[PS]Geobody Modelling and Reservoir Characterization of Siliciclastic Wara Formation in Khashman Field, Kuwait*

Bhaskar Chakrabarti[1], Meshal Al-Wadi[2], Lin Ye[2], and Jalal Dashti[2]

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Abstract

Exploration of Middle Cretaceous Wara Formation in Khashman area started in the 1960s and till date ten wells were drilled of which two had produced hydrocarbon. Facies architecture and reservoir properties prediction are major exploration challenges. On the basis of 3D Pre-Stack Time-Migrated seismic data, the present study applied new technologies to integrate seismic attributes and well data. The study came up with geobody modeling and reservoir characterization of Wara Formation, which helped to identify new drillable prospects.

Sequence Stratigraphic framework and depositional environment of Wara Formation (around 200 ft thick) are interpreted by integrating core and well logs and envisaged fluvio-deltaic deposits within a Lowstand Systems Tract.

3D seismic attribute volumes viz. Spectral Decomposition, Instantaneous Sweetness, and Relative Acoustic Impedance were generated in frequency and depth domain at Wara interval. Calibrated by litho-facies at the well locations, geobodies (channel sand) are identified in seismic-attribute volumes in the depth domain and subsequently extracted from core rendered attribute volumes by using Neural Network technique. Extracted geobodies were modeled to incorporate inside 3D structural model. Modeled geobodies show geometry and orientation of channel sand inside the Wara Formation across the Khashman Field. Subsequently the geobody was integrated with upscaled facies logs to populate facies in areas adjoining to geobody using stochastic simulation. Porosity and Water Saturation (Sw) logs were upscaled guided by facies model and then stochastically populated in the model.

Wara Facies model could delineate geometry, orientation, and areal continuity of sand bodies. Facies model predicts stacked channel sand with areal continuity and sand lenses with limited continuity and pinchouts. Porosity and Sw model predict isolated sand lenses have maximum 20% porosity and high Sw (50-70%) while stacked sand layers have maximum 35% porosity and low to moderate Sw (20-40%). Siltstone with low porosity (5-10%) and very high Sw (60-80%) has marginal reservoir potential.

The present study helped in understanding Wara facies architecture and prediction of reservoir facies and properties in the Khashman Field. The study has identified potential unexplored drillable prospects for Wara Formation in the Khashman Field. Successful drilling of identified prospects could add substantial reserve in the Wara Formation.

AAPG Annual Convention and Exhibition, April 22-25, 2012, Long Beach, California USA

Geobody Modelling and Reservoir Characterization of Siliciclastic Wara Formation in Khashman Field, Kuwait

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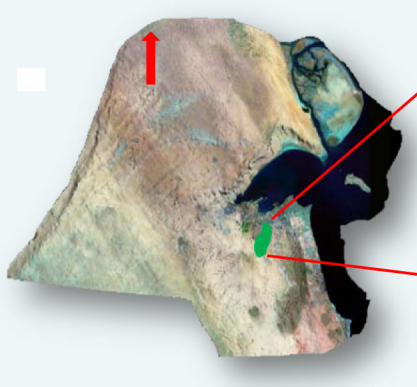
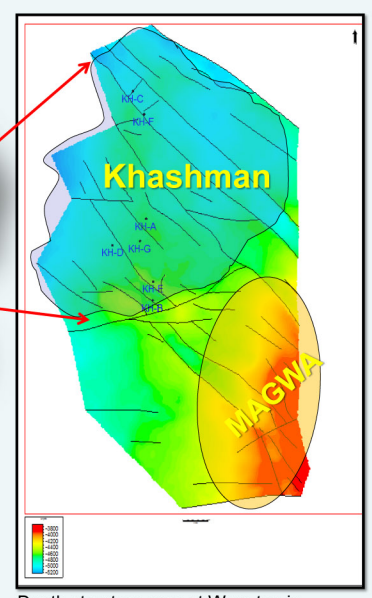
1: Kuwait Oil Company

