

PS Lower Palaeozoic Petroleum Systems of Western Iraq with Reference to Jordan*

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Abstract

The Lower Palaeozoic of northwest Arabia is characterised by similar major chrono-stratigraphic rock units, covering vast areas of eastern Jordan, northwest Saudi Arabia, eastern Syria and western Iraqi deserts. It is the most under-explored succession in Iraq, but it is considered to have significant exploration potential.

The Lower Silurian marine (hot) shale is the main proven source rock for the Palaeozoic hydrocarbons discovered in the area of study. However, some Upper Ordovician black shales (of the Khabour Formation of Iraq and its equivalent in Jordan) are also expected to be additional local source rocks within the region. Conversely, the Lower Ordovician Hiswah graptolitic shales of Jordan are originally lean, where analysed, and are not considered a major hydrocarbon source rocks. Similarly, preliminary geochemical results show that the Middle Cambrian Burj limestone does not have significant source potential in the marginal Jordanian wells, although it may have some potential where deposited in a more basinal settings such as in western Iraq.

Several promising sandstone reservoir rocks (of Cambrian, Ordovician, and Early Silurian ages) are present across the study area. However, the reservoir quality is a major exploration risk as most of these sandstones have been severely affected by quartz overgrowth and clay cementation. Only some Upper Ordovician Dubaydib subsurface sandstones of Jordan have chlorite-clay coatings, which prevented formation of the quartz overgrowth, preserving good reservoir quality. Seals are also available all-over the region both on local and regional scales; these include (but are not limited to) the shales and carbonates mentioned above as potential source facies.

The widespread occurrence of potential source, reservoir and seal rocks suggests that Lower Palaeozoic prospects below the deserts of western Iraq are quite promising frontiers for future hydrocarbon exploration.

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Abstract

The Lower Palaeozoic of northwest Arabia is characterised by similar major chrono-stratigraphic rock units underlying vast areas of desert in eastern Jordan, northwest Saudi Arabia, eastern Syria and western Iraq. It is the most under-explored succession in Iraq, but it is considered to have significant exploration potential.

The Lower Silurian marine (hot) shale is the main proven source rock for the Palaeozoic hydrocarbons discovered in the area of study. However, Upper Ordovician black shales of the Khabour Formation of Iraq and its equivalent in Jordan are also expected to be additional local source rocks within the region. Conversely, the Lower Ordovician Hiswa graptolitic

shales of Jordan are organically lean, where analysed, and are not considered to be major hydrocarbon source rocks. Similarly, preliminary geochemical results show that the Middle Cambrian Burj Limestone does not have significant source potential in the marginal Jordanian wells, although it may have some potential where deposited in a more basinal setting, such as in western Iraq.

Several promising sandstone reservoir rocks (of Cambrian, Ordovician, and Early Silurian ages) are present across the study area. However, the reservoir quality is a major exploration risk as most of these sandstones have been severely affected by quartz overgrowth and clay cementation

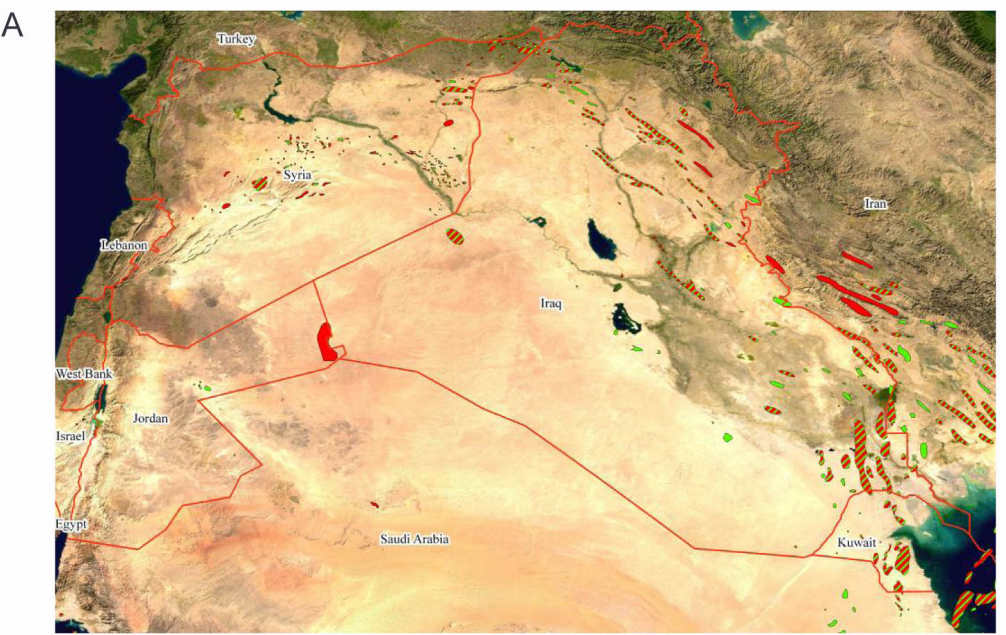
when dominated by quartz grains and deeply buried. Only some Upper Ordovician Dubaydib subsurface sandstones of Jordan have chlorite-clay coatings, which prevented formation of the quartz overgrowth, and thus preserved good reservoir quality. Seals are also available all-over the region both on local and regional scales; these include (but are not limited to) the shales and carbonates mentioned above as potential source facies.

The widespread occurrence of potential source, reservoir and seal rocks suggests that Lower Palaeozoic prospects below the deserts of western Iraq are quite promising frontiers for future hydrocarbon exploration.

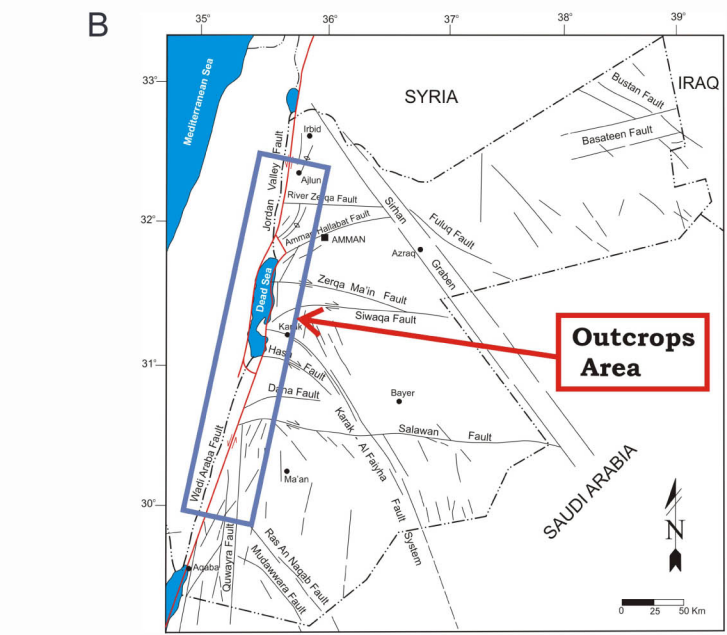
The main objective is identification and characterisation of the Lower Palaeozoic petroleum systems through:

1. Reconstruction of the depositional history and palaeogeographic maps,
2. Reconstruction of the diagenetic history to predict the reservoir quality, and
3. Reconstruction of the tectonic history to clarify the impact of tectonics in preservation of the Palaeozoic stratigraphy and hydrocarbons migration.

