[PS]Tectonic Controls on the Stratigraphic Architecture of the Permo-Triassic Khuff Formation, Eastern Saudi Arabia*

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Abstract

The Permo-Triassic Khuff Formation was deposited on a broad, low-relief carbonate platform trending northwest-southeast on the passive margin of the Neo-Tethys Ocean. The stratigraphic architecture of Khuff carbonates and their distribution in eastern Saudi Arabia, utilized well data, seismic interpretations, and potential field geophysical data. The Permo-Triassic section in Eastern Saudi Arabia was bordered by the Arabian shield to the west, Hail Arch in the north, and Hadramawt-Sana'a Arch in the south. The region was situated in low to moderate southern latitudes in a regional carbonate platform, where shallow warm water conditions prevailed during the Permo-Triassic. The passive margin is underlain by multi-terrain basement, which experienced differential tectonic subsidence that resulted in the formation of numerous sub-basins. There were three global geological events of great significance during the Permian-Triassic: the largest mass extinction known at the Permo-Triassic boundary; long-term dominance of superanoxia; and the earliest breakup of Pangea. Mud-rich facies were deposited mostly in sub-basins (paleo-lows), whereas grain-rich facies (reservoir) were deposited on the intervening paleotopographic highs. Isopach maps and regional composite cross sections across the region, constructed from seismic and calibrated with well data, indicate thickness variations corresponding to irregular basin topography resulted from differential subsidence of basement blocks. Basal Khuff clastics are interpreted to have been deposited in rifted basins, composed of horsts, grabens, and tilted normal fault blocks, imaged on flattened seismic sections that utilized the top of the Khuff as a datum. The rift evolved rapidly into a passive margin. Exploration concepts are being generated because of this understanding of tectonic, depositional, and stratigraphic controls of the Khuff Formation.

Tectonic Controls on the Stratigraphic Architecture of the Permo-Triassic Khuff Formation, Eastern Saudi Arabia

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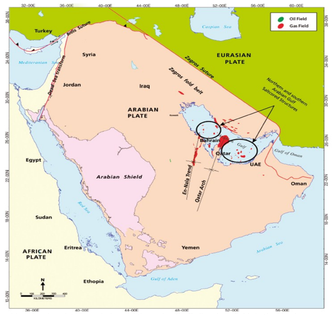
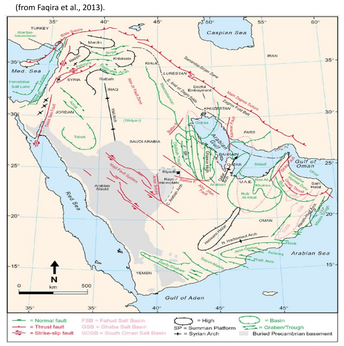
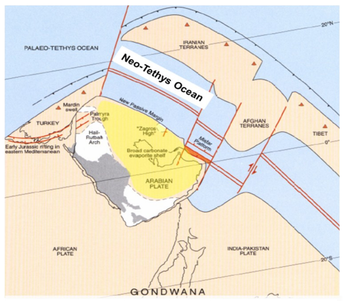
Regional Geology and Tectonic Setting



Map showing plate boundaries and the major Khuff oil and gas fields in the kingdom (from Faqira et al., 2013).

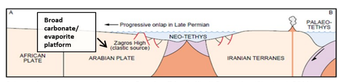


Map showing structural interpretation of the Arabian Plate in the Kingdom (Zeigler, 2001).



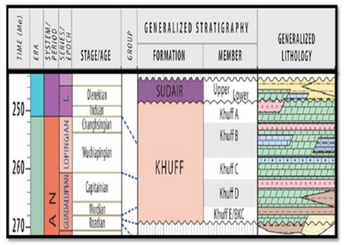
Middle Permian to Early Jurassic (255-182 MA) opening of the Neo-Tethys, northern extension and passive margin post-rift thermal subsidence (Sharland, 2011).

