

# **Calibrating Seal Risk against Global Analogues and Observations: Where Does the Middle East Fit?\***

**Duncan Macgregor<sup>1</sup> and Roger Davies<sup>2</sup>**

Search and Discovery Article #41825 (2016)\*\*

Posted July 5, 2016

\*Adapted from oral presentation given at AAPG/EAGE Hydrocarbon Seals of the Middle East, January 18-20, 2016, Muscat, Oman

\*\*Datapages © 2016 Serial rights given by author. For all other rights contact author directly.

<sup>1</sup>MacGeology Ltd., Reading, United Kingdom ([duncan@macgeology.co.uk](mailto:duncan@macgeology.co.uk))

<sup>2</sup>Davies Geoconsulting, Yorkshire, United Kingdom

## **Abstract**

Seals succeed or fail by five main mechanisms, which can be listed as follows:

- 1) Areal discontinuity of the rock type proposed as the seal, over a structure or fairway, termed ‘Seal Distribution’ in this article.
- 2) Excess pressure due to the development of a hydrocarbon column exceeding membrane capacity of the seal, termed ‘Seal Capacity’ in this article.
- 3) Tectonic fracturing of the seal, termed ‘Seal Integrity’ in this article.
- 4) Displacement of the seal by faulting, termed ‘Seal Displacement’ in this article.
- 5) Hydraulic fracturing of the seal, termed ‘Seal Hydraulic Fracturing’ in this article.

Seal Distribution is clearly analysed by facies and depositional environment mapping. Seal varies with lithology and grain size. Seal Integrity is dependent on a relationship between the seals ductility (i.e. lithology) and the tectonic strain imposed on it (i.e. tectonic regime). Seal Displacement is dependent on a relationship between the seal thickness and the displacement of faults, while hydraulic fracturing is dependent on a highly overpressured regime. The chance of a seal being successful is the product of the risk of all possible leakage processes. This may well vary between partial fill and full-to-spill cases. Quantification of each process, and therefore of the each of the risks involved, is hazardous and it is key therefore to calibrate to field analogues.

Seal Capacity and Seal Integrity are both lithology dependent and it is possible to rank potential seal lithologies by a combination of analysis, theoretical prediction and analogue observation, with evaporites providing the lowest risk seals followed by organic shales, then mudrocks in increasing grain size, then argillaceous carbonates. Seal Integrity and Seal Displacement are also dependent on the tectonic regime, which together with the age of the petroleum system, can be seen to impose constraints on the spectrum of lithologies that act as effective seals in a basin. Relatively few regional seals (and often mainly evaporites) are seen in old petroleum systems and thrust belts, whereas a wider range of seal types are seen in active petroleum systems and more quiescent tectonic settings. In some cases, the rate of hydrocarbon charge seems to exceed the rate of leakage through seals, expanding the range of sealing lithologies and models.

The availability of high quality, ductile and continuous regional seals is arguably the main factor controlling the high petroleum productivity of the Middle East. Key factors include the abundance of ductile evaporites and anhydritic shales, together with the availability of clastic shale seals in some regions, all lithologies with high Seal Capacity. Carbonate seals trap a smaller proportion of petroleum, but are unusually effective compared to other parts of the world. In the Arabian Basin, relatively thin seals are seen to work as regional seals (e.g. basal Sudair/Aghar Shale seal), which suggests few faults and low fault displacements, indicating Seal Displacement is rarely an issue. In the Zagros, the range and number of seals are diminished, but are still wider than seen in any other 'thrust belt'.

Because seals exert such an important influence on the Middle East petroleum systems, there is a strong argument for focusing play fairway/common risk segment mapping on seal rather than reservoir levels, particularly as in some cases, different reservoirs underlie the key seals. A methodology for such mapping is outlined, considering each potential seal leakage mechanism and tying to analogue observations where available. This is demonstrated for a series of seals in northern Iraq, where the most important considerations appear to be Seal Distribution and Seal Integrity, and where few pools are full to their structural spill points.

### **References Cited**

- Basili, R., and S. Barba, 2007, Migration and shortening rates in the northern Apennines, Italy: Implications for seismic hazard: *Terra Nova*, v. 19/6, p. 462-468.
- Blanc, E.J.-P., M.B. Allen, S. Inger, and H. Hassani, 2003, Structural styles in the Zagros simple folded zone, Iran: *Journal of the Geological Society (Formerly Quarterly Journal of the Geological Society)*, v. 160/3, p. 401-412.
- Brown, A.A., and R.G. Loucks, 2001, Evaluation of anhydrite seals through depositional, structural, and lithological analysis, example from the Jurassic Arab Formation, Al Rayyan Field, Qatar: AAPG Annual Meeting: An Energy Odyssey, Denver 2001, Abstracts.
- Grunau, H.R., 1987, A worldwide look at the cap-rock problem: *Journal of Petroleum Geology*, v. 10/3, p. 245-266.
- Long, S., N. McQuarrie, T. Tobgay, and D. Grujic, 2011, Geometry and crustal shortening of the Himalayan fold thrust belt: *GSA Bulletin*, published online 26 Jan 2011, doi 10.1130/B30203.1

Roure, F., E. Roca, and W. Sass, 1993, Neogene evolution of the Outer Carpathian flysch units: kinematics of a foreland, fold and thrust belt system: *Sed. Geol.*, v. 86, p. 177-201.

Sharland, P.R., D.M. Casey, R.B. Davies, M.D. Simmons, and O.E. Sutcliffe, 2004, Arabian Plate Sequence Stratigraphy - revisions to SP2: *GeoArabia*, v. 9/1, p. 199-214.

Yonkee, W.A., and A.R. Weil, 2015, Tectonic evolution of the Sevier and Laramide Belts within the North American cordillera orogenic system: *Earth Sciences Reviews*, v. 150, p. 531-593.