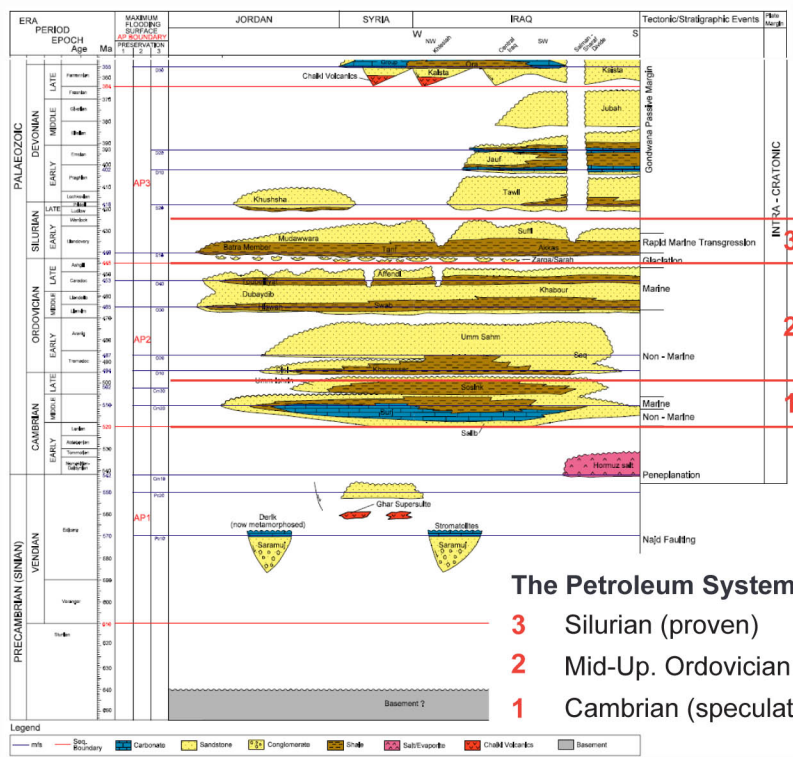
Study Area



A) Location map of NW Arabian Plate



B) The basement tectonics control most mega-sequences in the region through high impact on stratigraphy



Lower Palaeozoic of NW Arabian Plate (Modified after Sharland et al. 2001, 2004)

Introduction

Almost two thirds of Iraq's area has potential for the Palaeozoic prospects (particularly NW, W & SW Deserts).

Palaeozoic is the most under-explored succession in Iraq.

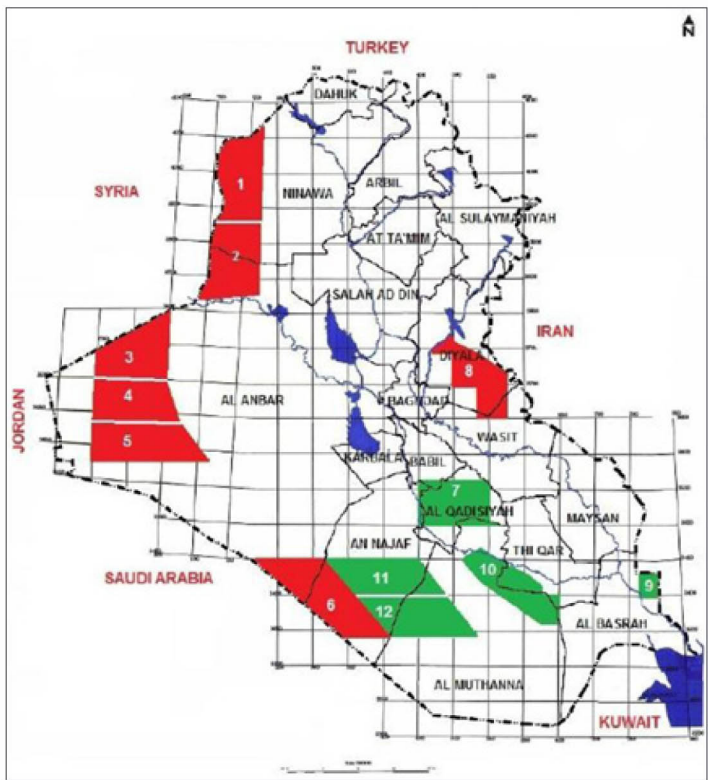
Its megasequence stratigraphy although little known, appears similar to other major Arabian Plate megasequences (APs) in neighbouring countries.

One discovery (i.e. Akkas Field) was made in 1993 in the Palaeozoic of Western Desert near Syrian border producing from the Upper Ordovician and Lower Silurian sandstones, mostly gas but with some light oil too.

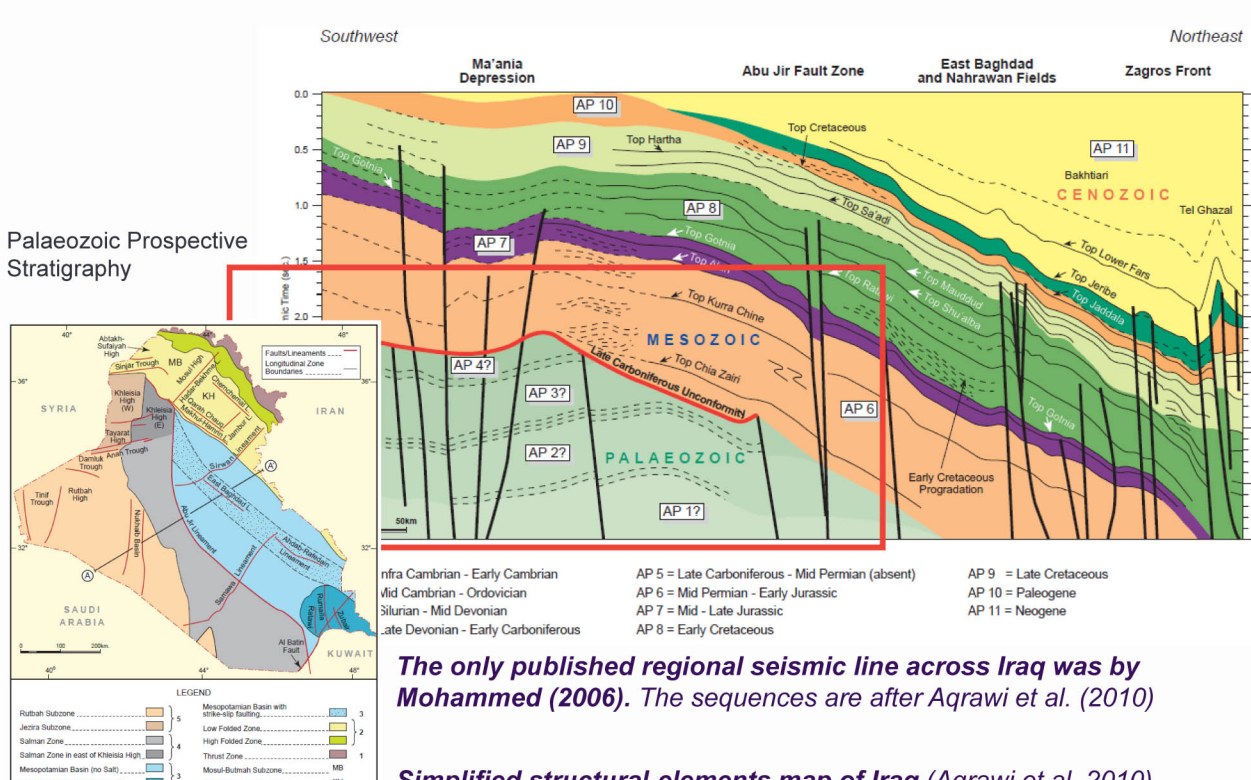
Only 9 exploration deep wells have penetrated the Palaeozoic, but without reaching the Cambrian Formations and/or Precambrian Basement.

