Acknowledgements

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 ~ 2050 miles\(^2\)
~ 1.3 million acres.

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

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

Gas production 8 billion SCF/D,
Associated gas ~ 2 BSDFD,
Non-associated gas ~ 6 BSCFD
from Paleozoic reservoirs.
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Jurassic Arab-D structure showing Oil Discoveries

- 2nd Haradh 1949
- 5th Hawiyah (1953)
- 3rd ‘Uthmaniyah (1951)
- 4th Shedgum (1952)
- 1st ‘Ain Dar 1948
- Abqaiq North
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

1st: Permian Khuff (1971)
2nd: Permian Khuff (1975)
3rd: Khuff & Devonian Jauf (1980)
4th: Khuff (1980)
6th: Devonian Jauf flank play (1994)
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E-W Seismic Depth Section, South Ghawar

Top Cretaceous
Top Jurassic
Triassic
Top Permian
Top Carb, Hercynian Unconformity
Top Ordovician
Basement

Depth (feet)
5,000
10,000
15,000
20,000
Deep Ghawar Structure

Base Silurian dip magnitude

Permian-Silurian isochron

Eroded

North
Ghawar Stress Field

Principal Compressive Stress
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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

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<th>Sonic</th>
<th>Neutron &amp; Density</th>
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Ghawar Oil Production & Water Management

Ghawar Oil Production & Water Management

Average Oil Rate

Million Barrels per Day

Water - Cut

Oil Rate

1993 1995 1997 1999 2001 2003

0 10 20 30 40 50

Water - Cut %

Million Barrels per Day
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Generalized Paleozoic Stratigraphy

- **Hercynian Orogeny**
- **Unayzah Fm:** Continental Clastics
- **Jauf Fm:** Shallow Marine Sands
- **Mila Fm:** Marine Carbonates
- **Saq Fm:** Continental Clastics
- **Qusaiba Fm:** Deep Marine Shales
- **Khuff Fm:** Carbonates & Evaporites
- **Hormuz Fm:** Evaporites
- **Oil Reservoir**
- **Gas Reservoir**
- **Source Rock**
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
Permian Khuff Reservoir Facies

- Exposure/Paleosol
- Tidal Flat Complex (Tight Dolomite)
- Burrowed Shallow Subtidal (Porous dolomite)
- Protected/Storm Washout Low-Angle X-Beds (Porous dolomite)
- High Energy Tidal Bar/Shoal Complex (Porous dolomitic limestone)
- S.L.
- Lagoon (Tight Limestone)
- Microcrystalline Dolomite Facies
- Oomoldic Facies
Seismic Impedance – Porosity in Khuff C Reservoir, Central Ghawar
Average $\text{H}_2\text{S}$ and Reservoir Temperature ($^\circ\text{C}$) 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

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**Early Permian Unayzah A Reservoir**

**Late Permian Khuff**

**Hercynian Unconformity**

**Silurian Qusaiba Shale**

**Unayzah B Reservoir**
Unayzah Reservoir Facies

Eolian

Lacustrine
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Devonian Jauf Reservoir

Reservoir: Estuarine and coastal sandstone
Source: Silurian Shales
Seals: Intraformational shale or basal Khuff shale & anhydrite
Charge: From below
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