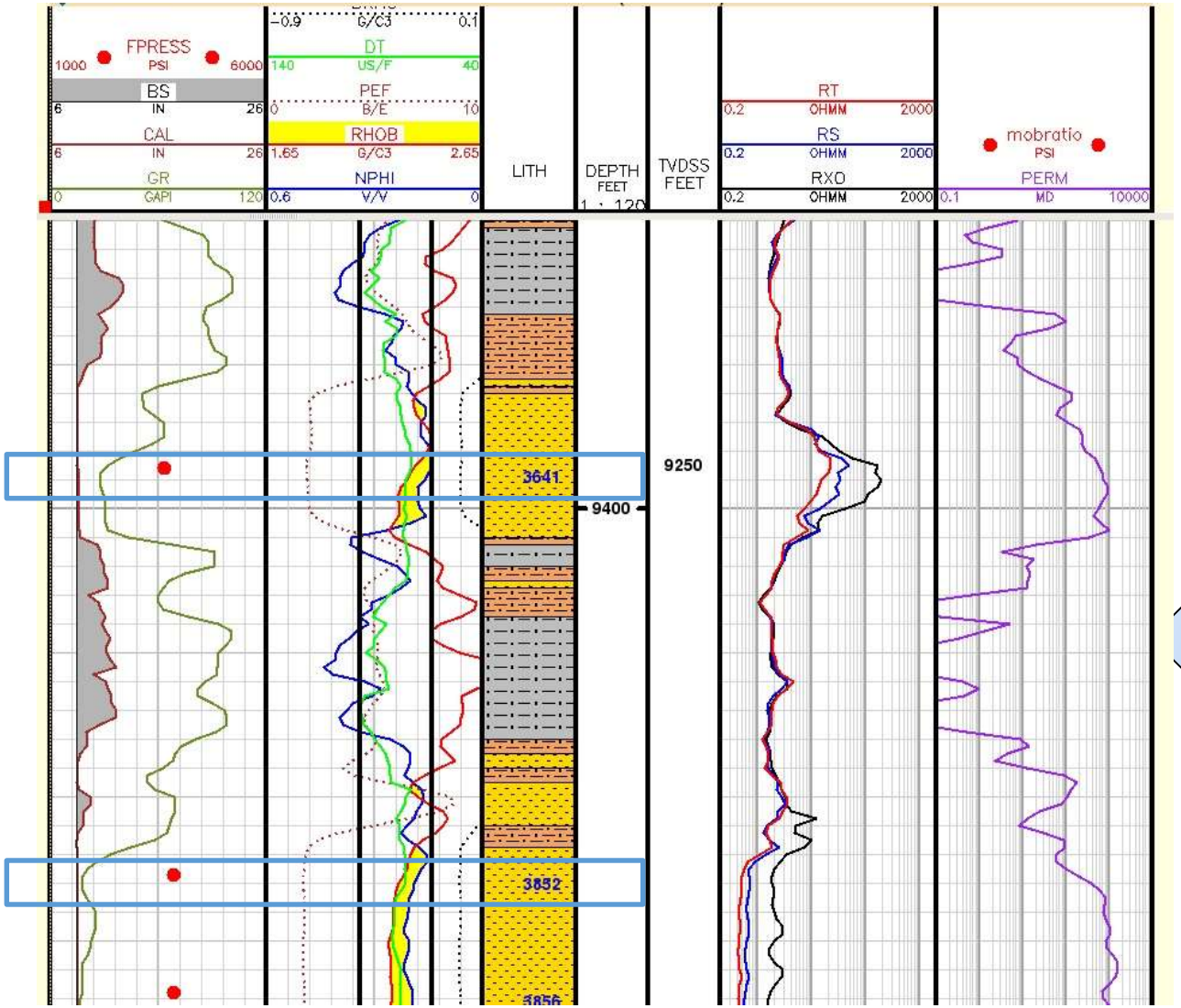




SEM from KOC Internal report 2011.

