

3-D Geological Modeling of the World's Largest Siliciclastic Reservoirs: Greater Burgan Field, Kuwait*

Jean-Michel Filak¹, Julien Van Lint¹, Erwan Le Guerroué¹, Nicolas Desgoutte¹, Gilles Fabre¹, Farida Ali², Eddie Ma², Kalyanbrata Datta², Reham Al-Houti², and Sethu Madhavan²

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Abstract

The late Albian to early Cenomanian Burgan-Wara formations from Southeast Kuwait Greater Burgan field constitute the largest siliciclastic oil reservoir on earth. The sedimentology and stratigraphy is here reviewed in terms of depositional environment and lateral stratigraphic correlation. An updated geological model is built, based on new interpretations that have significant impact on the reservoir management of this giant field. The integration of newly defined core based rock-types and seismic reservoir characterization from a database of more than 1,100 wells allowed to characterize the major reservoir heterogeneities and build the first high-resolution 3D geological model for the Burgan field.

The Burgan and Wara formations represent four third-order cycles, deposited in coastal settings. The variability inherent to the depositional style leads to a complex reservoir scheme. The Lower Burgan is dominated by stacked braided channels representing homogeneous, high quality reservoirs. Higher in the stratigraphy, lateral facies variability and heterogeneities are observed in tidal dominated units. Mud dominated units occur within the Upper Burgan and Lower Wara formations and provide good sealing capacities. Small, laterally strongly variable and heterogeneous fluvio-tidal dominated units are representative of the Upper Wara Formation.

A high-resolution 3D geological model of more than 900 million cells is built, based on the new structural and stratigraphic framework interpretations to capture the complexity of the Burgan Field reservoirs. Rock-types are defined, based on more than 900 well logs and core petrophysical properties measurements. The seismic reservoir characterization, focused on inversion techniques and calibrated with the newly defined rock-types provides crucial information on sandstone proportions distribution, especially in areas with lower well control.

The challenge of a fully integrated geomodel for such giant and complex field is here achieved with a specific workflow combining geological, geophysical and reservoir engineering techniques. The final model represents the first attempt to simulate, at high resolution, the

largest siliciclastic oil field in the world and provides a comprehensive way to understand the field heterogeneities and behavior. This model will allow best reservoir management and increased oil recovery.

Reference

Sixsmith, P.J., G.J. Hampson, S. Gupta, H.D. Johnson, and J.F. Fofana, 2008, Facies architecture of a net transgressive sandstone reservoir analog; the Cretaceous Hosta Tongue, New Mexico: AAPG Bulletin, v. 92/4, p. 513-547.

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**AAPG 2012 Annual Convention & Exhibition
Long Beach, April 25th, 2012.**

Presenter's notes: Good morning.

In the name of KOC and Beicip-Franlab, I have the pleasure today to present you and to share with you the results of an integrated study initiated 3 years ago on Greater Burgan Field in Kuwait. The final output of this long-term study is given by the title of my talk today:

“3D Geological Modeling of the World's Largest Siliciclastic Reservoirs: Greater Burgan Field, Kuwait.”

 **Greater Burgan: A Giant field**

 **Modeling challenges**

 **Tailor-made modeling workflow**

 **Stratigraphic and structural model**

 **Property modeling (Rock-types and Seismic Reservoir Characterization)**


 **Outcomes**

Presenter's notes: The outline of the presentation will be the following:

- After a brief introduction on the project
- I will present you Greater Burgan Field for you to measure the size and the complexity of this super-giant field
- I will then review the modeling challenges we have faced during the study
- Based on these challenges a specific workflow has been defined, I will detail it with you
- Then I will review briefly the geological and structural settings of the field
- To be able finally to expose you the main steps of the model building
- I will end with the outcomes and lessons learned of such type of study.

Main objectives:

- Build a 3D high-resolution geological model for the Burgan, Maaddud & Wara reservoirs;
- Produce the necessary input for the dynamic simulation of the field;
- Deliver tools to reduce drilling uncertainty in Wara and Burgan reservoirs.

 **Study challenge: due to the size and the complexity of the field, a specific workflow adapted to such challenging model has been built, combining geological, geophysical and reservoir engineering techniques.**

 **First attempt to simulate at high resolution the world's largest clastic oil field.**

Presenter's notes: The present work is the result of a three years study initiated in June 2009 on behalf of KOC-SEK.

The main objectives of this integrated study were to:

Build a 3D high-resolution geological model for the Wara, Maaddud & Burgan reservoirs;

Produce the necessary input for the dynamic simulation of the field;

Deliver tools to reduce drilling uncertainty in Wara and Burgan reservoirs.

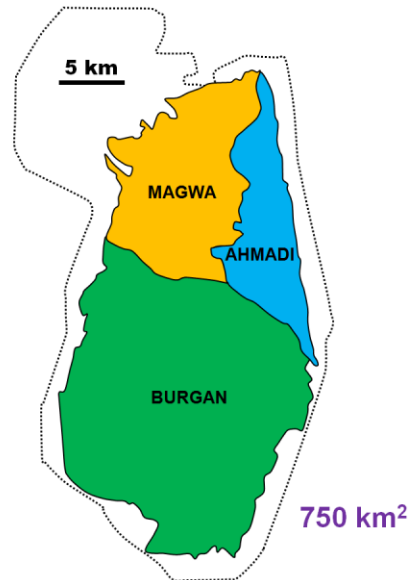
Study challenge: due to the size and the complexity of the field, a specific workflow adapted to such challenging model has been built, combining geological, geophysical and reservoir engineering techniques.

First attempt to simulate at high resolution the world's largest clastic oil field.