# AAPG

*Advancing the World of Petroleum Geosciences.*

# EAGE

EUROPEAN  
ASSOCIATION OF  
GEOSCIENTISTS &  
ENGINEERS

## **Calibrating seal risk against global analogues and observations : where does the Middle East fit?**

**Duncan Macgregor**

MacGeology Ltd.

**Roger Davies**

Davies Geoconsulting



# AAPG

*Advancing the World of Petroleum Geosciences.*

## Order of Presentation

- Seal Failure Processes and Examples
- Middle East Seal Overview
- Case Study-Northern Iraq/Kurdistan



# AAPG

*Advancing the World of Petroleum Geosciences.*

## Seal Processes and Reasons for Failure

### SEAL PROCESS AND RISK

Capillary Seal Capacity

Seal Continuity

Seal Fracturing/Integrity

Hydraulic Seal Capacity

### PHYSICS

$P_{res} - P_{seal} < P_{seal\ capacity}$

Seal continuous over structure and thickness > fault throws

Fracture permeability path established in seal

$P_{res} > P_{fracture}$

### KNOWLEDGE REQUIRED

Pore Throat Distribution (Lithology and Grain Size)

Seal Thickness, Fault Throw (structural regime)

Degree of Fracturing (structural regime), Ductility (lithology)

Pressure Regime, Reservoir Geometry



# AAPG

*Advancing the World of Petroleum Geosciences.*

## Proven Seal Lithologies

- A trap can be any geometry where a rock of **low capillary entry pressure (a reservoir)** passes upwards (topseal) and if required also laterally or downwards (fault or strat traps) to a rock of **high capillary entry pressure (a seal)**
  - >90% of cases = evaporite or shale/mudstone
  - but also :
    - Volcanics – e.g. Triassic of Algeria
    - Sills – e.g. Brazil
    - Basement – lateral seal, e.g. Uganda
    - Lateral Changes in diagenesis/cementation – diagenetic traps, tar sealed traps (e.g. California)
    - Siltstones – e.g. Indonesia
    - Carbonate mudstones – e.g. Middle East, Tunisia
    - Tight Carbonates – e.g. Middle East
    - Conglomerates – e.g. Kenya, Reconcavo Basin

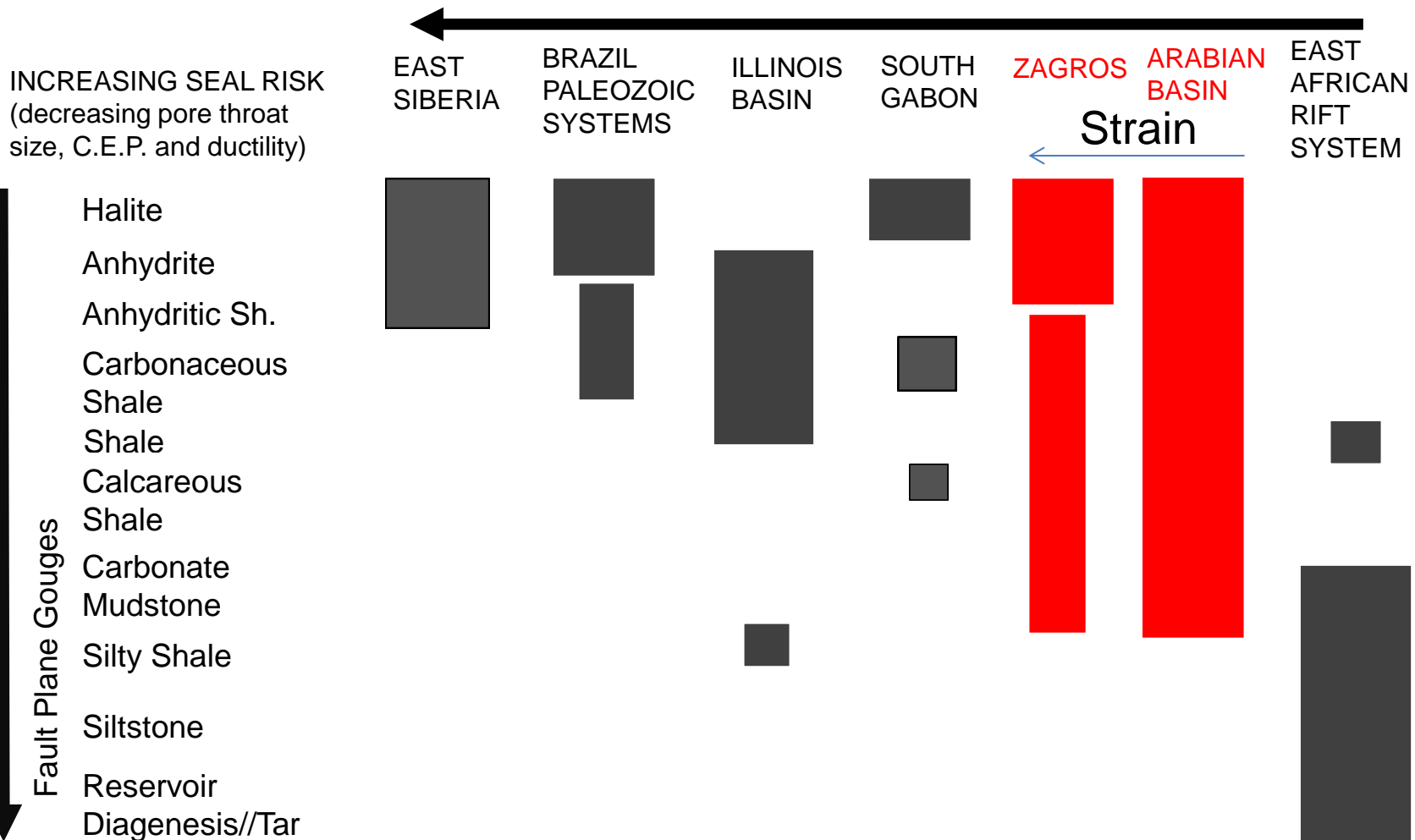


# AAPG

Advancing the World of Petroleum Geosciences.