Upper Zubair - Seals

WELL FAGA – A (West of the Field)

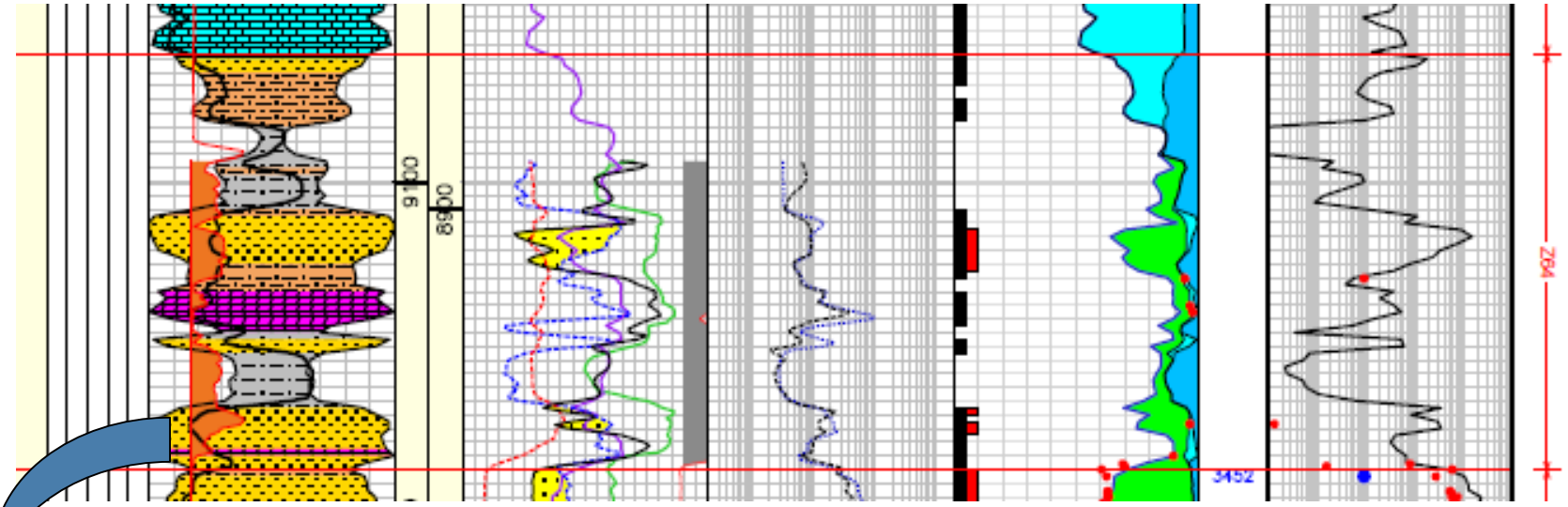


Zubair – Changes in Permeability and F. Pressure

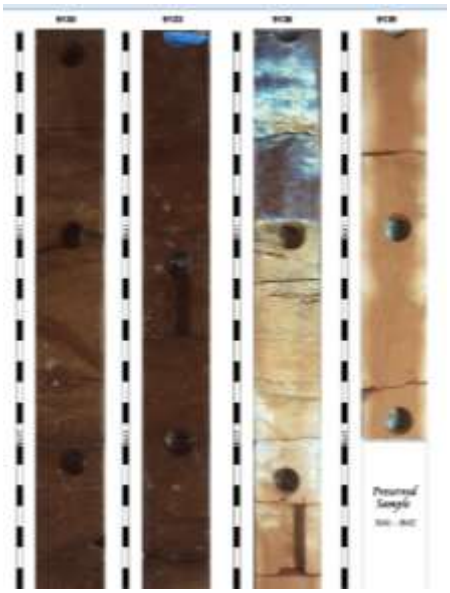
Upper Zubair Z51 Shale

Upper Zubair - Seals

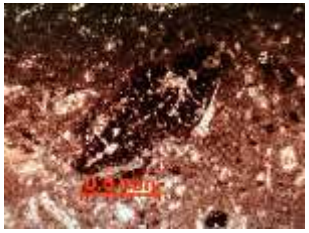
WELL FAGA - F (N of the Field)