Burgan: World's largest siliciclastic oil field

Country	Field Name	Production bd
Saudi Arabia	Ghawar	5 000 000
Kuwait	Burgan	1 200 000
Azerbaijan	Azeri-Chirag-Guneshli	850 000
Mexico	Ku-Maloob-Zaap	800 000
Abu Dhabi	Zakum	750 000
Russia	Samotlor	750 000
Mexico	Cantarell	660 000
Russian	Priobskoye	650 000
Iran	Ahwaz	600 000
Saudi Arabia	Shaybah	500 000

Source IHS CERA



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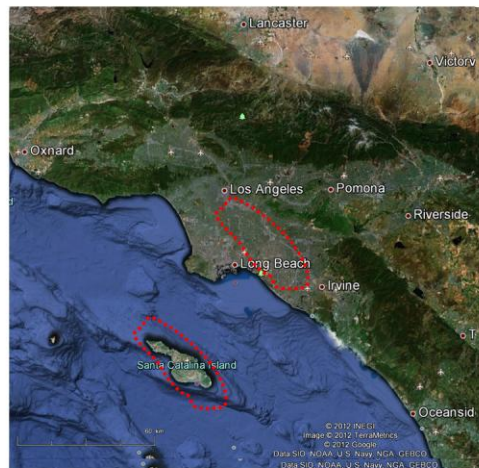
Presenter's notes: Greater Burgan field is the second largest oil field known in the world.

In the table presented here you can observe the daily rate production in barrels for several giant field in the world. With a daily rate of production of 1,2 million of barrels, Burgan is the largest siliciclastic field known in the world. Ghawar on the top of the list is a carbonate field.

3 main structures constitute Greater Burgan field: the fields of Magwa and Ahmadi to the north of the structure and the biggest one Burgan toward the south.

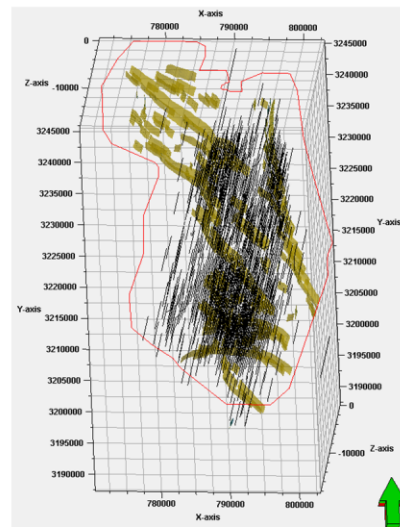
The total surface of Greater Burgan Field is around 750 square kilometers.

Greater Burgan Field: a way to compare...



Presenter's notes: To let you get an idea of the size of Greater Burgan field, you have all recognized on the right side of the slide a satellite image of Los Angeles and Long Beach area and on the left side of the slide, at the same scale the Kuwait. The red dotted line circles the Greater Burgan field complex on the left and let us compare it with Santa Catalina Island on the right.

- Full integrated study (honoring all data)
- Super-sized field: 20 x 37,5 km (1200 wells...)
- 3 main reservoirs (Burgan, Mauddud and Wara)
- Complex reservoir scheme (fluvial/tidal settings)
- Reservoir thickness: 1500 ft
- 250 faults to be considered
- Time frame reduced due to operational constraints



How to optimize a workflow for such a challenging model?

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Presenter's notes: The modeling of Greater Burgan field represented different challenges.

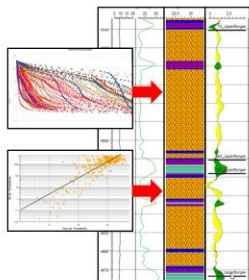
- The size of the field: 20*37,5 km
- 1200 were drilled since the discover in 1936
- 3 main reservoirs (Wara, Burgan and Mauddud Formations)
- The reservoir scheme is complex with mixed fluvial/tidal deposits
- The total reservoir thickness reaches 1500 feet
- 250 faults have to be considered
- And finally the time-frame to perform the study was reduced due to operational constraints of KOC

How to optimize a workflow for such a challenging model?

Sequence stratigraphy scheme
Depositional model

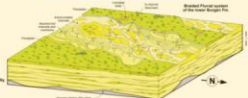
50 cored wells described

Rock-Typing

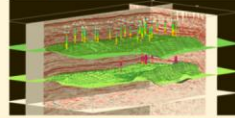


Rock-Types defined in 1000 wells
With associated properties
(Porosity, Permeability, Sw)

Stratigraphic model



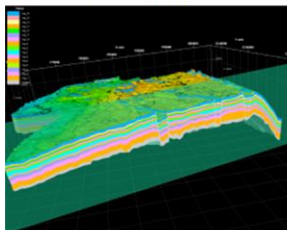
Structural model



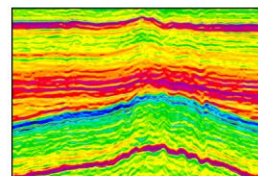
Seismic horizons interpretation
Fault interpretation

1250 km² of 3D seismic
500 km of 2D lines

3D geological model

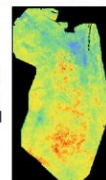


Seismic Reservoir Characterization



Seismic elastic
inversion

Generation of sand
proportion maps to
constrain the model



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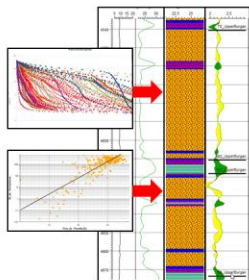
Presenter's notes: To deal with a such challenging model, a tailor-made workflow has been proposed, to integrate all the information available. In a preliminary step, the structural and stratigraphic framework has been built. On a side, the stratigraphic model based on core descriptions (50 cored wells) to build a high-resolution sequence stratigraphy scheme and to propose a depositional model; on the other side the structural model (1250 km² of 3D seismic and 500 km of linear 2D lines) for seismic horizons and fault interpretations.

