Regional Geology: Jordan

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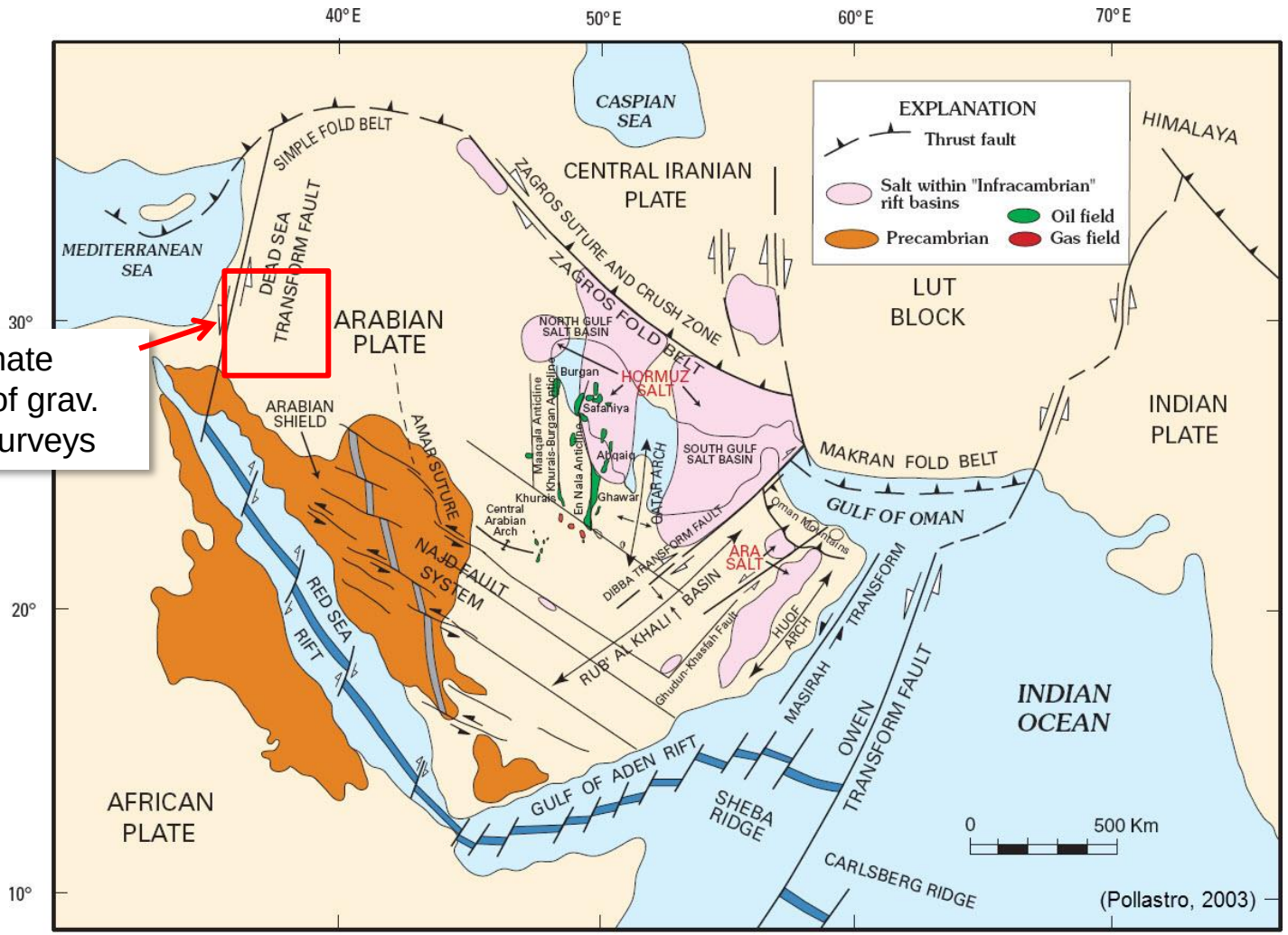
Regional tectonic setting

Approximate location of grav. & mag. surveys



Arabian Plate showing general tectonic and structural features, Infracambrian rift salt basins, and oil and gas fields of Central Arabia and North Gulf area. Modified from Al-Husseini (2000).

Tectono-evolution: Infracambrian

Infracambrian: Jafr rift basin development linked to the Najd Fault Zone activity

- The Arabian Shield comprises basement granitoid rocks, exposed in the west and south of the country:
  - This provided the primary source of the siliciclastic materials that dominate the Palaeozoic successions of northern Arabia and Jordan.
  - Crystalline basement rocks extensively intruded by Late Neoproterozoic dykes (Aqaba Complex) are exposed near Aqaba and Wadi Rum in south Jordan.
- Throughout the Palaeozoic, the Arabian Plate was close to the northern margin of Gondwana.
- The Infracambrian Jafr Basin was formed during the Late Precambrian to Early Cambrian, together with other extensional features across the northern part of Gondwana.

Tectono-evolution: Carboniferous

Carboniferous: Tilting due to mid ocean spreading

- Following the Infracambrian extension, the Palaeozoic remained tectonically quiet, until Late Carboniferous compressional tectonics led to a regional tilt of the area.
- This movement eroded the Palaeozoic section beneath the Hercynian unconformity, with erosion progressively from east to west in Jordan.
- As a result, the Silurian and Ordovician are completely absent in the western part of the country.
- The Late Carboniferous compressional stress is assumed to originate from the mid ocean spreading of the Arabian Plate, the active collisional zone in North Africa, located too far away.

Tectono-evolution: Mesozoic

Mesozoic: Rifting and the formation of the Azraq and Sirhan Grabens

- Rifting associated with the opening of the Neo-Tethys took place within Syria and in proximal areas between the Permian/Triassic and Early Jurassic.
- During the Late Cretaceous to Tertiary, these grabens became inverted due to the shortening during the Zagros – Taurus formation and now form the chain of the Syrian Arc.
- While this inversion was taking place in the Syrian Arc region, extensional tectonics occurred in northern Jordan and led to the opening of the Late Cretaceous to Early Tertiary Azraq and Sirhan Grabens.
- Graben formation may be the result of a multiple reactivation along the former Najd structures, where syndepositional fault activity during the Cretaceous and Cenozoic controlled sediment thickness and depositional facies.

Tectono-evolution: Tertiary

Tertiary basin formation along the Dead Sea Fault

- From the Middle Miocene, major strike-slip movements occurred along the Dead Sea and resulted in the formation of a series of (sinistral) en échelon faults.
- These are associated with well-defined pull-apart basins (Dead Sea Basin, Galilee Basin, and Gulf of Aqaba Basin).
- The Dead Sea pull-apart basin is narrow and long, displaying c.100 km left lateral displacement along the transform fault.
- The Neogene strike-slip faulting in Jordan also modified the structural style of the older basins further east, including the Azraq and Sirhan Grabens.
- The Neogene to Pleistocene basalts of northern Jordan were formed as a result of extensional movements in the Dead Sea transform.
- Extensive uplifting and predominantly basaltic volcanism are characteristic of the eastern flank of the rift structure.
- In the Dead Sea region the uplift is of the order of 1-2 km. Radiometric dating of the volcanics of Jordan indicates that the activity began in the Oligocene and continued to recent times.