Schematic Plate Cross-section



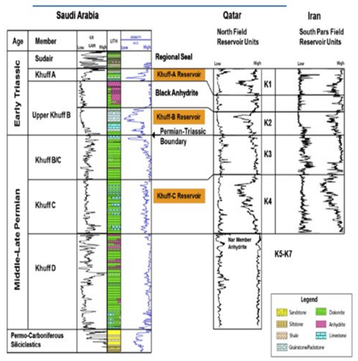
Schematic plate cross-section of the Permian-Triassic Khuff Formation (Sharland, 2011).

Khuff Formation Stratigraphic Framework



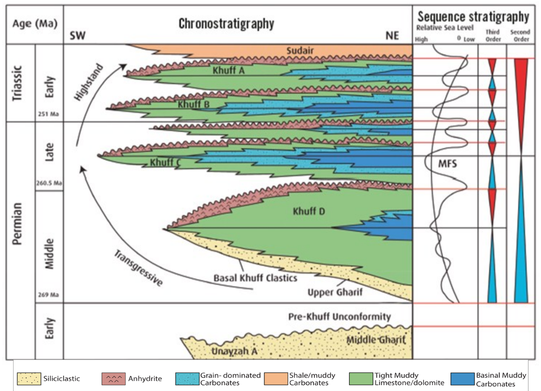
The Khuff Formation is of middle Permian (Capitanian) to Early Triassic (Induan) age, mainly composed of shallow-water carbonates and evaporates.

Khuff Formation Stratigraphy Type Log



Type log of the Khuff Formation in Saudi Arabia based on well logs and stratigraphic correlation from central Saudi Arabia, North Field of Qatar (Well NWD1; Bashari, 2005), and South Pars field in Iran. (Faqira et al., 2013).

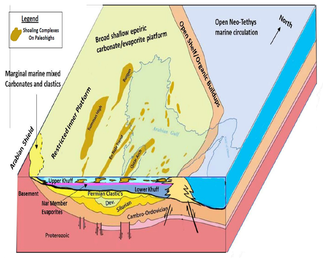
Key Khuff Formation Cross Sections



A schematic stratigraphic framework diagram of Khuff Formation: it is composed of one 2nd order composite sequence defined by the basal Pre-Khuff Unconformity, the top sequence boundary is marked by the base of Sudair Formation. The HST of the 2nd order Khuff sequence is composed of thicker carbonates, grainier reservoir facies, and associated evaporites with well-developed grainstone facies within Khuff.

Stratigraphic correlation and nomenclature of the Khuff Formation across the Arabian Gulf region (modified from Strohmenger et al., 2002 and Alshahran, 2006).

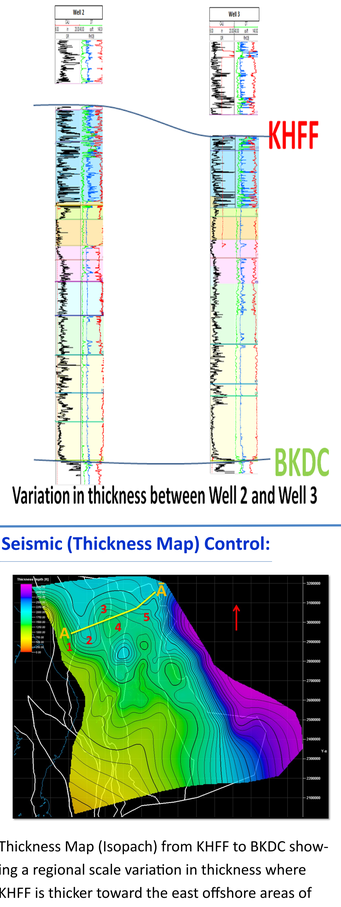
Depositional Environment Schematic Model



Schematic gross depositional environment model of the Khuff Formation (Murris, 1981; Al-Jallal, 1995; Alsharhan and Narin, 1997; Alsharhan, 2006; and Faqira et al., 2009 and 2011).

Photograph of Khuff Formation outcrop clearly showing the sharp contact between Khuff B and Khuff B/C, and the P/T boundary. Photo courtesy of Raed Dukhayyil.