Once the structural and stratigraphic framework has been set, the properties have been determined. Based on interpreted logs available in 1,000 wells, rock-types with associated properties (Porosity, permeability and Water saturation) have been defined. To constrain the model in zones with poor well information, a seismic reservoir characterization has been performed, and sand proportion maps have been generated as a result of a seismic elastic inversion. Finally, this integrated workflow allows to simulate all the properties (Facies, porosity, permeability and Water saturation) with an accurate constrain of more than 1000 wells and seismic data.

Sequence stratigraphy scheme
Depositional model

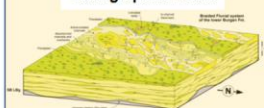
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Rock-Typing

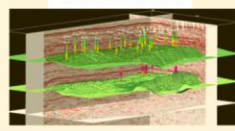


Rock-Types defined in 1000 wells
With associated properties
(Porosity, Permeability, Sw)

Stratigraphic model



Structural model

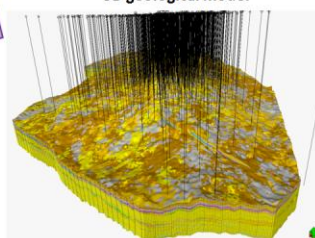


Seismic horizons interpretation
Fault interpretation

1250 km² of 3D seismic
500 km of 2D lines

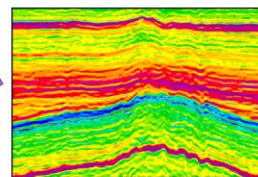
INTEGRATED WORKFLOW

3D geological model



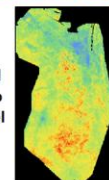
Facies, Porosity, Permeability, Sw simulation
High well control (1000 wells) + seismic constrains

Seismic Reservoir Characterization



Seismic elastic
inversion

Generation of sand
proportion maps to
constrain the model



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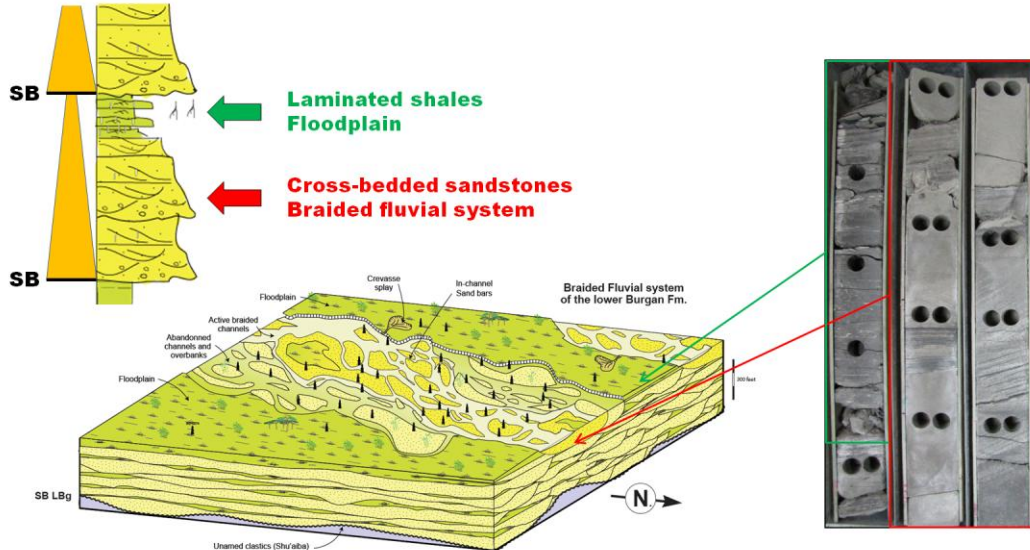
8

Presenter's notes: To deal with a such challenging model, a tailor-made workflow has been proposed, to integrate all the information available. In a preliminary step, the structural and stratigraphic framework has been built. On a side, the stratigraphic model based on core descriptions (50 cored wells) to build a high-resolution sequence stratigraphy scheme and to propose a depositional model; on the other side the structural model (1250 km² of 3D seismic and 500 km of linear 2D lines) for seismic horizons and fault interpretations.