Main Basins and Structural Features

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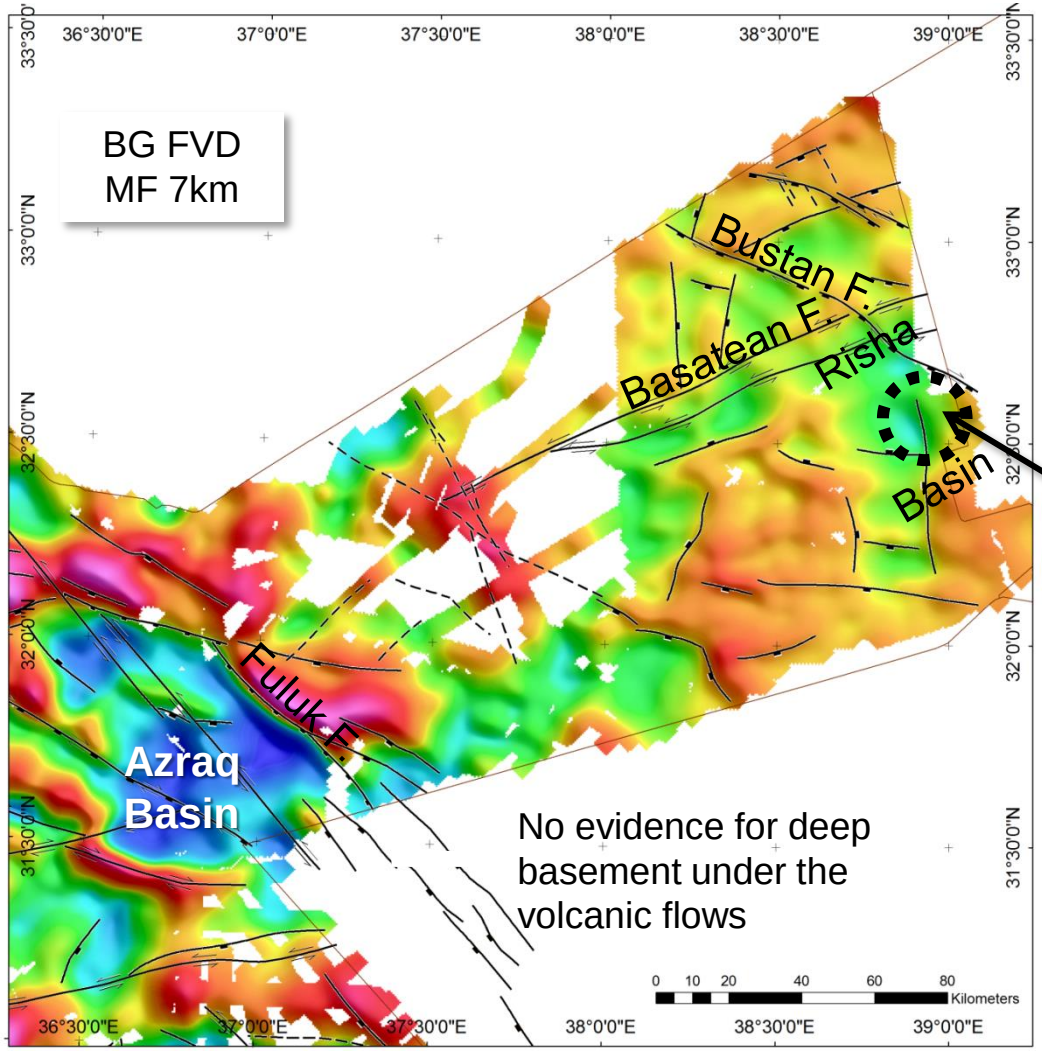
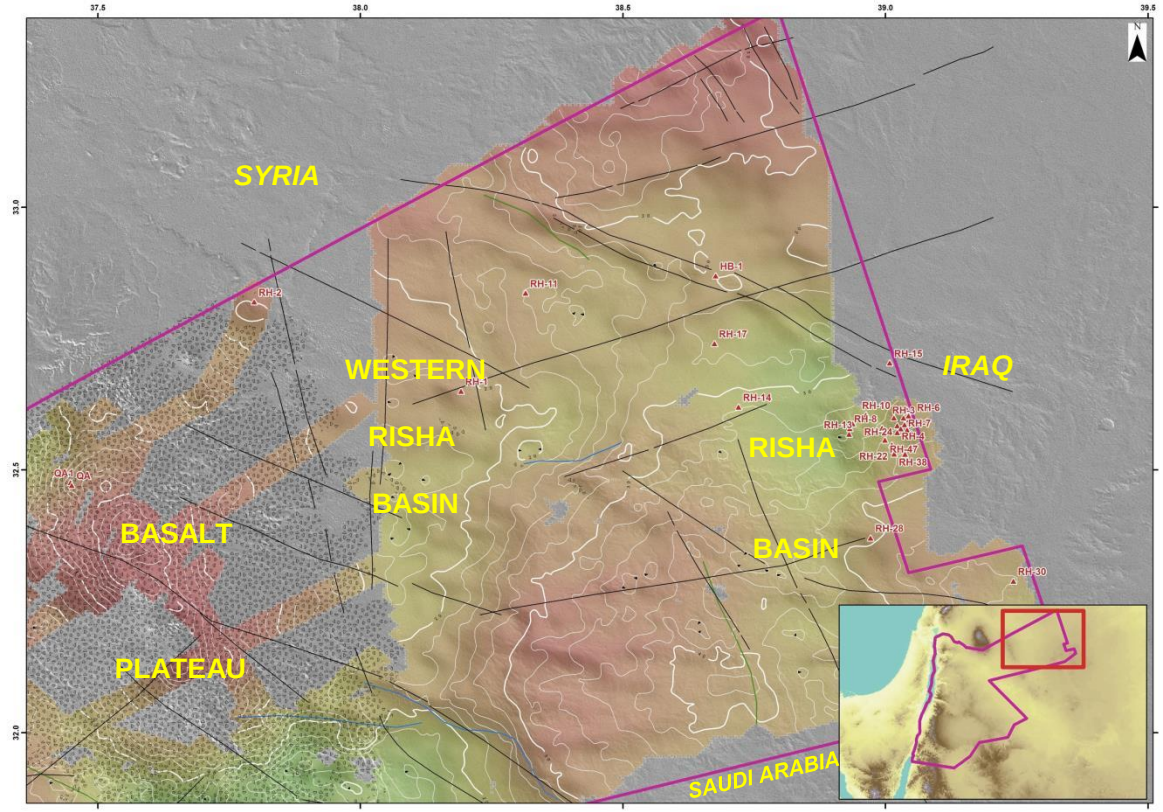
NE Jordan structural interpretation

The north-central portion of the country is characterised by a broad area of young volcanic deposits associated with highs on gravity and magnetic enhancements



Risha Basin



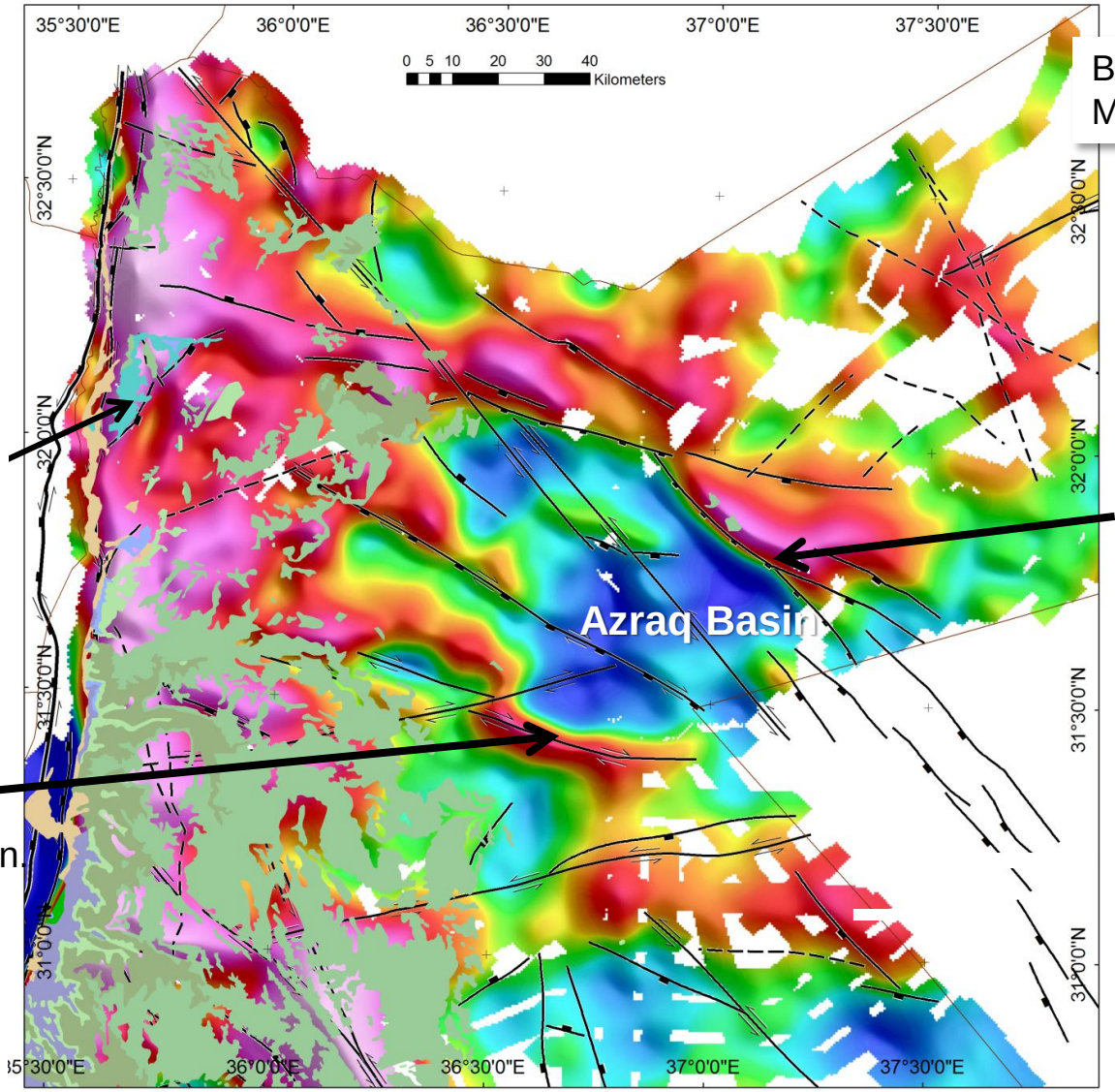
- Part of the major Palaeozoic Tabuk Basin.
- Palaeozoic beds dip and thicken to the east and are unconformably overlain by Mesozoic to Cenozoic formations which dip and thicken to the west.
- Surface lineament pattern is dominated by major sets, striking ENE-WSW and NW-SE.
- The area has not undergone a significant amount of deformation, having not been affected by new faults or by the reactivation of old faults.