Introduction to Study Area

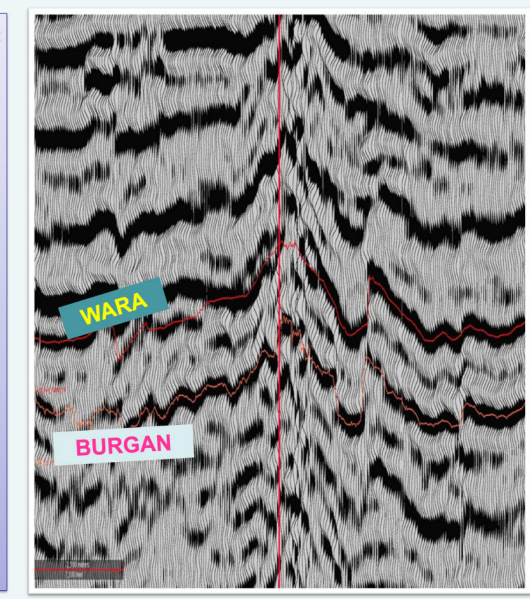


Khashman Field (highlighted in green) in South Eastern part of Kuwait

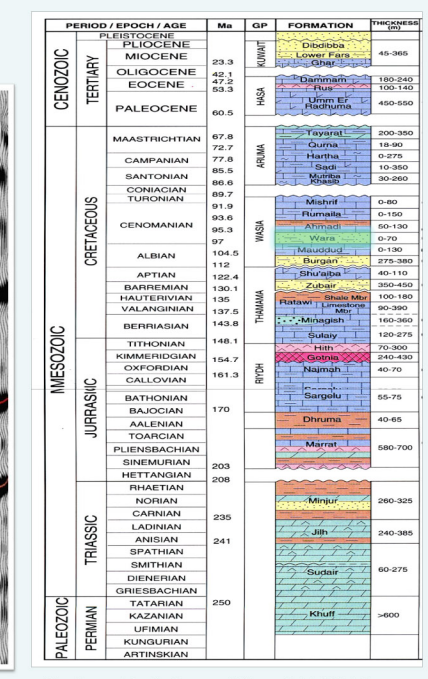


Depth structure map at Wara top in Khashman and adjoining Magwa Area

- Khashman is situated in South-East part of Kuwait approximately 7-8 km WNW of Magwa Field.
- Three sets of faults viz. NW-SE, NE-SW and E-W are recognized at Wara level.
- NW-SE faults are oldest and E-W faults are youngest.
- Younger faults are mostly strike-slip faults.
- Horst – graben structure at Wara level is characteristic feature.
- Exploration in Khashman started in early 1960s targeting Mid Cretaceous Wara reservoirs.
- Till date 8 wells are drilled penetrating Wara Formation.
- Two wells viz. KH-A, KH-E have produced hydrocarbon from Wara reservoir.
- Hydrocarbon indications are observed in Wara in two more wells.
- Drilled wells in Khashman show Wara and underlying Burgan reservoirs have single oil-water contact (OWC).

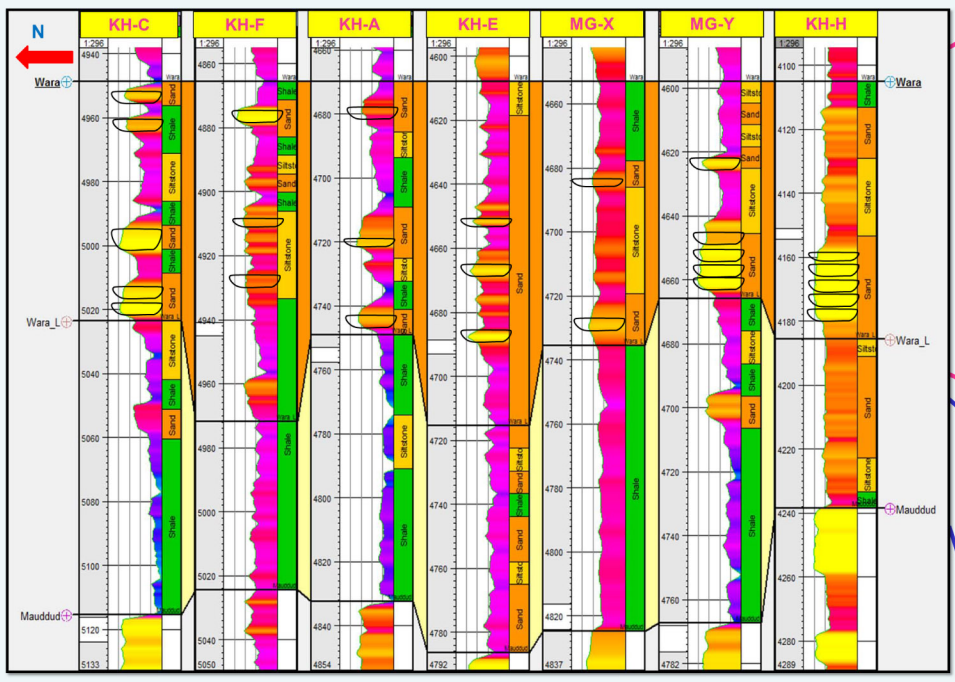


Seismic section along arbitrary line passing through Khashman

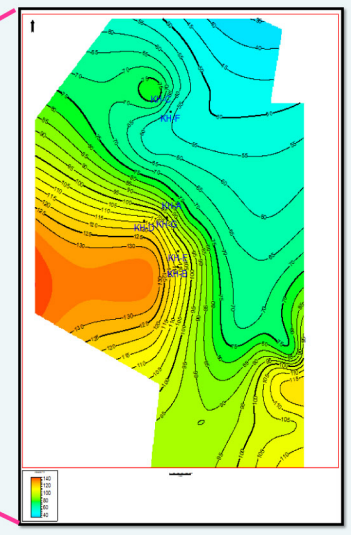


Stratigraphic Column of Kuwait highlighting Wara Formation of Cenomanian Age

Depositional Model of Wara Formation in Khashman Area

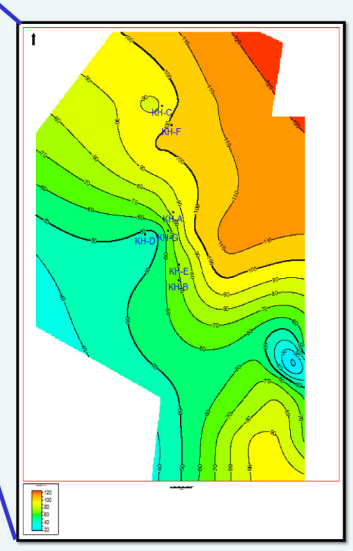


Stratigraphic correlation of Wara in Khashman and adjoining Magwa wells: Isolated channel point bar of Upper Wara in Khashman wells and coalesced channel point bar in Magwa wells; Lower Wara is dominantly shaley

