

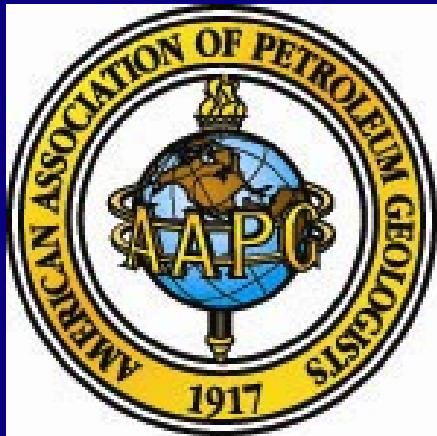
Ghawar: The Anatomy of the World's Largest Oil Field



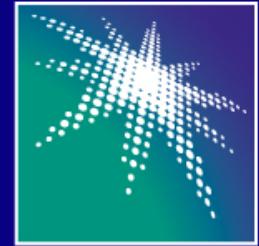
Abdulkader M. Afifi

Saudi Aramco

Acknowledgements



ExxonMobil



السعودية
Saudi Aramco

Dave Alexander, Mohamed Ameen, Scott Amos, Dave Cantrell, Greg Gregory, Chris Heine, Wyn Hughes, Tom Keith, Maher Al-Marhoon, John Melvin, Ali Al-Muallem, Abdulla Al-Naim, Han Sibon, Aus Al-Tawil, Kamal Al-Yahya, Hong Bin Xiao.

Outline

- **History of discoveries**
- **Structure**
- **Oil Reservoirs**
 - **Jurassic Arab-D**
- **Gas Reservoirs**
 - **Permian Khuff**
 - **Permo-Carboniferous Unayzah**
 - **Devonian Jauf**
- **Summary**

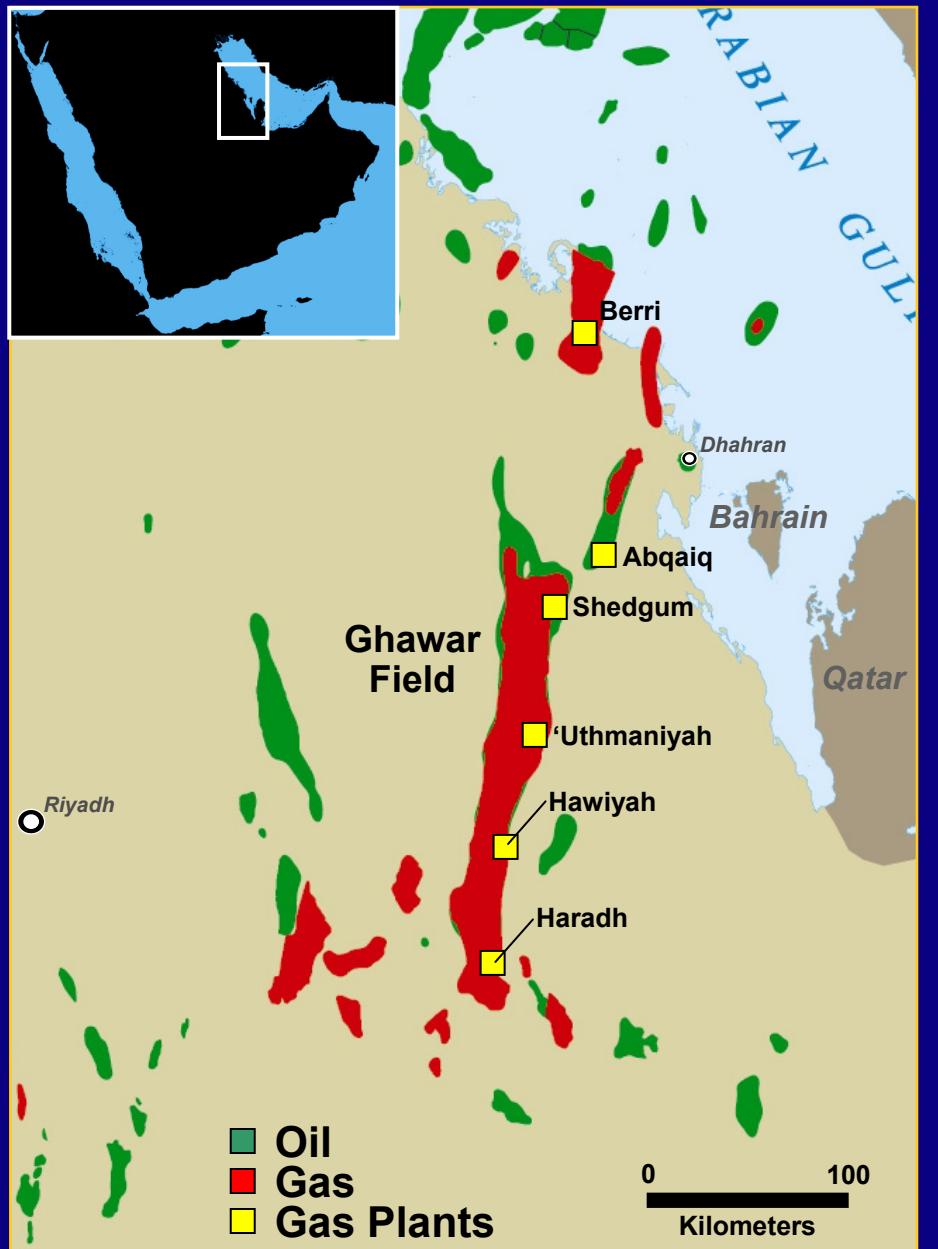
Ghawar Field

Size 174 x 16 miles,
area \sim 2050 miles²
 \sim 1.3 million acres.

Oil discovery: 1948
On stream: 1951
Peripheral water injection: 1965.

Oil production \sim 5 million B/D
from Jurassic Arab-D.

Gas production 8 billion SCF/D,
Associated gas \sim 2 BSDFD,
Non-associated gas \sim 6 BSCFD
from Paleozoic reservoirs.

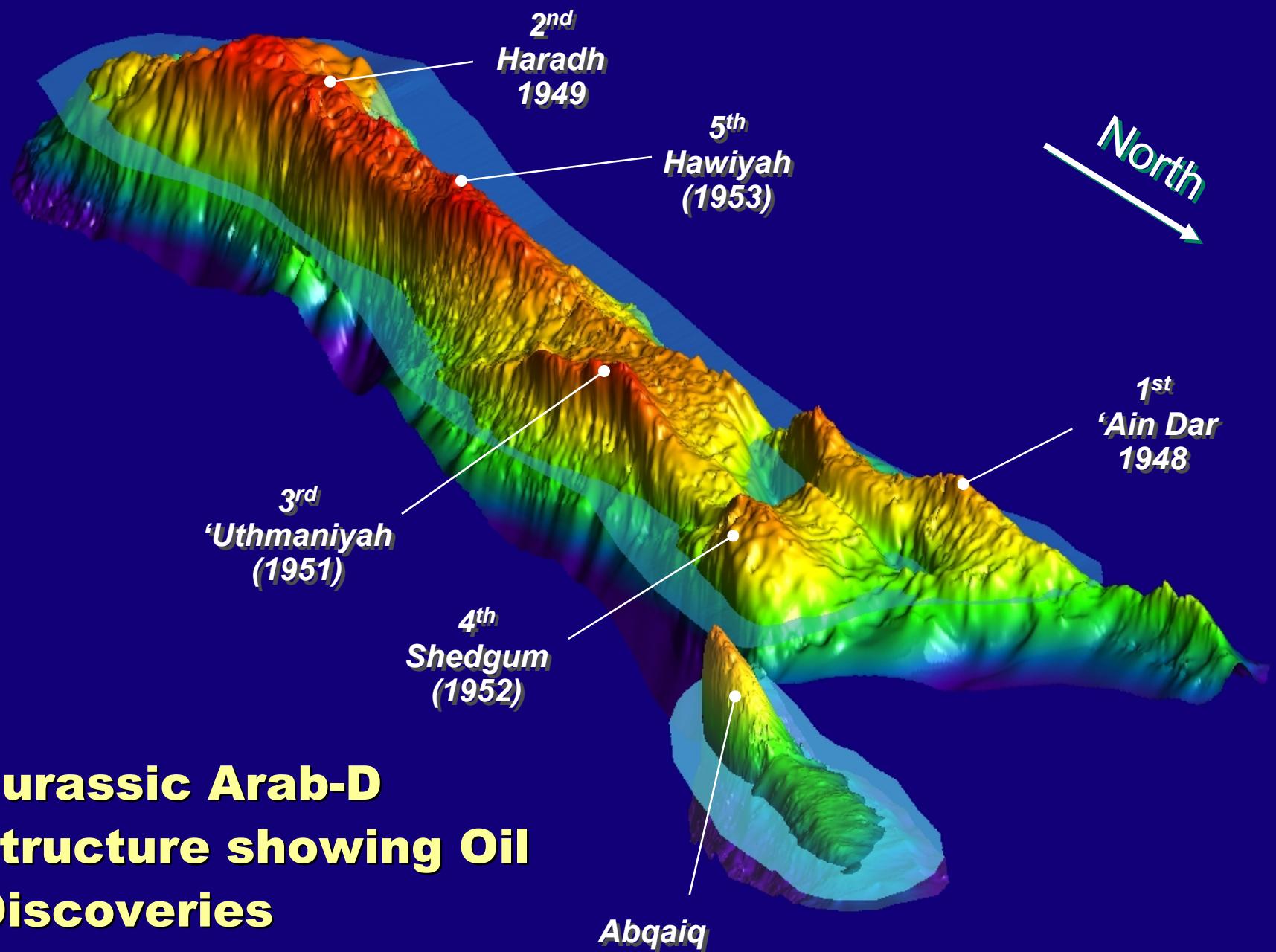


Ghawar Size Comparison



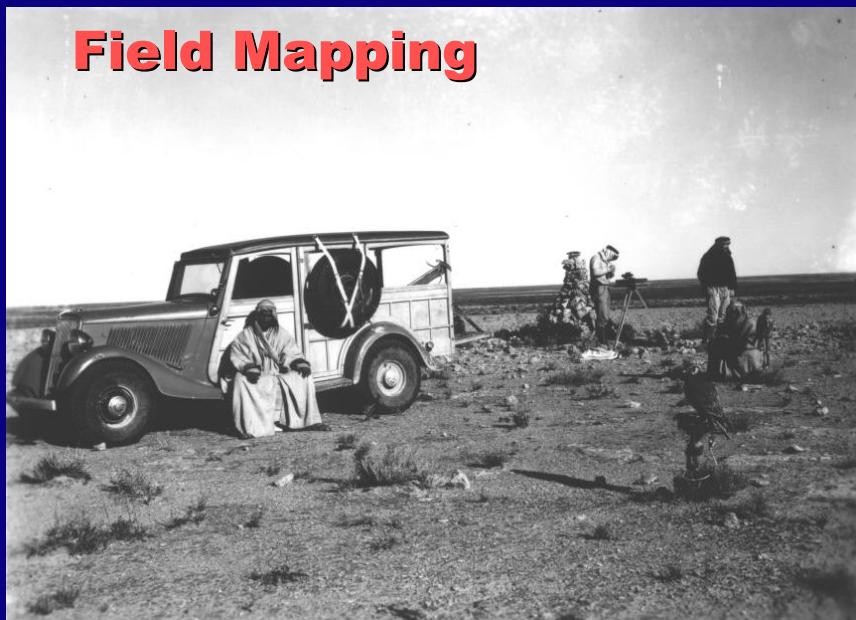
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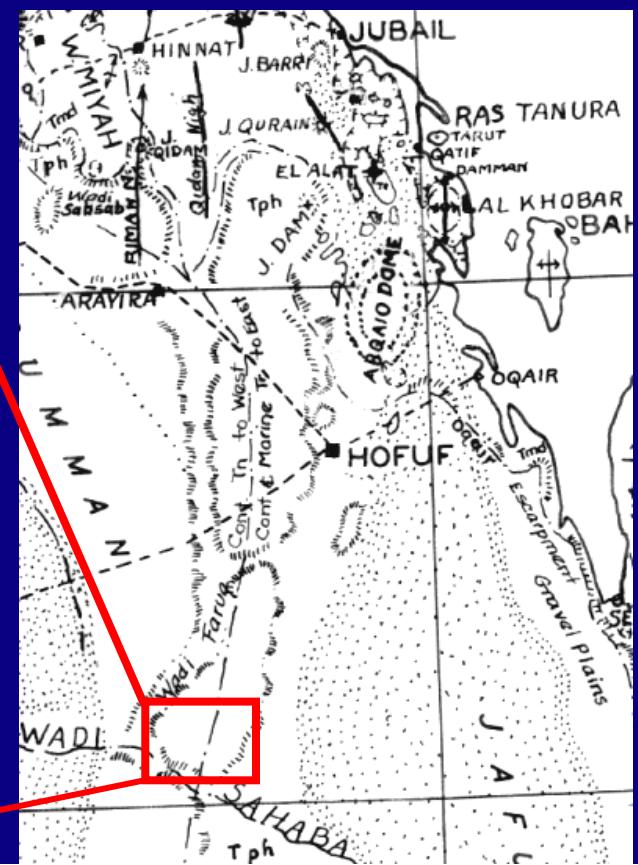