NW Jordan structural interpretation

Broad gravity high in the northern mountains, indicates presence of uplifted dense basement

Area of Triassic and Jurassic rocks in a faulted uplift

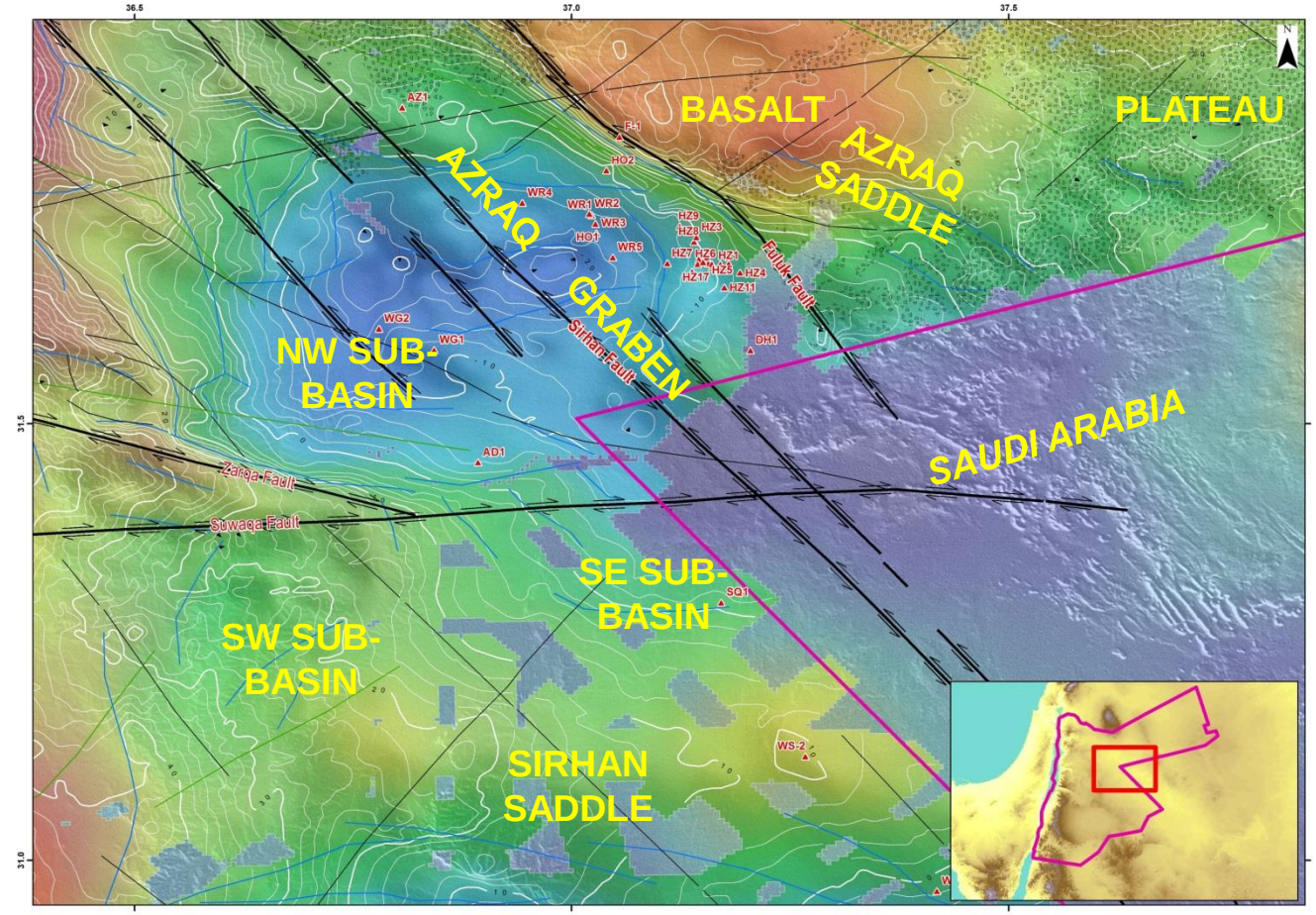
The Swaqa Fault bounds the southern side of the Azraq Basin.



BG FVD 7km Matched Filter

- The Fuluk Fault is a major bounding fault of the Azraq Basin.
- Cretaceous rocks exposed at the surface on the upthrown side indicate at least 3000m of fault offset.

Azraq Graben



Bordered by the Sirhan Saddle to the south, by the Central Platform to the west, by the Basalt Plateau to the north, and by the Jordan-Saudi Arabia border to the east, parallel to the Azraq Graben axis.

Four main depositional centres within the area:

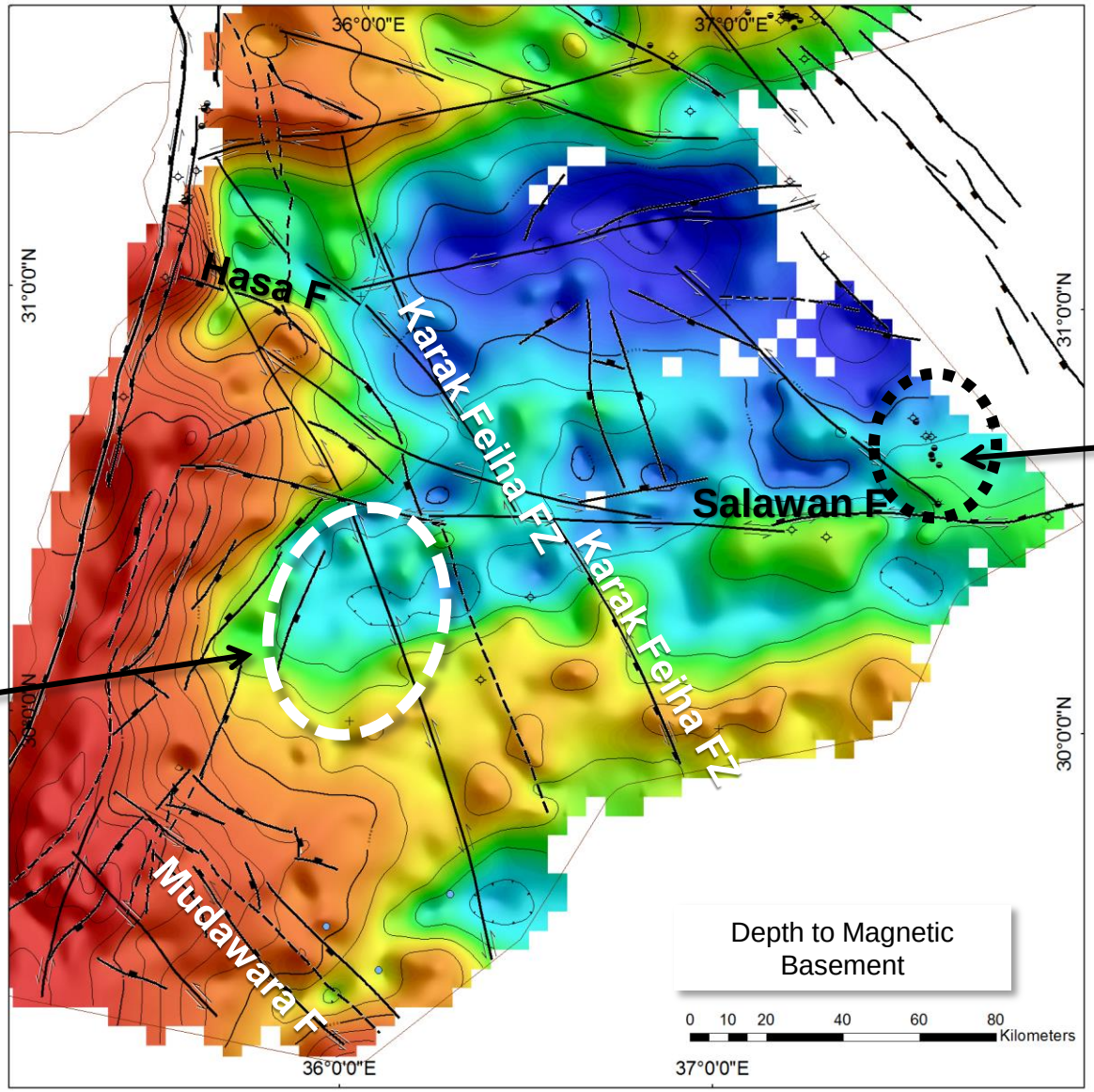
1) the Azraq Graben itself in the NE

2) its extension to the west here called the NW sub-basin

3) a smaller SW sub-basin

4) small SE sub-basin

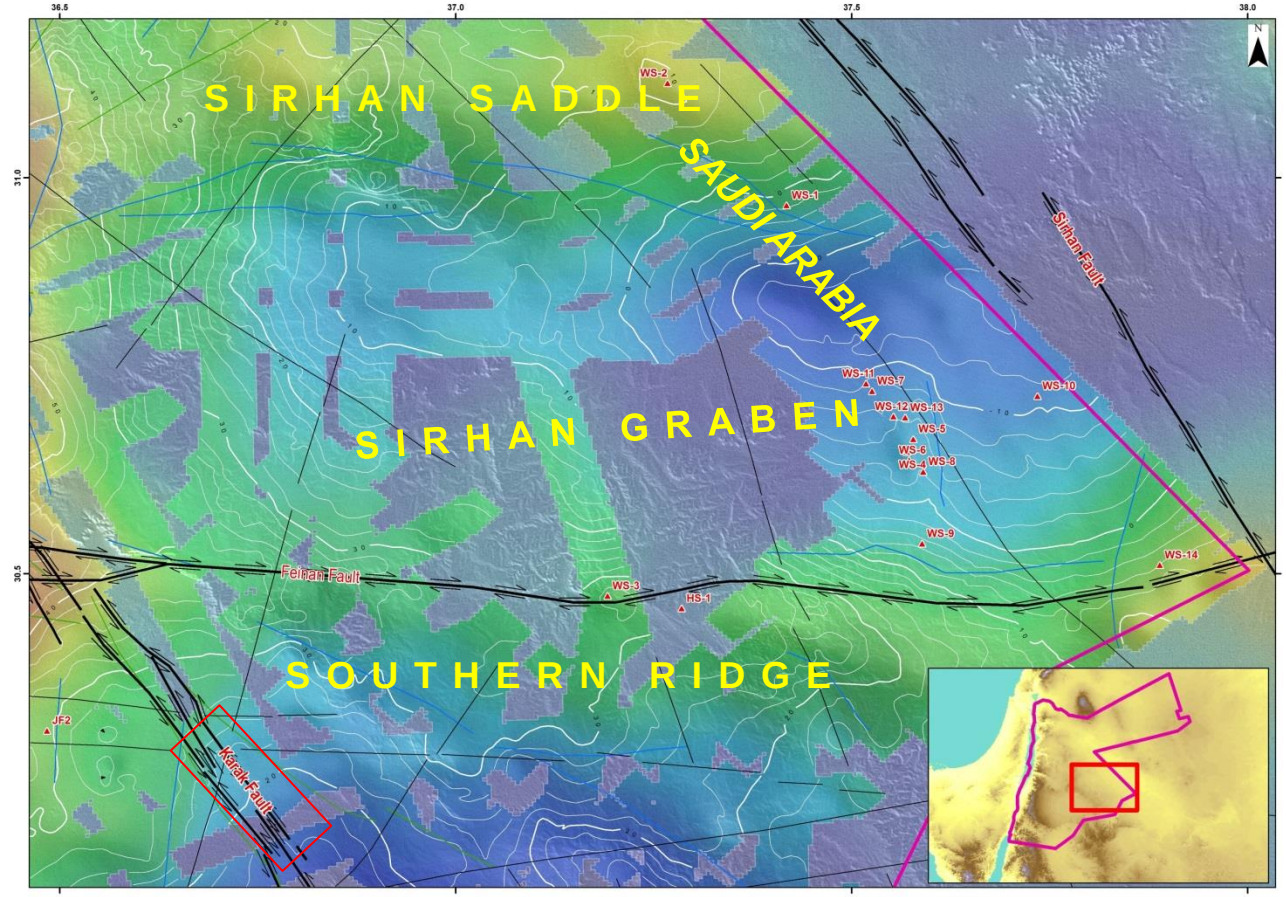
South Jordan structural interpretation



Jafr Subsurface Basin

Sirhan Area

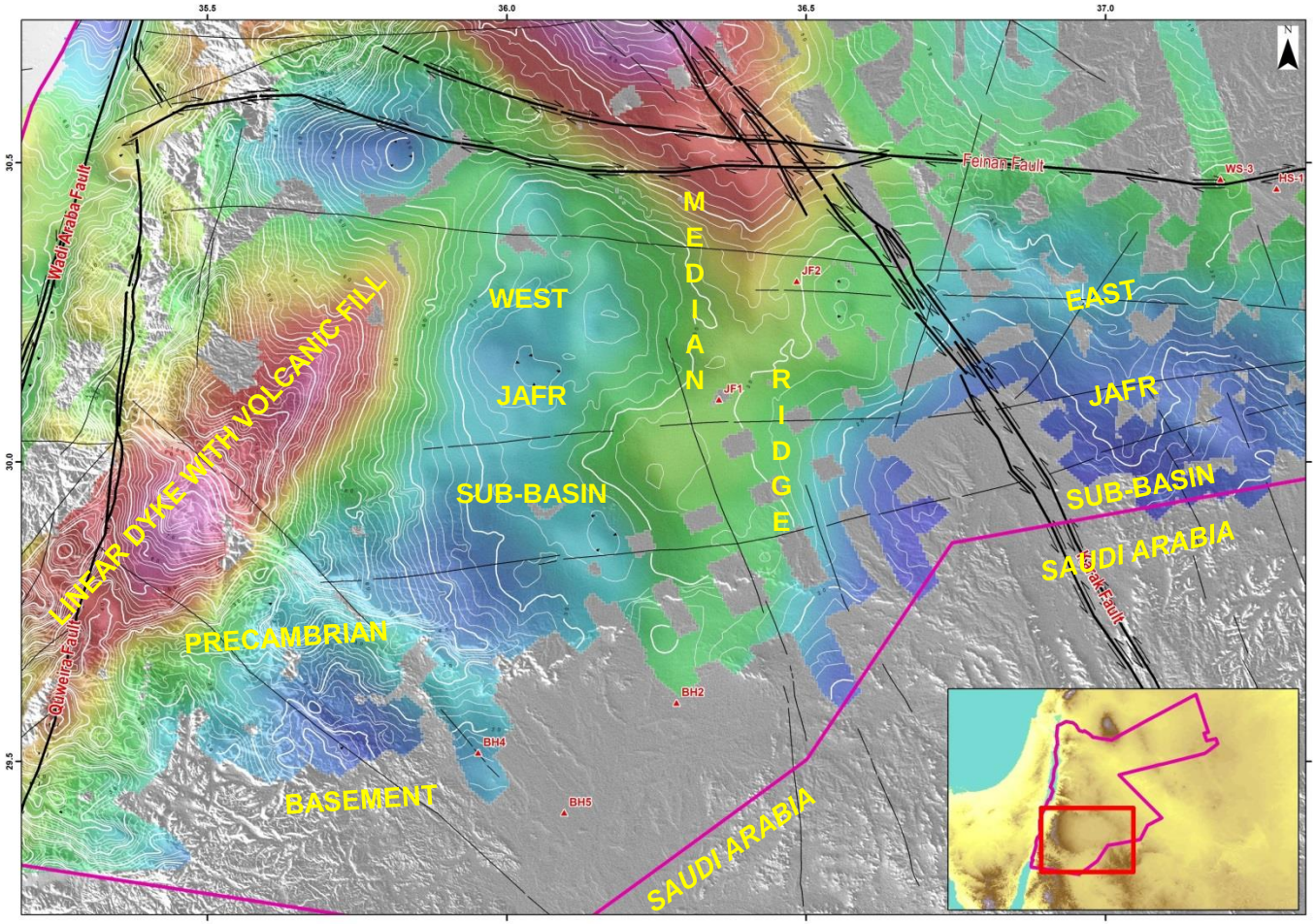
Sirhan Graben



- Bordered by the E-W trending Sirhan Saddle, in the west by the NW-SE striking Karak Fault, and in the south by the Cretaceous to Palaeozoic outcrop area.
- In the eastern part, it is open on the parent regional Azraq Graben, extending across northern Jordan from Syria to Saudi Arabia.

Infracambrian Jafr Basin

- Bounded by the WNW-ESE striking Feinan Fault to the north and by the NW-SE striking Karak Fault to the east.
- To the south, it is bordered by the elevated basement and Palaeozoic sediment, and at the west it is bounded by a NNE-SSW striking positive subsurface feature, expressed on the surface as a major lineament, considered as a segment of the Jafr Fault.



Representative Chronostratigraphy

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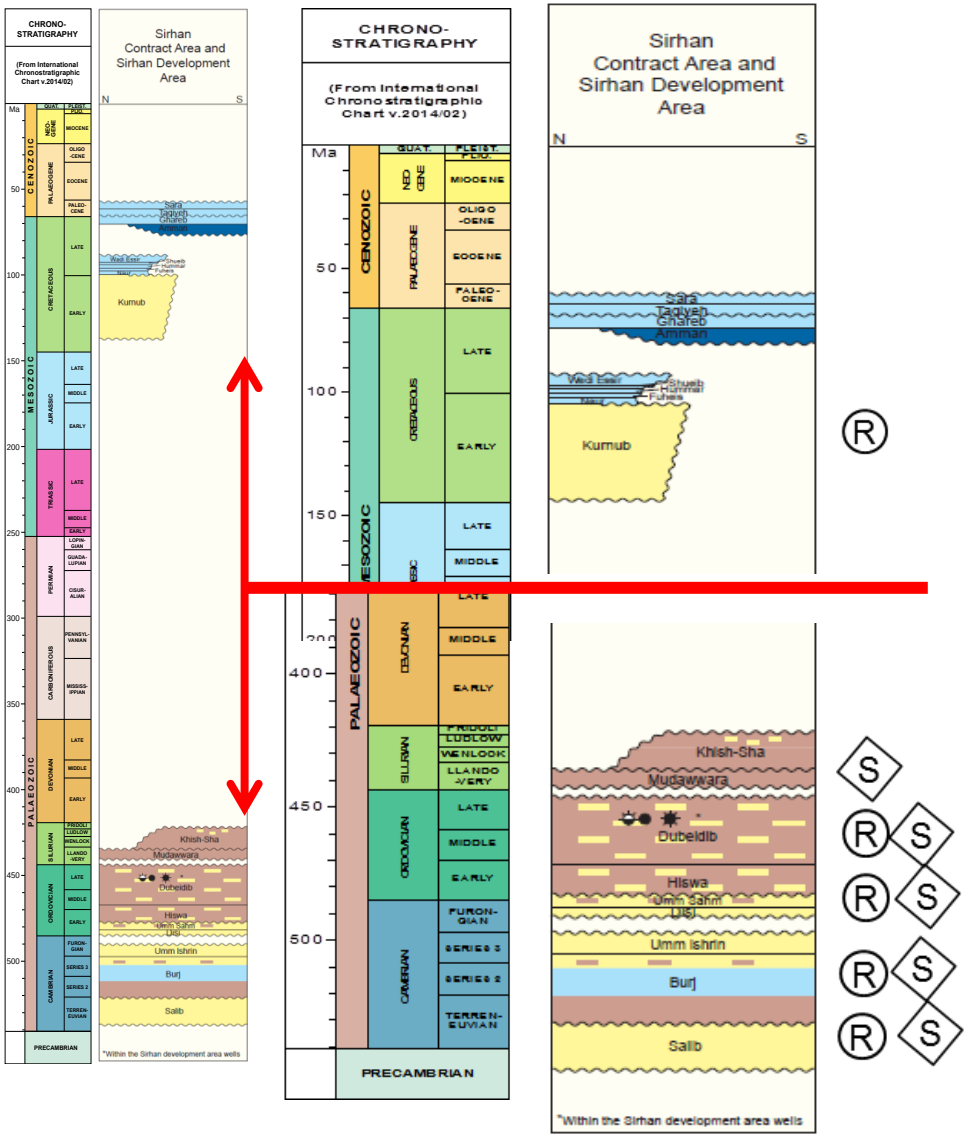
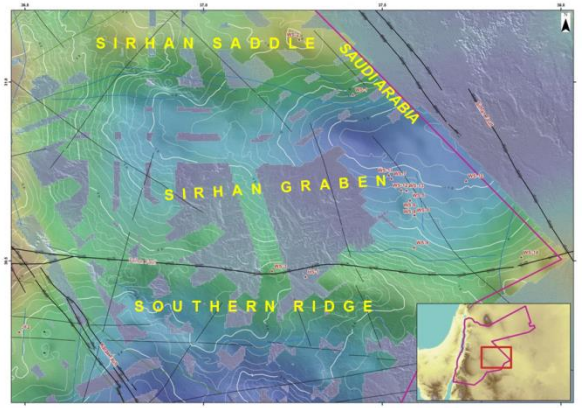
Sirhan