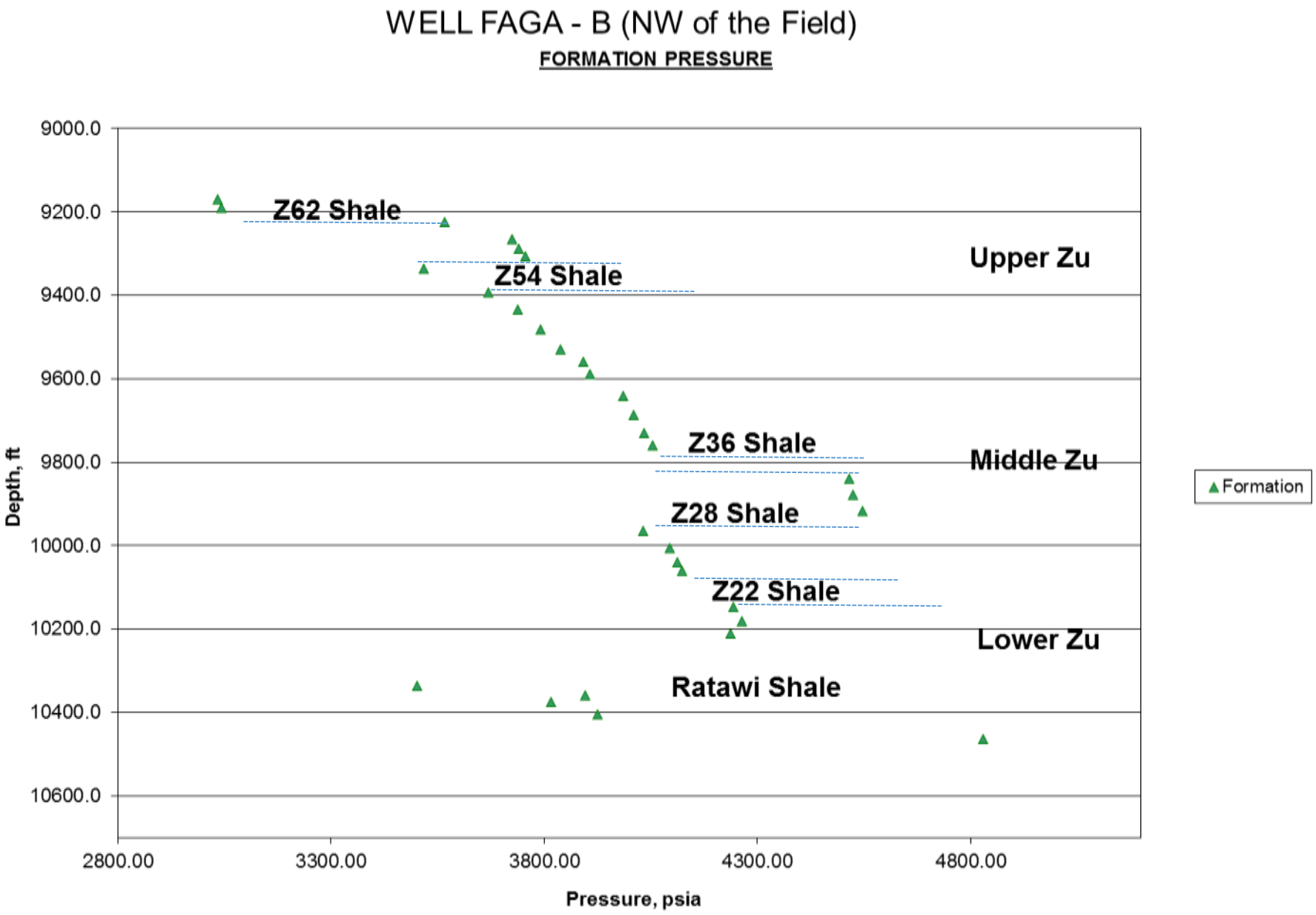
Core Photo –
UV Light



Photomicrographs from Th.Sections. 9117’