Jurassic Arab-D structure showing Oil Discoveries

Field Mapping



Khamees
ibn Rimthan
Ernie Berg

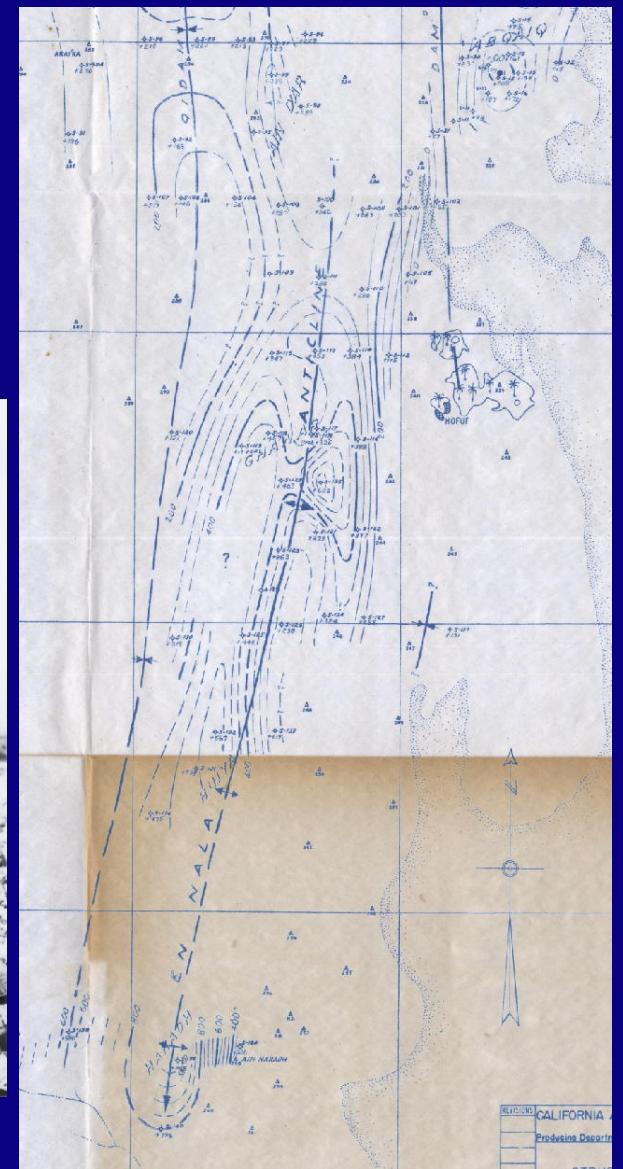


The Innovation of Structural Drilling for Exploration

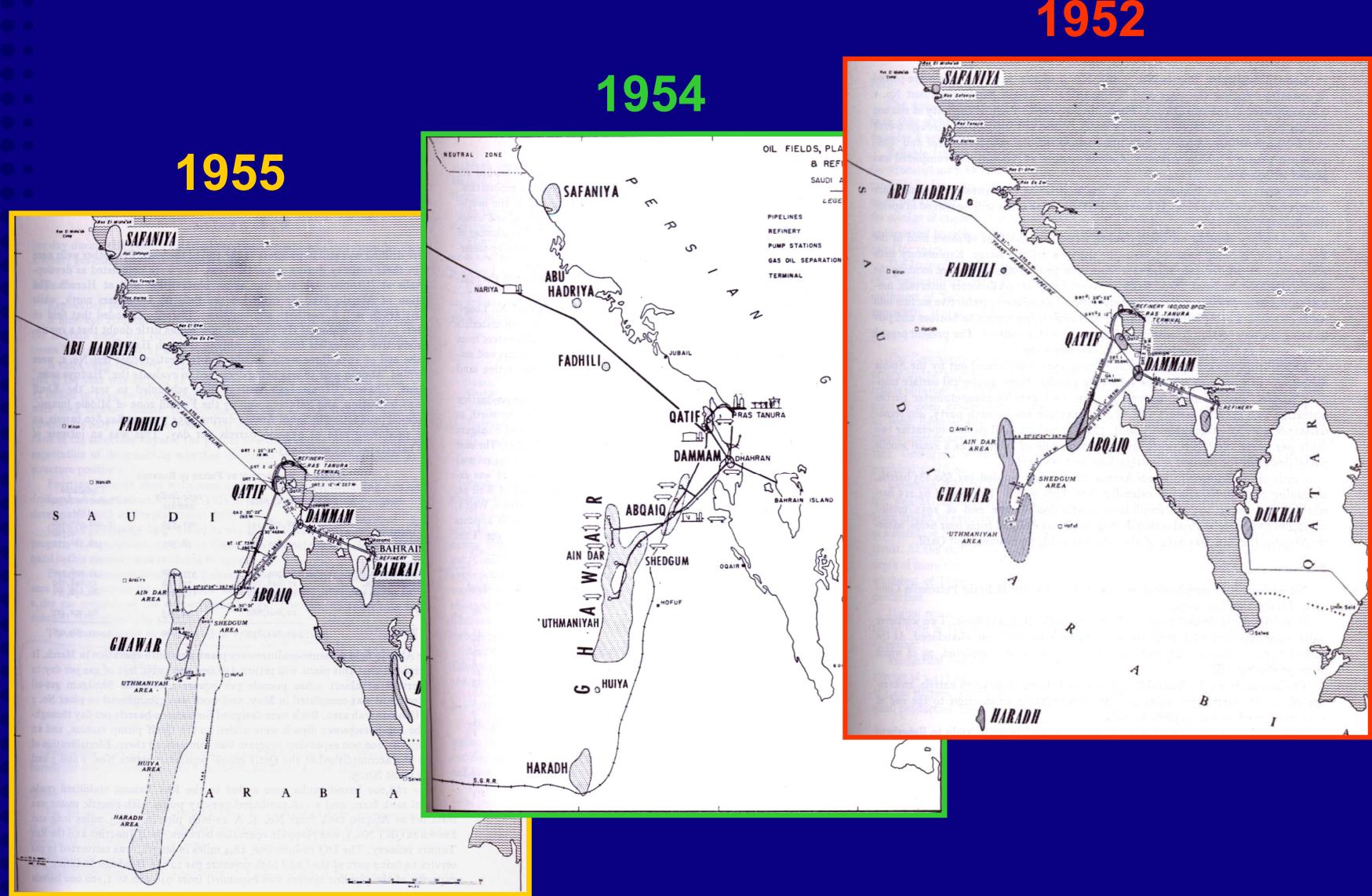
Max Steineke
Chief Geologist
&
AAPG Powers
Medalist