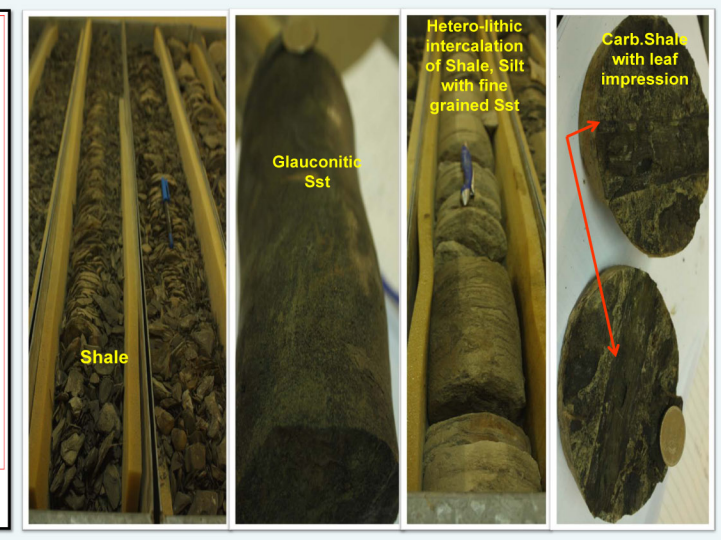


Isochore Map: Upper Wara thickening in WSW direction in Khashman

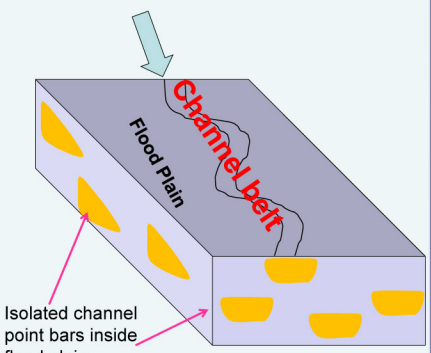
Core Photograph of Upper Wara in well KH-A



Isochore Map: Lower Wara thickening in North / NE direction



Core Photograph of Lower Wara in well KH-A



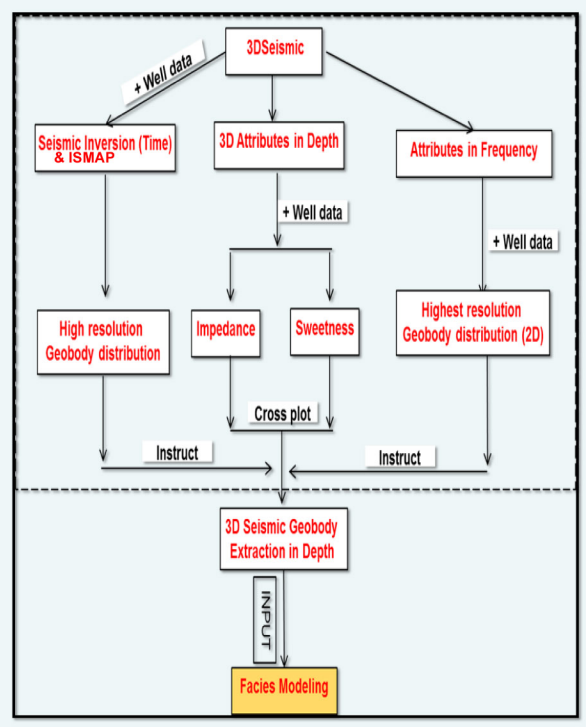
Depositional Model of Upper Wara: Isolated point bars inside flood plain clay / shale. Individual point bars are apart from each other with limited reservoir continuity

- Wara Formation in Khashman area divided into two units: Upper and Lower Wara
- Upper Wara deposition took place in distributary channel system.
- Upper Wara channels are isolated point bars inside levee and flood plain and have poor lateral and vertical connectivity.
- Upper Wara point bar sand are major reservoir in Khashman.
- Upper Wara thickness in Khashman increases towards WSW.
- Lower Wara in Khashman is predominantly shale with variable argillaceous content and occasionally interbedded with siltstone and fine grained, massive glauconitic sandstone.
- Lower Wara sediments represents deposition during transgression. Occasional presence of fine grained sandstone (glauconitic) possibly represents transgressive lag of marginal to shallow marine origin.
- Isochore map shows Lower Wara is thickening towards North / NE.
- Reservoir potential of Lower Wara in Khashman is poor.

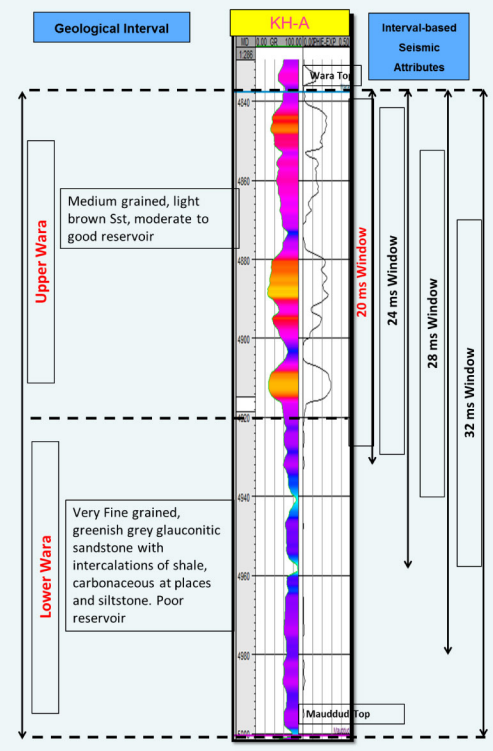
Seismic Facies and Geobody Interpretation - Methodology