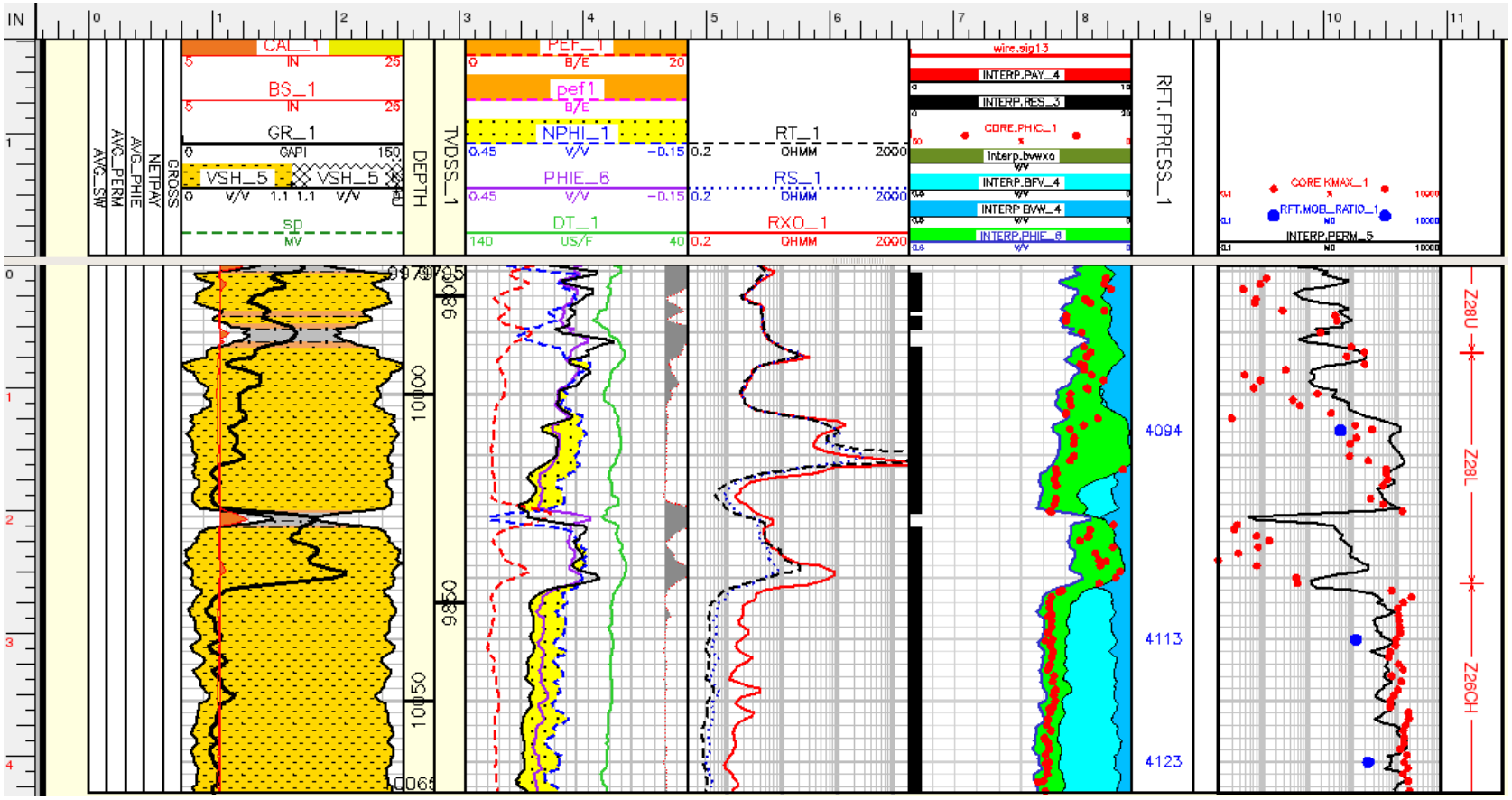


Zubair – Pressure Changes and Seals