## Ranking of Seals by Lithology

Petroleum system age



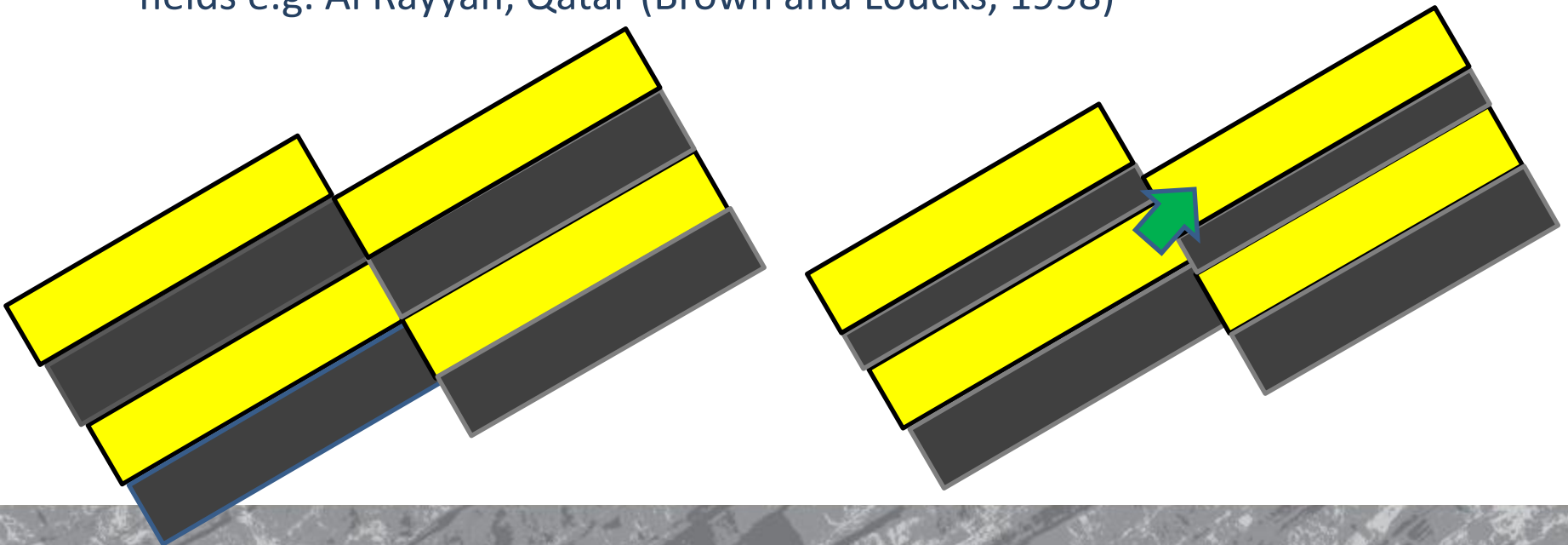


# AAPG

*Advancing the World of Petroleum Geosciences.*

## Seal Continuity

- Many authors (e.g. Grunau) have noted relationships between reserves and seal thickness
- In reality this represents the continuity of a seal
  - A thick seal is less likely to be displaced on a fault
- So the key is the relationship between the thickness of the seal and the throw on faults within a structure
- Has been noted controlling intraformational seals in many Middle East fields e.g. Al Rayyan, Qatar (Brown and Loucks, 1998)





# AAPG

*Advancing the World of Petroleum Geosciences.*

## Strain / Ductility

- Will strain/structural shortening lead to brittle fracturing through the seal?
- Varies with
  - Rock ductility – salt etc flows
  - Pressure conditions
  - Compaction
  - Degree of shortening
- Significant mechanical contrasts in Middle East carbonate-marl-shale- evaporite stratigraphies
- **Key Issue in Case Study in Northern Iraq/Kurdistan**