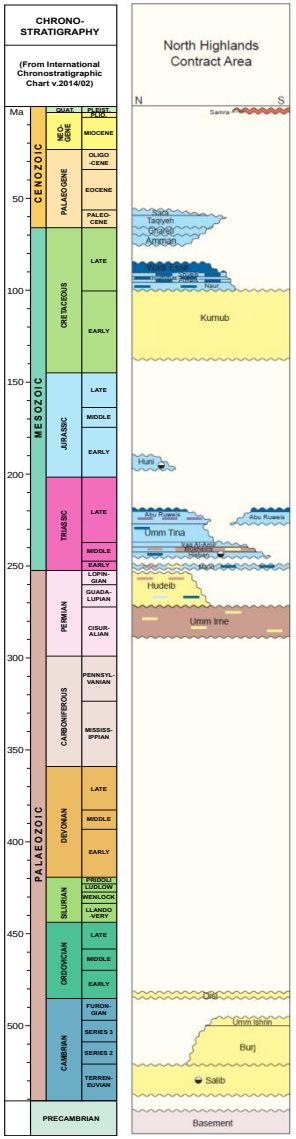
Ghareb Fm., Late Cretaceous, potential source

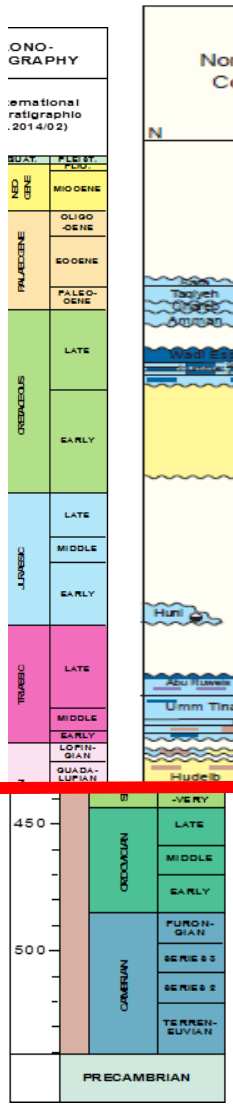
Kurnub Fm., Cretaceous reservoir

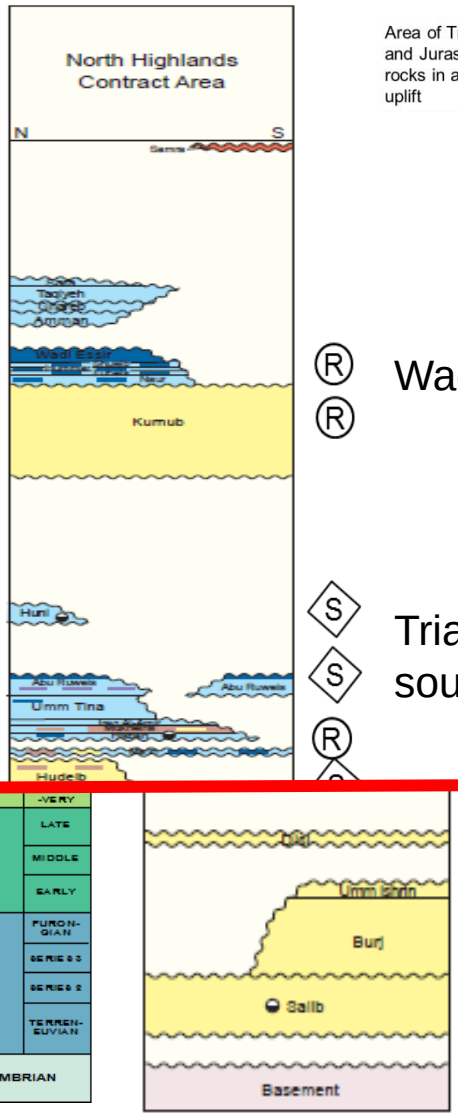
Silurian to Cretaceous erosion

Palaeozoic reservoirs and sources

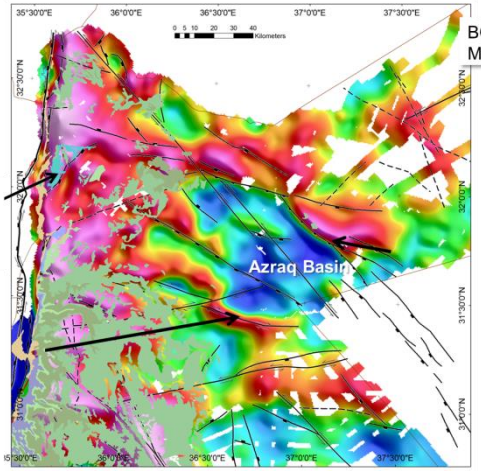
North Highlands







Area of Triassic and Jurassic rocks in a faulted uplift



Ⓡ Ⓡ Wadi Essir Fm. reservoir

Ⓢ Ⓢ Ⓡ Triassic reservoirs and sources

Ⓡ Decrease in Palaeozoic reservoirs

Source

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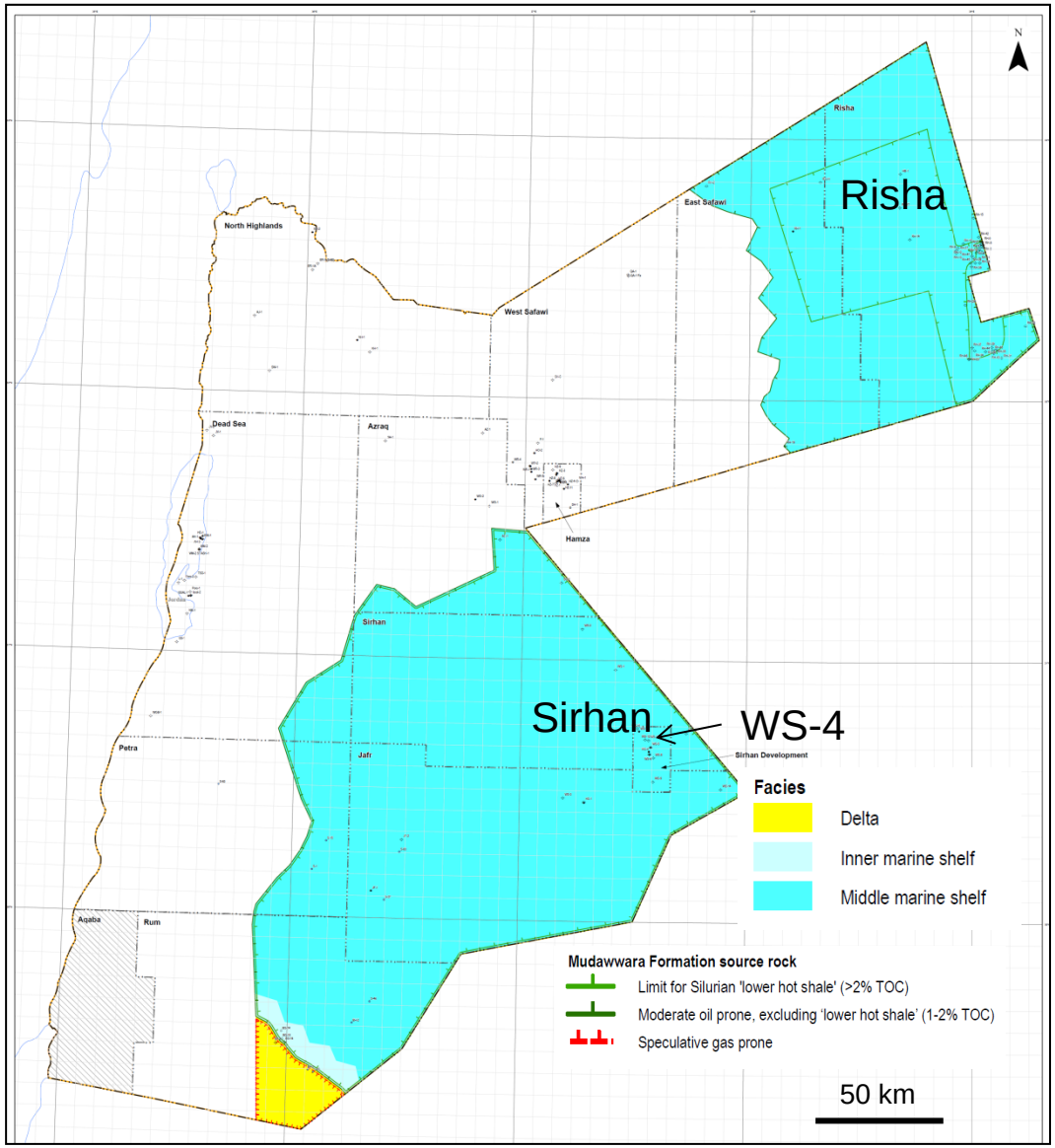
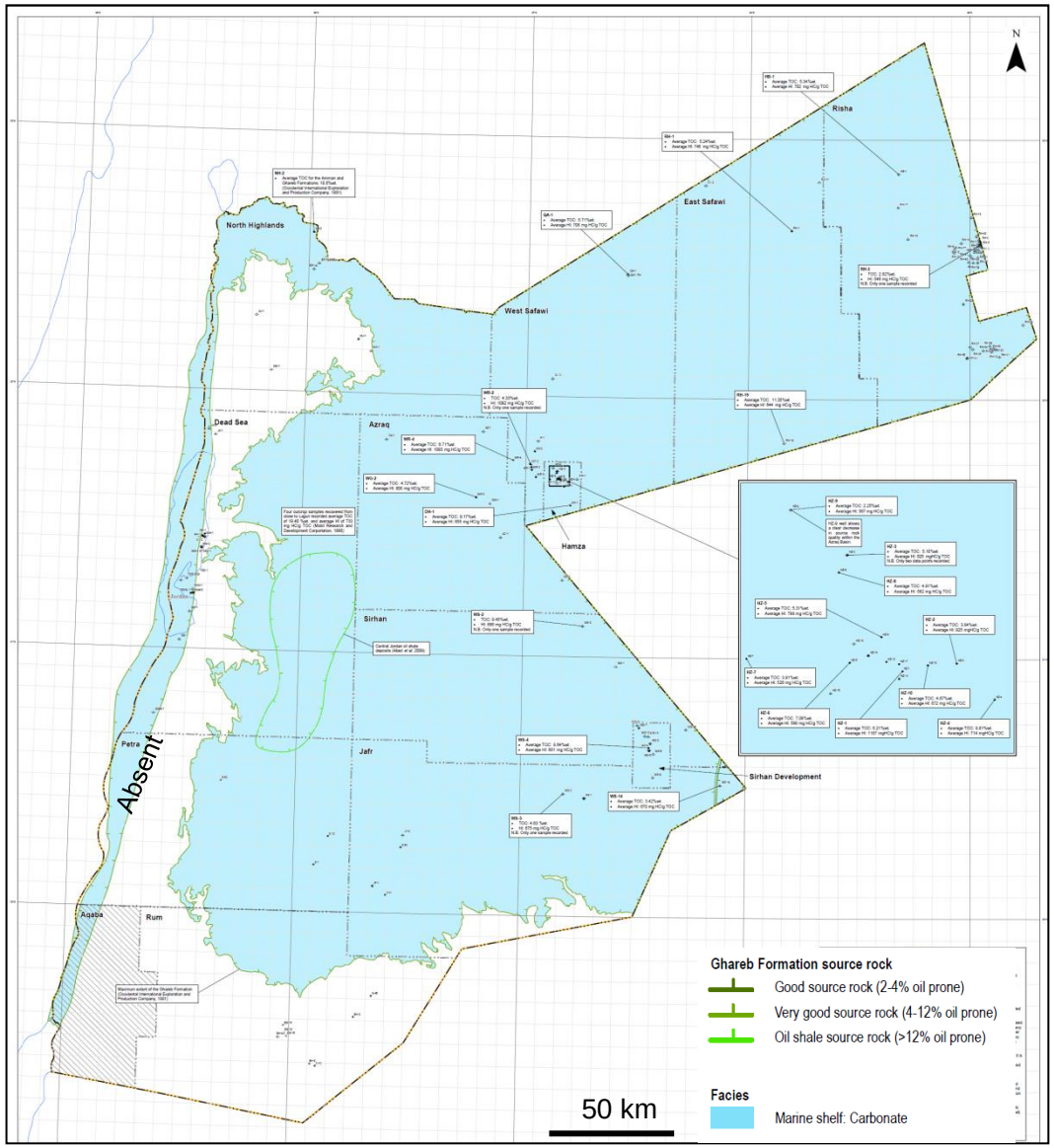
Mudawwara Fm. (Silurian)