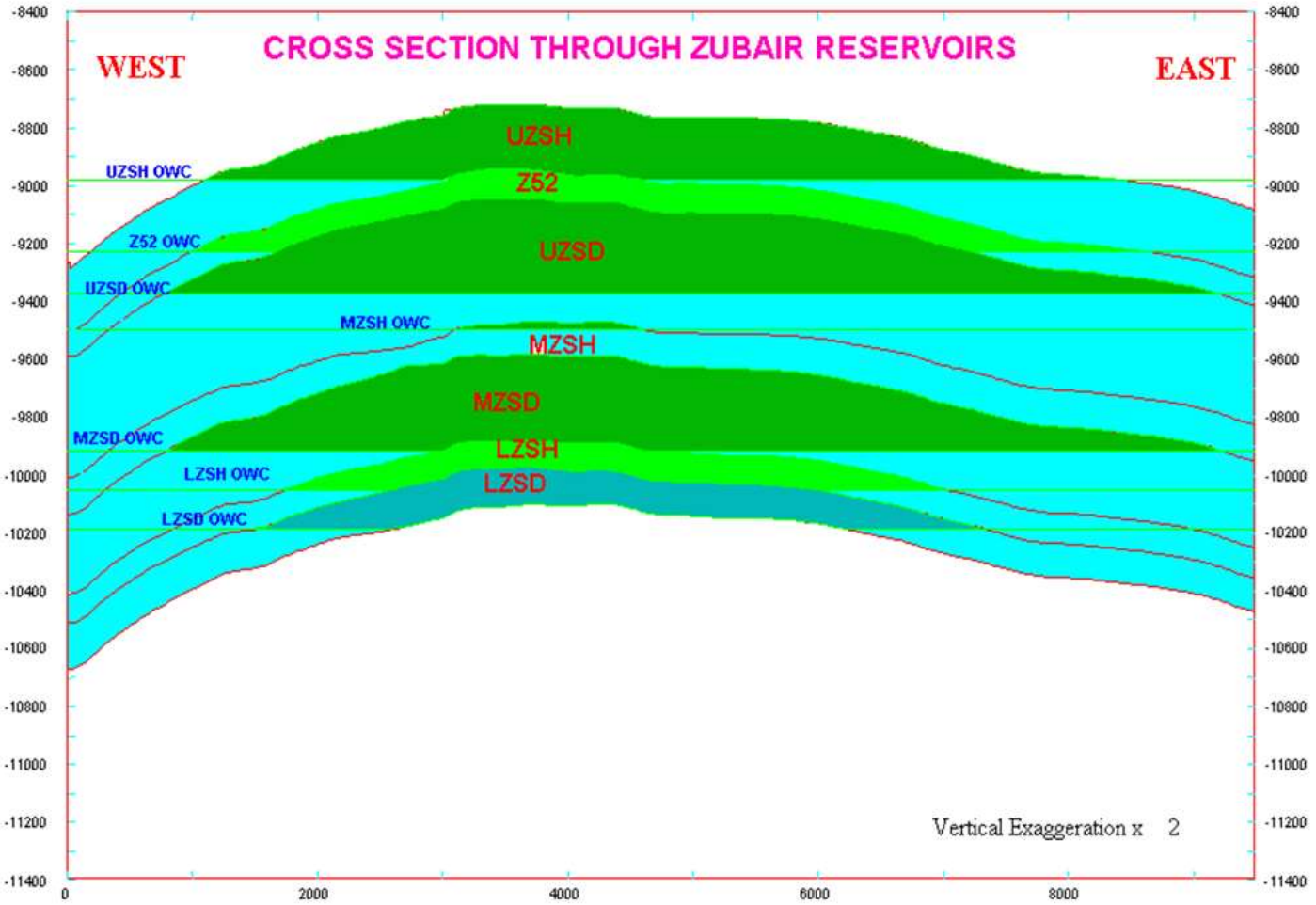
Zubair - OWC

WELL FAGA - B (NW of the Field)