Workflow

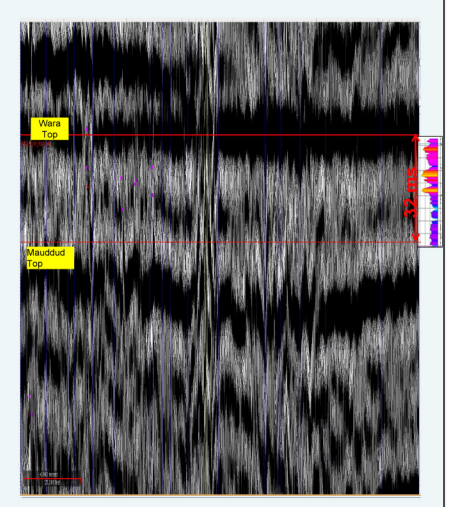
- Deposition model of Upper Wara indicates isolated channel reservoirs are with limited continuity.
- Prediction of these sand bodies are major challenge in Wara for exploration.
- Spectral Decomposition amplitude and phase volumes (attributes in frequency domain), Pre-Stack and Post-Stack seismic inversion and integrated multi attribute approach (ISMAP) in time domain and Relative Acoustic Impedance and Instantaneous Sweetness in depth domain are used.
- In Spectral Decomposition a Discrete Fourier Transform (DFT) method is used on 32 ms analysis window of Pre-Stack Time Migrated 3D seismic cube for its transformation into amplitude and phase spectra tuning cubes of 1-125 Hz.
- Generated seismic attributes describe the features of seismic signal at the level of Wara reservoir from studying amplitude / phase in frequency domain and amplitude / frequency in time / depth domain respectively.
- Seismic geobodies identified from different seismic attributes are analyzed and calibrated with drilled wells to define their geological features.
- Finally they were integrated together to extract seismic geobodies in depth domain.
- Extracted geobodies are then incorporated into facies model.



Seismic Facies and Geobodies Interpretation - Workflow



Analysis windows of seismic attributes



Arbitrary seismic section over Khashman showing analysis window of Wara Formation for Spectral Decomposition

Abstract # 1236208, AAPG Annual Convention and Exhibition, April 22-25, 2012, Long Beach, California USA

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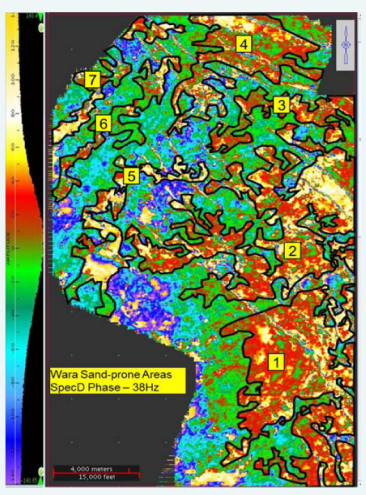
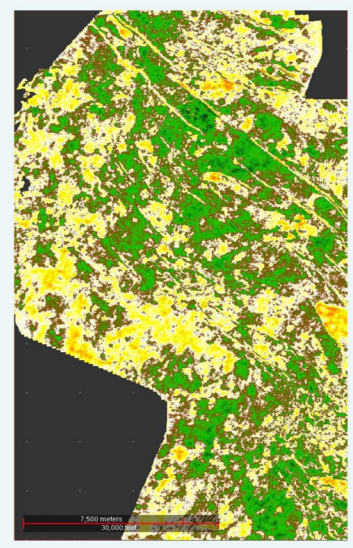
Seismic Facies Interpretation – Spectral Decomposition and ISMAP Results



Interpreted sand-prone areas (yellow-red) over Spectral Decomposition 38 Hz Phase tuning map for Wara formation

- Integration with drilled well data helps to correlate seismic anomalies with Wara sand bodies.
- Based on calibration results seven sand-prone geobodies (yellow-red phase values) are interpreted in Wara Formation.
- Sand prone geobodies 1,2 and 3 are trending WSW-ENE while 4,5 and 6 are trending NE-SW.
- Compared to full bandwidth conventional seismic attributes, noise reduced Spectral Decomposition frequency slices provide more detailing in geobody resolution and delineating reservoir prone areas.

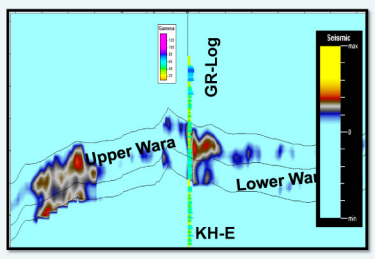


ISMAP of Upper Wara showing predicted sand prone areas (brown-yellow)

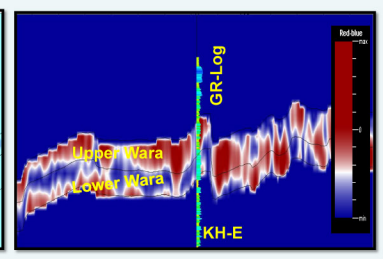
- ISMAP is an multi attribute approach to integrate Pre-Stack and Post-Stack seismic attributes and apply statistical approach to map net reservoir from seismic attribute slices.
- Predicted sand map of Upper Wara from ISMAP shows predicted sand prone areas (brown – yellow).

- Predicted sand map from ISMAP is in time domain, while predicted map from Spectral Decomposition is in frequency domain.
- Comparison between these two results indicates over 80% matching.
- This calibration has been integrated into final geobody extraction.

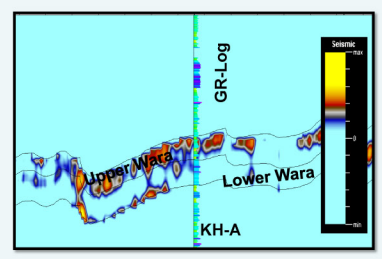
Seismic Geobody Interpretation, Extraction in Depth Domain and Geobody Modeling



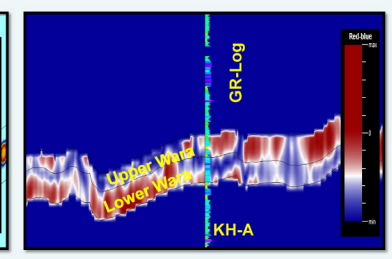
Calibration of Relative Acoustic Impedance Volume at Well KH-E (producer from Upper Wara): High Impedance for Upper Wara sand