- Main source horizon for generation of hydrocarbons in the Risha and Sirhan areas.
- 'Lower hot shale' unit represents the greatest source potential within the Mudawwara Fm. and is found in the south of Jordan and in the west of the Risha area.
- In addition, an 'upper hot shale' unit is apparent in the Mudawwara Fm. in the east of the Risha area that provides a second source of good potential within the formation.
- It is suggested that light oil/condensate discovered in WS-4 and WS-6 can be correlated to Silurian source rocks .
- However, the high maturity of the hydrocarbons suggests that the source is perhaps located further to the east of the Sirhan area where the Mudawwara Fm. is buried more deeply.
- Gas discovered in the Risha area is thought to have been generated by the Mudawwara Fm., however, maturity analysis suggests that this gas has either migrated from an area of higher maturity or has come from deeper source horizons.

Ghareb Fm. (Maastrichtian)



- Contains best potential for generation of hydrocarbons
- TOC 0.41-21.53%wt, av. 6.52%wt
- Mature for hydrocarbon generation in Dead Sea area
- Immature over most of Jordan

Other source rocks

- **Wadi Essir Fm. (Turonian)**
  - TOC values of between 0.41 and 6.43%wt.
  - Main contributing source horizon for oil discovered in the Azraq Graben
- **Shueib Fm. (Cenomanian) and Naur Fm. (Cenomanian)**
  - both contain TOC values of up to 5%wt. and have possibly contributed minor amounts of hydrocarbons in this area.
- Source rocks of **Triassic and Jurassic age** are believed to be the main contributing source horizons in the North Highlands contract area
  - Late Triassic contains the greatest source potential with TOC values reaching up to 1.9%wt.
  - No oil or gas accumulations have been found in this area so far, but weak oil shows have been discovered within Triassic rock in wells NH-1, NH-2 and AJ-1
  - It is possible that Triassic source rocks have contributed minor amounts of hydrocarbons to the west of the Risha area and in the Azraq Graben.
- **Shales of Ordovician age in the Dubeidib and Hiswa Fms.** are considered to contain good source potential.
  - TOC values of up to 2%wt. have been recorded in the Hiswa Fm., whilst TOC values of up to 4%wt have been recorded for the thin siltstone and shale beds of the Dubeidib Fm.
- The **Cambrian Burj Fm.** is thought to contain some source potential and is a possible generative source rock for the Jafr contract area around JF-1 and JF-2 wells.

Reservoir

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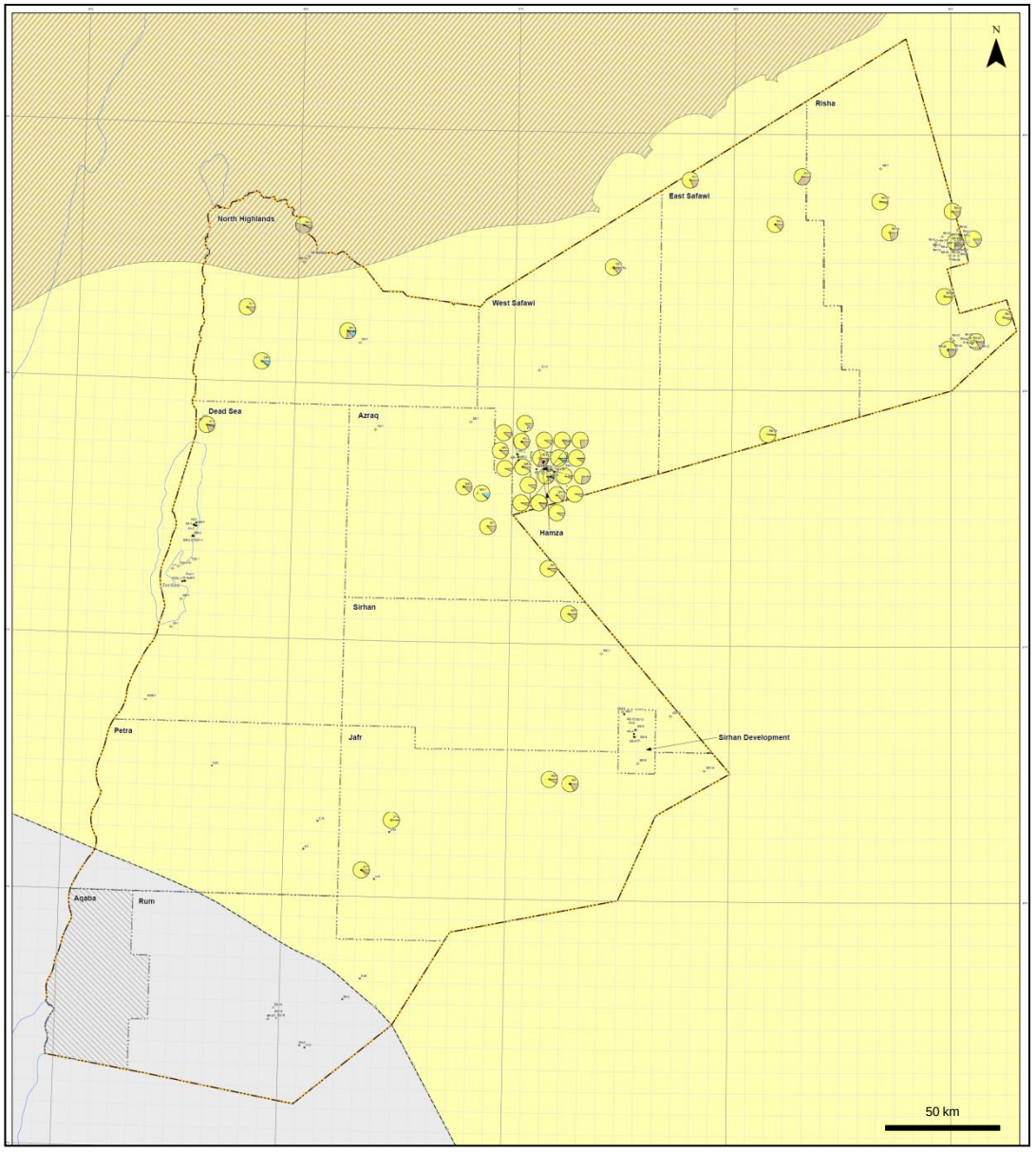
Kurnub Fm.; Early Cretaceous



Coastline
International border
Assumed limit of erosion
Contract areas
Exclusion zone