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Depositional settings

Type sequence 1: Braided channel system

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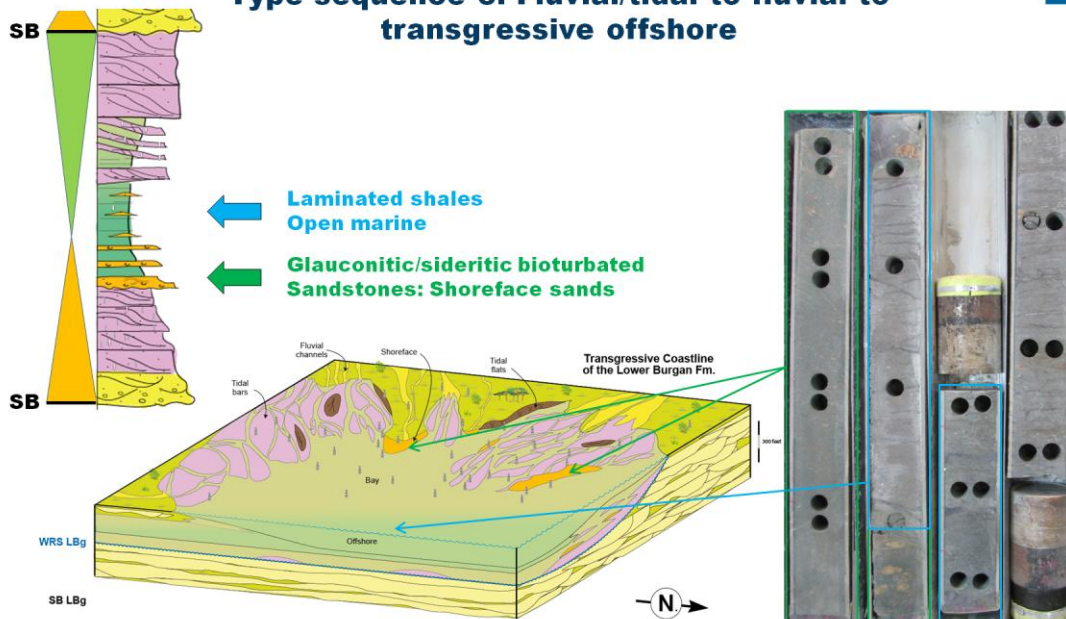
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Presenter's notes: To build the stratigraphic framework of the model, high-resolution sequence stratigraphy concepts have been applied to define type sequences at the scale of the field. I will now briefly present you the main sequence types. On this slide, you can observe the type sequence corresponding to fluvial braided channel deposits, characterized by an erosive base at the bottom of the sequence, developed stacked cross-bedded sandstones covered by shales and marls corresponding to flood plain deposits.

Depositional settings

Type sequence 3: Fluvial/tidal to fluvial to transgressive offshore

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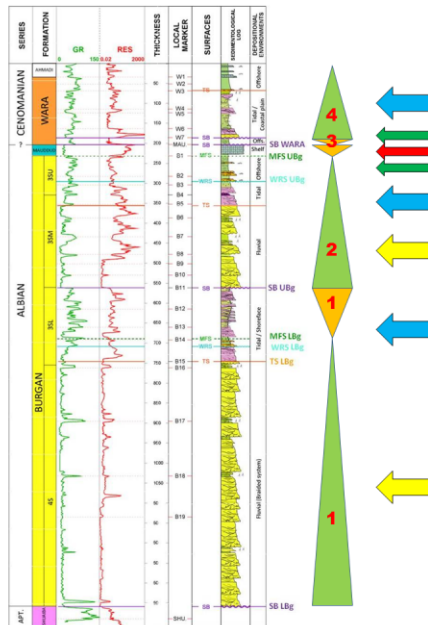
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Presenter's notes: In the more distal part of the studied area, open marine settings prevail. The type sequence shows the transition from fluvial at the base to tidal and then open marine laminated shales in the transgressive part, with associated transgressive glauconitic sands, and finally a return to tidal settings in the regressive part of the sequence.



Presenter's notes: The definition of type sequences at the scale of the basin allows to define regional key markers and to build the lateral architecture of the main geological sand bodies. In this composite schematic cross-section, you can visualize the variation of depositional environments and lateral architecture from South Burgan field to Ahmadi-Magwa fields. Stacked braided channels with good connectivities pass seaward to tidal bars and channels with smaller extension and worth connectivities associated with the increase of the shale content.



Albian to Cenomanian age;

4 main 3rd order cycles;

3 main reservoirs (Burgan, Maaddud and Wara).

- Massive and homogeneous sandstone reservoirs (stacked braided channels)
- Heterogeneous silty sandstone reservoirs (tidal dominated units)
- Mud prone units (open marine settings)
- Fractured compact carbonates (Maaddud)

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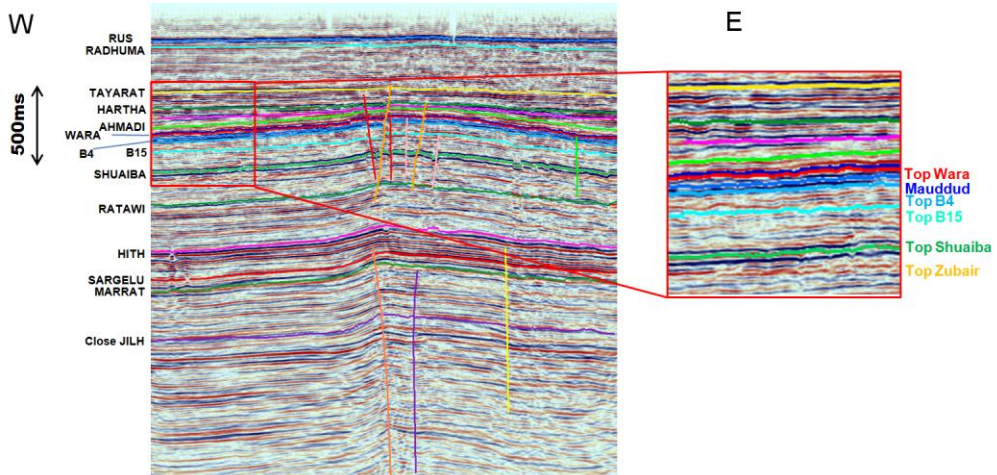
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Presenter's notes: 4 main 3rd order cycles have been defined and correlated at the scale of the field, ranging from Late Albian to Early Cenomanian Age.