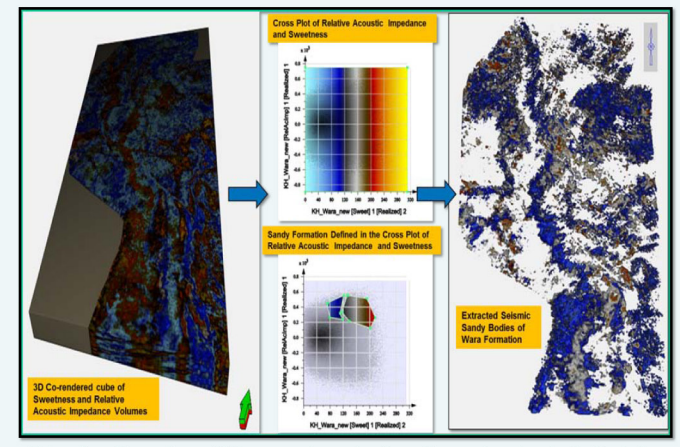
Calibration of Sweetness Volume at Well KH-E (producer from Upper Wara): High Sweetness value for Upper Wara sand



Calibration of Relative Acoustic Impedance Volume at Well KH-A (producer from Upper Wara): High Impedance for Upper Wara sand

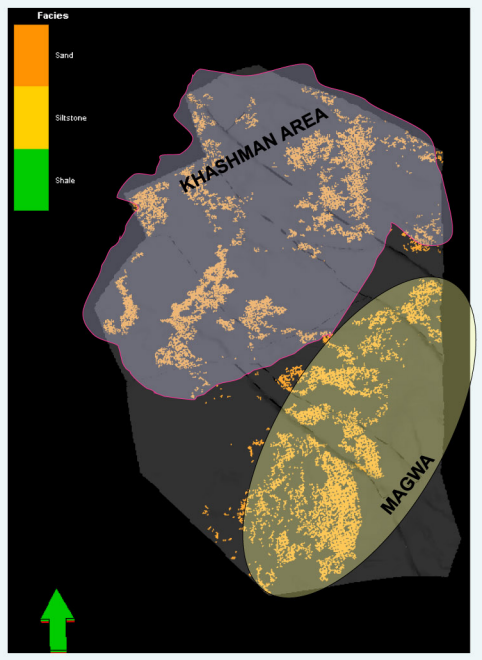


Calibration of Sweetness Volume at Well KH-A (producer from Upper Wara): High Sweetness value for Upper Wara sand

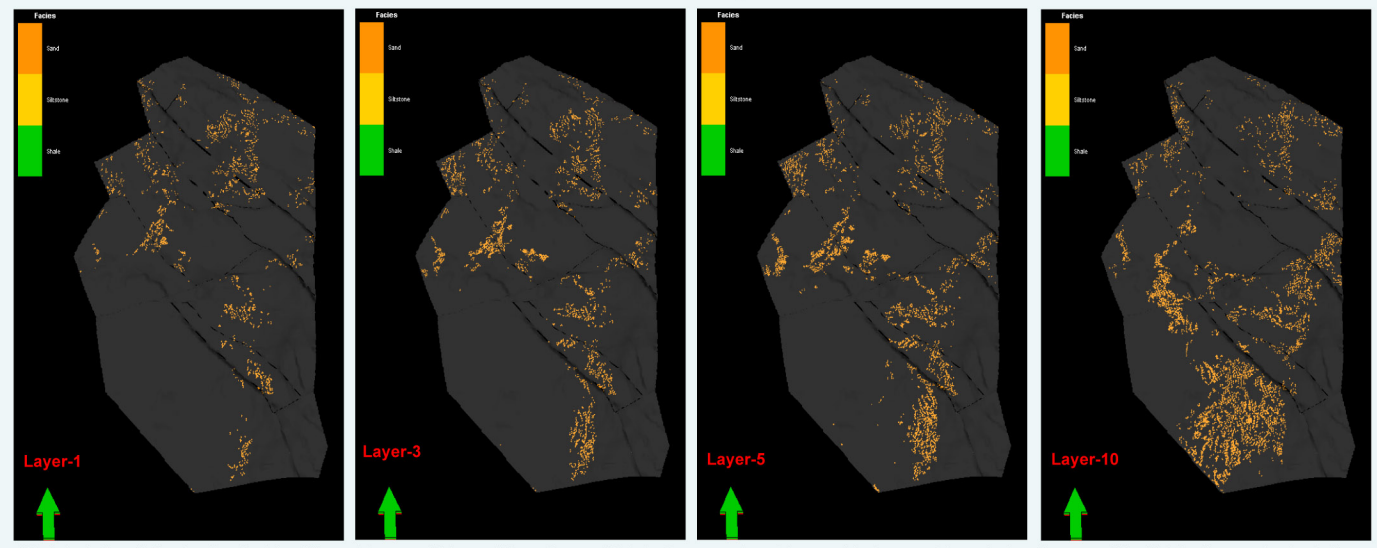


Extraction Procedure of Wara sandy geobodies; Co-rendered cube in the left, cross-plot with cut-off polygons in the middle and extracted geobodies in the right

- Seismic Geobodies are extracted from the integration of above-mentioned attribute volumes.
- Extracted sandy geobodies incorporated into 3D grid.
- Geobodies were up-scaled and modeled inside 3D grid using geometrical modeling method.
- Modeled geobodies show orientation and distribution of channels sand inside different layer of Upper Wara.