In addition, few shallow boreholes (Key Hole wells) that drilled in the west of Iraq by the Geological Survey of Iraq for stratigraphic purposes have penetrated the Palaeozoic too.

Last August the 4th Bidding Round was announced by Iraq MoO for Exploration, in which many Blocks have potential for Palaeozoic targets.



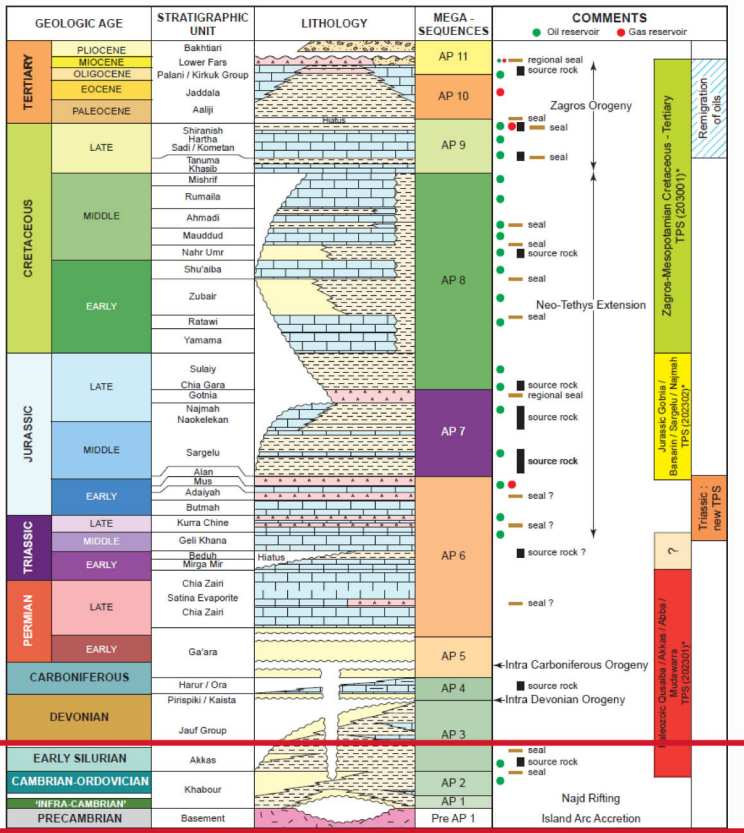
The Exploration blocks announced by Iraq Oil Ministry for the 4th bidding round



The only published regional seismic line across Iraq was by Mohammed (2006). The sequences are after Aqrawi et al. (2010)

Simplified structural-elements map of Iraq (Aqrawi et al. 2010)

Potential Lower Palaeozoic Plays



Iraq Petroleum Systems Elements

Cambrian Play

Reservoirs: Sandstones of Salib and Umm Ishrin and their equivalents.
Source: Burj Limestone
Seal: Hiswa Shales and equivalents

Ordovician Play

Reservoirs: Sandstones of Hiswah and Khabour/Dubaydib and their equivalents
Source: Burj Limestone (Potential) and Khabour/Dubaydib Shale and equivalents in addition to Lower Silurian 'Hot Shale' (i.e. Hoseiba Member of Akkas Fm)
Seal: Hiswa Shales and equivalents

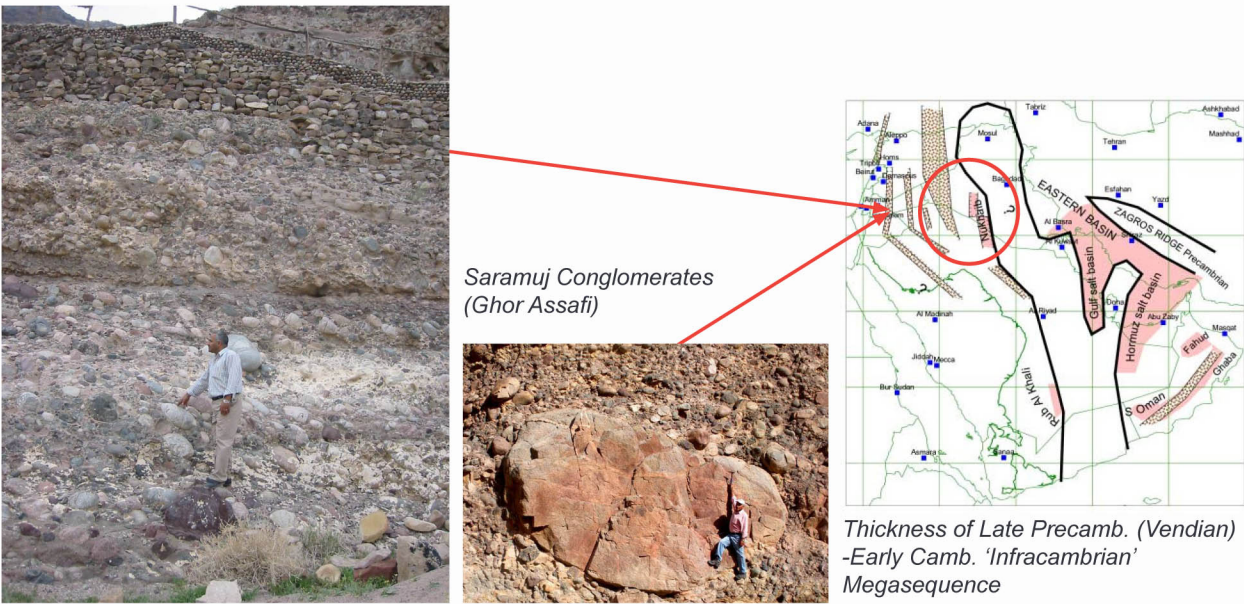
Silurian Play

Reservoirs: Sandstones of Mudawwarah and their equivalents
Source: Mudawwarah Shales and equivalents
Seal: Mudawwarah Shales and equivalents