Lithofacies

Sand
Sand, mud
Eroded or non-deposition

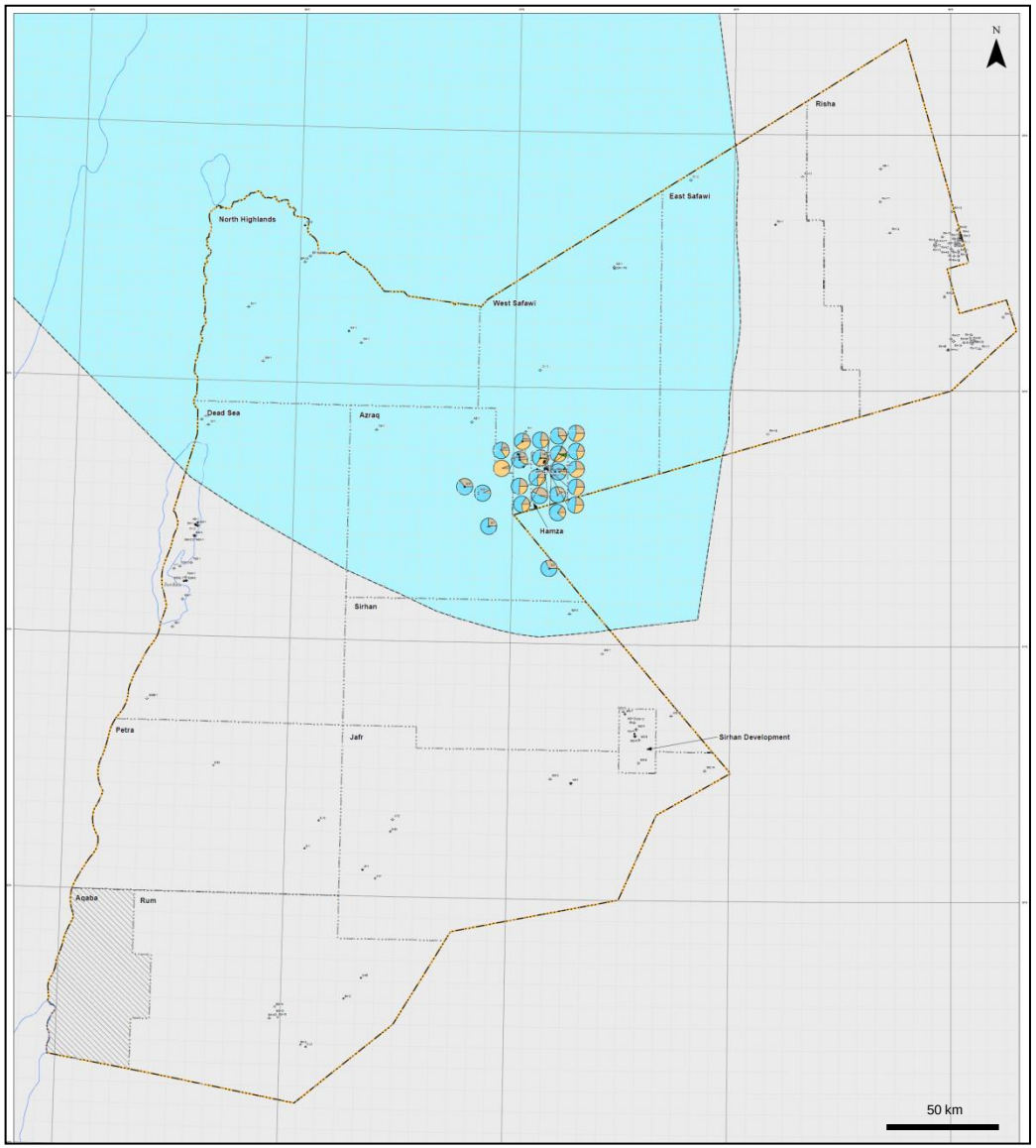
Hydrocarbon shows

Gas
Oil
Oil and gas
Gas shows
Oil shows
Gas with oil shows
Oil and gas shows
Dry
Water well
Bitumen
Unknown

Kurnub

Sand
Shale
Limestone
Dolomite
Dolerite
Anhydrite

Shueib Fm.; Late Cretaceous



Coastline
International border
Assumed limit of erosion
Contract areas
Exclusion zone

Lithofacies

Carbonate
Eroded or non-deposition

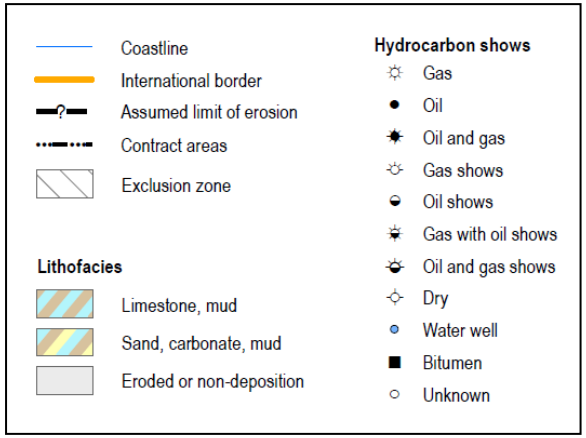
Hydrocarbon shows

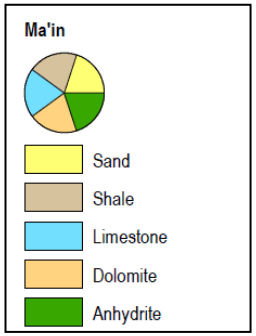
Gas
Oil
Oil and gas
Gas shows
Oil shows
Gas with oil shows
Oil and gas shows
Dry
Water well
Bitumen
Unknown