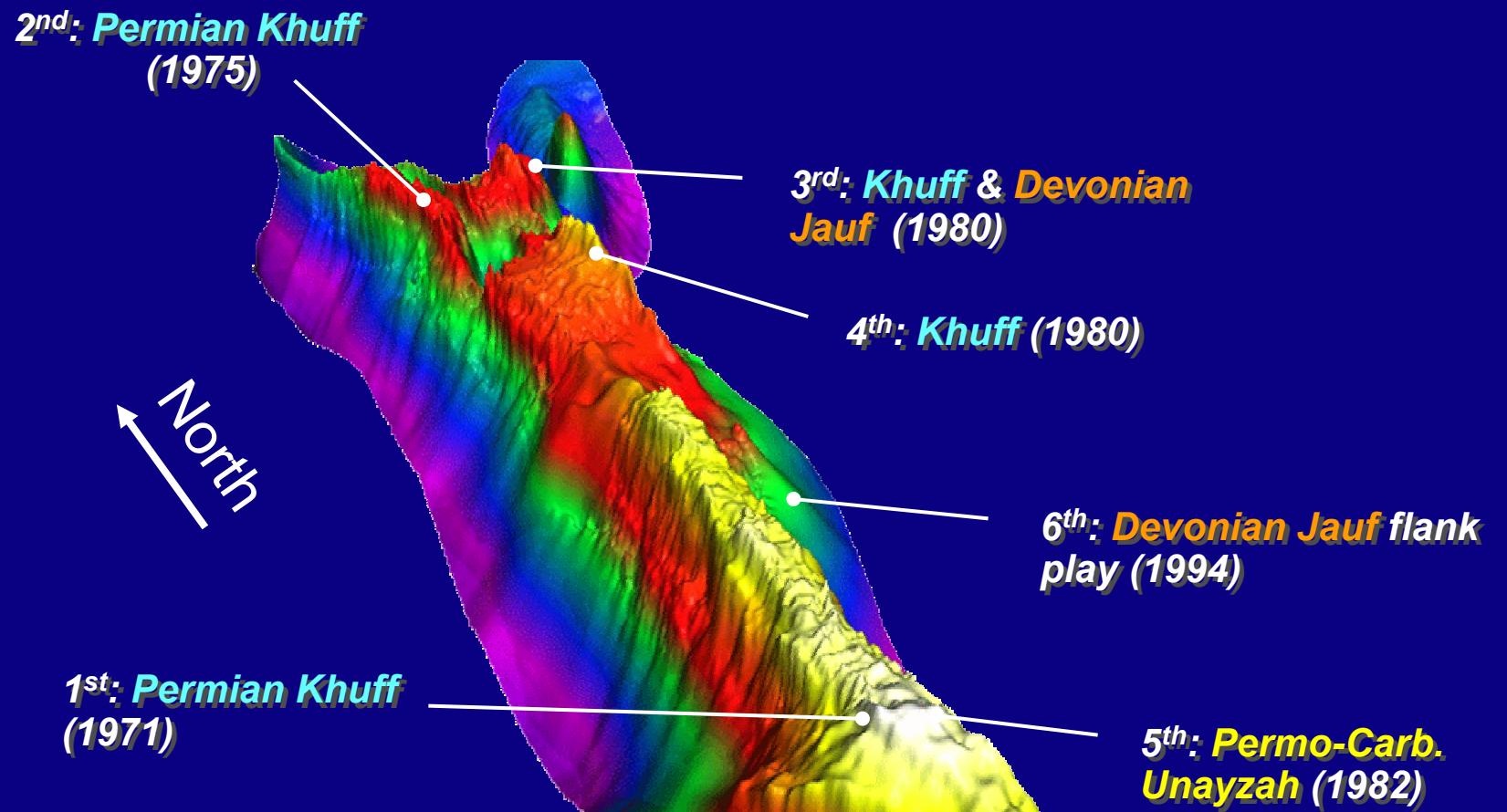


Early structural map
of Ghawar



Ghawar Delineation 1948-1955



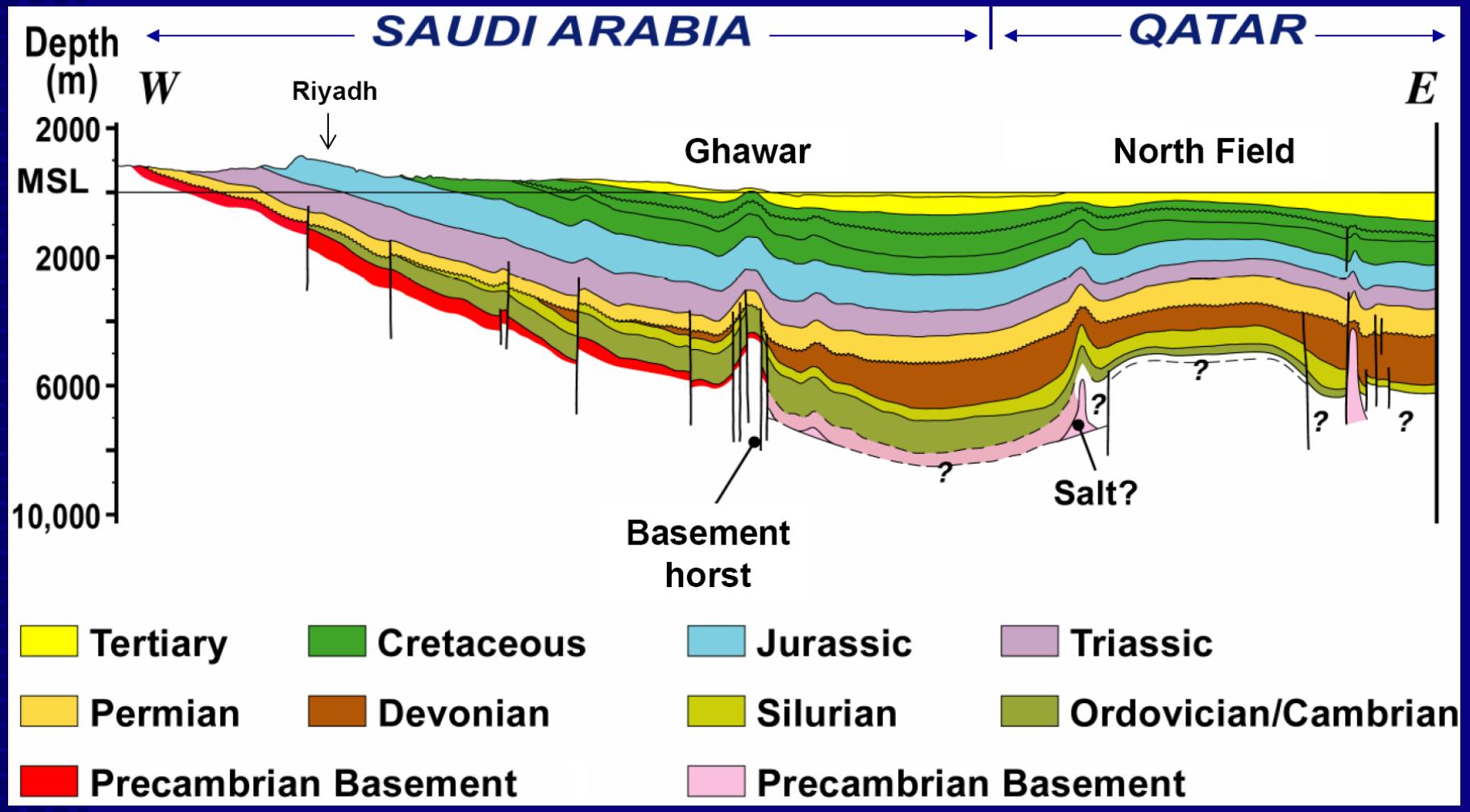


Permian Khuff Structure showing Gas Discoveries in Paleozoic Reservoirs

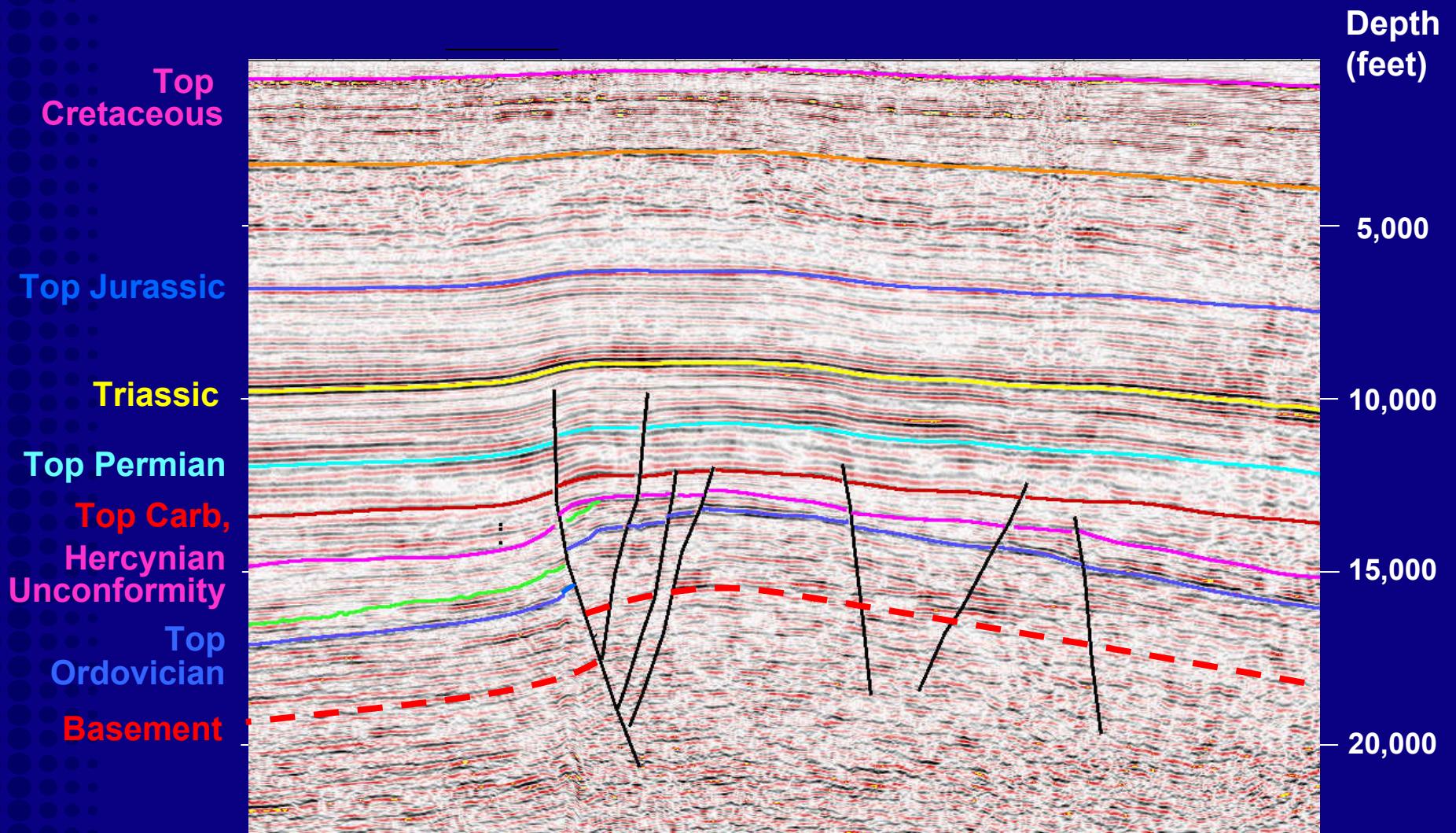
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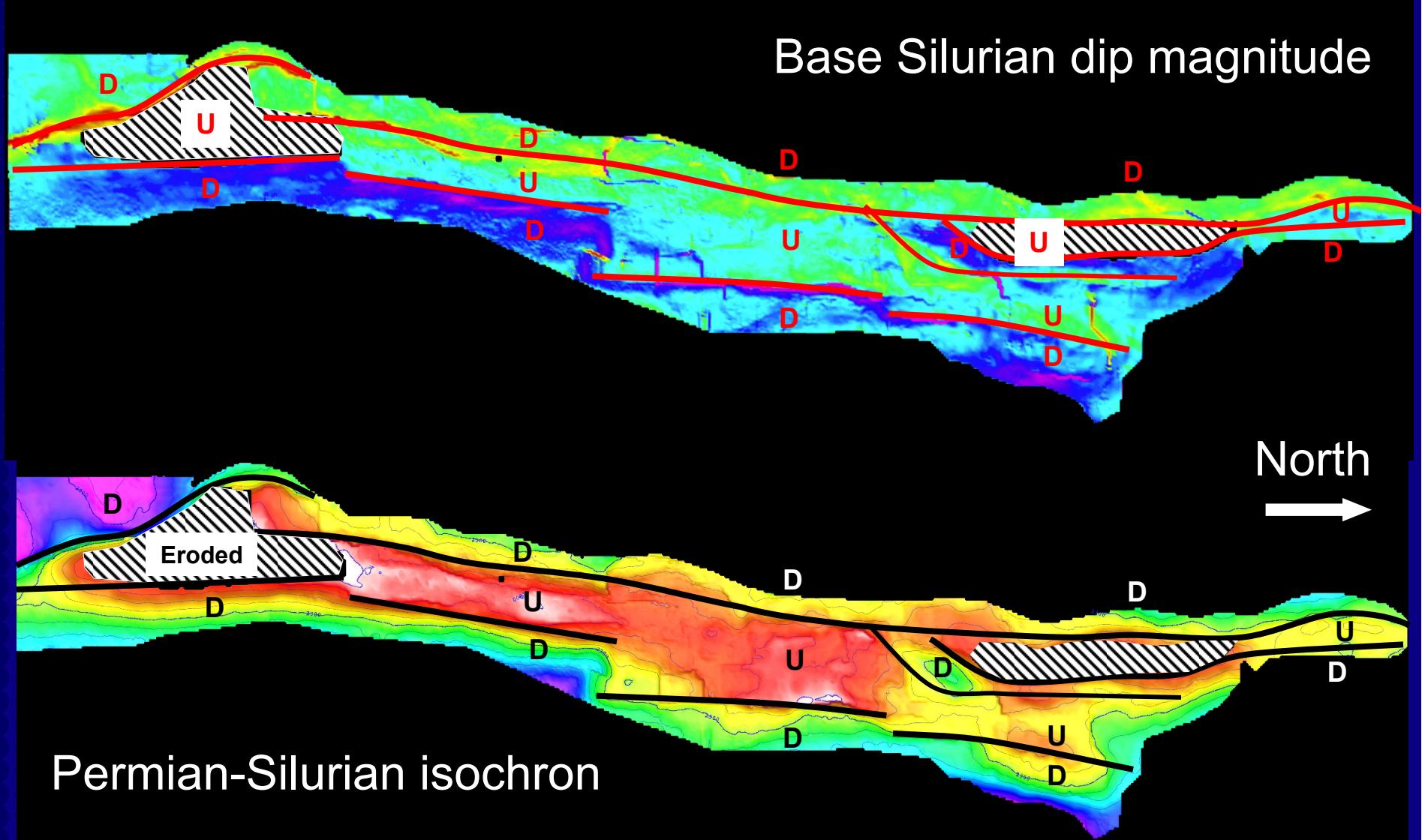
Regional E-W Cross Section

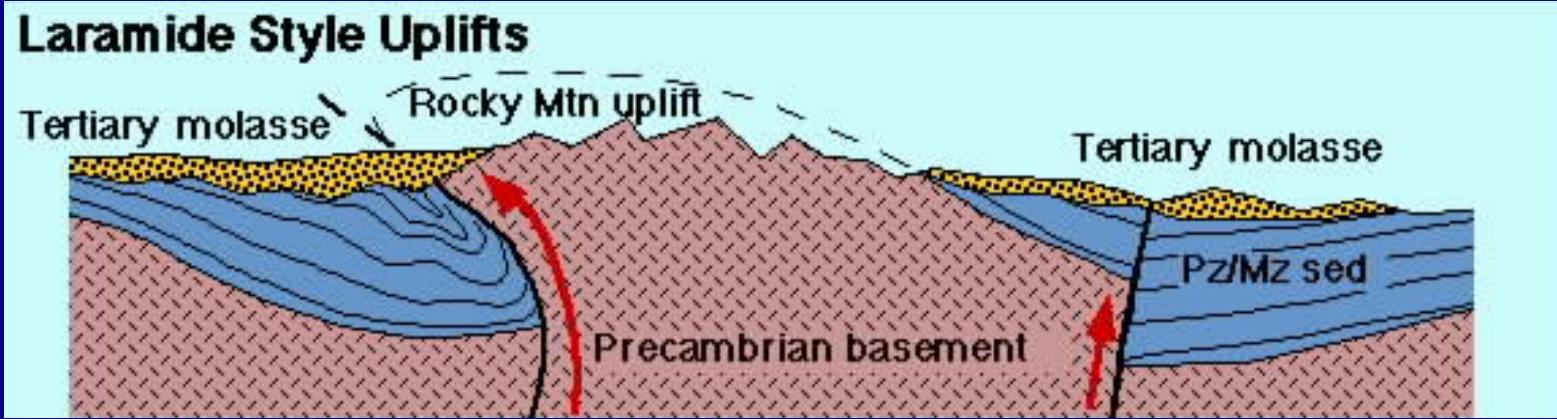
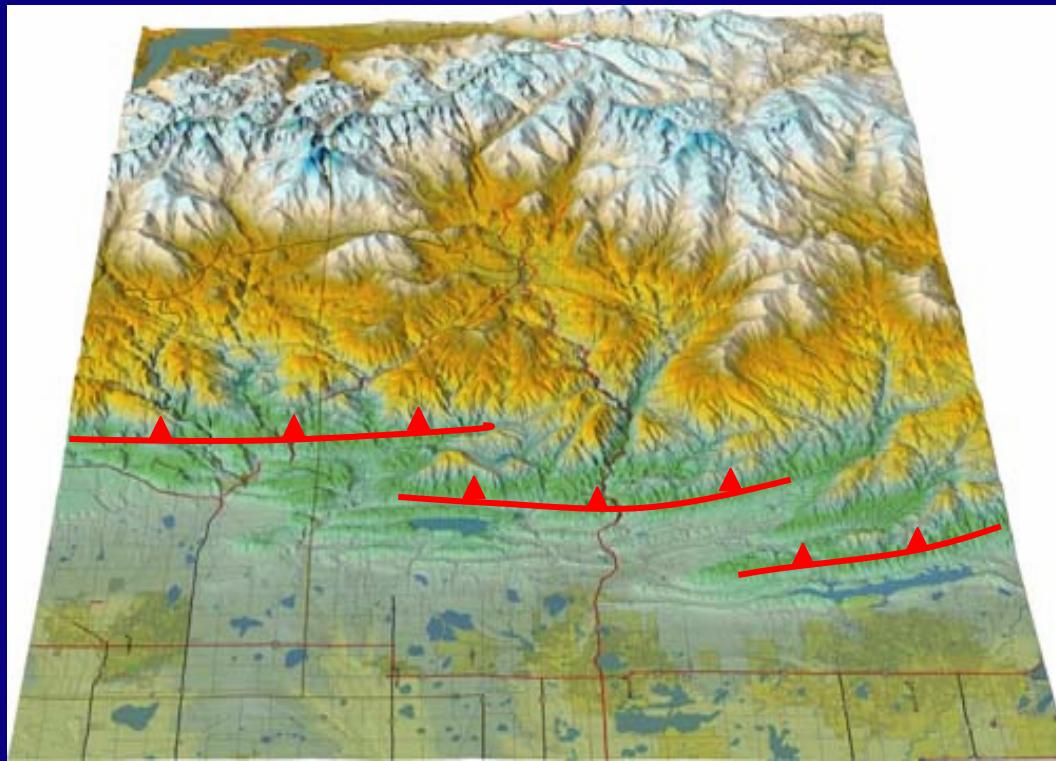