Burgan, Maaddud and Wara Formations constitute the 3 main reservoirs characterized by:

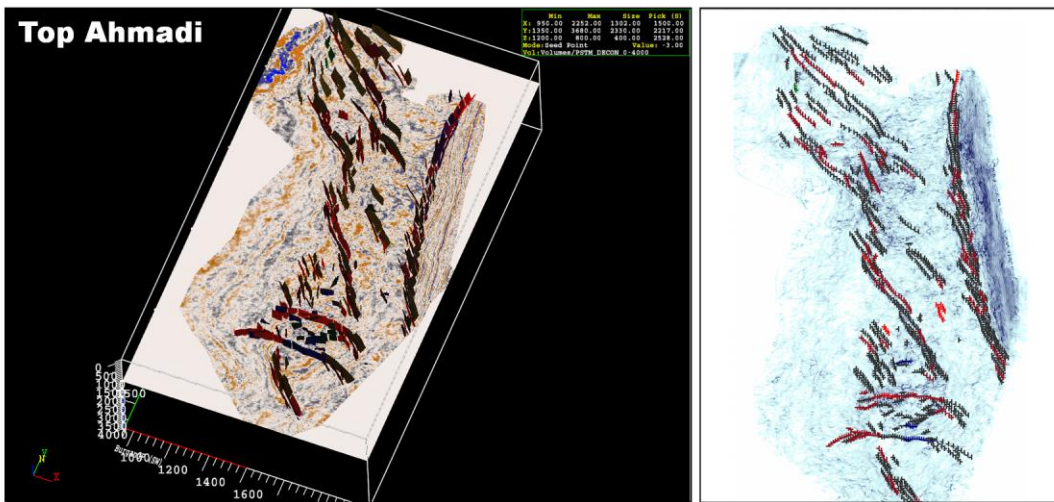
- Massive and homogeneous sandstone reservoirs (stacked braided channels in Lower and Middle Burgan)
- Heterogeneous silty sandstone reservoirs (tidal dominated units in Upper Burgan and Wara Formations)
- Mud prone units (open marine settings in Upper Burgan and base Wara Formation)
- Fractured compact carbonates (Maaddud)



- 6 interpreted seismic horizons to build the structural framework
- From Top Zubair to Top Wara Formations

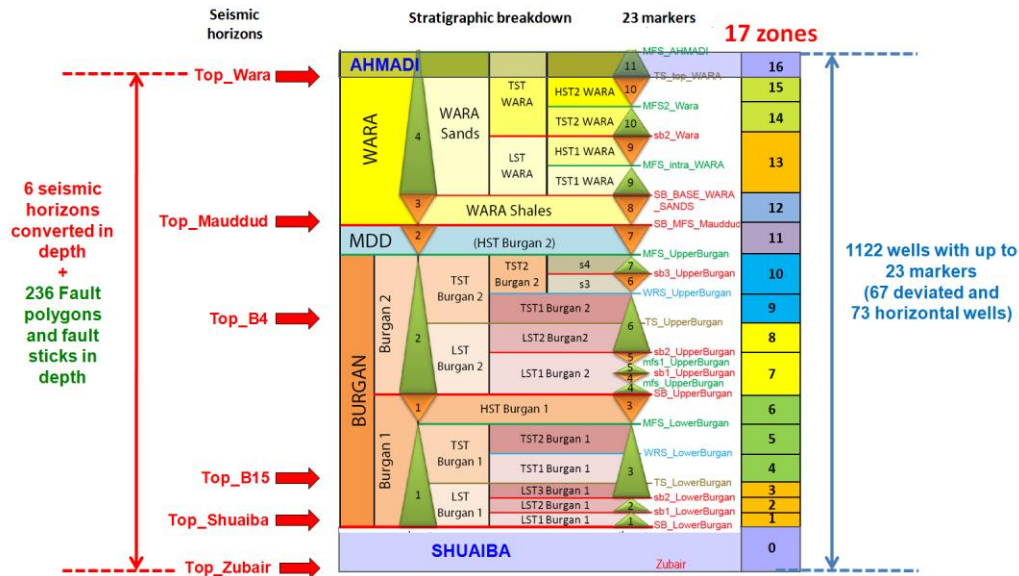
Presenter's notes: The structural interpretation has been performed on 6 interpreted seismic horizons to build the structural framework, from Top Zubair to Top Wara Formation.

On this seismic section you can have an idea of the reservoir thickness which represent 500ms in time.



250 faults interpreted on 3 main seismic horizons (Ahmadi, Mauddud and Shuaiba)

Presenter's notes: 250 faults have been interpreted on 3 main seismic horizons (Ahmadi, Mauddud and Shuaiba) constituting the top, the middle and the base of the studied interval. These faults are with the seismic horizons the main input for the structural model.



Presenter's notes: As an output of the stratigraphic and structural analysis, 6 seismic horizons, 236 faults polygons, 1122 wells with up to 23 stratigraphic markers were loaded in the geomodeling software to define the structural model. 17 zones constitute the reservoir breakdown from Shuaiba to Ahmadi formations.

Rock-Typing must provide:

Strong geological guides to build the 3D geological model;

Facies association based on
Texture, Granulometry

Sequence Stratigraphy

Geological
control

Accurate petrophysical properties distribution.

Porosity and permeability
Pore throat and Pc

Petrophysics &
flow properties

Presenter's notes: Once the structural and stratigraphic framework is established, the next step consists in the definition of rock properties to model the reservoir behavior. The IFP group approach is based on the Rock-Types definition that combines:

-A strong geological guide to build the geological model based on facies association and sequence stratigraphy analysis as a result of the sedimentological analysis.

-An accurate petrophysical and flow properties distribution by the integration of dynamic data (porosity, permeability, pore throat distribution and capillary pressures).