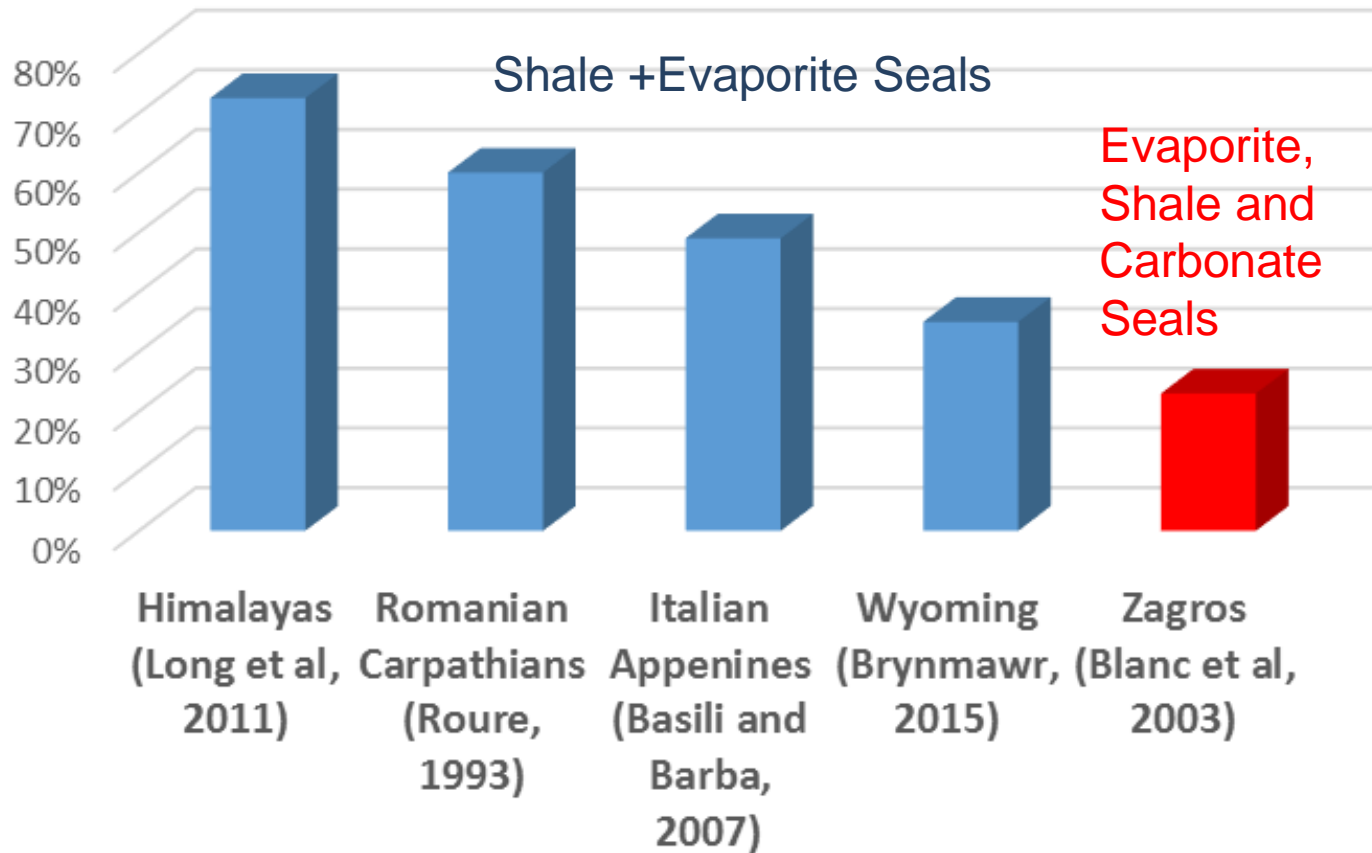
Sharp et al , 2010



# AAPG

*Advancing the World of Petroleum Geosciences.*

## Degree of Shortening/ Strain in Thrust Belts





# AAPG

*Advancing the World of Petroleum Geosciences.*

## Dynamic Seals

- Dynamic sealing can occur where the rate of migration into a trap exceeds that of the rate of leakage as controlled by the properties of the seal
- Leakage controlled by seal or fault plane permeability
- Can lead to columns exceeding structural closure, leakage between pools, greater chance of cross-sealing faults and tar belt seals
- Seen in very active Neogene depocentres, e.g. Los Angeles Basin, Uganda, **Northern Iraq-Kurdistan**

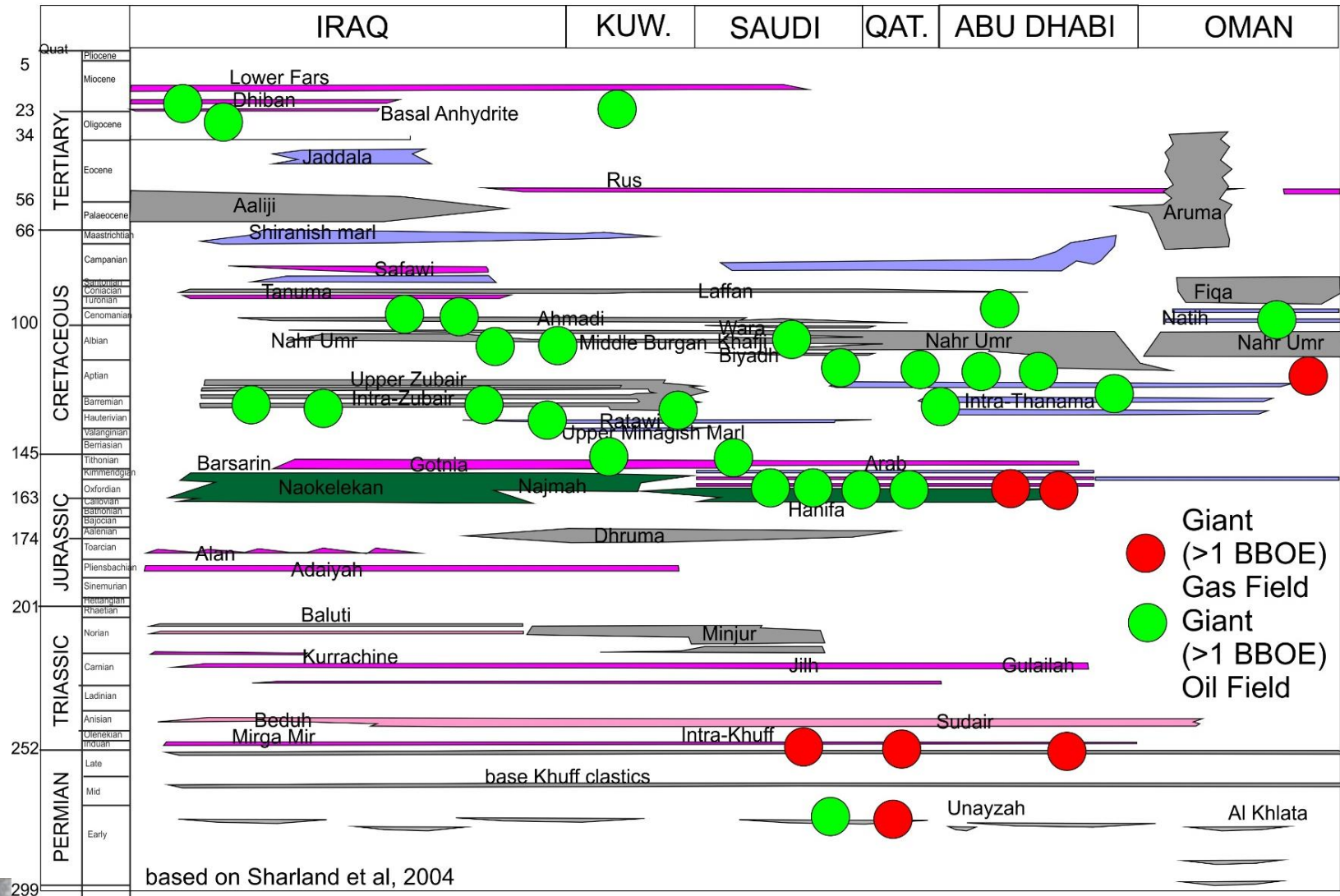




# AAPG

Advancing the World of Petroleum Geosciences.