E-W Seismic Depth Section, South Ghawar

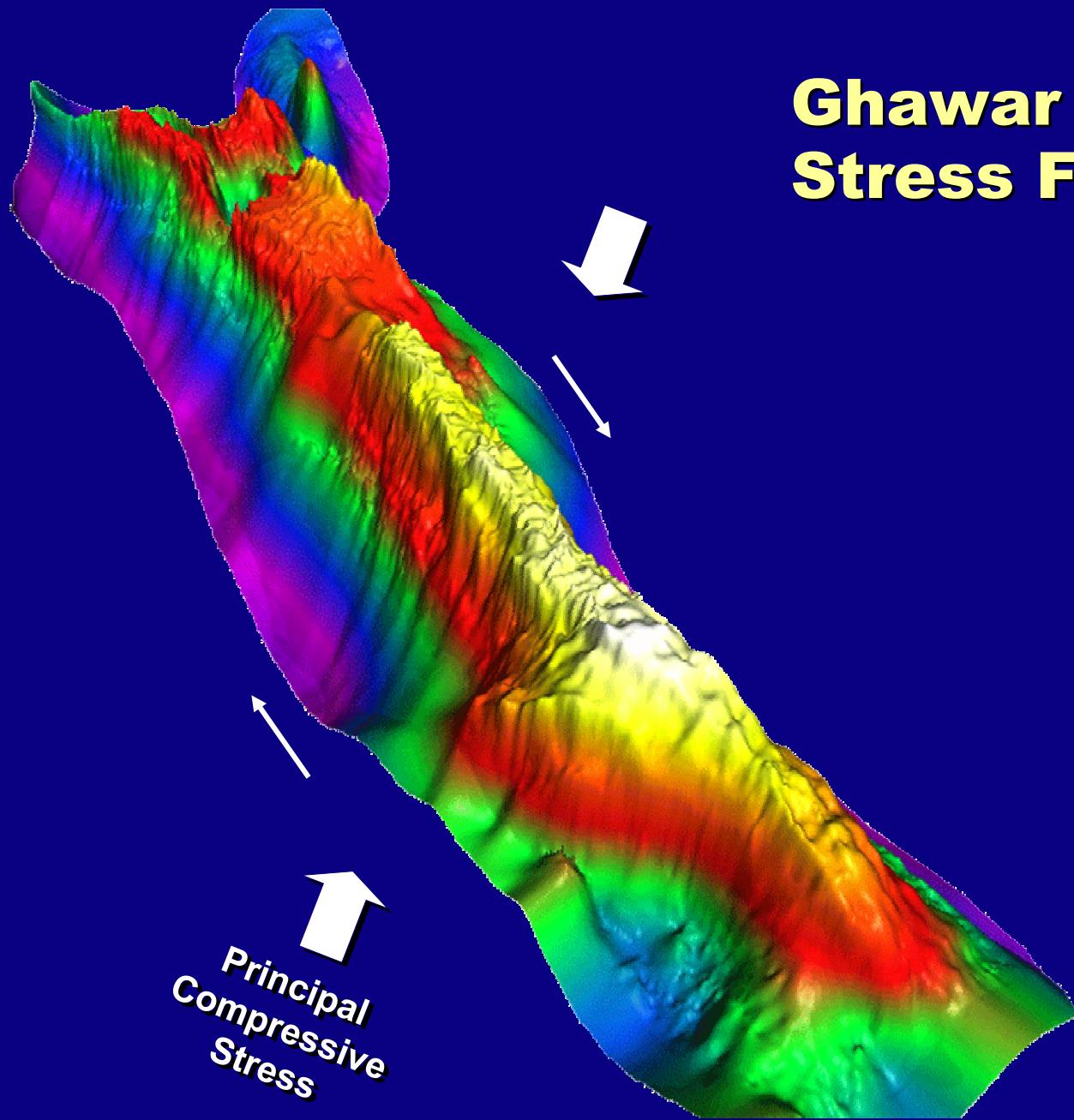


Deep Ghawar Structure





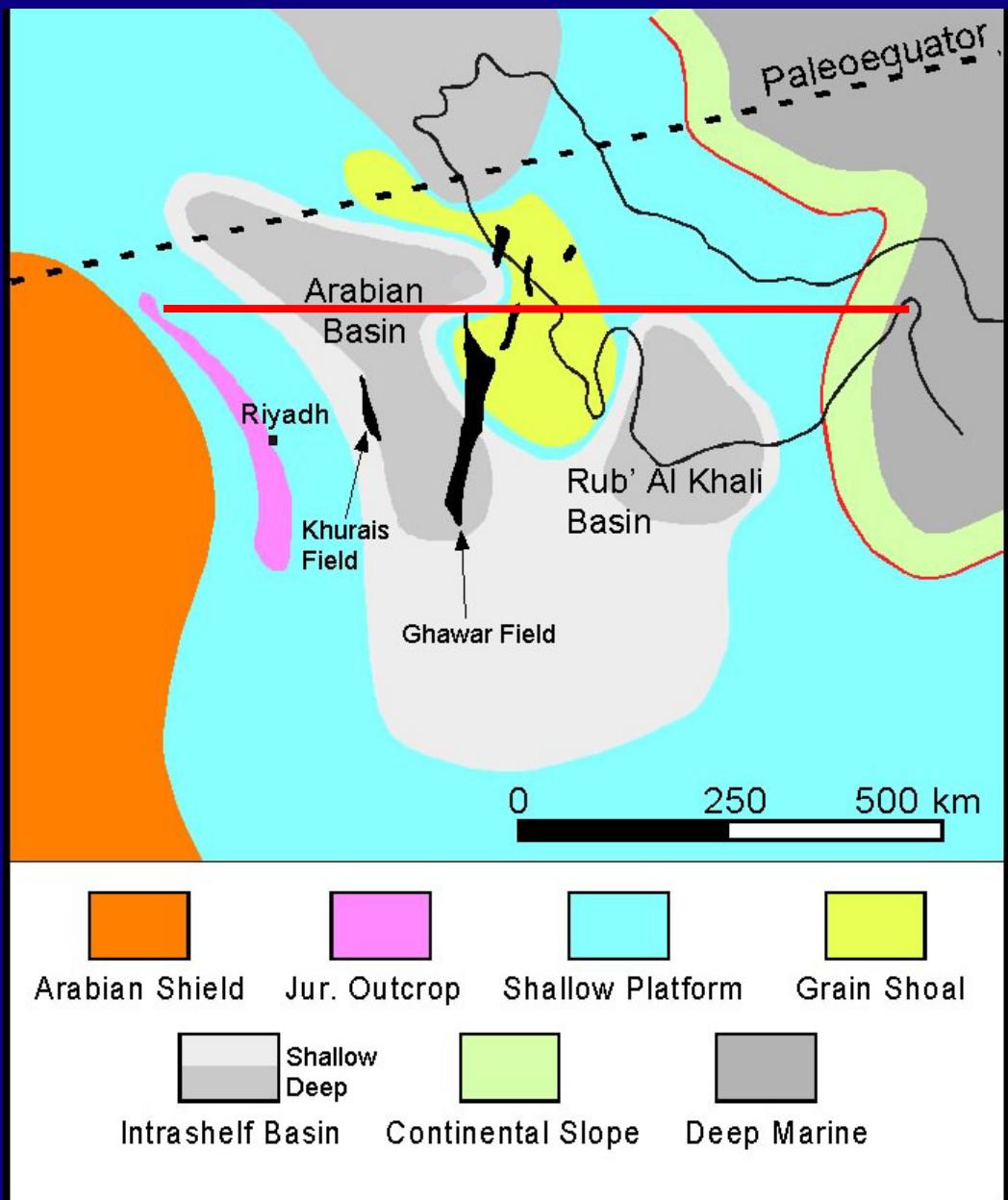
Ghawar Stress Field



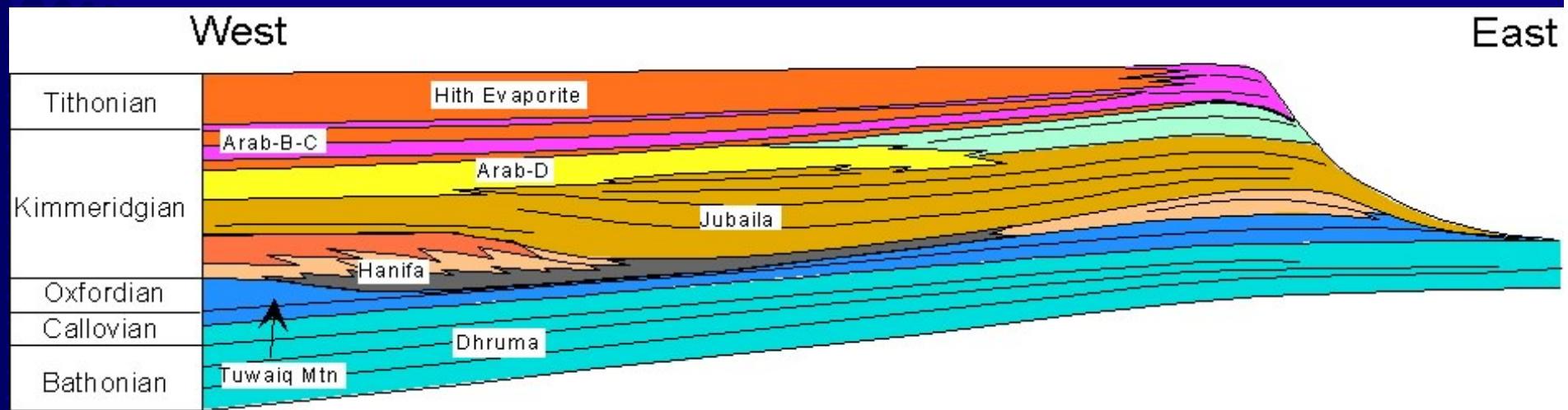
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Regional Arab-D Depositional Environments



Regional Jurassic Stratigraphy (After Murris, 1980)