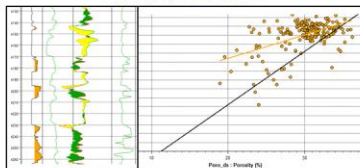
Geological data



Sedimentology
Stratigraphy
Correlations

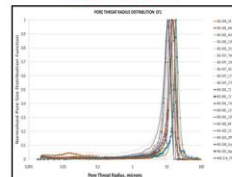


Petrophysical data



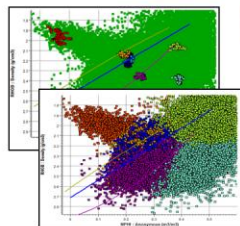
Raw logs and well log interpretation
Porosity / permeability relationships (CCAL)

Dynamic data

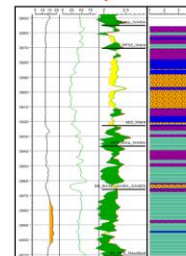


Capillary pressure
Pore throat distribution

Discriminant analysis

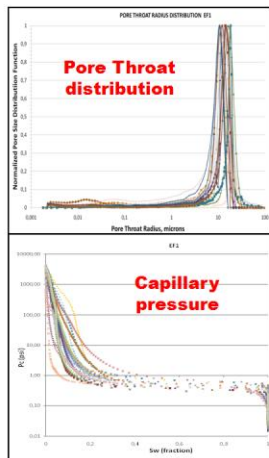


Electrofacies definition on 50 key cored wells
Calibration with core description

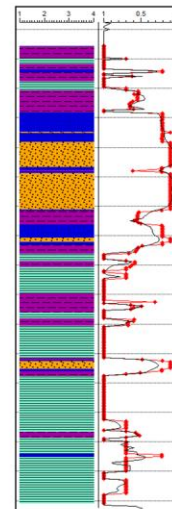
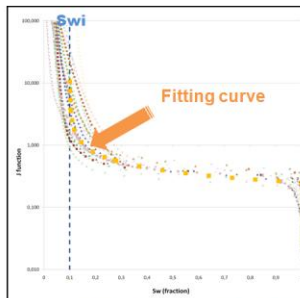


Rock-type definition on 1000 wells
according to the well log availability

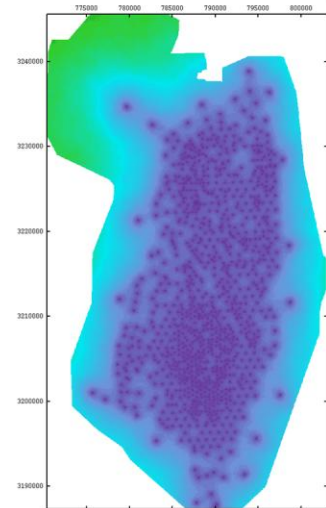
Presenter's notes: The rock-typing workflow combines geological data (sedimentology, stratigraphy) and petrophysical data (raw logs, well log interpretation and porosity/permeability relationships). A discriminant analysis is performed in EasyTrace, a software developed by IFP, to define electrofacies on key cored wells calibrated with core description and core measurements. The integration of dynamic data at the ultimate step allows to define rock-types with the same petrophysical characteristics and reservoir behavior, extended and defined in 1000 wells according to the log availability.



Screening and classification of dynamic data per class of Rocks



Presenter's notes: The seismic reservoir characterization workflow starts with seismic data preparation (misalignment correction and well to seismic calibration) in a view to perform an elastic inversion based on P and S impedance models. The following step consists in the matrix properties prediction using discriminant analysis at wells (probabilistic approach). "Seismic poles" are discriminated on predefined Rock-Types using seismic elastic attributes. The final outputs are sand proportion maps for each reservoir.



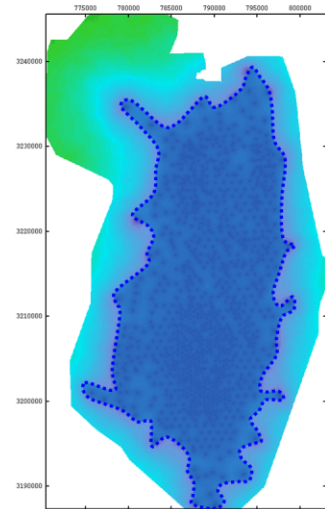
Presenter's notes: As you can observe it on this map of the Greater Burgan Field:

- A high density well control characterize the hinge of the structure
- But the flanks and surrounding areas are less controlled by well data.

To get rid of the lack of data in specific zones of the field and to get accurate constrains for the model a seismic reservoir characterization workflow has been performed to:

- provide accurate constrains in-between wells and in low well control areas for the geological model;
- And generate dominant lithology maps and associated probability maps for the complete studied areas.

- High density well control on the hinge of the structure



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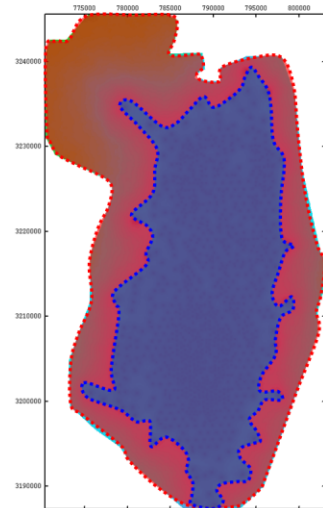
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High density well control on the hinge of the structure

Low control on the flanks and surrounding areas



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High density well control on the hinge of the structure

Low control on the flanks and surrounding areas

Seismic Reservoir Characterization workflow allows to:

- Provide accurate constrains in-between wells and in low well control areas for the geological model;
- Generate dominant lithology maps and associated probability maps.