## Arabian Basin Seals



Salt/Anhydrite

Anhydritic Sh.

Shale.

Organic Shale.

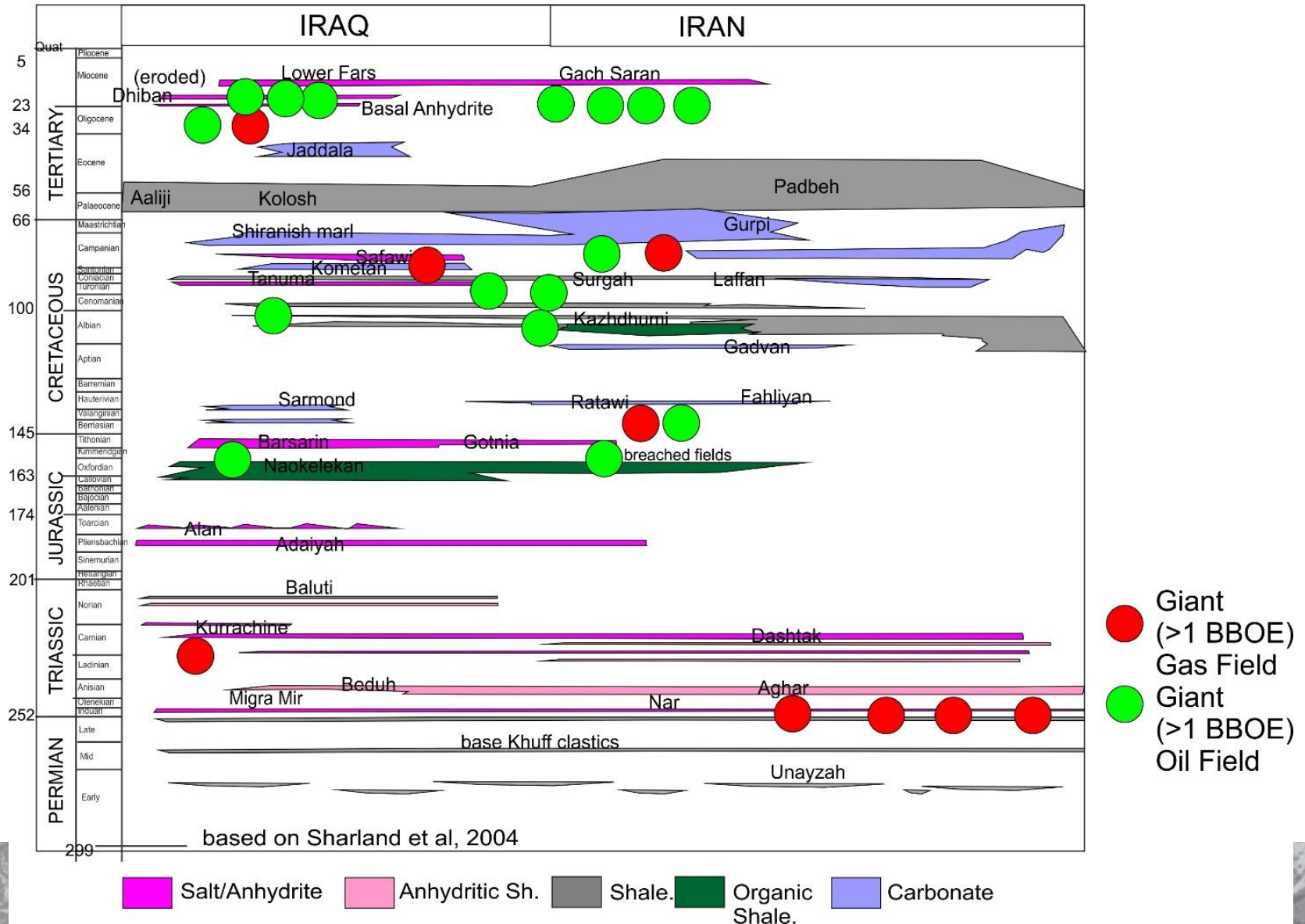
Carbonate



# AAPG

Advancing the World of Petroleum Geosciences.

## Zagros Foreland/'Thrust Belt' Seals





# AAPG

*Advancing the World of Petroleum Geosciences.*

## Northern Iraq/ Kurdistan

### Example : CRS Mapping Approach

- Risk of Seal = Chance of Adequate Seal Capacity x Chance of Seal not Displaced x Chance of Seal Not Fractured
- Hydraulic fracturing not likely or considered
- Map lithological and strain system changes
  - Evaporite distributions are critical as these are best seals
  - Clastic inputs to system from rising mountains to NE
  - Higher risk towards carbonate platforms to west
  - Increase in strain towards Zagros front
- Vital to calibrate to observations of columns in fields
- Vital to relate risk to a sustainable column height
  - Risk will be different for different column heights
  - Northern Iraq/Kurdistan fields generally not full to spill