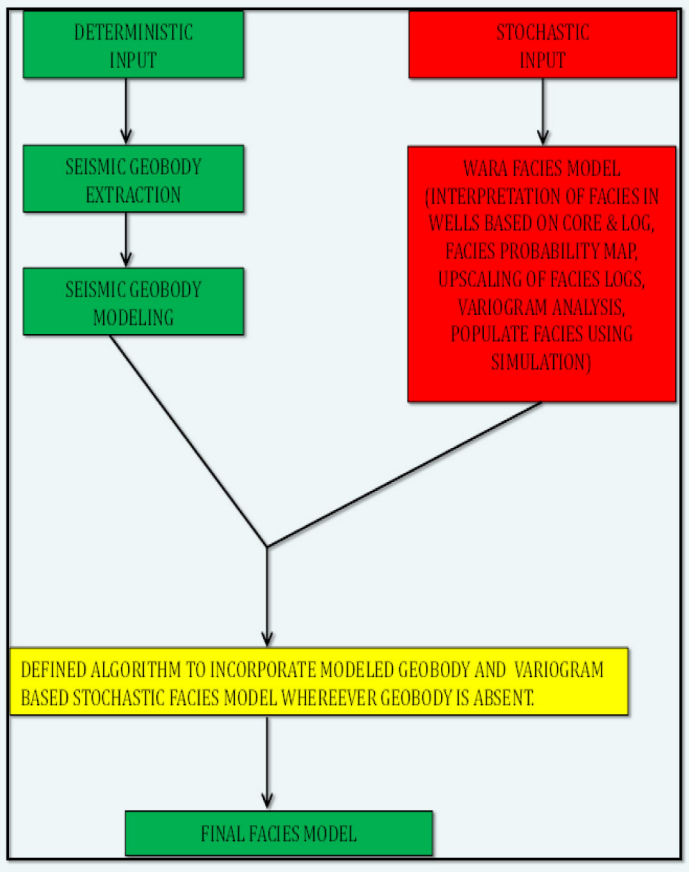


Up-scaled Wara sandy geobody in 3D Model



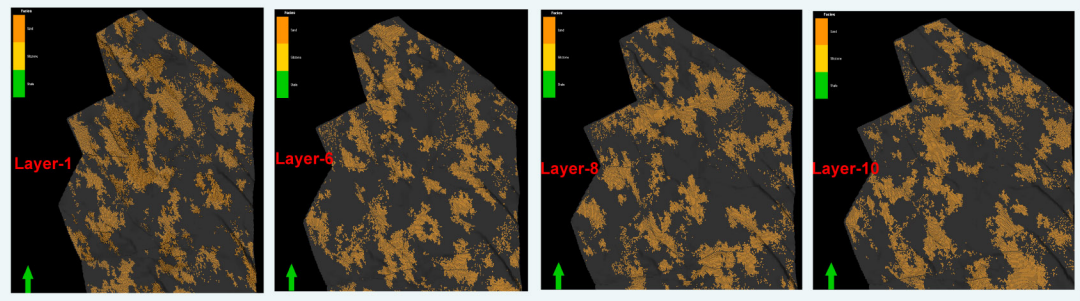
Modeled Sand Geobodies inside different layers of Upper Wara (Layer-10 is bottom most and Layer-1 is top most layer) showing possible distribution and orientation of channel sand in Khashman and adjoining Magwa areas

Wara Facies Model in Khashman Area

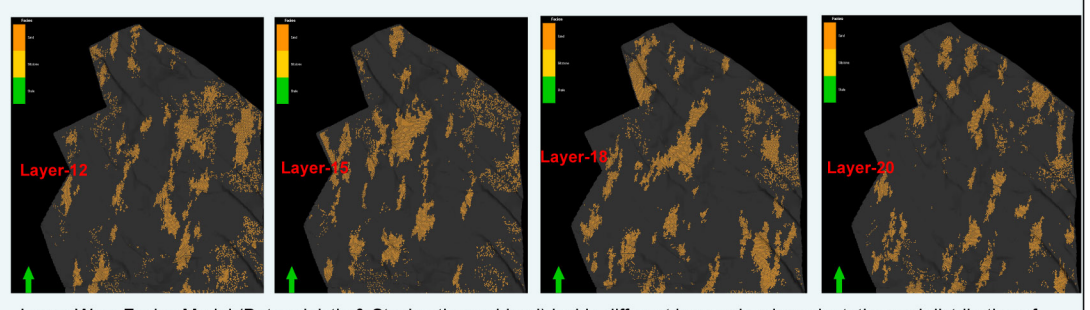


Wara Facies Model Workflow

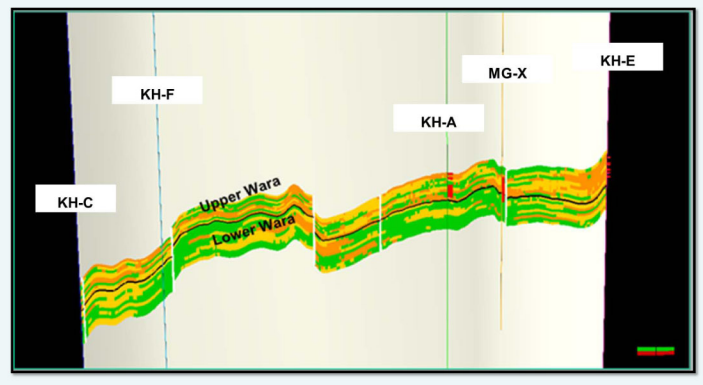
- Wara Facies model in Khashman is finally an integration of Deterministic and Stochastic facies input.
- Deterministic input is derived from seismic extracted geobodies.
- Stochastic input is derived from well data based interpretation.
- Final model honors both well data and regional seismic.