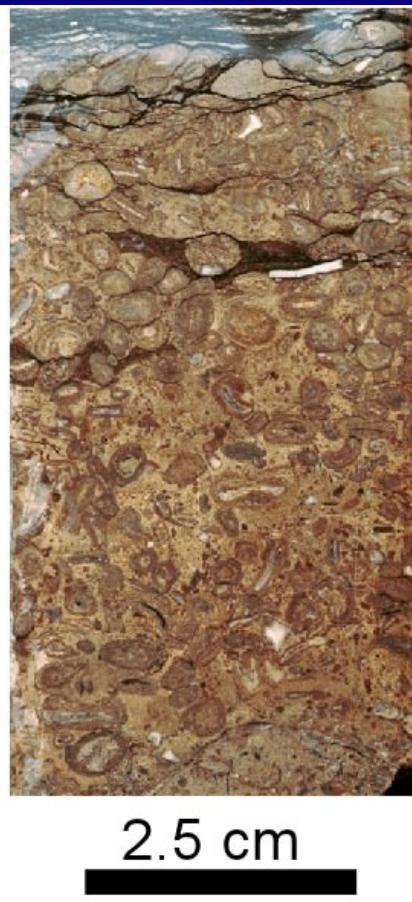


Main Arab-D Lithofacies

Up-section



Lime
mudstone



Intraclast oncoid
rudstone



Coral stromatoporoid
wackestone



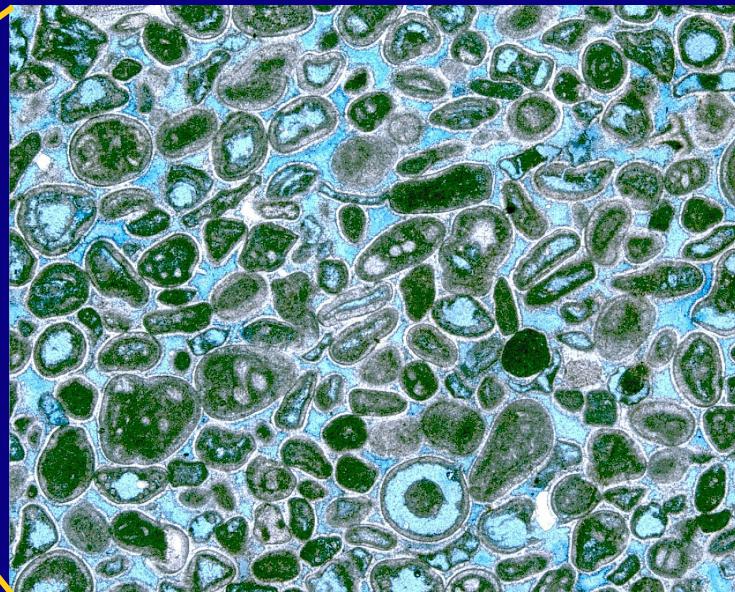
Cladocoropsis
wackestone

Main Arab-D Lithofacies

Up-section

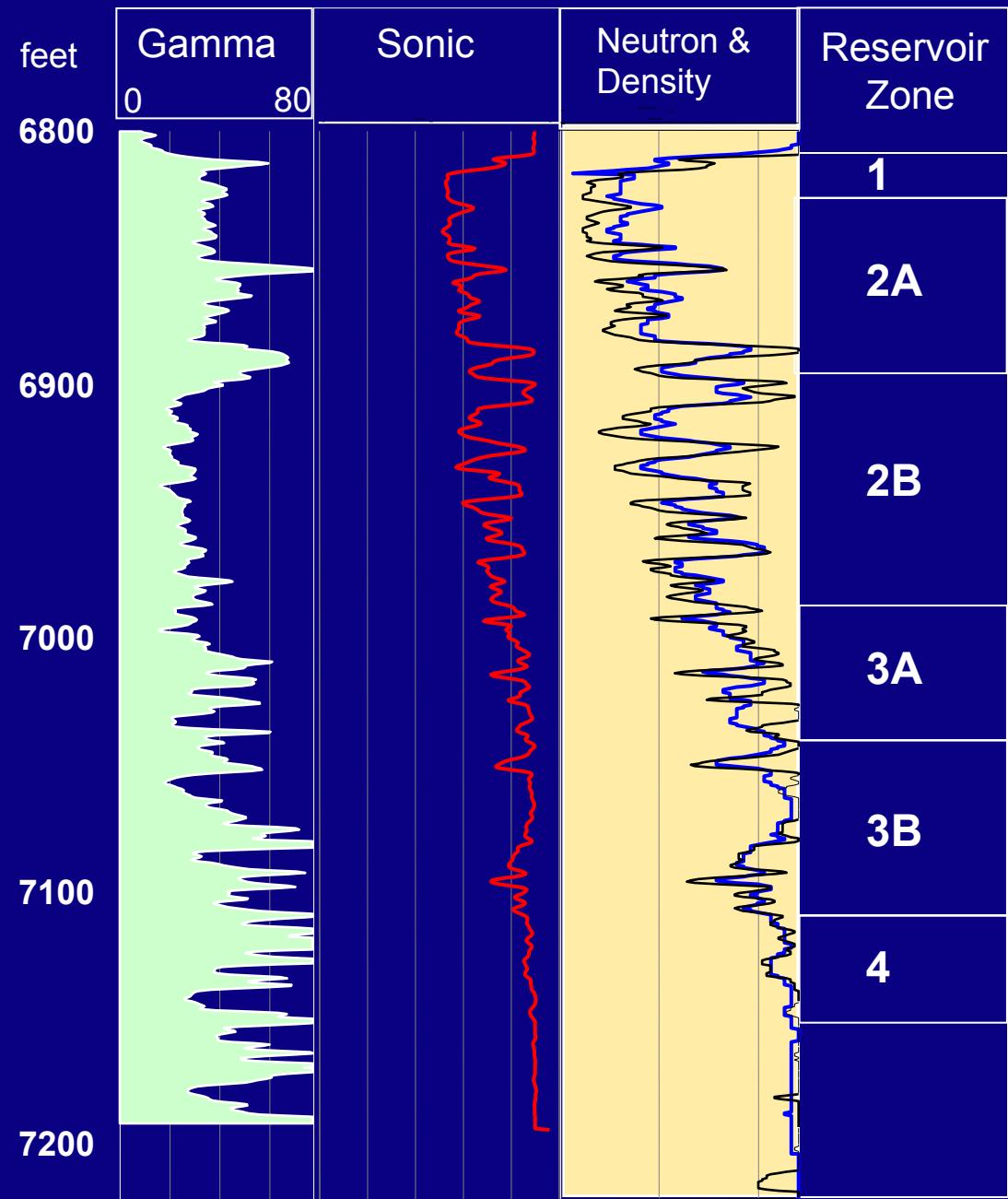


Ooid - coated grain
grainstone

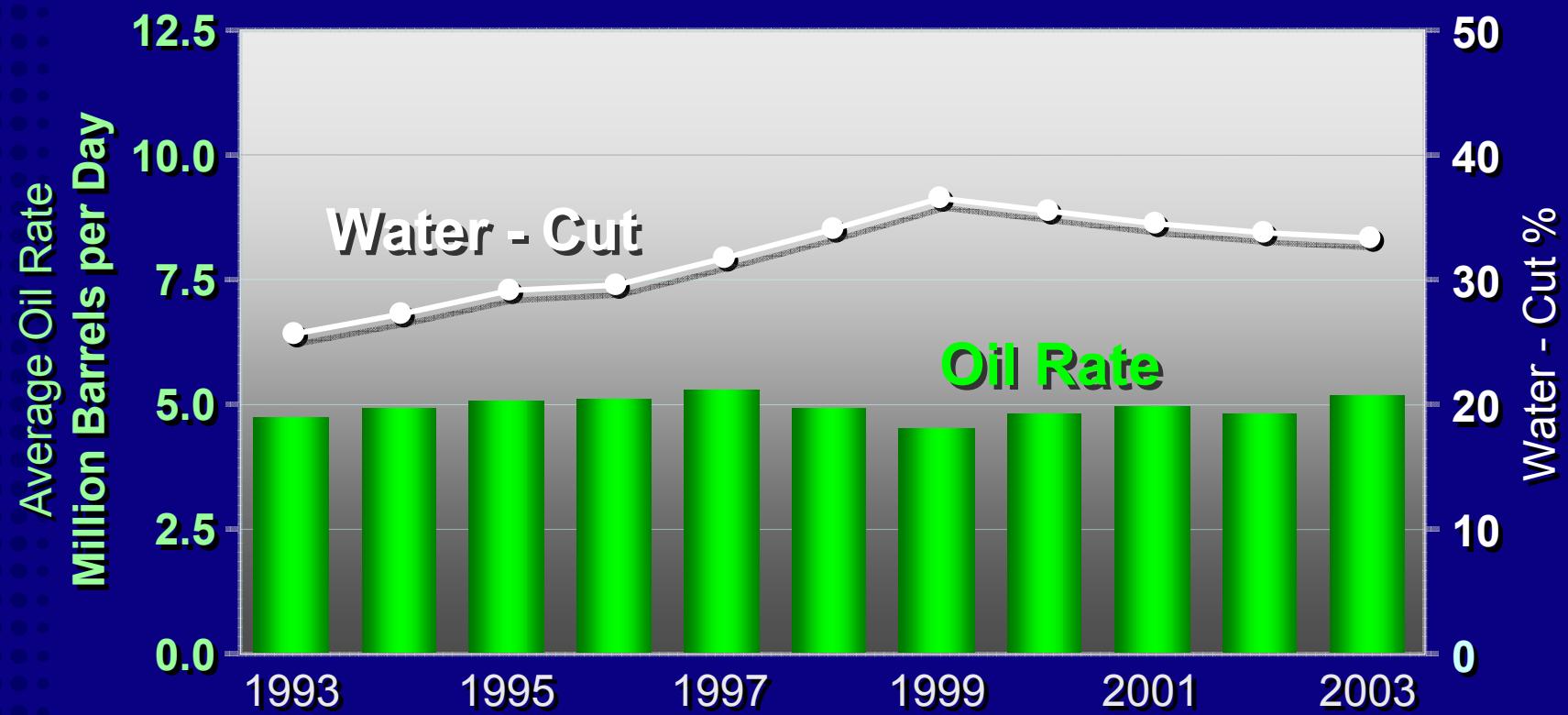


Nodular
anhydrite
(top seal)

Typical Profile of the Jurassic Arab-D Reservoir



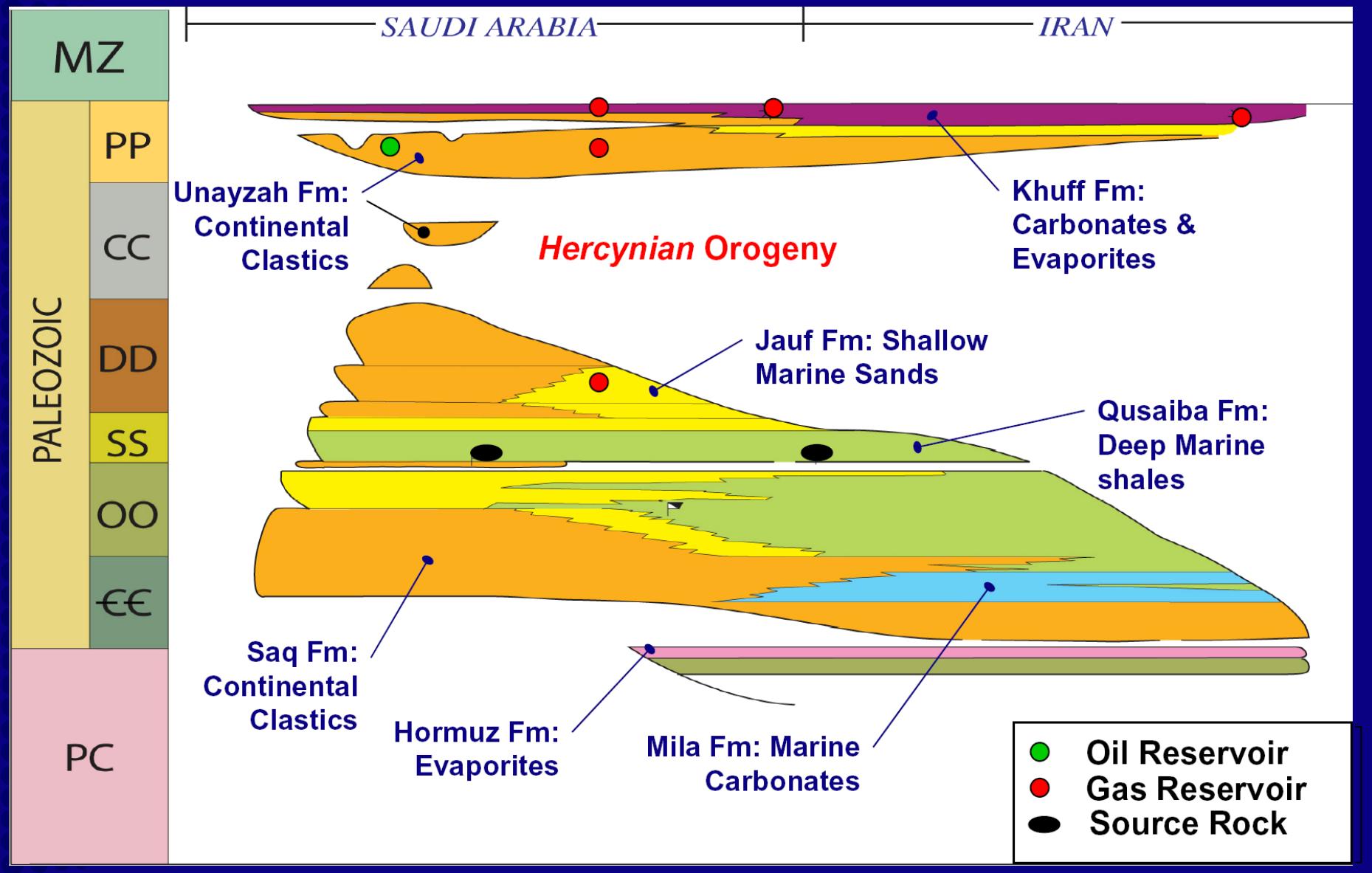
Ghawar Oil Production & Water Management



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Generalized Paleozoic Stratigraphy



Permian Khuff Gas Reservoirs

3 stacked carbonate reservoirs, with separate G/W contacts

Source: Silurian Qusaiba hot shale

Seals:

- 1- Intra-Khuff dolomite & anhydrite.
- 2- Overlying Triassic shale.