Middle Zubair Sands

Zubair - OWC



The cross section shows the multiple fluid contacts

Illustration modified from Azim, et al. 2006.SPE 101303

Zubair - Tar mats

Tar mats

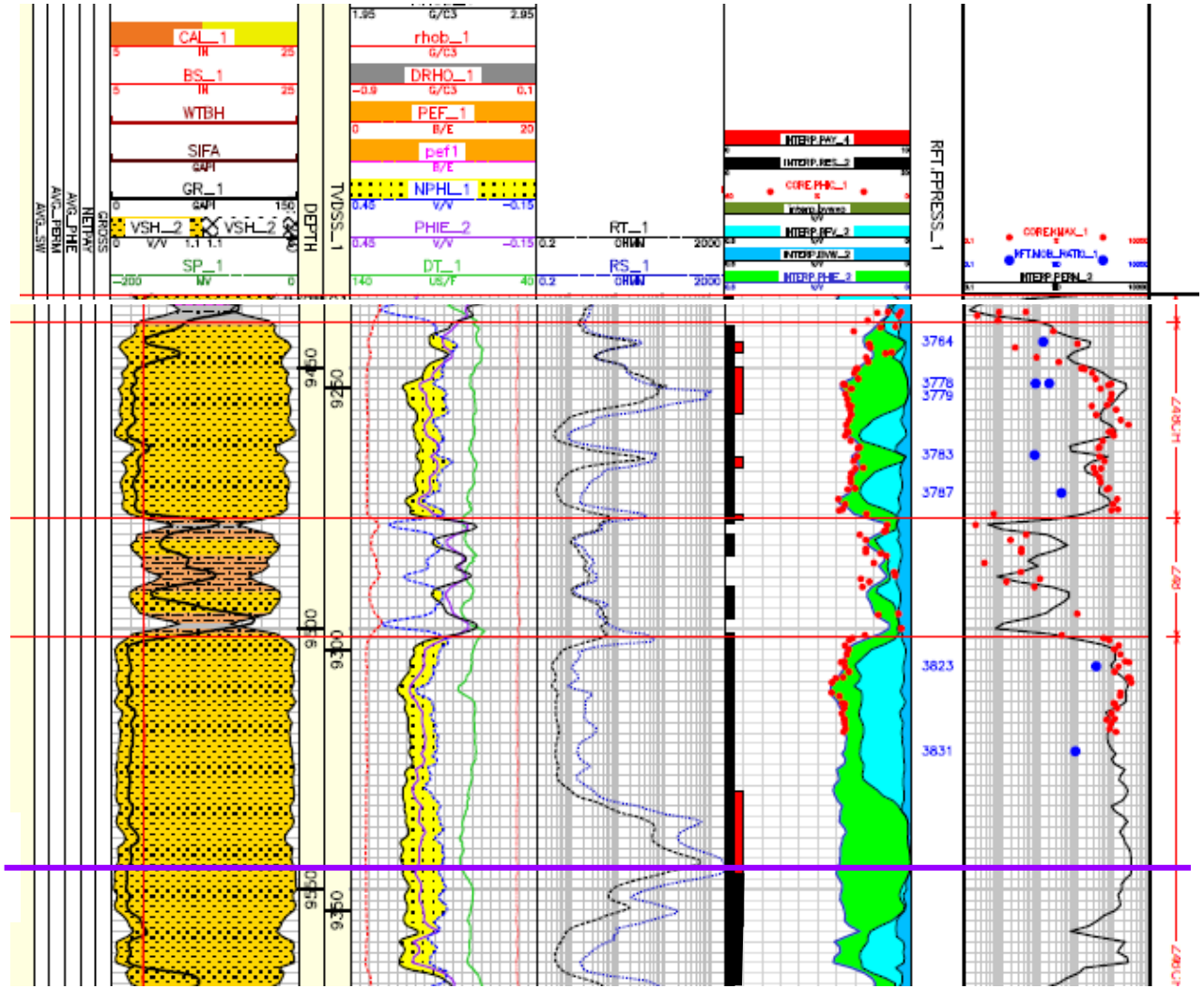
- Identified from production data, logs, geochemical studies: Asphaltene content 50 - 80%, as per Iatroscan (Geochemical) Analysis. (Azim et. al 2006)
- Historical Tar at:
  UZSD -9345 to -9446 (TVDSS)
  MZSD -9895 to -9932 (TVDSS)
- Simulation study (HAL for KOC, 2011): tar mats reduce transmissibility by 99%
- Some latest studies show other tar zones (Immobile Oil), however it is indicated that are not impermeable across the field

Azim, Shaikh Abdul, Al-Anezi, Salah, Hassan, Yahya, James Stephen, Mandal, D., Al-Ajmi, Hamad. 2006. "Identification, Origin, and Distribution of Tarmats in Upper Zubair Sand Reservoir, Raudhatain Field, North Kuwait". Abu Dhabi International Petroleum Exhibition and Conference, 5-8 November 2006, Abu Dhabi, U.A.E. SPE Paper No 101303

Halliburton Overseas Limited for Kuwait Oil Company, 2011. "Reservoir Simulation Study Report Zubair Reservoir Raudhatain Field. North Kuwait". Internal Report