# Main Northern Iraq/ Kurdistan Seals

## Kirkuk



## MAPPED LEVELS

Shaikan  
Shaikan

# Miran

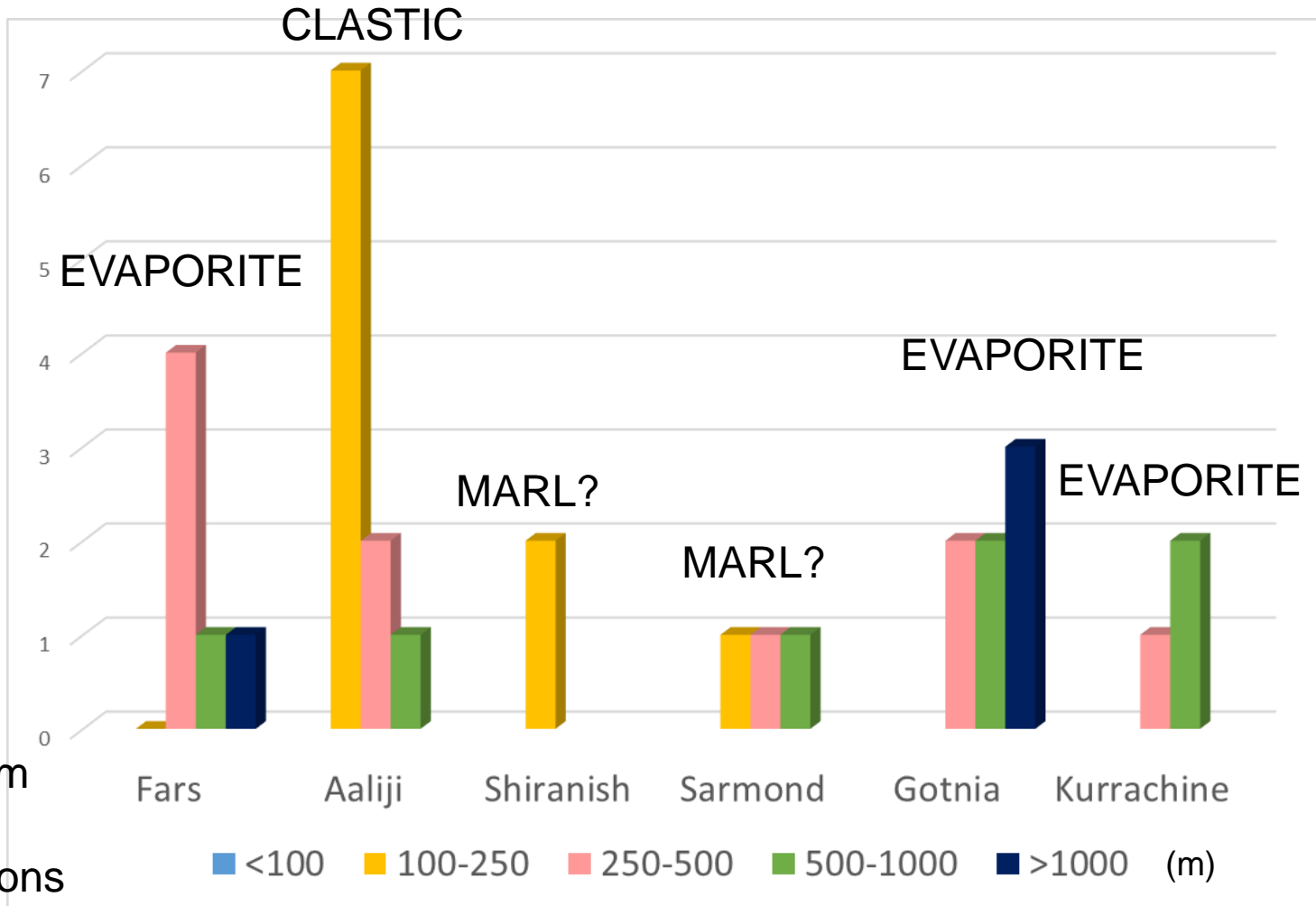
# Bina Bawl



# AAPG

Advancing the World of Petroleum Geosciences.