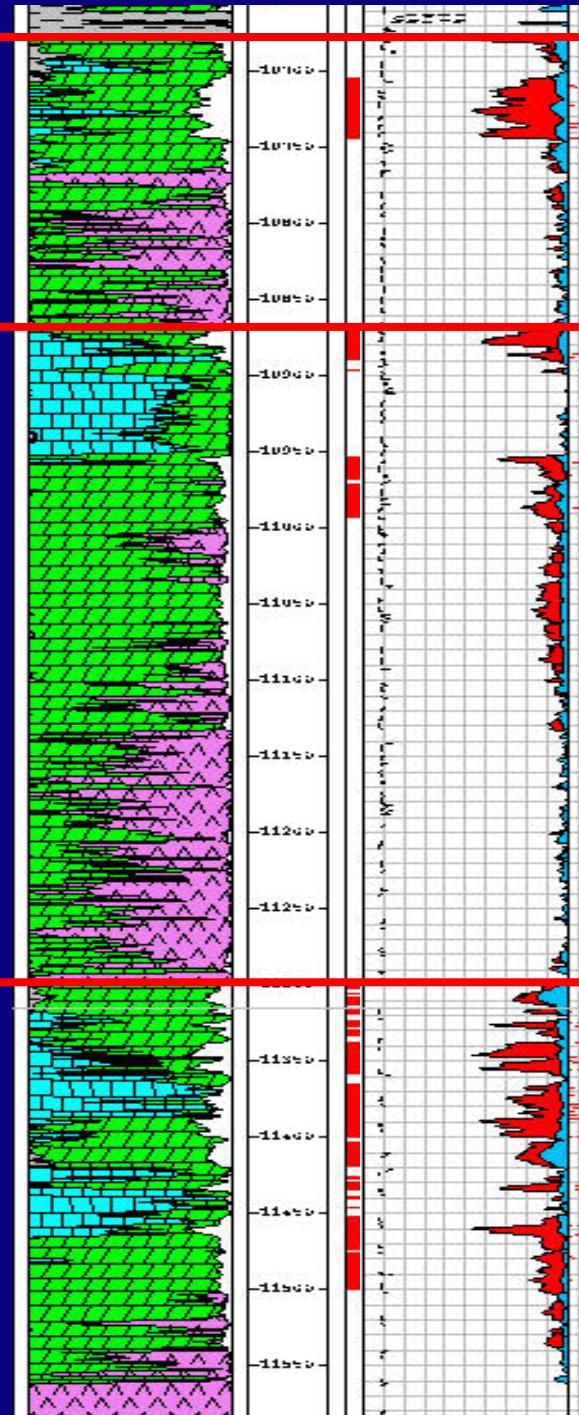
Charge: Laterally, from the north

Khuff A Reservoir

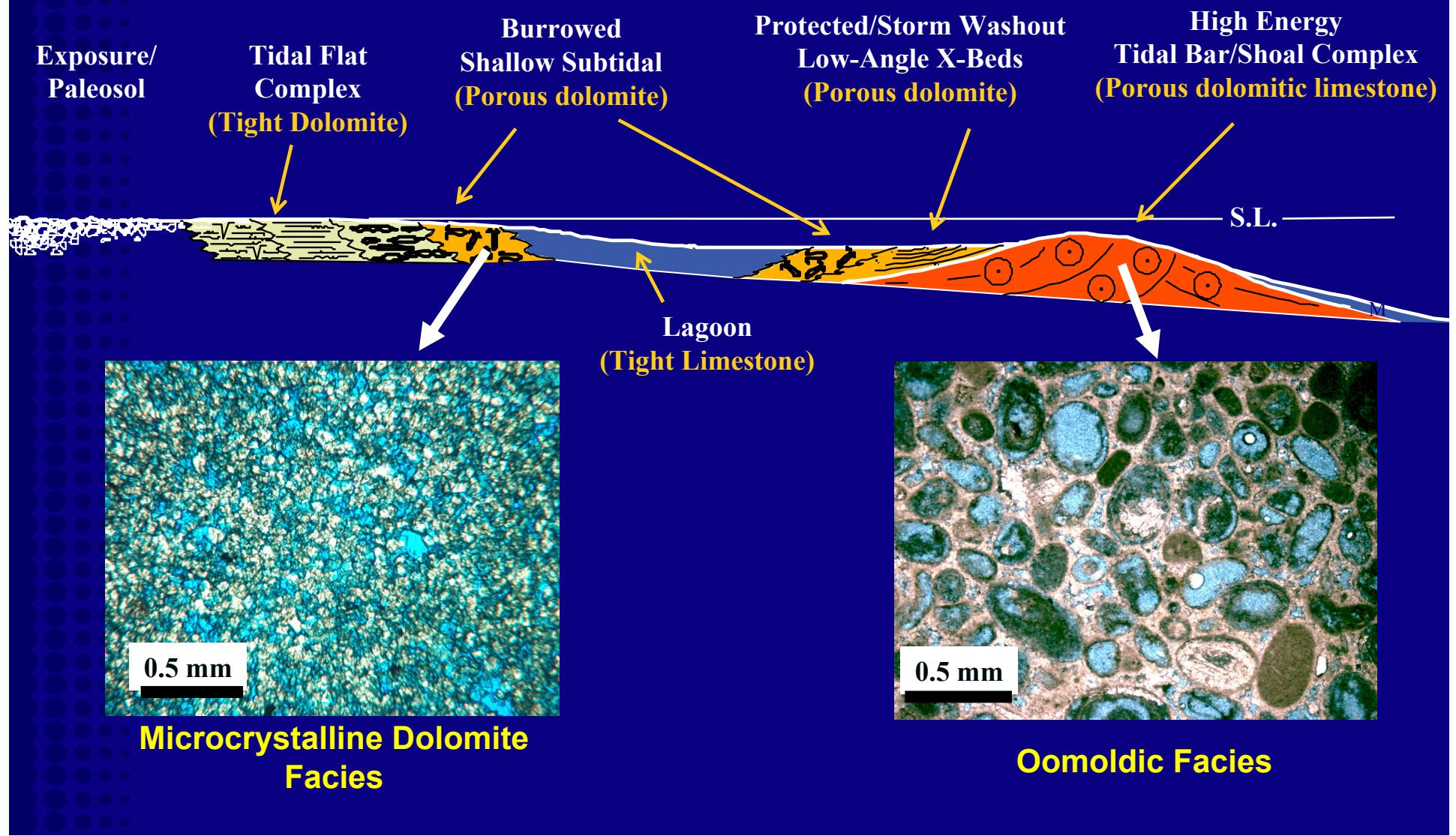
Khuff B Reservoir

Khuff C Reservoir

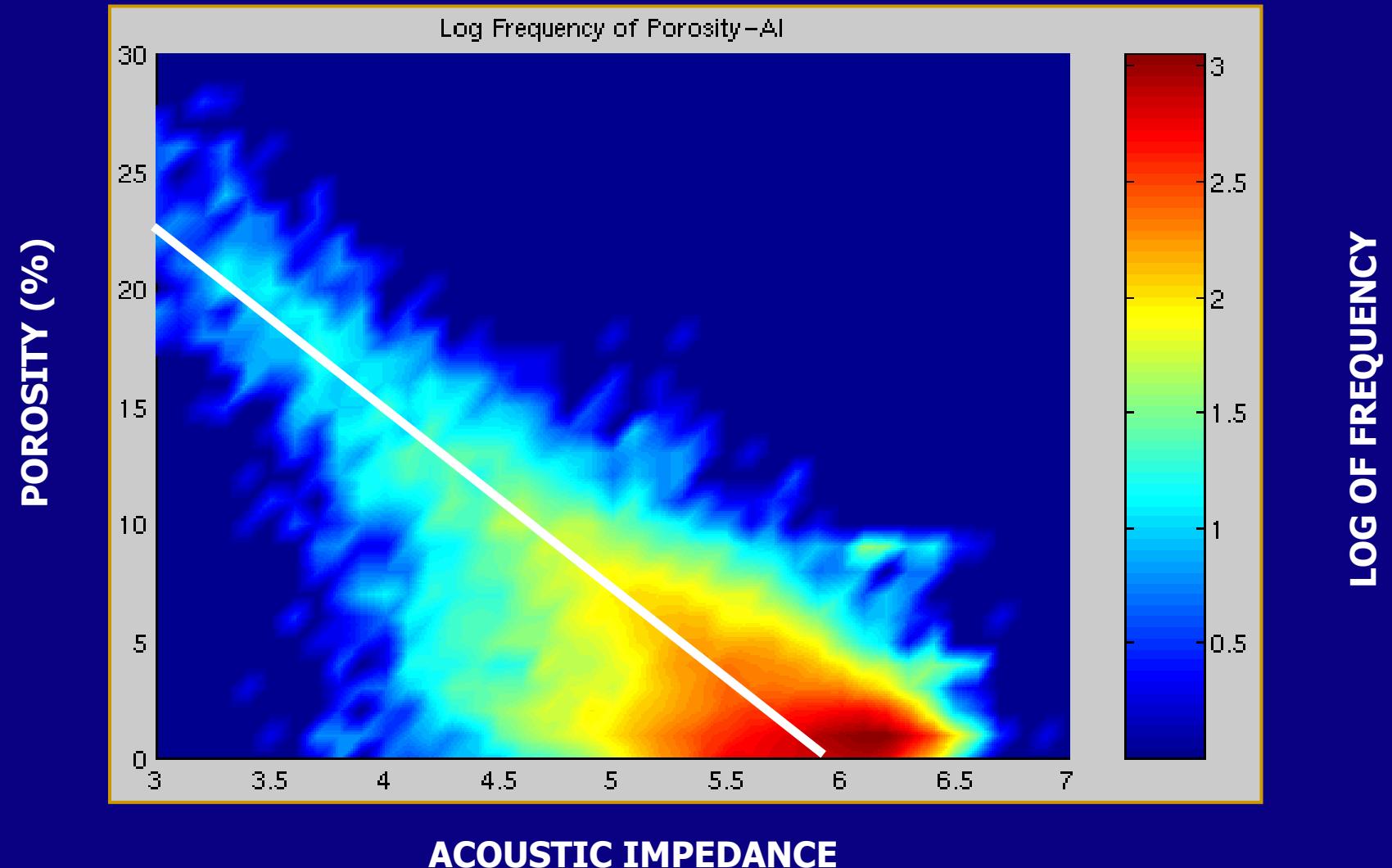
250 feet



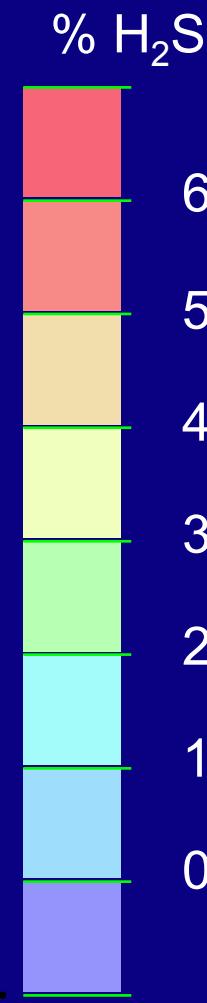
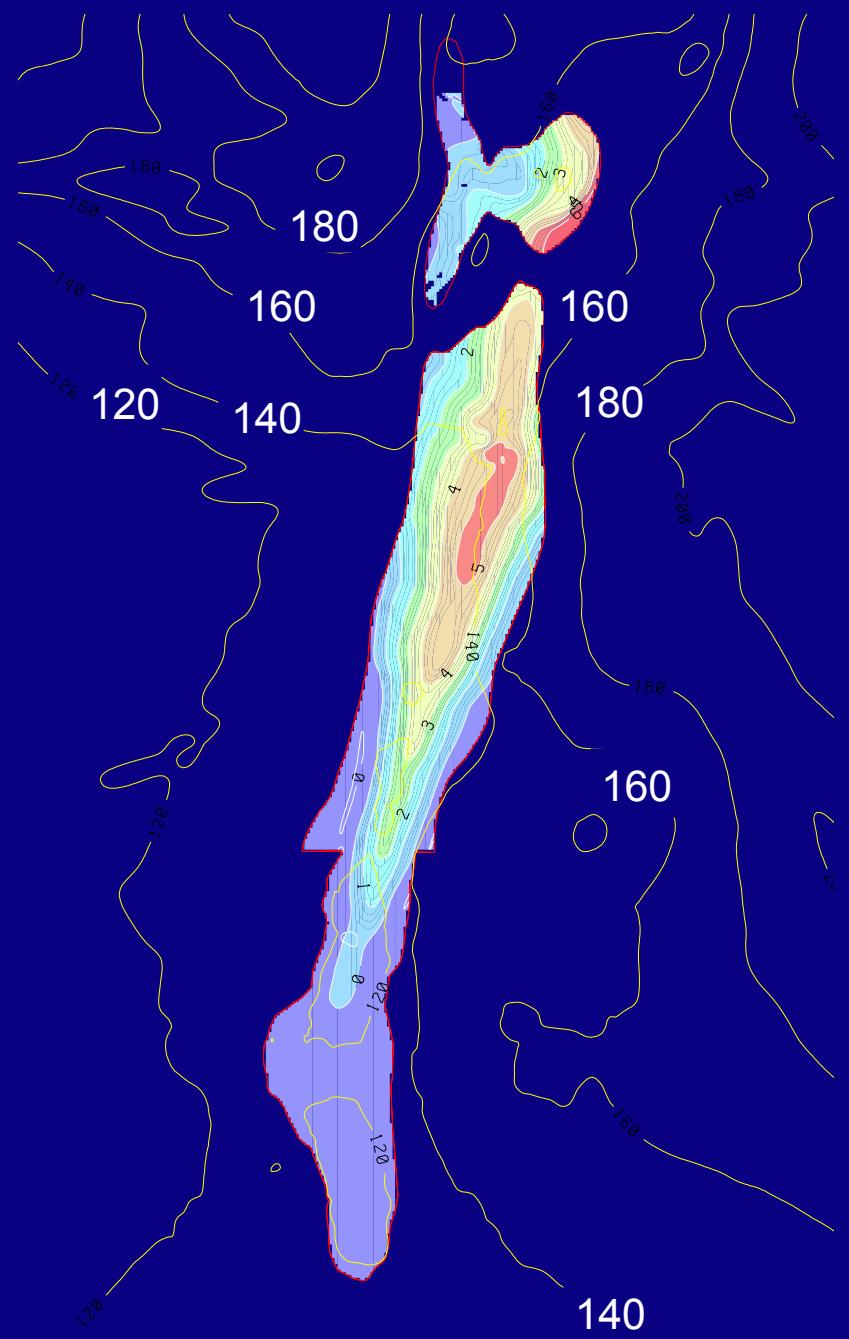
Permian Khuff Reservoir Facies