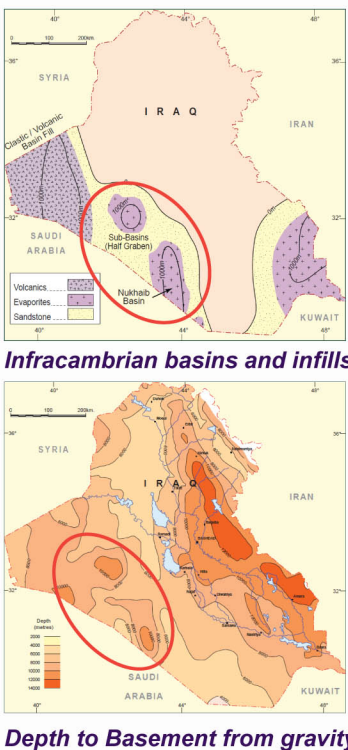
Lower Palaeozoic

(Aqrawi et al. 2010 modified after Verma et al. 2004)

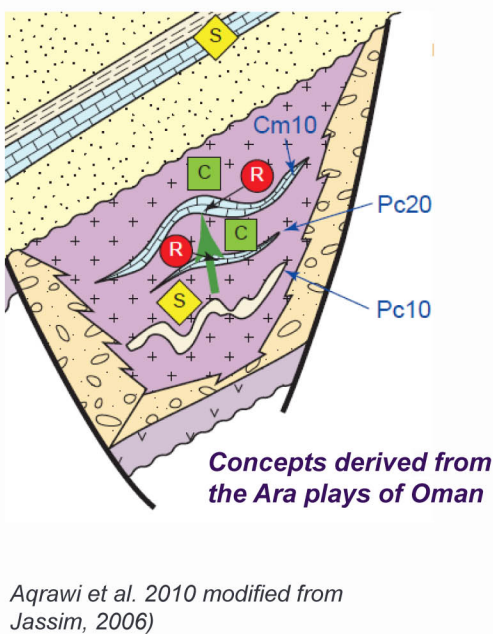
The speculative petroleum system of Lower Sequence of AP1



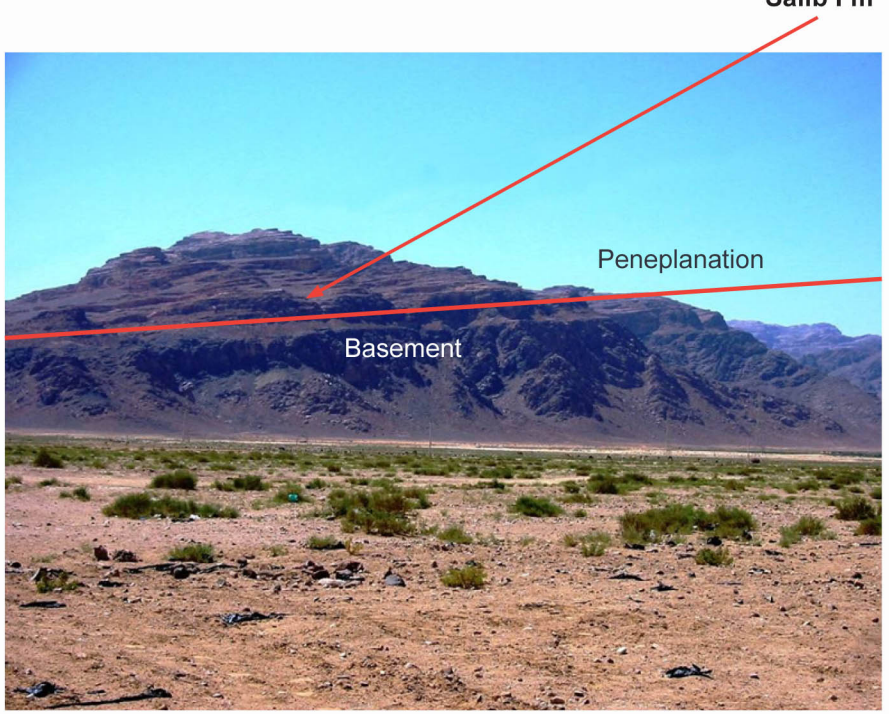
This speculative Infracambrian Play may be an integrated petroleum system, although has not been penetrated in W & SW Iraq yet!



Depth to Basement from gravity data

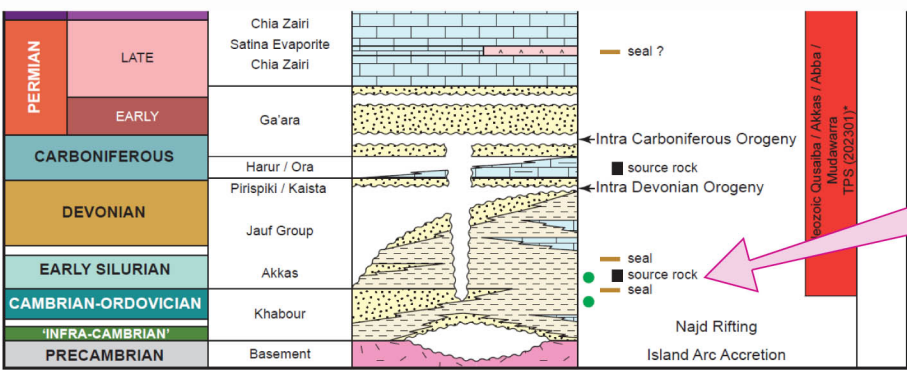


Aqrawi et al. 2010 modified from Jassim, 2006)