## Kurdistan Seals : Histogram of Column Heights



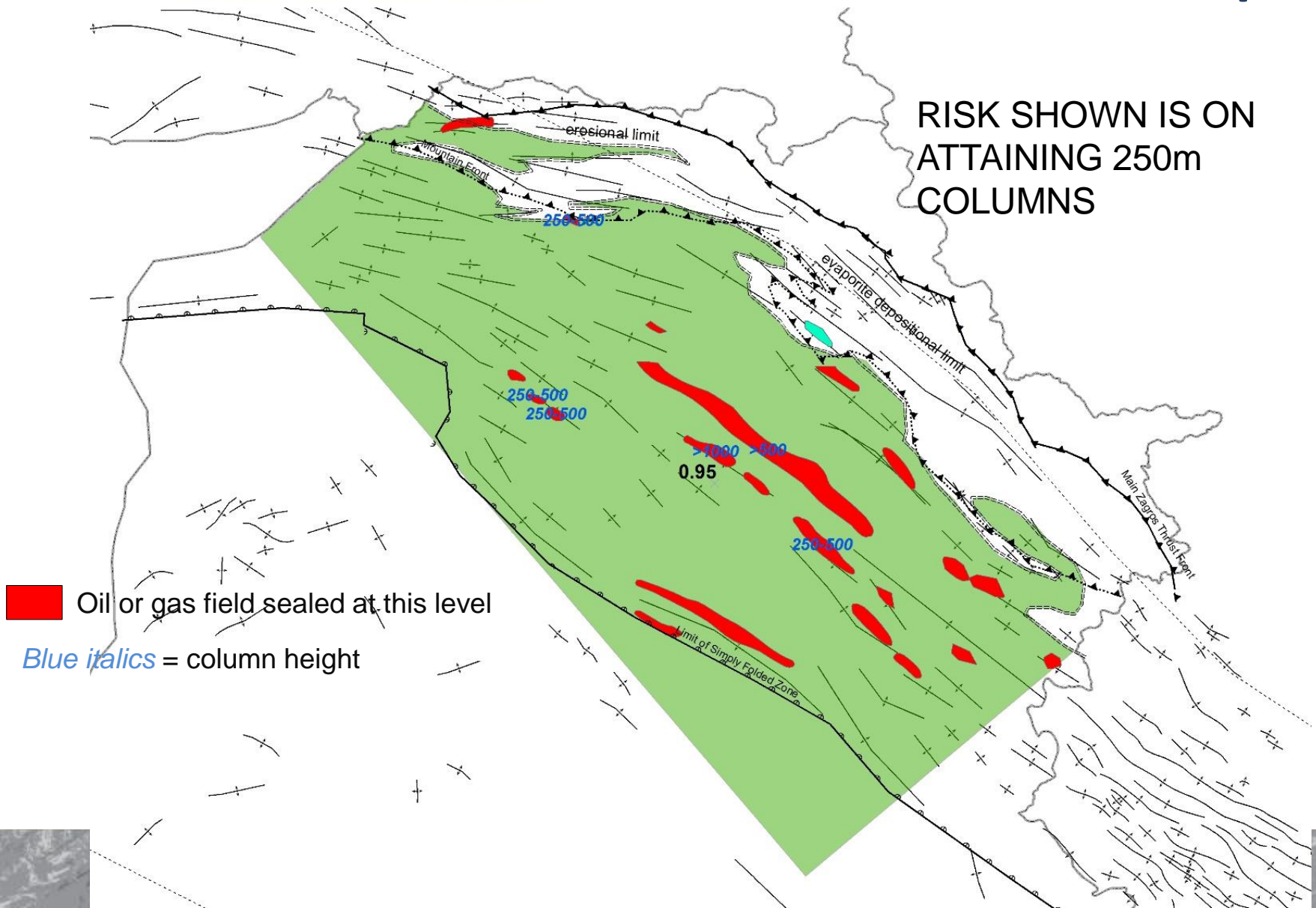


# AAPG

Advancing the World of Petroleum Geosciences.