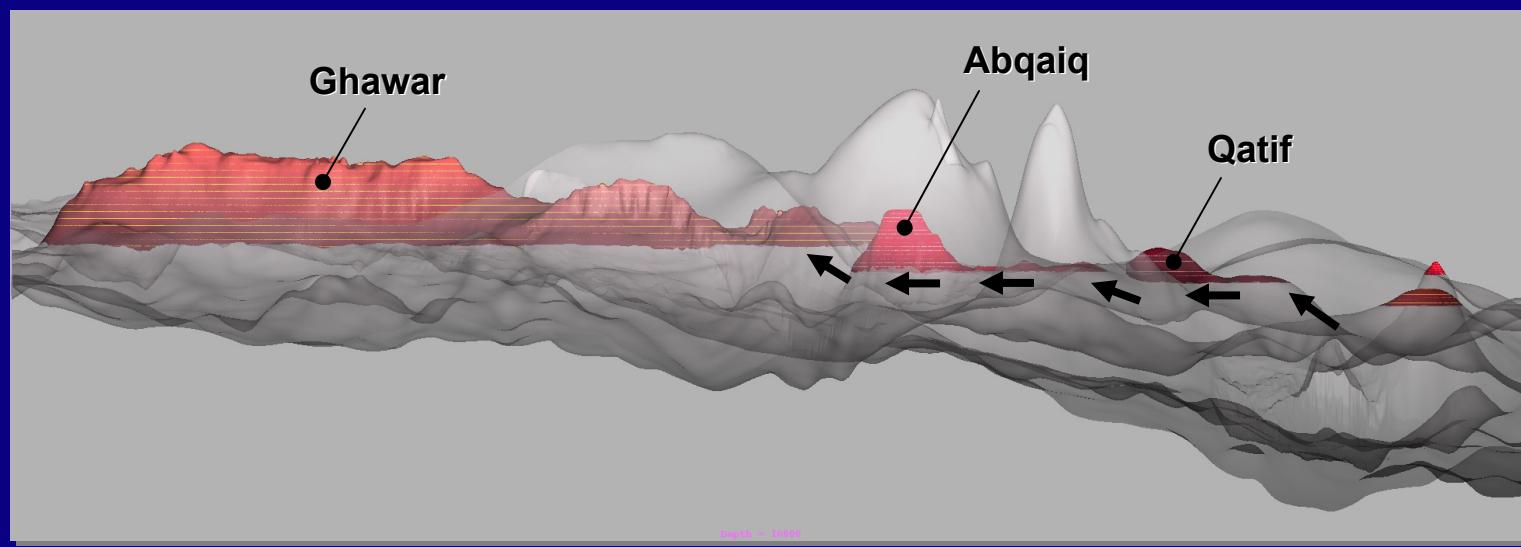
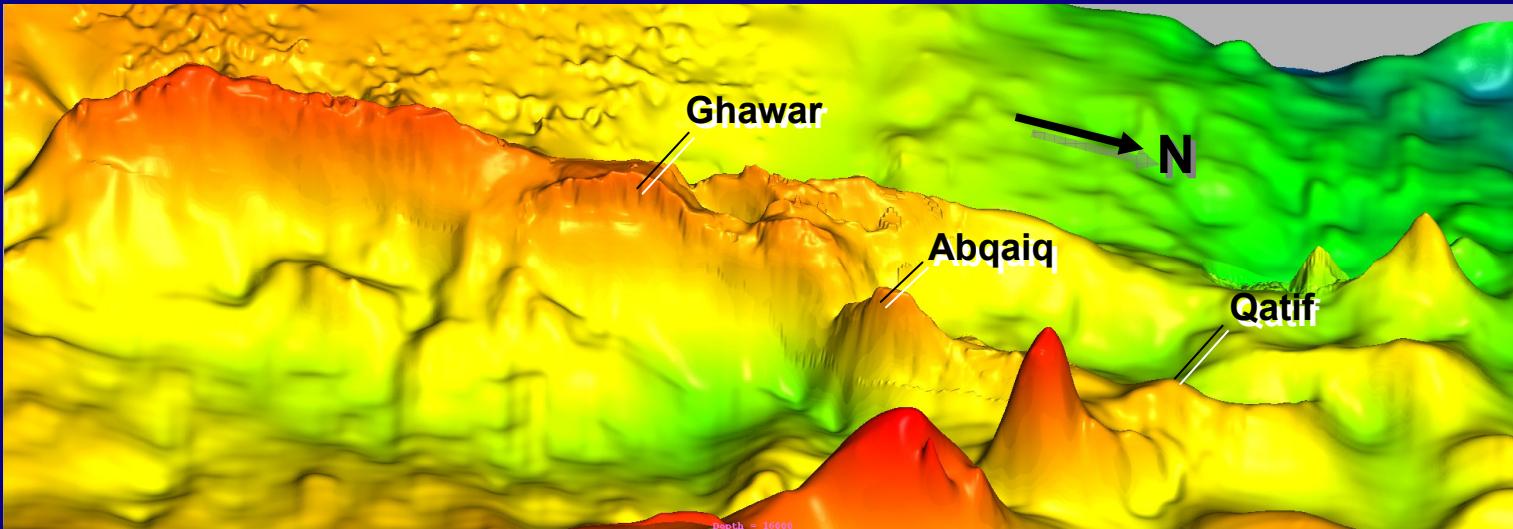
Seismic Impedance – Porosity in Khuff C Reservoir, Central Ghawar



Average H₂S and Reservoir Temperature (°C) in the Khuff Reservoirs



Gas Charge into the Khuff B Reservoir



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Permo-Carboniferous Unayzah Reservoir

Reservoir: Eolian & fluvial sandstone

Source: Silurian Shales

Seals: Basal Permian Khuff shale & anhydrite

Charge: from below

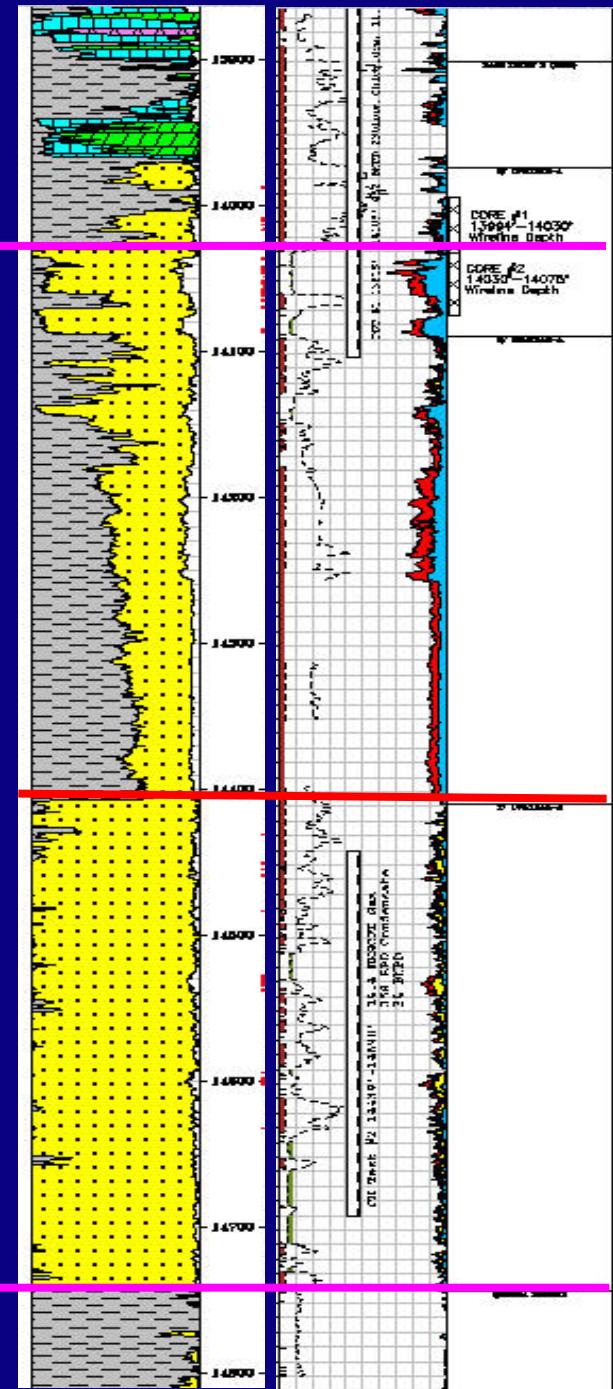
Late Permian
Khuff

Early
Permian
Unayzah A
Reservoir

300 FT

Unayzah B
Reservoir

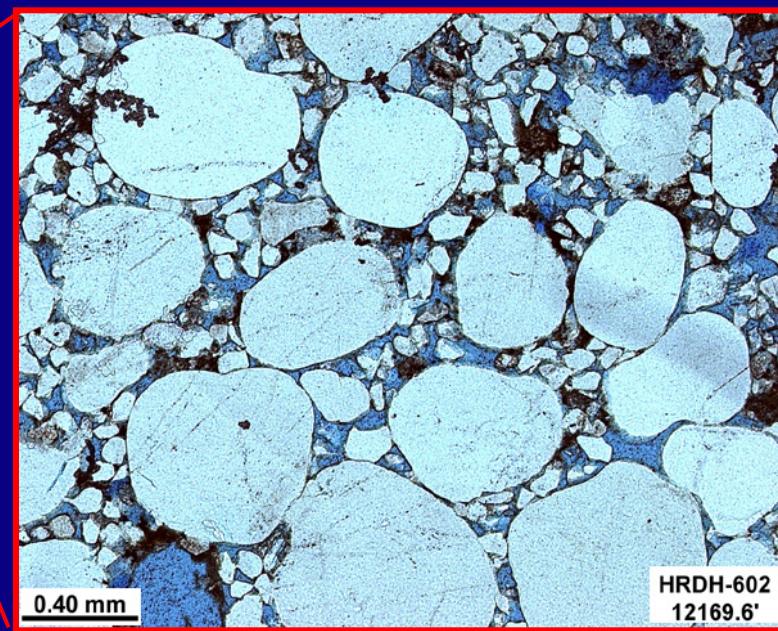
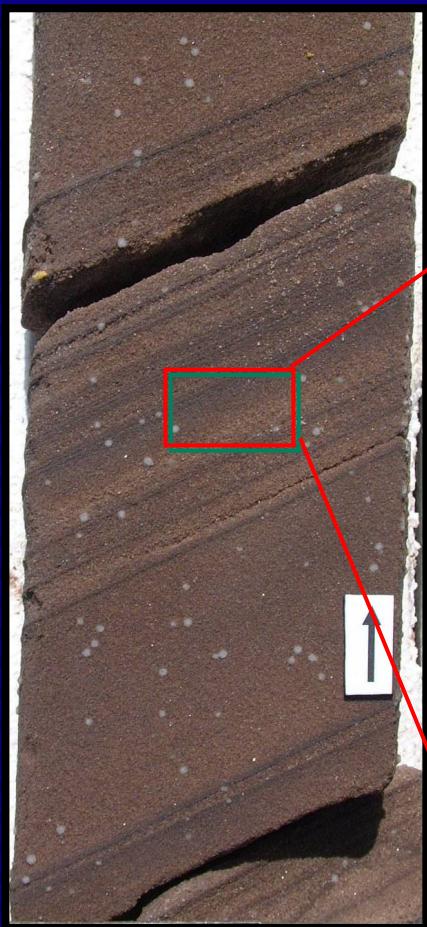
Hercynian Unconformity
Silurian Qusaiba Shale