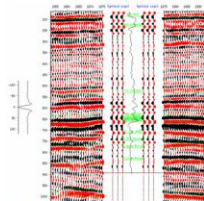


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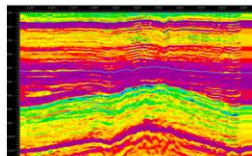
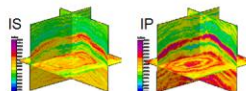
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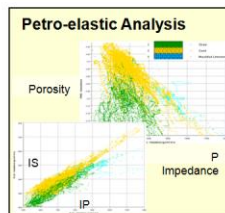
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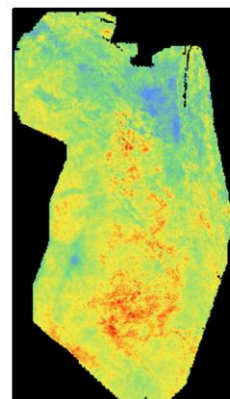
Seismic data preparation
Mis-alignment correction
Well-to-seismic calibration



Elastic inversion
P and S impedance models
Full field inversion



Matrix properties prediction
Discriminant analysis at wells
Seismic facies discriminated on predefined Rock-Types.



Seismic constrains
Sand proportion maps for each reservoir

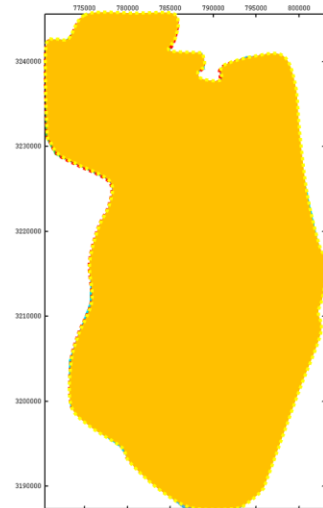
Presenter's notes: The seismic reservoir characterization workflow starts with seismic data preparation (misalignment correction and well to seismic calibration) in a view to perform an elastic inversion based on P and S impedance models. The following step consists in the matrix properties prediction using discriminant analysis at wells (probabilistic approach). "Seismic poles" are discriminated on predefined Rock-Types using seismic elastic attributes. The final outputs are sand proportion maps for each reservoir.

High density well control on the hinge of the structure

Low control on the flanks and surrounding areas

Seismic Reservoir Characterization workflow allows to:

- Provide accurate constrains in-between wells and in low well control areas for the geological model;
- Generate dominant lithology maps and associated probability maps.

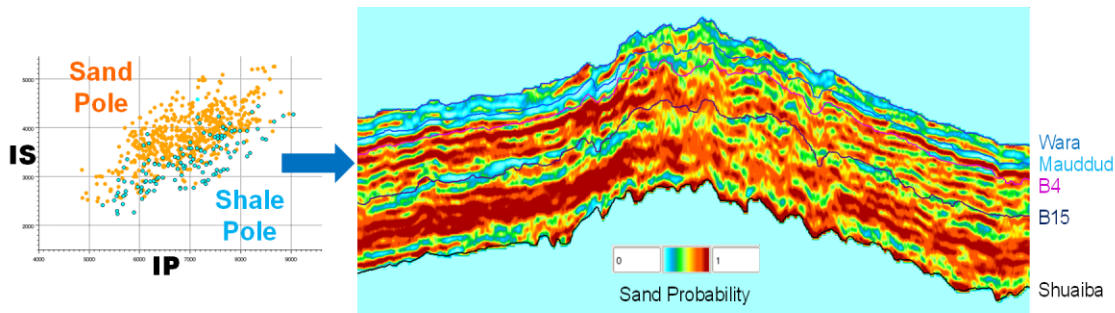


Presenter's notes: As you can observe it on this map of the Greater Burgan Field:

- A high density well control characterize the hinge of the structure
- But the flanks and surrounding areas are less controlled by well data.

To get rid of the lack of data in specific zones of the field and to get accurate constrains for the model a seismic reservoir characterization workflow has been performed to:

- provide accurate constrains in-between wells and in low well control areas for the geological model;
- And generate dominant lithology maps and associated probability maps for the complete studied areas.



- Sand vs. shale discriminant analysis based on elastic inversion results provides a sand probability volume
- Seismic maps are extracted for each interval and tied to all available well data (1000 wells used in the geomodel)
- Geomodel constrained with Sand proportion maps

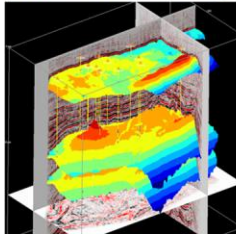
April 25th, 2012

3D Geological Modeling of the World's Largest Siliciclastic Reservoirs: Greater Burgan Field, Kuwait.

Presenter's notes: As outputs of the seismic reservoir characterization :

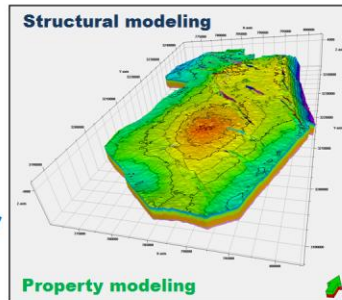
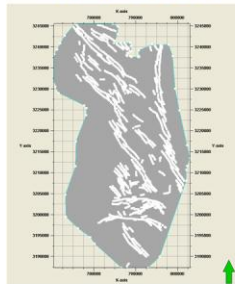
- Sand vs. shale discriminant analysis based on elastic inversion results provides a sand probability volume
- Used to extract seismic maps for each interval and tied to all available well data (1000 wells used in the geomodel)
- The geomodel is then constrained with these Sand proportion maps.