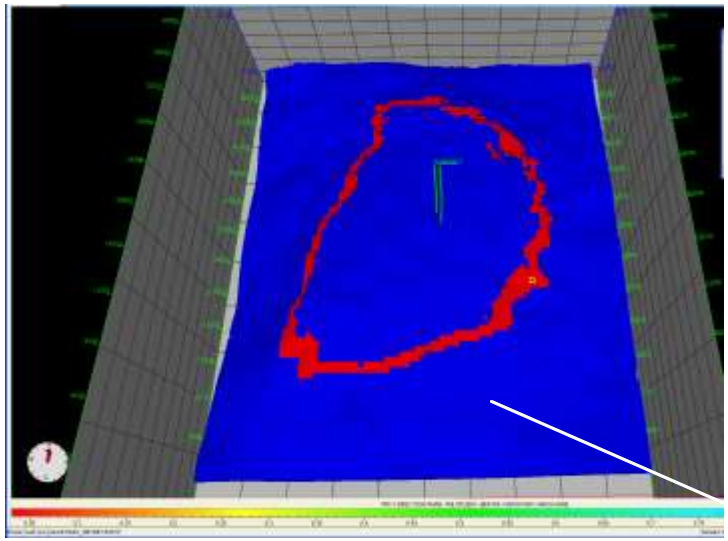
Zubair - Tar mats

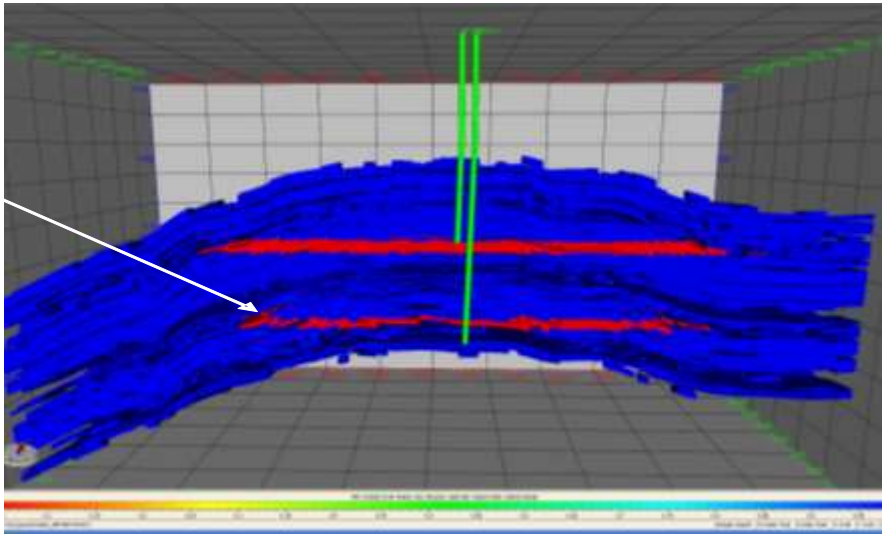
UZSD – WELL FAGA – F (OBM)



UZSD Hist. Tar mat

Zubair - Tar mats





Tar mat representation through transmissibility reduction for MZSD. "Reservoir Simulation Study Report Zubair Reservoir Raudhatain Field. North Kuwait". 2011. Halliburton Overseas Limited for Kuwait Oil Company. Internal Report.

Characterization of Major Seals in Zubair Reservoir Leading to Multiple Fluid Contacts, Raudhatain Field, North Kuwait

Summary

The seals are identified as

1. Shale Seals of homogeneous lithology, bounding reservoirs with very different pressures, correlatable across the field as seen in all the three members.

2. Shale Seals which becomes silty but still maintain its character as a “seal package”.

3. Diagenetic Seals that occurs as calcareous sandstones / sandy limestones reduce the permeability and become tight and sealing reservoirs, identified at the top of upper and lower Zubair.

4. Tar mat occurrences behave as seal in clean sandstones and allows to identify three types of fluids, documented at the upper Zubair and at the middle Zubair.

Characterization of Major Seals in Zubair Reservoir Leading to Multiple Fluid Contacts, Raudhatain Field, North Kuwait

Challenges and Opportunities

Production from Thin Pays

Time framed correlation, distribution of facies and relationship Kv / Kh will support new locations of wells aimed to produce from thin pays, with the more characterization of seals. Production from the Tar zones

Tar Mat as effective seal

The controlling influence of the tar mat close to the oil water contacts has the most significant impact on the reservoir performance.

Injection and the seals

Applied studies with preserved samples, detailed correlation, reservoir engineering data to maximized recovery

Uncertainties

May be minimized with detailed biostratigraphic studies, detailed well surveillance

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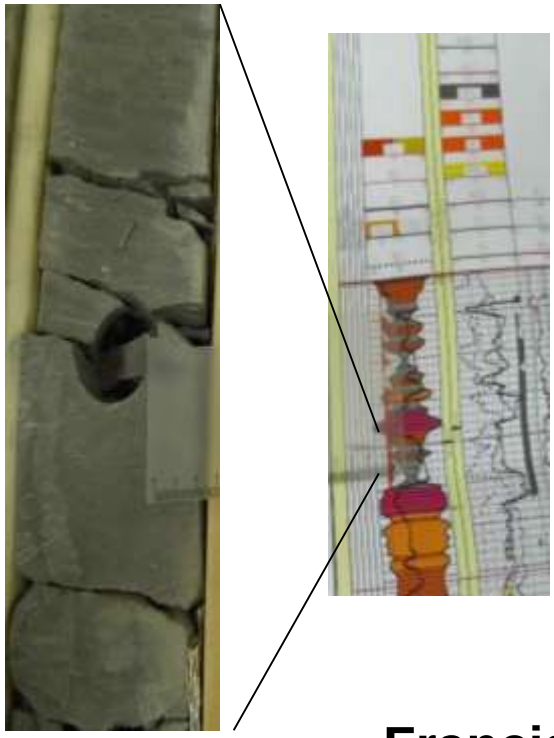