Unayzah Reservoir Facies

Lacustrine

Eolian



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Devonian Jauf Reservoir

250 FT

Jauf
Reservoir

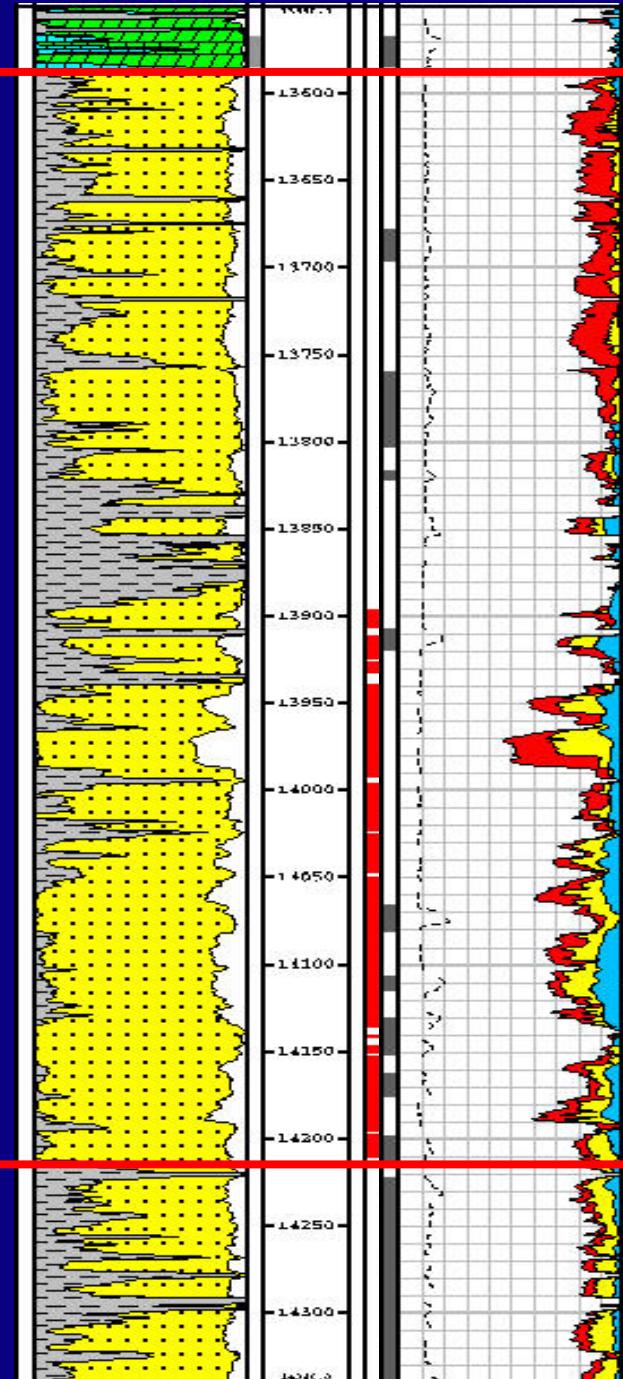
Reservoir: Estuarine and coastal sandstone

Source: Silurian Shales

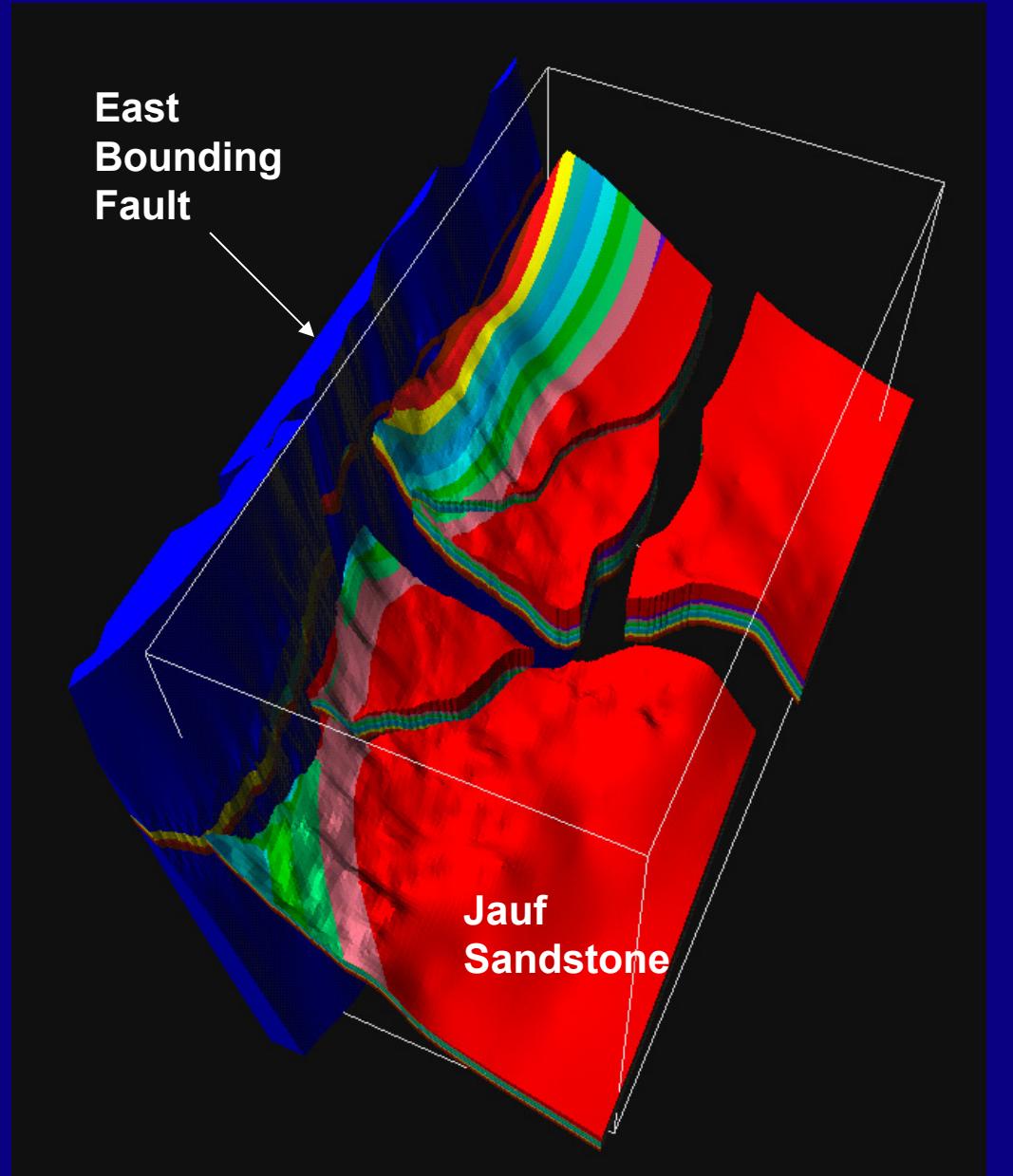
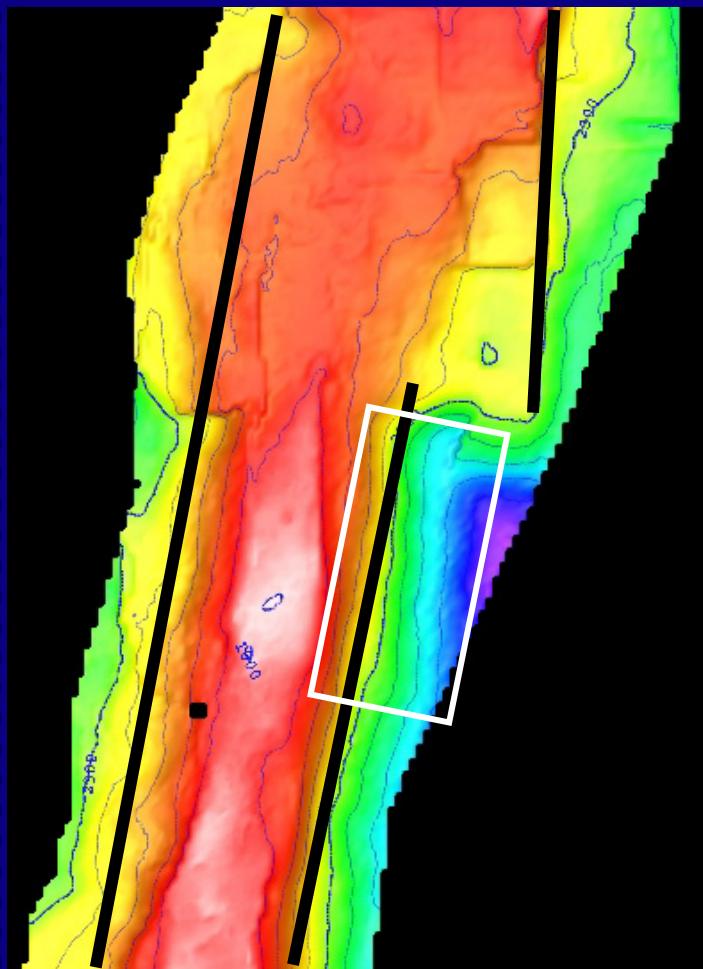
Seals: Intraformational shale or basal Khuff shale & anhydrite

Charge: From below

Devonian Tawil Formation



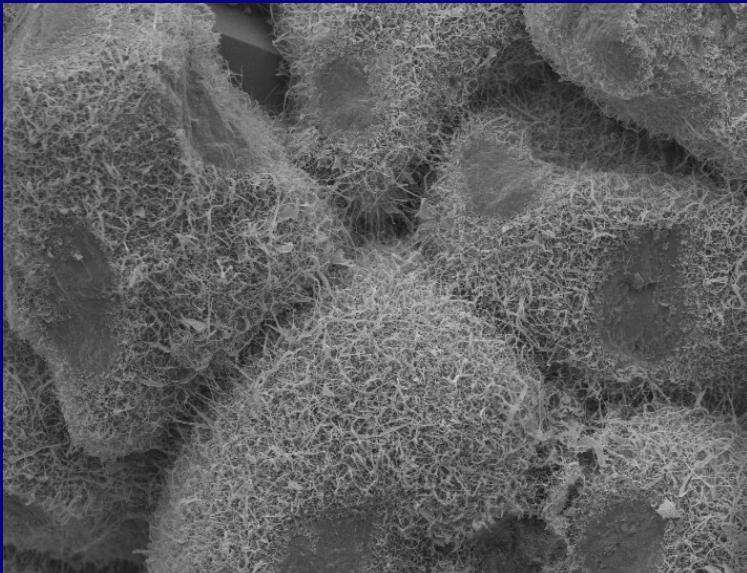
Fault-Unconformity Gas Trap in the Devonian Jauf Sandstone, Ghawar E Flank



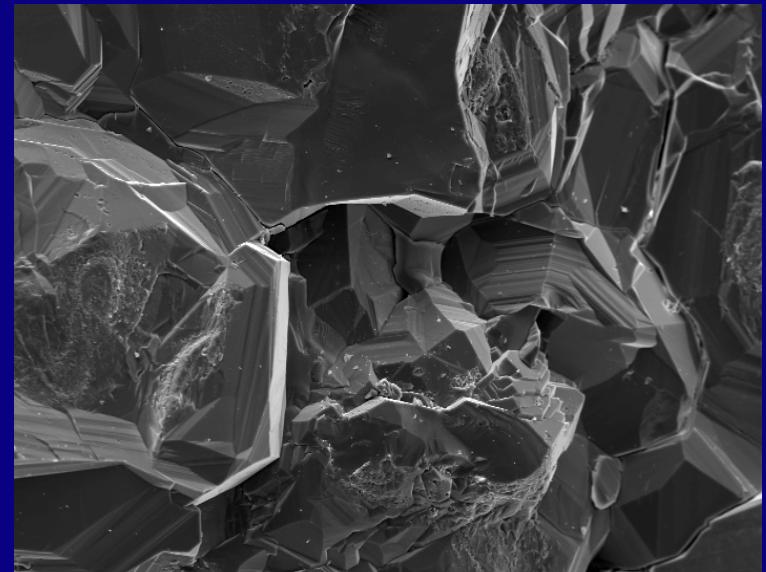
Deep Sandstone Diagenesis

Devonian Jauf Sandstone

HWYH 201 , 14,734 ft
Illite grain coatings retard
quartz cementation,
preserving porosity



HWYH 207 , 13,745 ft
Extensive quartz
cementation



Summary

- Ghawar is a large Hercynian basement horst, which was reactivated episodically, particularly during the Late Cretaceous.
- The Arab-D carbonate reservoir contains the world's largest oil reserves due to the combination of large structure, prolific source, excellent reservoir quality & effective anhydrite seal. Production ~ 5 million B/D under peripheral water drive.
- Ghawar contains large non-associated gas reserves in the deeper Paleozoic Khuff carbonates and the Permo-Carb & Devonian sandstones. The main challenge to deep gas exploration & development is to predict areas of good reservoir quality.

.....The End