## Fars (Miocene) Seal CRS Map

RISK SHOWN IS ON  
ATTAINING 250m  
COLUMNS



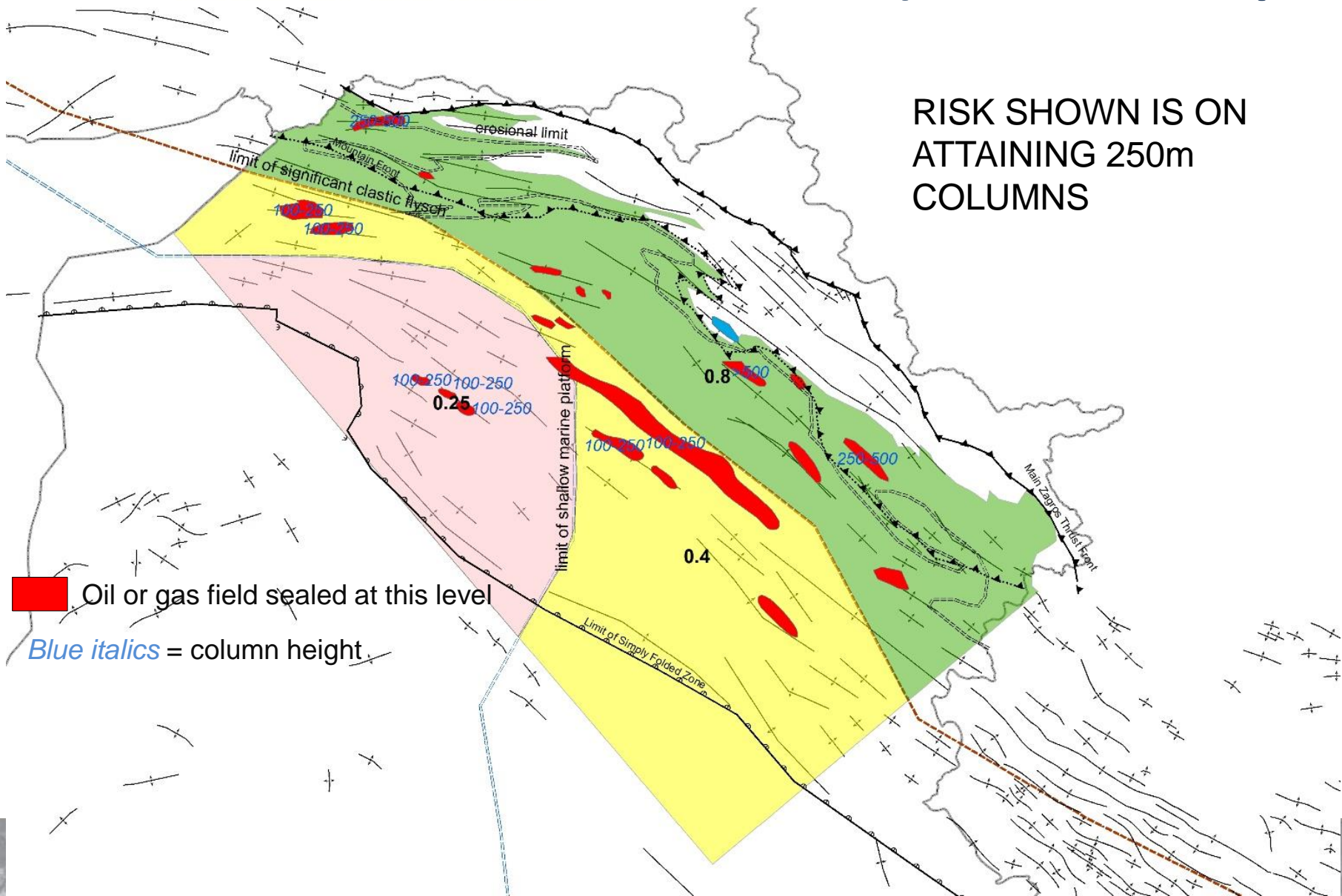


# AAPG

Advancing the World of Petroleum Geoscience

## Aaliiji (Paleocene-Latest Maastrichtian) Seal CRS Map

RISK SHOWN IS ON  
ATTAINING 250m  
COLUMNS





# Base Shiranish (Campanian) /Wahrah Seal CRS Map

RISK SHOWN IS ON ATTAINING 250m COLUMNS

0.5  
100-250  
Butmah

0.2  
100-250-100

0.3

0.2

0.1

0.4

Mountain Front

limit of shallow marine platform

limit of significant clastic flysch

Main Zagros Thrust Front

Bina Bawl

Jaq Jaq

Miran West

limit of shallow marine platform

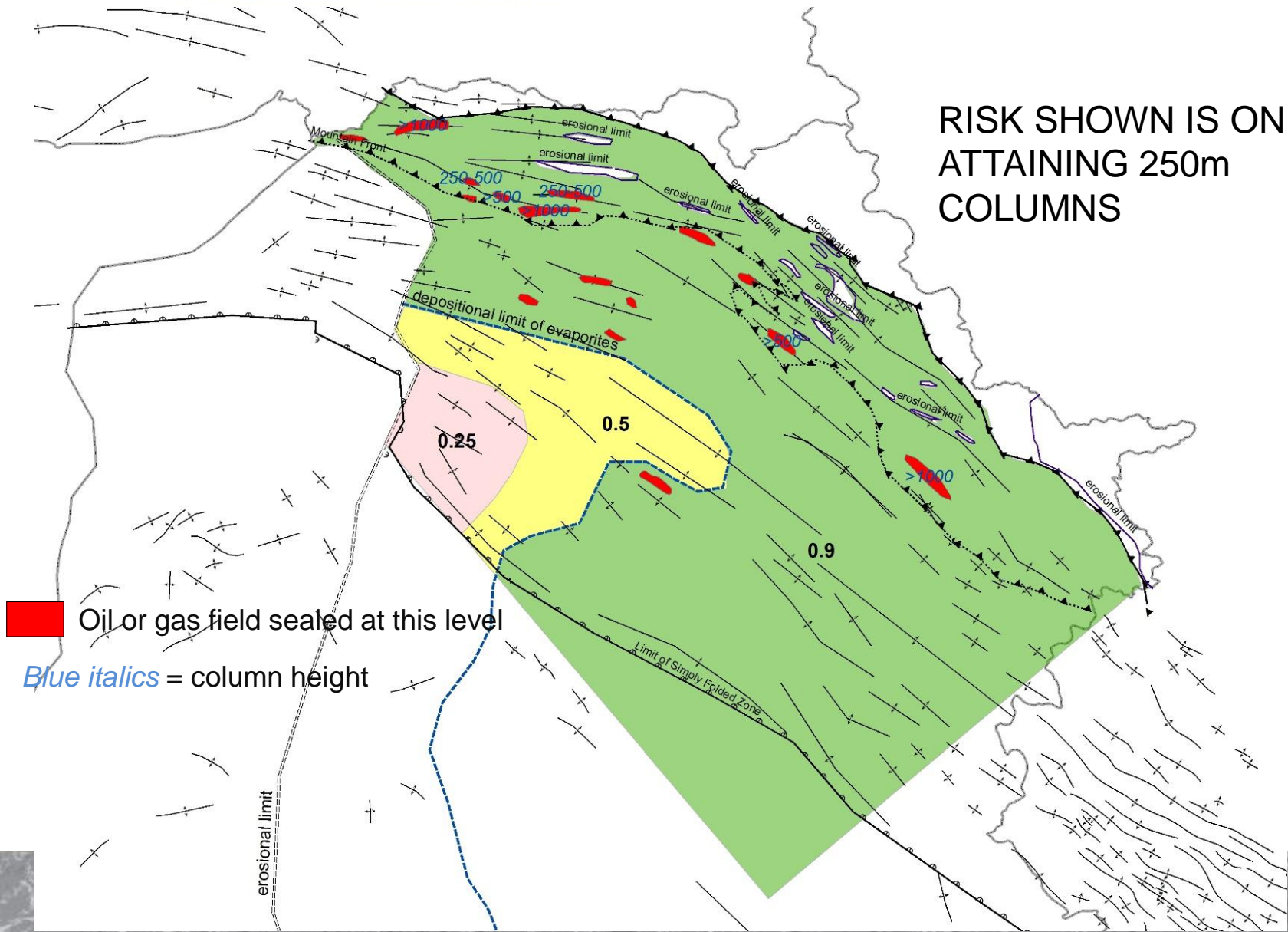
limit of Simply Folded Zone

Oil or gas field sealed at this level

*Blue italics* = column height



# Gotnia (Late Jurassic) Seal CRS Map





# AAPG

*Advancing the World of Petroleum Geosciences.*

## Conclusions

- Seal risk is the chance of lack of retention by any mechanism, i.e.  
$$\text{Seal Chance} = 1 - (\text{Chance of Capillary Breach} \times \text{Chance of Seal Displacement} \times \text{Chance of Seal Fracturing} \times \text{Chance of Hydraulic Breach})$$
- There is therefore a need to calibrate to seal column observations in nearby fields or in petroleum systems of similar tectonics and age/activity. A spectrum of lithologies of increasing capillary and brittle failure risk is established to enable this calibration
- Seal risk is often low (and petroleum retention therefore high) in the Middle East, due to a) the commonness of ductile high capillary capacity evaporites, b) low fault densities and displacements in the foreland, c) high current charge rates and d) relatively low strain, even in foreland settings
- Some seals are effective for low column heights only, so seal risk varies with the column height required
- Risks can be assessed either at a play level (e.g. capillary seal capacity) or a prospect specific level (e.g. seal displacement).