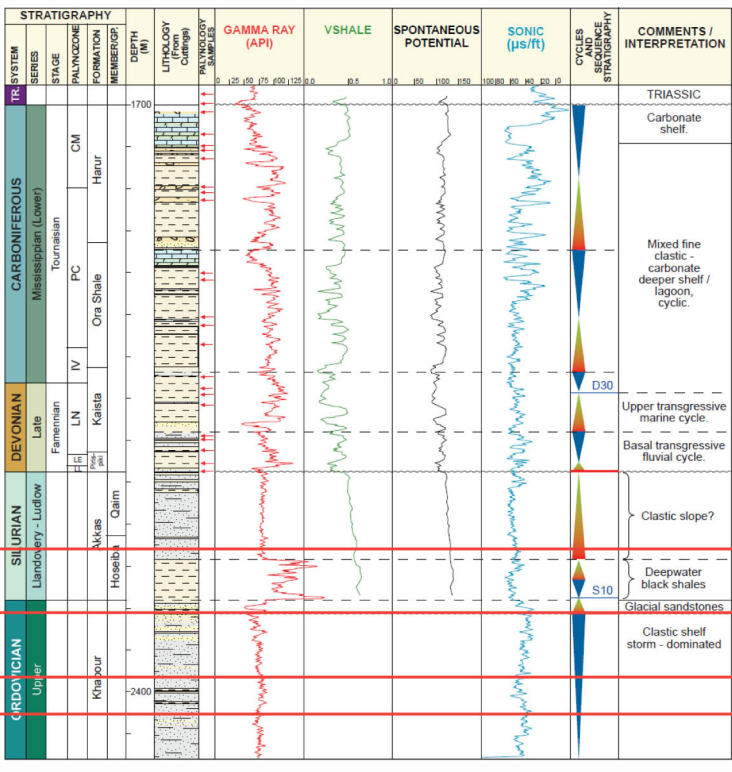
Peneplanation of the Precambrian Basement near Aqaba-Jordan

Source Rocks

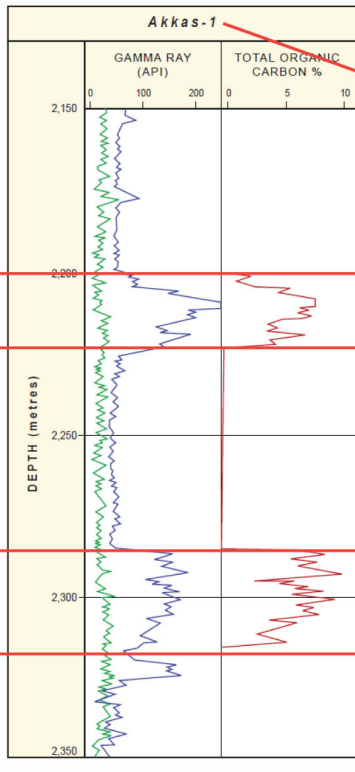


- The Lower Silurian marine (hot) shale is the main proven source rock for the Palaeozoic hydrocarbons (particularly light oils) discovered in western Iraq. The internal is absent in the north of Iraq, due to erosion beneath an intra-Devonian unconformity
- Upper Ordovician black shales of the Khabour Formation are expected additional Lower Paleozoic source rocks.
- Limestone of the Middle Cambrian Burj Formation may have some source rock potential where deposited in deeper marine settings.

Lower Silurian marine (hot) shale
0.95-16.62% TOC in Akk-1 and 1-9.94% TOC in Kh-1
Upper Ordovician black shales
0.9-5% TOC in Akk-1



The penetrated Palaeozoic succession in well Khlesia-1 (Aqrawi et al. 2010 modified from Al-Hadidy, 2007)



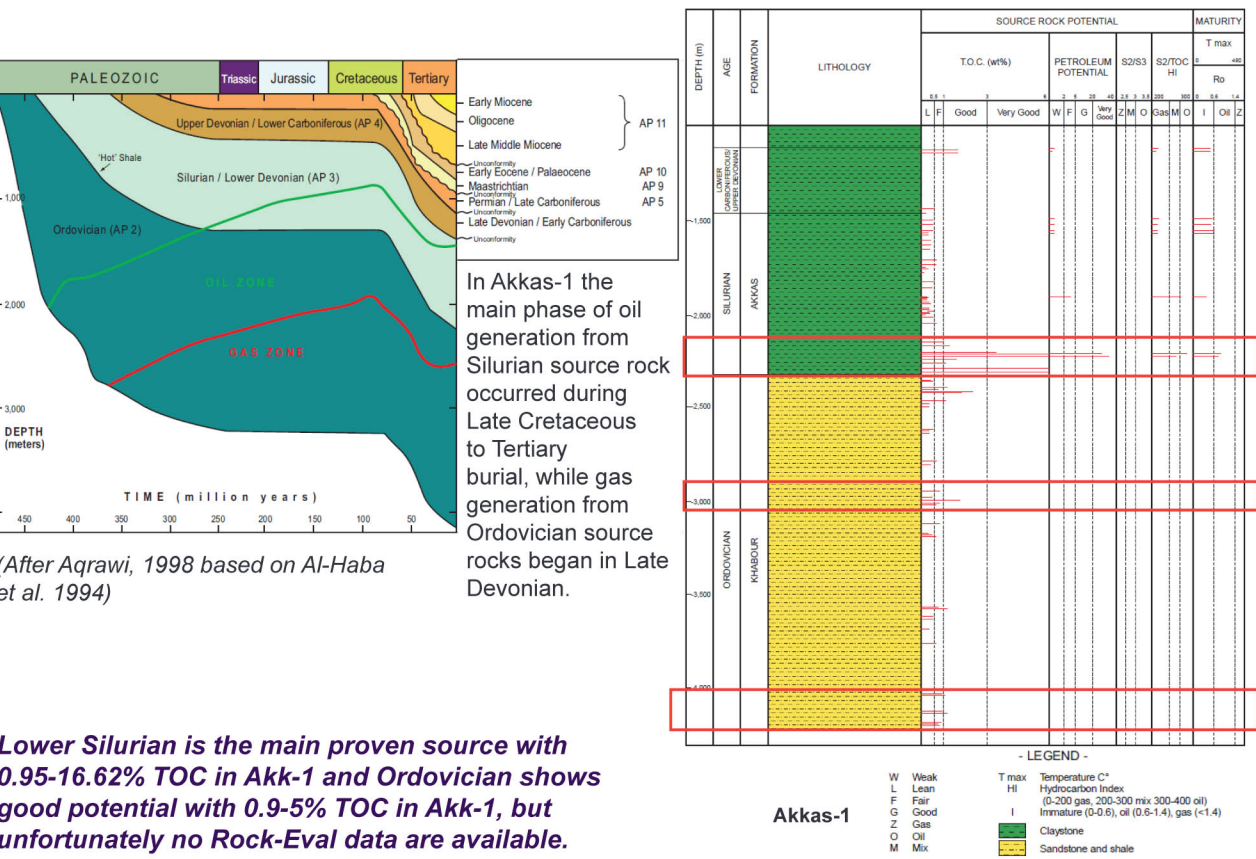
The Lower Silurian Akkas 'hot shale' of around 65m is the only proven source in the Palaeozoic of Iraq in Akkas Field (after Al-Haba et al. 1994)

(Aqrawi et al. 2010 modified from Aqrawi, 1998)