Thanks

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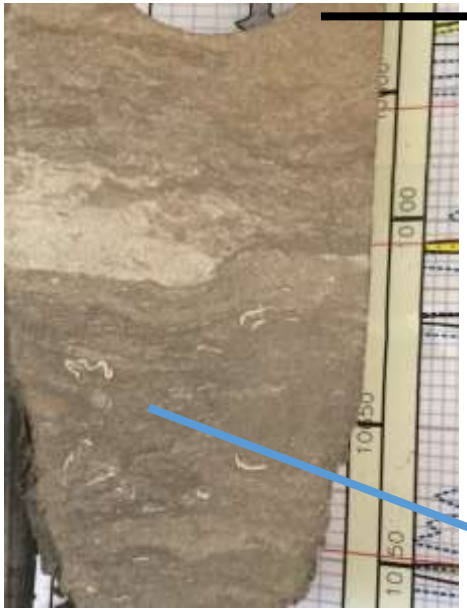
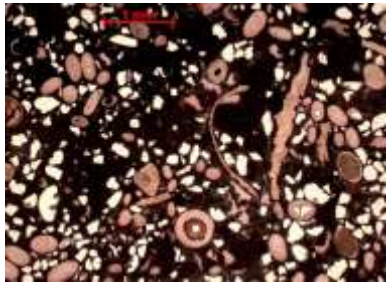
The methods – Material & Interpretation

Lower Zubair Sand. Z02 layer. WELL FAGA – E (OBM)

10629 ft. MD

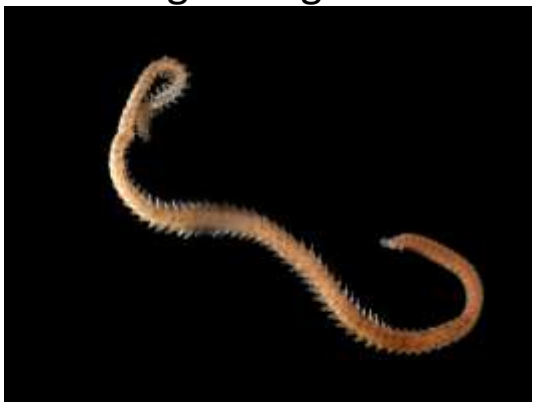


Photomicrograph: Thin section from this plug. Notice the bioclasts, oolites, ooids and the cement.
The white grains = Quartz.



Interpretation:
Polychaete
worm

Compare to: Phyllodocid polychaete from the Belgian continental shelf.
Lab image. Length: ~18 mm



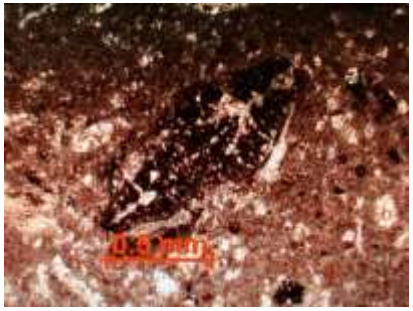
The methods – Material & Interpretation

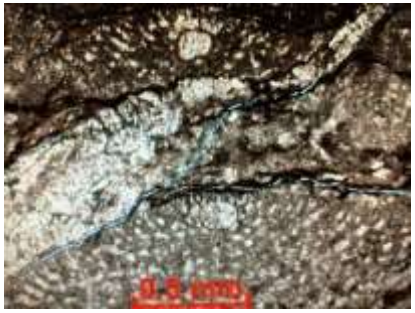
Upper Zubair – WELL FAGA – F (OBM)
Study thin sections. Identification of microfossils, minerals

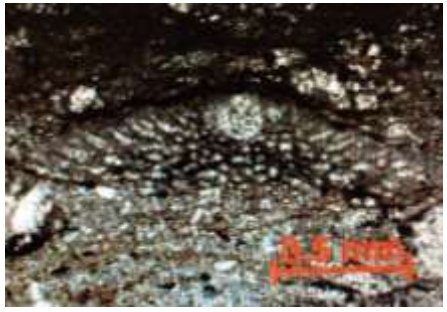
9101.35 ft. Pyrite

9094.20 ft
Stylolites. Nodules

9117 ft. Large benthic Foraminifers







Galea Alvarez, 2015