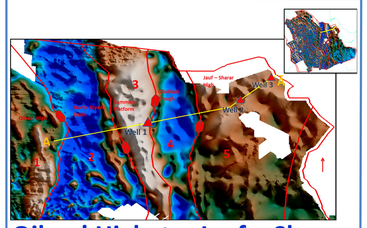
Thickness Control:



Variation in thickness between Well 2 and Well 3

Seismic (Thickness Map) Control:

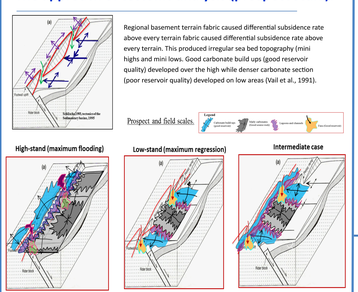
Thickness Map (Isopach) from KHFF to BKDC showing a regional scale variation in thickness where KHFF is thicker toward the east offshore areas of Saudi Arabia



Qibaa' High to Jauf – Sharar High Seismic Cross Section

Low Magnetic Map displaying the high and low terrain basins across the central to eastern parts of the Arabian Plate.

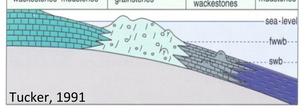
The approach of tectonic analysis (prospect scale):



Sediments influx in carbonate basins, role of medium-term to local tectonics

Regional to medium scale:

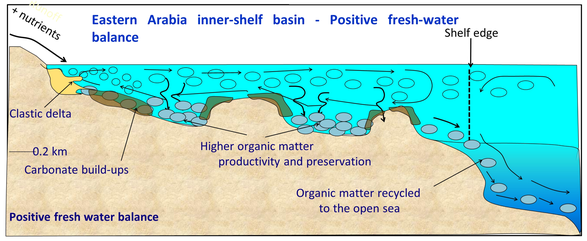
CARBONATE RAMP			
inner ramp		mid ramp	outer ramp
protected/subaerial	wave-dominated	below fairweather wave-base	below storm wave-base
lagoonal–tidal flat–supratidal carbonates, sabkha evaporites palaeosols, palaeokarsts	beach-barrier/ strandplain/sand shoals, patch reefs	thin-bedded limestones storm deposits ± mud mounds	shales/ pelagic limestones
wackestones–mudstones	grainstones	grain/rud/float/ wackestones	mudstones



Tucker, 1991

CARBONATE RIMMED SHELF			slope	basin
subaerial	protected	maximum wave action	below fairweather wave-base	
supratidal carbonates	lagoonal and tidal flat carbonates	reefs and carbonate sand bodies	resedimented carbonates	shales/ pelagic limestones
mudstones	wackestones–mudstones	boundstones/ grainstones	grain/rud/float/ wackestones	mudstones

Tucker and Wright, 1990



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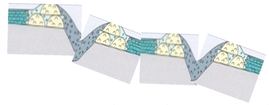
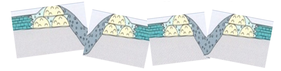
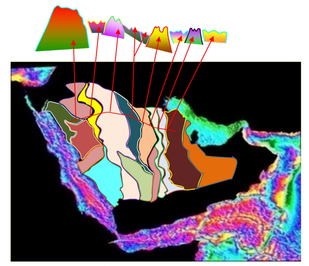
Folding and easterly rotation of East Arabia:



Carbonate reservoirs and source rock are controlled by the basins geometry:

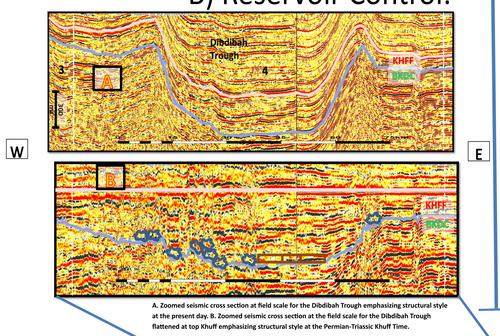




Basement terranes of Saudi Arabia as mapped by FrogTech (2008) and schematic cross section for East Arabia basin showing its desiccation into mini-basins.