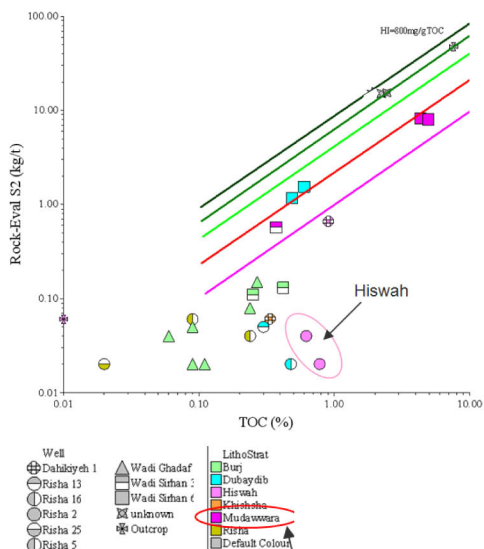
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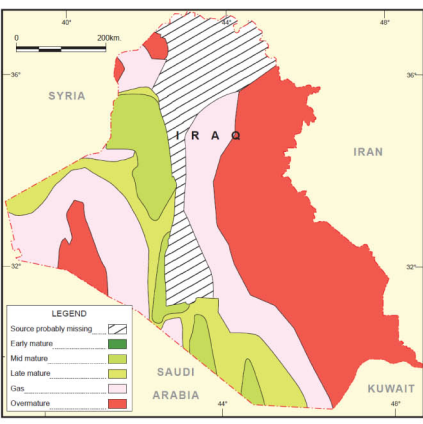
1) Statoil ASA, Stavanger, Norway. 2) Statoil UK, London, U.K. 3) Natural Resources Authority, Amman, Jordan.



Potential Ordovician source rocks in Jordan (Hiswa and Dubaydib) only show moderate source potential based on the available well sample data



Cross-plot of TOC content against S2 yield for Jordanian core and outcrop samples



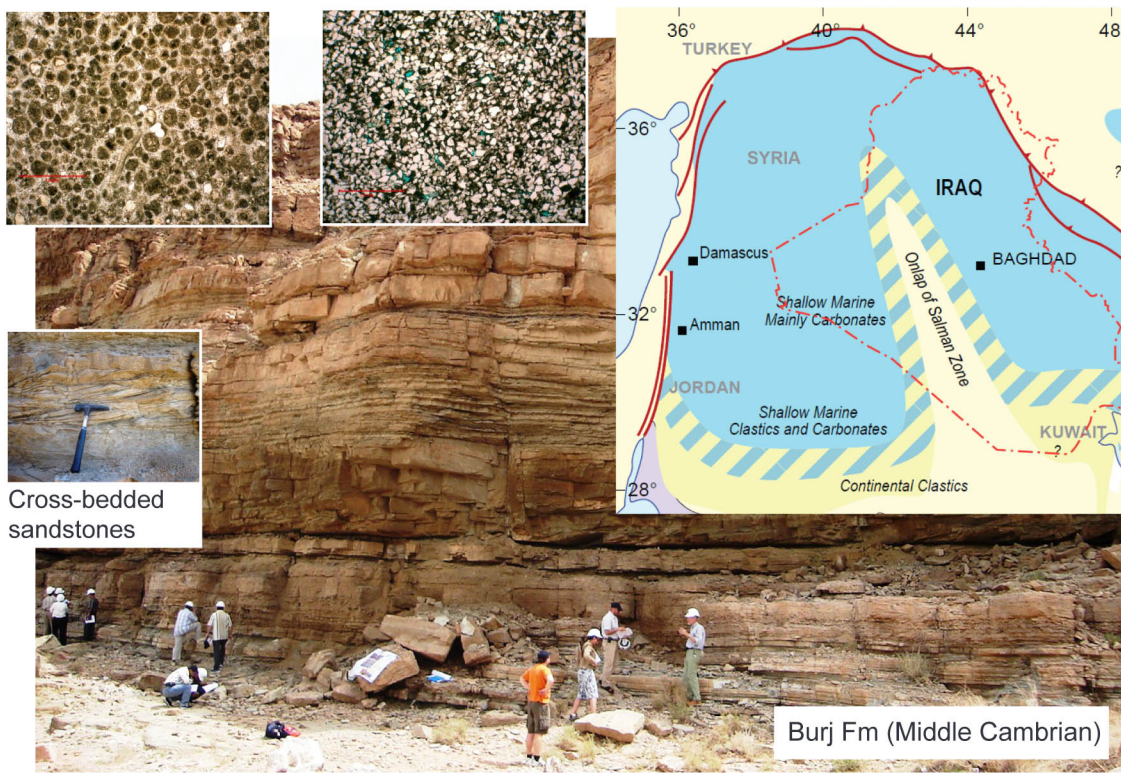
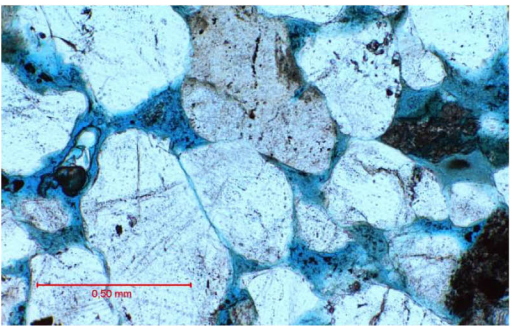
The maturity map of the Lower Silurian 'Hot' Shale



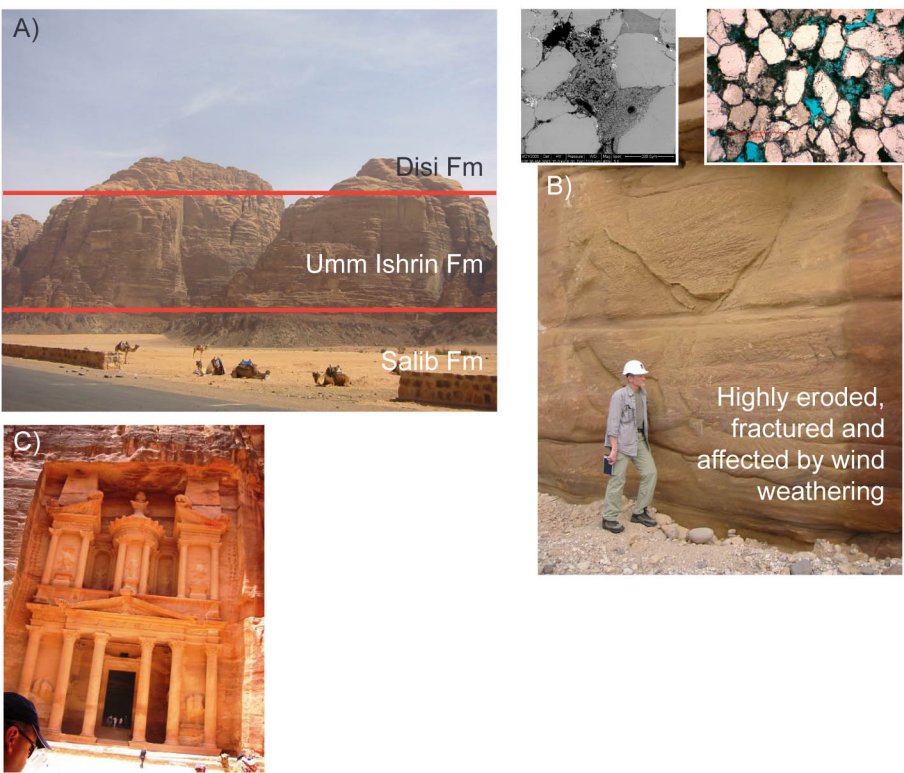
Ordovician may subcrop below Hercynian unconformity