Structural modeling



6 main seismic horizons

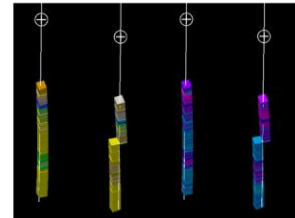
236 interpreted faults



High resolution grid (50m * 50m)
3ft vertical resolution to capture the main heterogeneities for better reservoir characterization (thin layers)

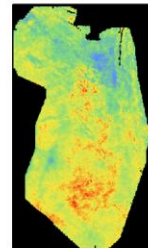
~1 Billion cells model

Property modeling



16 Rock-Types defined in 1000 wells
 (for each reservoir)

Seismic constrains:
 sand proportion maps (each interval)

April 25th, 2012

3D Geological Modeling of the World's Largest Siliciclastic Reservoirs: Greater Burgan Field, Kuwait.

Presenter's notes: The integrated workflow ends up with the construction of the 3D geological model:

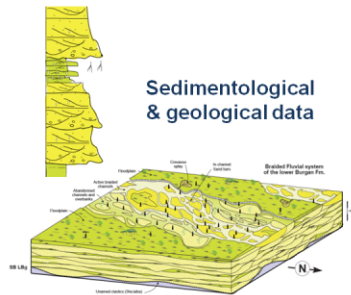
The structural modeling based upon the interpreted 6 seismic horizons and 236 faults

The property modeling that integrates the 16 rock-types defined in 1000 wells for all the reservoirs and the seismic constrain with sand proportion maps generated for each intervals.

A high resolution grid of 50m*50m have been chosen to capture the main heterogeneities and for a better reservoir characterization of the thin layers

Leading to a close to 1 billion cells model

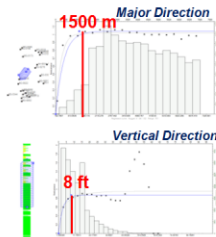
- Variograms to define the size and the orientation of the sedimentary bodies (length, width and thickness);
- Direct impact on the degree of connectivity of the geological features;
- Definition based on:



Sedimentological
& geological data



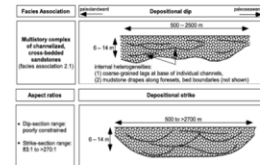
Data analysis



Bibliography & analogs



Photography (Dr. Sharon Johnson)



From Sixsmith et al., 2008

Variograms per facies and units

April 25th, 2012

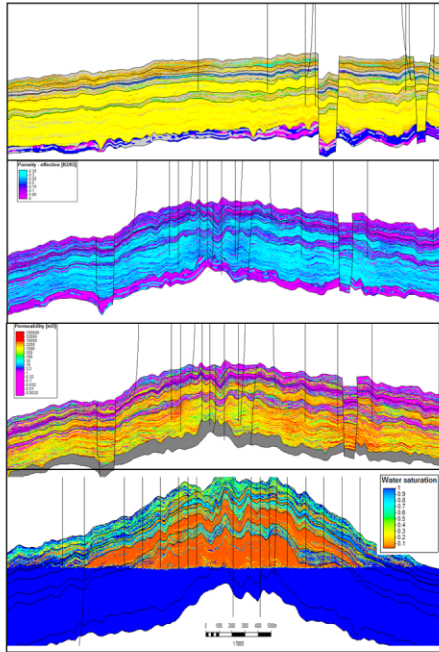
3D Geological Modeling of the World's Largest Siliciclastic Reservoirs: Greater Burgan Field, Kuwait.

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Presenter's notes: The facies modeling has been performed using variograms definition to define the size and the orientation of the sedimentary bodies (length, width and thickness). This important step is crucial as it has a direct impact on the degree of connectivity of the geological features.

Its definition is based on the integration of the available data, including sedimentological and geological data, results of the well data analysis at well in Petrel and finally bibliography and analogs.

Variograms have been defined per facies and per zones.



Facies

SIS (Sequential Indicator Simulation)

- Variograms per facies and units;
- Trend Modeling (seismic constrains).

Porosity

GRS (Gaussian Random Simulation)

- Simulation facies per facies and zone by zone
- Same variograms as facies
- Based on upscaled Phi log per facies.

Permeability

- Based on Phi/K core relationships per facies.

Saturation

- J-Function per facies (capillary pressure).

Presenter's notes: The properties have been simulated for each intervals as a result of the property modeling.

- Facies has been simulated using SIS (Sequential Indicator Simulation) using variograms per facies and units and trend modeling to integrate seismic constrains;
- Porosity has been simulated using GRS (Gaussian Random Simulation). Simulations were performed facies per facies and zone by zone using the same variograms as facies. The porosity is based on the upscaled Phi log per facies.
- The permeability is then generated using the Porosity/permeability relationship per facies
- And finally the saturation is calculated form the defined J-function per facies.

Giant Field 3D modeling: Yes we can...



- First attempt to simulate, at very high resolution, the largest siliciclastic oil field in the world, honoring all available;
- Challenge of an integrated 3D geomodel for such giant and complex field achieved with a specific workflow combining geological, geophysical and reservoir engineering techniques;
- The final model provides:
 - a comprehensive way to understand the field heterogeneities and reservoir behavior;
 - an efficient tool for reservoir management and increasing of oil recovery.

Presenter's notes: This study represents the first attempt to simulate, at very high resolution, the largest siliciclastic oil field in the world; The challenge of an integrated 3D geomodel for such giant and complex field has been achieved with a specific workflow combining geological, geophysical and reservoir engineering techniques;

The final model provides:

a comprehensive way to understand the field heterogeneities and reservoir behavior;
an efficient tool for reservoir management and increasing of oil recovery.

We did it...

Acknowledgements

➤ Huge thanks to KOC for authorization of publishing these results

➤ Electronic version of abstract available on www.beicip.com

➤ Visit us at BEICIP Inc. booth (531)



Presenter's notes: I would like to give a huge thanks to KOC for the authorization of publishing these results

An electronic version of the abstract will be available on www.beicip.com

And please visit us at BEICIP Inc. booth (531)

Thank you for your attention...