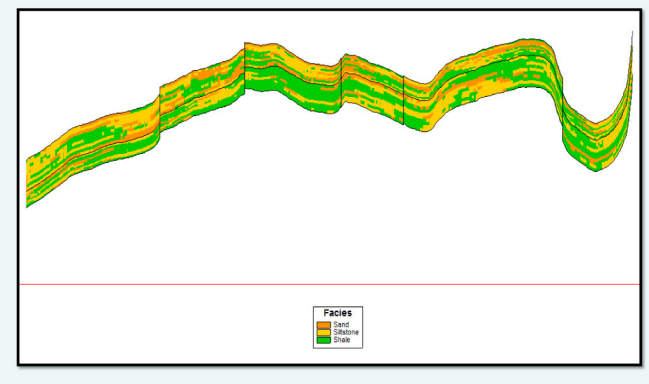
Upper Wara Facies Model (Deterministic & Stochastic combined) map view inside different layers showing orientation and distribution of sand bodies in Khashman Area



Lower Wara Facies Model (Deterministic & Stochastic combined) inside different layers showing orientation and distribution of sand bodies in Khashman Area



Wara Facies Model: Cross-section view along arbitrary line joining drilled wells; perforation intervals produced hydrocarbon are shown in red blocks



Wara Facies Model: Cross-section view along E-W arbitrary line inside Khashman

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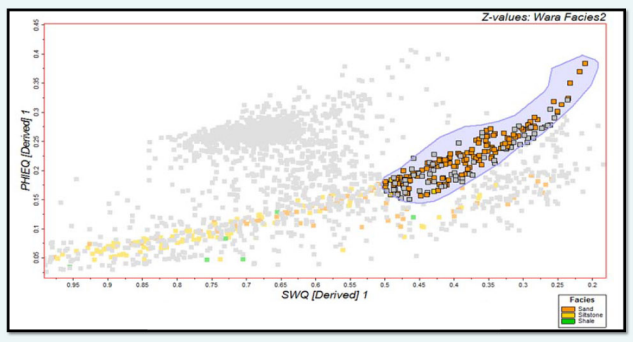
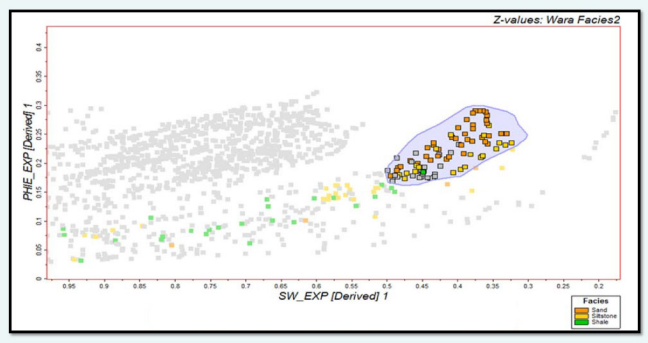
Analysis and Prediction of Reservoir Quality

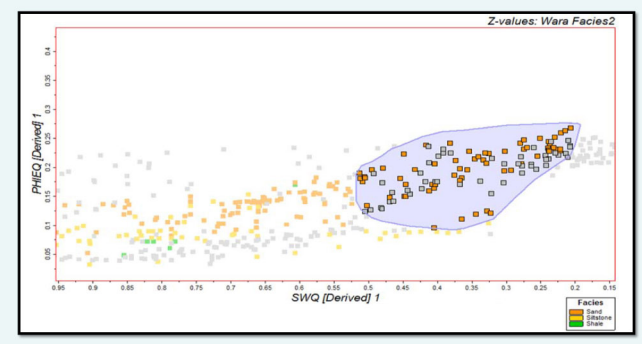
- Porosity (Φ, phi) and Water Saturation (Sw) are analyzed in drilled wells to understand reservoir quality of Upper and Lower Wara.
- Phi vs Sw plots of three drilled wells are presented which show average Upper Wara sand porosity is 0.2 to 0.22 while that for Lower Wara it is 0.12.
- Cross plots show that average Sw of sand deceases with increasing porosity.
- Average Sw for Upper Wara sand is 0.45-0.55 and that for Lower Wara is more than 0.55.
- Upper Wara sand is major reservoir in Khashman.
- Porosity and Sw models are generated for prediction of reservoir quality in Khashman area.
- Porosity and Sw model show good matching with drilled wells.
- Average porosity map shows that Upper Wara reservoir has potential prospective areas in southern part of Khashman area while Lower Wara has potential in northern and north-eastern part.
- Porosity, Sw model along with knowledge of testing results help to define two possible boundary conditions (Condition1: Phi> 0.1and Sw< 0.5. Condition: 2. Phi> 0.1 and Sw< 0.55) for Upper Wara reservoir predictability.
- Two possible net pay maps are prepared based on the boundary conditions mentioned for Upper Wara delineates the prospective areas for exploration.



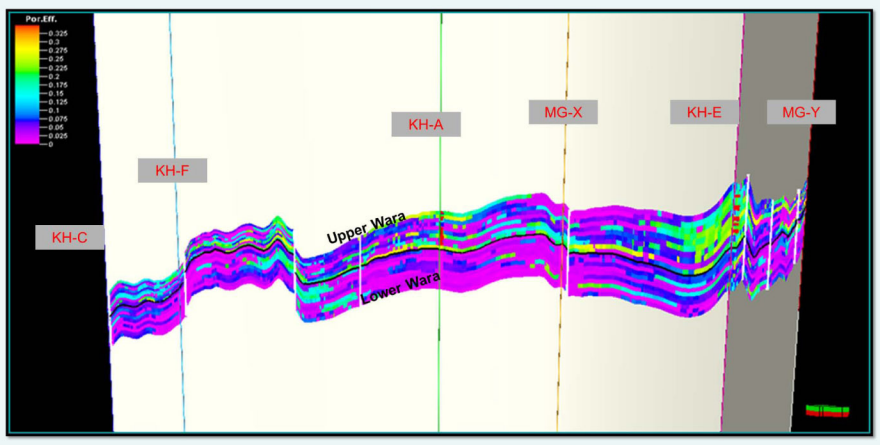
Wara Formation: Porosity – Sw Plot in well KH-E



