Deciphering the fracture networks of carbonate reservoirs in northern Iraq

Graham Banks, PhD
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WZ fieldwork is a team effort. Success is due to the wisdom, enthusiasm and professionalism of our team of WZ geoscientists, security and logistics staff, and the support of the people of Kurdistan.
AIMS AND CONTENTS

Principal aims

- Give an overview of hydrocarbon exploration in NE Iraq
- Introduce the main carbonate units
- Display the spatial and temporal relationships between reservoir lithology, grain size, loading, folding, faulting and fracture types
- Demonstrate a tool and technique for fracture network studies
- Conclusions

- Promote discussion about defining reservoir characteristics of several prolific carbonate units
LOCATION AND REGIONAL TECTONICS

Present-day collision and rotation of Arabian Plate, thus regional dextral transpression

Kurdistan region of northern Iraq

AGU blogosphere, 2010
CURRENT HYDROCARBON EXPLORATION

Favourable PSCs

37 operating companies, including large NOCs

Stable and safe compared to rest of Iraq

Potential to be a significant global energy region
Kirkuk Field. 25BBL recoverable and proven. Production since 1927 (Verma et al., 2004)

Resource estimate: 40 BBO and 60 TCF of gas (USGS, 2010)

Under explored: >100 undrilled anticlines

High discovery to well ratio

Region can be divided into four structural domains

The two Foothills Fold and Thrust domains have received most exploration and yielded most discoveries to date
TECTONOOSTRATIGRAPHIC EVOLUTION

1. Permian – Early Jurassic
   rifting of N. Gondwana
   - Trap and seal creation
   - Hydrocarbons generated

2. Jurassic – Mid Cretaceous passive margin in sub-equatorial setting
   - Type II source rocks deposited, hydrocarbons generated
   - Reservoirs deposited

3. Late Cretaceous – Late Tertiary convergence of Arabian and Eurasian plates
   - Early traps formed?
   - Reservoirs and seals deposited
   - Type II source rocks deposited, hydrocarbons generated

4. Pliocene – present-day dextral transpression
   - Trap and seal creation
   - Hydrocarbons generated

Legend

- Clastics
- Evaporites
- Carbonates
- Calc-clastics
- Source rocks (some carbonatic)

Modified after PGA, 2006
STRATIGRAPHY OF ZAGROS FOOTHILLS

- Dominated by carbonate rocks
- Stacked, well-sealed reservoirs currently undergoing unloading and modelled hydrocarbon charge

**Legend:**
- Yellow: Sandstone/conglomerate
- Brown: Mudstone, siltstone and marlstone
- Blue: Argillaceous/shaley limestone
- Purple: Anhydrite-halite
- Limestone
- Dolomite
- Cap rock seal
- Reservoir
- Source

*Simplified stratigraphy and lithologies of WZ Blocks*

September, 2011
Composite section through Garmian and Kurdamir blocks

Consider number/timing of reservoir fracturing events

Modified after WZ Corporate Presentation 2008
LOWER FARS FORMATION

- Fine grained carbonate (?wackestone) splits into thumb-sized fragments
- Pressure solution seams ‘relaxed’ then served as oil conduits, as did other joint sets and bedding planes

- Hydrocarbon charge during reduction of horizontal compressive stress
- Anew play in the Zagros Foothills Domain?
Grainsize and facies influence mechanical and fracture stratigraphy

Dense fracturing in fine lagoonal units

Lower joint density in mouldic porosity unit

‘Fore-reef’ slope unit: Taller mechanical units
Calcite ‘Filled’ Fractures

- Bajawan Formation (Top Oligocene)
- Some would name this a, “Healed fracture”, especially on a micro-resistivity image.

- Closer inspection reveals hydrocarbon filled, connected, apertures.
- A more apt name for this fracture type is partially cemented fracture.
Lagoonal host rock has low matrix porosity-permeability.

Mouldic porosity may thus be ineffective where isolated.

Moulds cut by conductive joints charged with oil.

Need to think beyond core and borehole data for estimating resource volume and reservoir character.
Low-level Aerial Photography (LAP) tool, modified after that of David Peacock, *pers. comm.*

Enables detailed mapping then analysis of fracture networks in x-z plane

More comprehensive and visual fracture study than with scanlines

*and in Journal of Structural Geology 23 (2001)*
Enables detailed analysis of fracture networks in x-z plane, without optical data skews.

Without LAP tool and analysis

With LAP tool and analysis
Inevitable curiosity then mischief that accompanies a new tool
WHERE THE DEEPER RESERVOIRS OUTCROP

The Zagros and Taurus mountains regions are ideal for characterising carbonate reservoirs.

Anticlines are tall and deeply incised with excellent exposure.

Region’s conventional Cretaceous reservoirs exposed at surface; This is the prolific Qamchuqa Fm’s type section.
SHIRANISH FORMATION

- Wackestone
- Friable: high fracture density
- NNE-SSW strike-slip fault
- Oil on all fracture sets here
- Oil lubricated faults?
KOMETAN FORMATION

- 4 fracture sets, all bitumen stained
- Several oil flux and fracturing events
- Presence of oil facilitated this strike-slip faulting?
QAMCHUQA FORMATION

- Dolomitised limestone
- Coarse grained
- Bedding is steeply dipping
- Oil seeping from rotated (thus pre-folding) breccia zone. Needs more study.
BALAMBO FORMATION

- Complex folding in a carbonate-rich source rock
- Fractures at ~90° to beds regardless of current dip, thus pre-folding
CONCLUSIONS

- Much hydrocarbon potential in NE Iraq

- Categorising fracture types/sets and their temporal relationships to tectonic/folding events is critical for modelling reservoir network, thus hydrocarbon extraction

- Fracture sets record failure episodes throughout loading and unloading history, not just the folding of competent rock layers

- Fracture density seems to be most influenced by grain size, porosity and mechanical linkage of units

- Orientations of fracture sets represent changes in stress field’s history, including the pre-mountain building era

- Presence of oil may heavily influence/facilitate faulting