Targeted Reservoirs

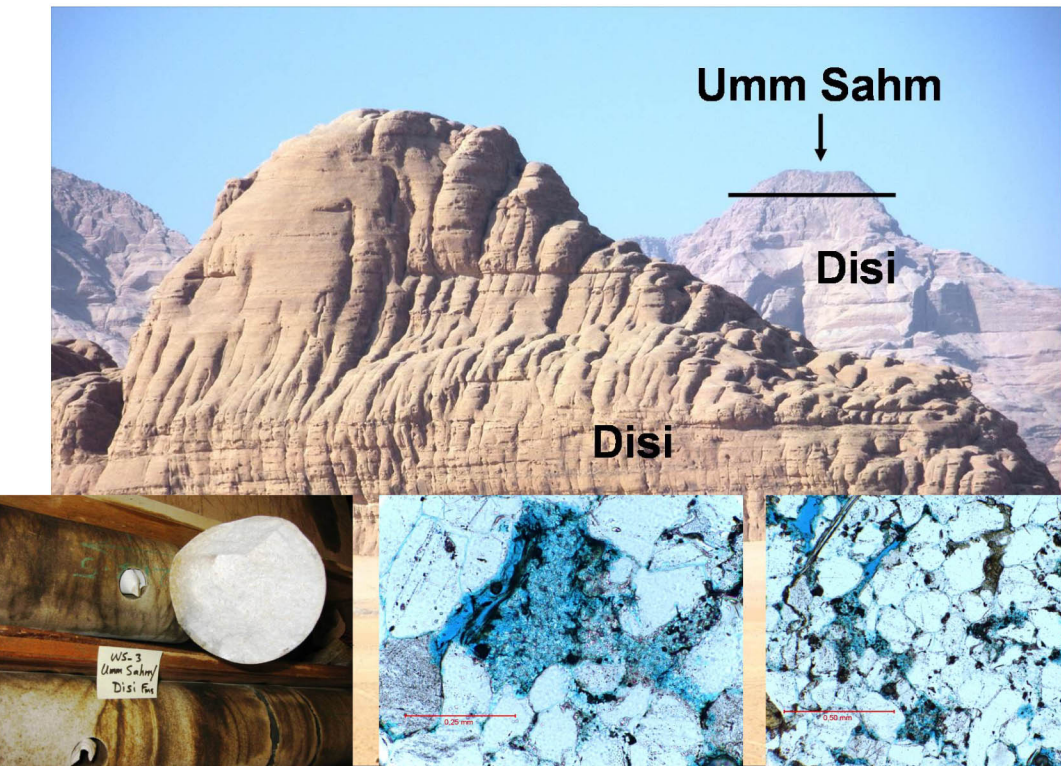
- Medium-coarse grained subangular and medium sorted sandstone.
- Mostly quartz (78%) but rich in K-feldspars (7%) and illite clay (12%).
- Quite porous but some quartz overgrowth have developed due to compaction.



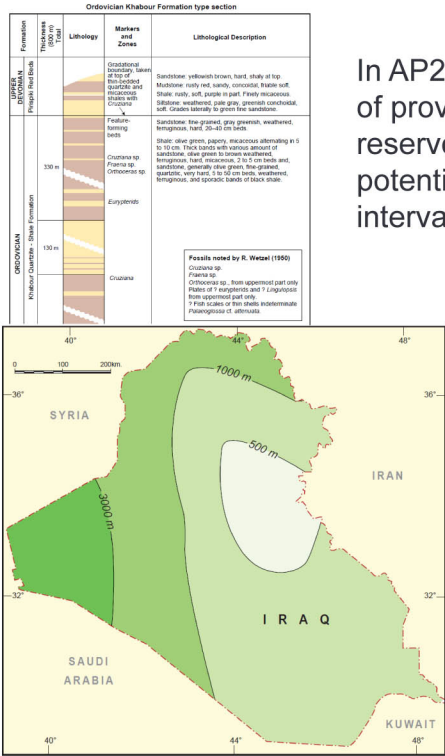
Palaeogeographic reconstruction of the Middle Cambrian of NW Arabia. Deeper water development of the Burj Formation in the Sirhan Graben towards the east may have been favourable for source rock development



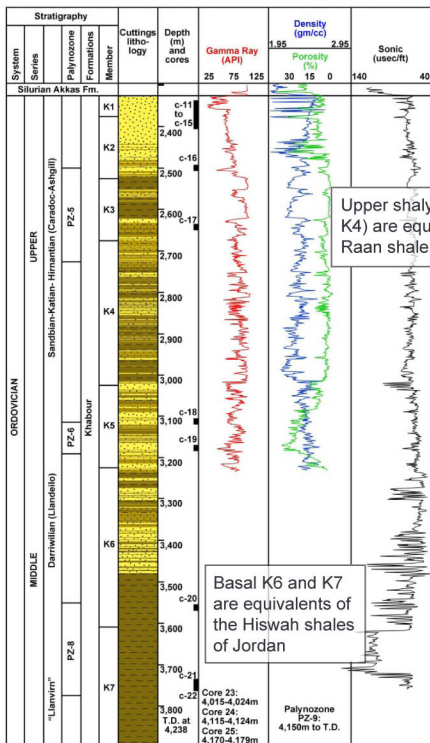
The Upper Cambrian Umm Ishrin Formation at Wadi Rum (A), at the Bridge of Wadi Mujib (B), and at Petra (C)



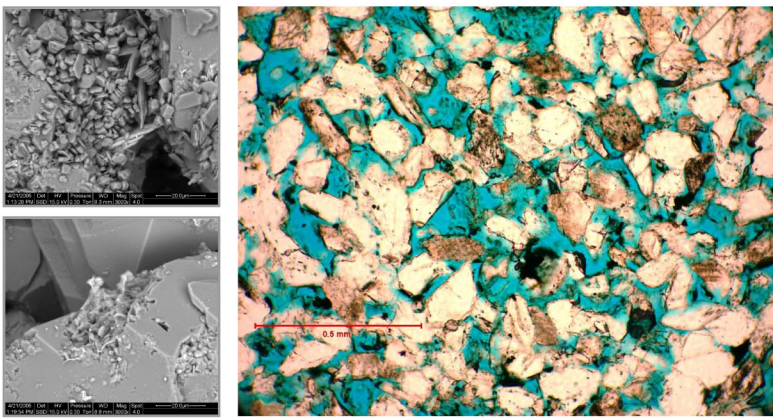
Disi Fm (Up. Camb.-Low. Ordv.) covered by Umm Sahm (Mid. Ordv.) near Disi Village, and in well WS-3 at 2112.8m depth