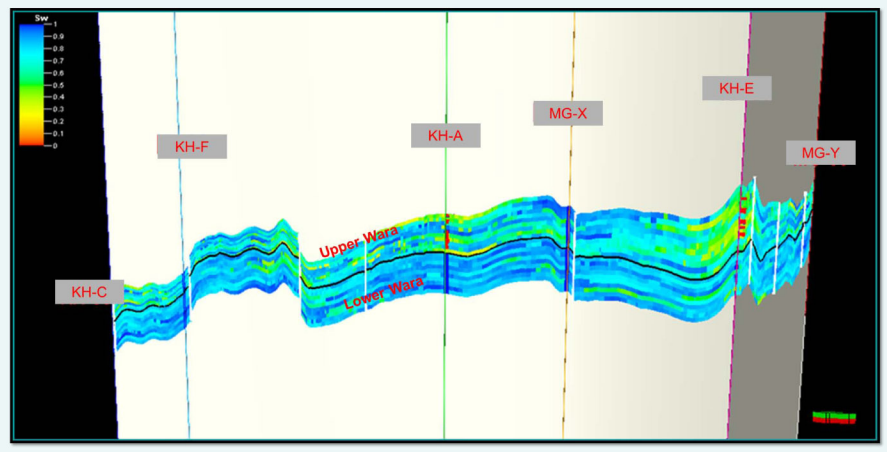
Wara Formation: Porosity – Sw Plot in well KH-A



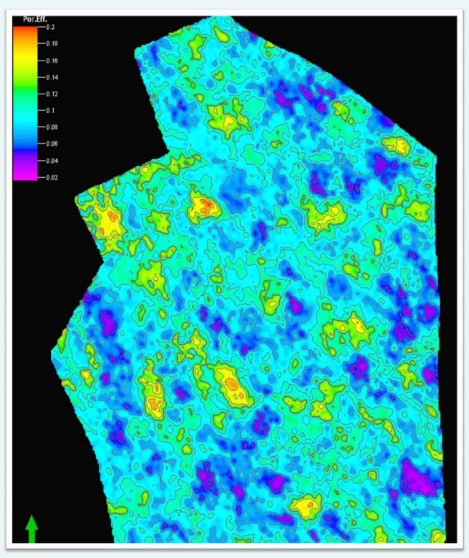
Wara Formation: Porosity – Sw Plot in well KH-H



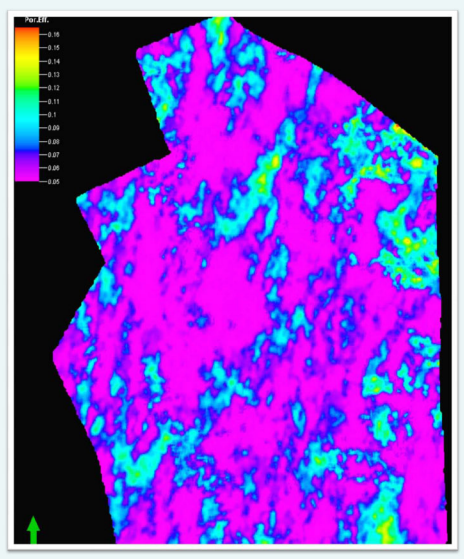
Porosity Model of Wara: Section along line joining drilled wells



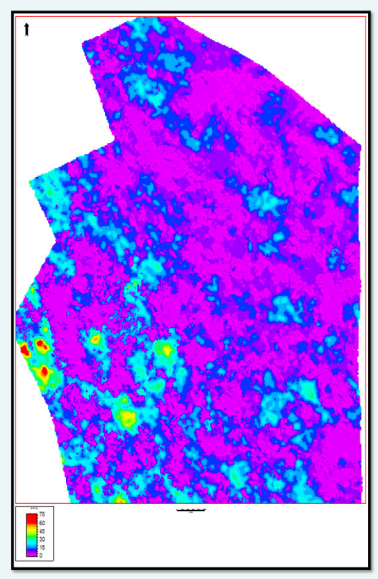
Sw Model of Wara: Section along line joining drilled wells



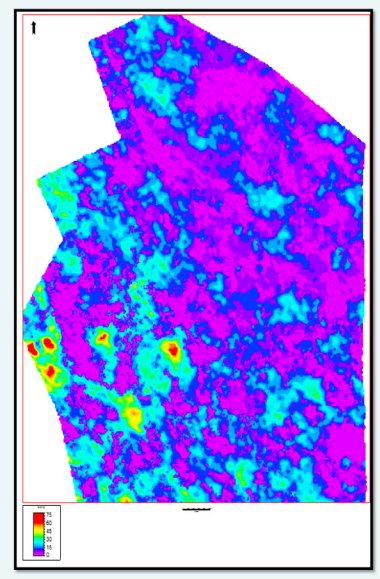
Porosity Map: Upper Wara in Khashman



Porosity Map: Lower Wara in Khashman



Net Pay Map of Upper Wara in Khashman: phi>10%, Sw<50%



Net Pay Map of Upper Wara in Khashman: phi>10%, Sw<55%

Formation	Reservoir	Facies	Reservoir Quality	Prospective Areas
Wara	Upper Wara	Dominantly channel sand with silt and minor shale	Moderate to Good ✓ Ø>0.1, Sw<0.5 ✓ Ø>0.1, Sw<0.55 Average core permeability 30-40 md.	Southern and central part of Khashman
	Lower Wara	Dominantly shale with minor sand / silt intercalations (Hetero-lithic)	Poor (Average Ø: 0.1and Average Sw>0.5).	Northern part of Khashman

Summary of Upper and Lower Wara reservoir quality in Khashman

Conclusions

- Present study helped in understanding Wara facies architecture , delineation of reservoir facies and prediction of reservoir properties.
- The study identified potential unexplored drillable prospects for Wara Formation in Khashman Field.
- Successful drilling of identified prospects could add substantial reserve in Wara Formation.