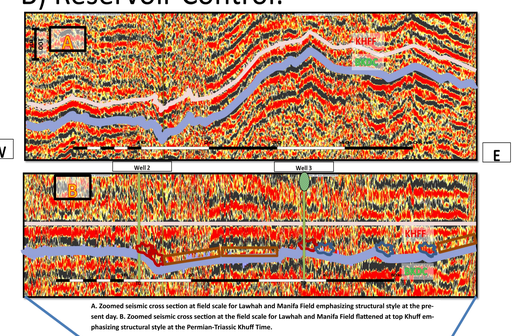
Tectonic Controls:

B) Reservoir Control:



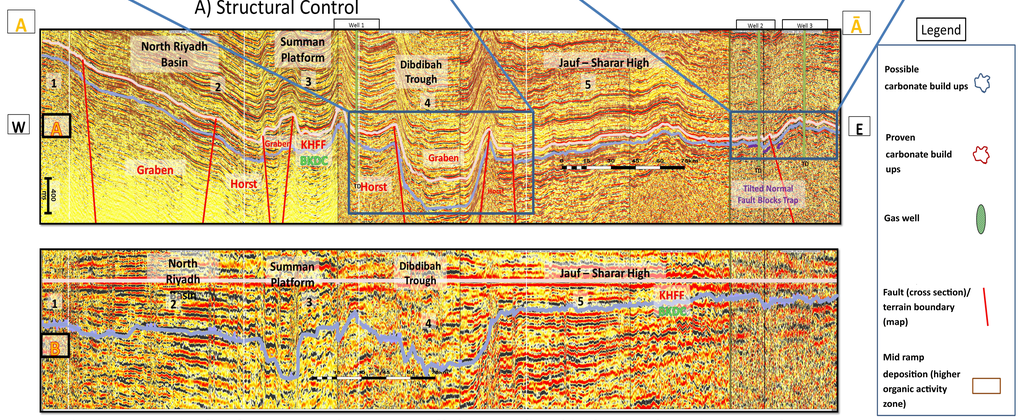
A. Zoomed seismic cross section at field scale for the Dibdibah Trough emphasizing structural style at the present day. B. Zoomed seismic cross section at the field scale for the Dibdibah Trough flattened at top Khuff emphasizing structural style at the Permian-Triassic Khuff Time.

B) Reservoir Control:

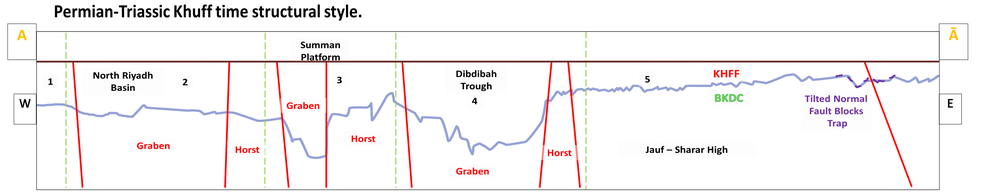


A. Zoomed seismic cross section at field scale for Lawhah and Manifa Field emphasizing structural style at the present day. B. Zoomed seismic cross section at the field scale for Lawhah and Manifa Field flattened at top Khuff emphasizing structural style at the Permian-Triassic Khuff Time.

A) Structural Control



A. Seismic cross section line from west onshore to east off-shore Saudi Arabia showing the main present day structural style. B. Seismic cross section line from west onshore to east off-shore Saudi Arabia showing the main Permian-Triassic Khuff time structural style.



Schematic cross section highlighting the major regional faults and structural style at basin scale from west onshore to east offshore Saudi Arabia showing the main Permian-Triassic Khuff time structural style.

Conclusion

Seismic cross section and Khuff thickness maps (Isopach) constructed from seismic data and calibrated with interpreted well petro-physical data indicates that thickness variations in the Khuff corresponded to irregular basin topography. Horsts, grabens and tilted normal fault blocks interpreted from seismic cross section across the East Arabia basin indicate that the Permian-Triassic Khuff deposited over a low strain basin. As a result, carbonate buildups and grain-rich facies (reservoir) are deposited on paleotopographic highs, whereas shales and mud-rich facies are deposited at paleotopographic lows.

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