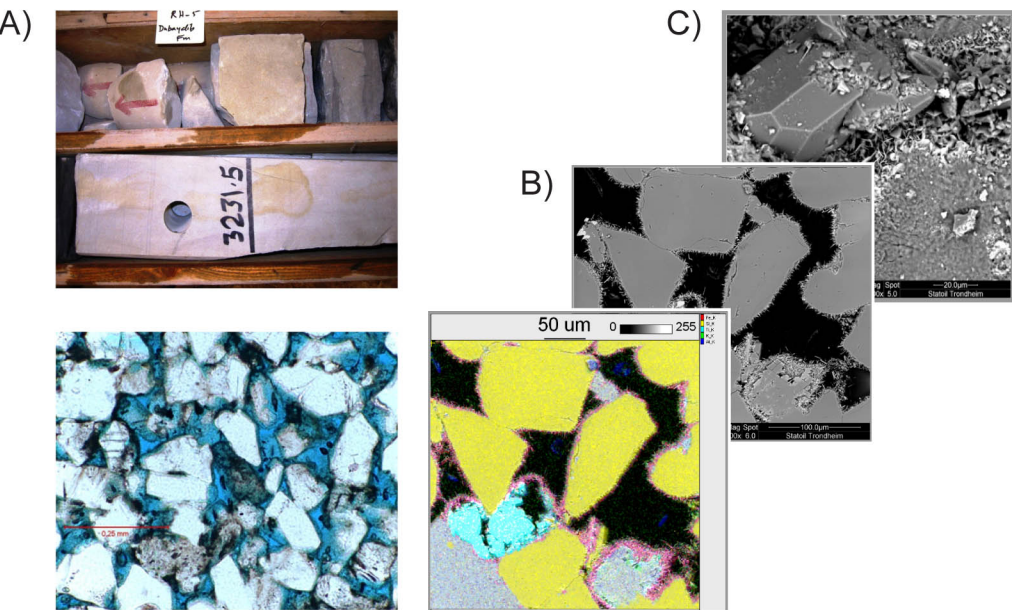
Thickness map of AP2 (Aqrawi et al. 2010 modified after Jassim, 2006)



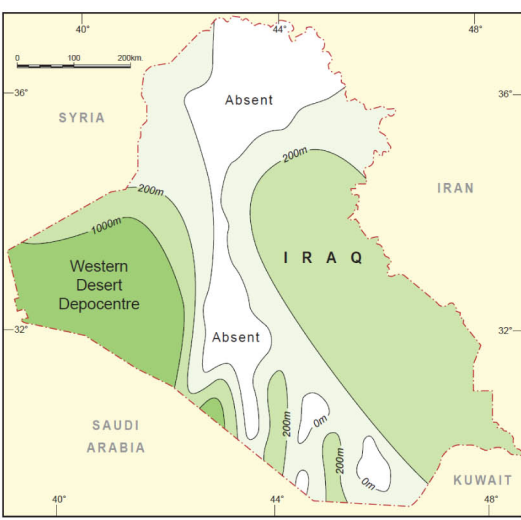
The Upper Ordovician stratigraphy in Akkas-1 (Aqrawi et al. 2010 modified from Al-Hadidi, 2007)



The proven upper Khabour reservoir equivalent; upper Dubaydib sandstone (Upper Ordovician) at outcrop has a good porosity and the feldspars have partly dissolved and altering to clays, but the quartz grains have already developed some overgrowth, which is expected to increase with depth of burial.



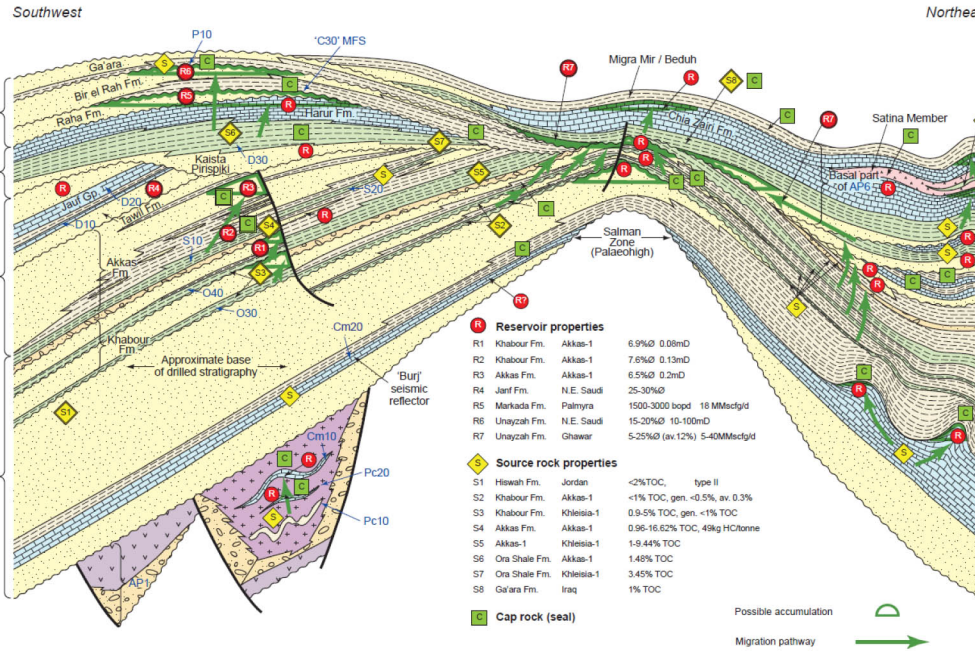
The proven Khabour gas reservoir equivalent; Upper Ordovician Dubaydib (Risha) Fm in well RH-5 at 3232.55m depth (A) preserves a quite good reservoir quality, as the chlorite coatings (B) prevent further quartz overgrowths (C).



Thickness map of AP3 (Aqrawi et al. 2010 modified from Jassim, 2006)



The proven Akkas oil reservoir equivalent; Lower Silurian sandy beds of the lower Mudawwara are at the outcrop.



Summary of Iraq Palaeozoic Petroleum Systems (Aqrawi et al. 2010)

Trap Types

The common trap types are large and gentle 4-way closures or 3-way closures against fault in addition to some potential stratigraphic traps.

Lower Palaeozoic Petroleum Systems of Western Iraq; Some conclusions

- The widespread occurrence of potential source, reservoir and seal rocks suggests that the Lower Palaeozoic plays and prospects are quite promising for future hydrocarbon exploration over NW, W & SW Iraq Deserts.
- However, the reservoir targets would be controlled by the active regional/local active petroleum system, which is mainly defined geographically by areas of source rock occurrence / maturation and reservoir burial depth.
- The Western Desert is currently considered to have the best Lower Paleozoic prospectivity since the Akkas Field is situated in this area, although the SW Desert may also have some potential.