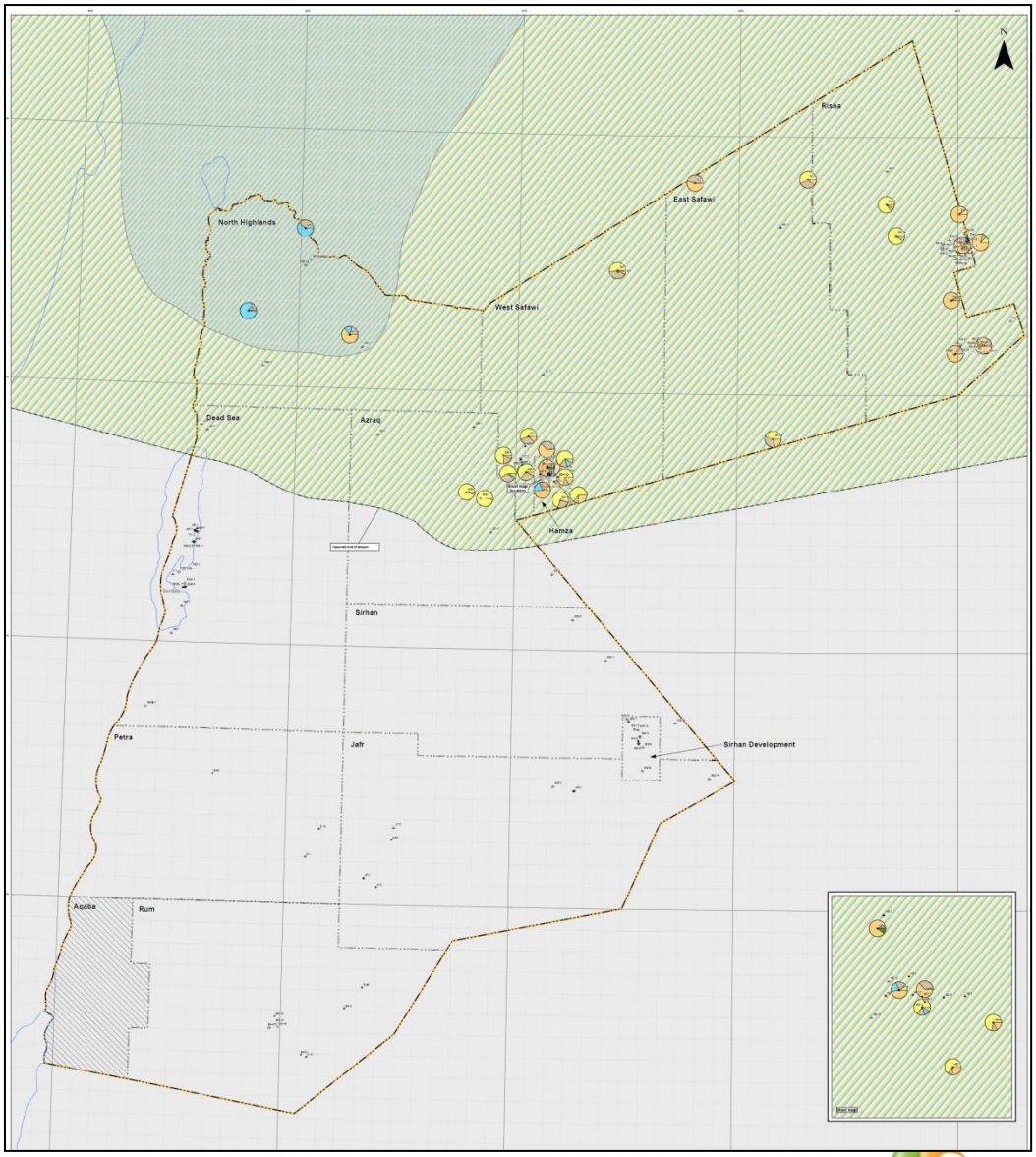
Shueib

Sand
Shale
Limestone
Dolomite
Anhydrite

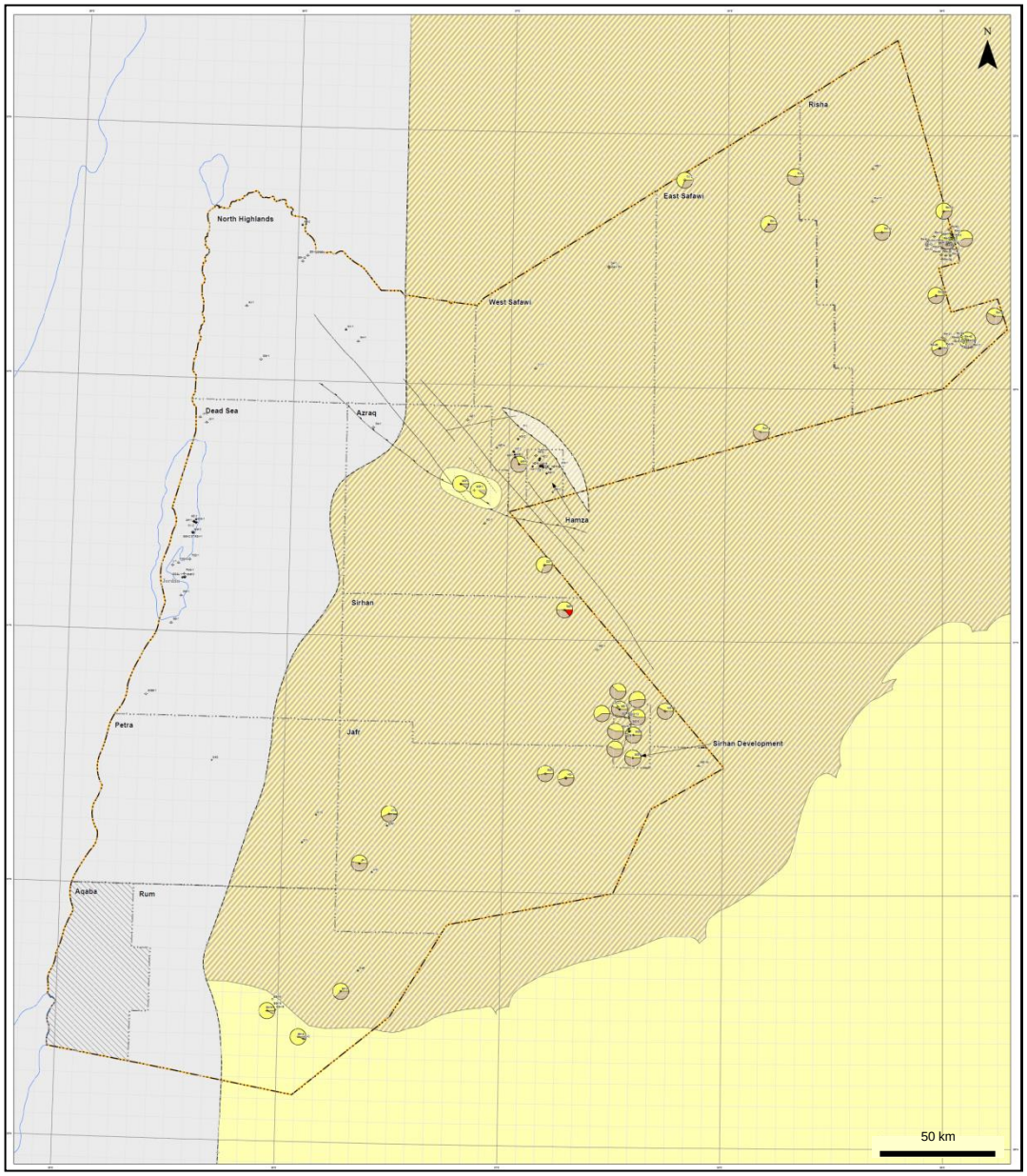
Ma’in Fm.; Early Triassic







Dubeidib Fm.; Ordovician



Coastline
International border
Assumed limit of erosion
Contract areas
Exclusion zone

Structure (Azraq block)
Main fault (fault zone)
Fault with apparent downthrow
Fault, undifferentiated
Inferred fault, undifferentiated

Hydrocarbon shows
Gas
Oil
Oil and gas
Gas shows
Oil shows
Gas with oil shows
Oil and gas shows
Dry
Water well
Bitumen
Unknown

Lithofacies
Sand
Sand, mud
Eroded or non-deposition

Dubeidib

Sand
Shale
Limestone
Dolerite

Reservoir

- Azraq Sandstone (Lower Amman Fm., Late Cretaceous) and the siliciclastic **Kurnub Fm. (Early Cretaceous)**
  - Considered potential reservoirs
  - Restricted to the Azraq and North Highlands contract areas
- **Shueib** and Hummar Fms. (Cenomanian)
  - Proven reservoirs in the Hamza oil field, producing from enhanced carbonate lithologies
  - Good coverage, but crop out towards the south
- Iraq Al Amir and **Ma'in Fms.** (Triassic)
  - Limestones and dolomites are considered potential reservoirs in the northern part of the country (Naylor *et al.,* 2013).
  - Weak oils shows have been reported from Triassic rocks in deep wells in the North Highlands (Naylor *et al.,* 2013; Luning and Kuss, 2014).
  - Limited to the northern and northeastern parts of the country
- **Dubeidib Fm.** (Ordovician)
  - Proven reservoir in the Risha gas field, producing from the Risha Mbr. In the same formation, small quantities of light oil were also encountered in the Sirhan area in wells WS-4 and WS-6
  - Absent in the North Highlands
  - The glaciogenic Risha Mbr. of the Dubeidib Fm. thins westwards
- Siliciclastics of the Salib, Umm Sahm, Umm Ishrin and Disi Fms. and the limestones of the Burj Fm. (Cambrian and Ordovician) form potential reservoirs, especially in the south and northeast of the country.
  - Show good distribution across the whole country
  - Strata generally thicken towards the north and northeast

Hydrocarbon Occurrences

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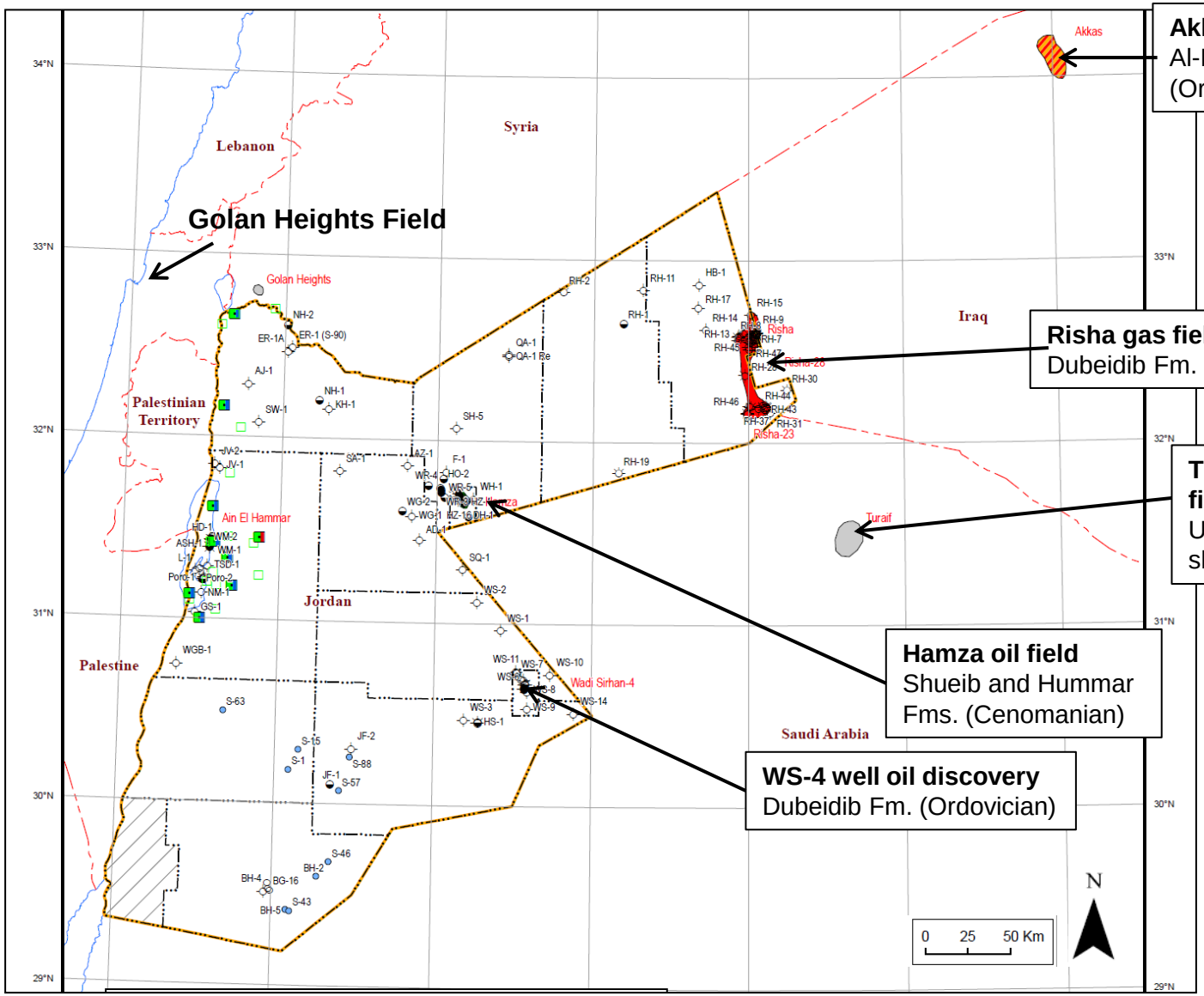
Hydrocarbon occurrences



Akkas gas field
Al-Khabour Fm. (Ordovician)

Risha gas field
Dubeidib Fm. (Ordovician)

Turaif tight gas field
Unconventional – shale gas

Hamza oil field
Shueib and Hummar Fms. (Cenomanian)

WS-4 well oil discovery
Dubeidib Fm. (Ordovician)

Fields
- Oil
- Gas
- Oil and gas

Seeps
- Seep, gas
- Seep, oil
- Seep, oil, bitumen
- Seep, oil, gas
- Seep, oil, other
- Seep,other