Defining Zagros structural domains in the Kurdistan region of northern Iraq
ACKNOWLEDGEMENTS

This work was a team effort
Success is due to the wisdom, enthusiasm and professionalism of our team of WZ geoscientists, security and logistics staff, and the people of Kurdistan

I thank WZ management and colleagues for assistance, peer review and permission to present this work.
AIMS AND CONTENTS

Principal aims
- To give an overview of hydrocarbon exploration in Kurdistan
- Demonstrate tools used in Kurdistan for New Ventures studies
- Update published definitions of Zagros structural domains

Contents
- Location and regional tectonics
- Summary of current hydrocarbon exploration
- Summary of petroleum systems
- Tectonostratigraphic evolution
- Main challenges to exploration
- Review of structural domains of the Zagros orogenic belt
- Conclusions
LOCATION AND REGIONAL TECTONICS

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

Favourable PSCs
38 operating companies, including NOCs

Taurus Mountains

Zagros Mountains

Legend
- Urban Areas
- KRG Boundary
- Political Boundary
- PSC WesternZagros Fields
- Gas Field
- Condensate Field
- Oil Field
- Kurdistan PSC Blocks
- Awarded
- Open

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CURRENT HYDROCARBON EXPLORATION

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: well rate

Stable and safe compared to rest of Iraq

Region has potential to be a significant global energy player
For the Zagros Foothills region, all elements are in place and low risk

- 2 major, producing plays: Tertiary Main Limestone Group and Upper-Mid Cretaceous Group
- Multiple source rocks (Paleocene, Cretaceous, Jurassic, Triassic)
- Multiple reservoirs (Miocene to Triassic). Mainly fractured carbonates
- Excellent evaporite and shale top seals
- >100 large, undrilled anticlines
- Favourable timing of trap formation v hydrocarbon generation-migration
  - Contractional tectonics from Late Cretaceous
  - Main deformation Miocene – today (Zagros and Taurus fold and thrust belts)
  - Current hydrocarbon generation and abundant hydrocarbon seeps
TECTONOSTRATIGRAPHIC EVOLUTION

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

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

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

1. Permian – Early Jurassic rifting of N. Gondwana
- Hydrocarbons generated

Legend
- Clastics
- Evaporites
- Carbonates
- Shales
- Source rock

Figure modified after PGA, 2006
MAIN CHALLENGES TO EXPLORATION

Data and expertise

- Much lost during decades of political instability
- Large distances between wells
- Kurdish geology literature still influenced by pre-Plate Tectonic and pre-Sequence Stratigraphy axioms
- Existing naming conventions do not reflect geological processes and are misleading

Exploration and Operations

- Large traps buried by Pliocene not seen on satellite imagery
- Active deformation
- Wellbore instability and overpressured zones
NEW VENTURE EXPLORATION TOOLS

Advanced processing and study of satellite imagery is key for:

a. Discerning outcrop lithologies

b. Mapping and analysing major structures

Red = healthy vegetation

Magenta = fractured clays/carbonates reservoir at surface

Green / blue = iron oxides

Springs

Banks and Watkins, 2008
NEW VENTURE EXPLORATION TOOLS

c. Identifying subtle/deep faulting that may have affected reservoir units:

- The structural trend appears to be WNW-ESE
- Minor NE-SW strike slip
- No major lineament (a) visible

Major NE-SW lineaments show syn- / post-Mid Miocene reactivation

En echelon folds (#) above the Sinjar-Herki fault ("active pre- Late Cretaceous", Jassim and Goff, 2006).
Late Cretaceous ophiolite

Igneous & metamorphic

Legend
System / Series
- Pleistocene - Holocene
- Neogene
- Paleogene
- Cretaceous
- Jurassic
- Triassic
- Permian
- Devonian
- Ordovician
- KRG Boundary

Thick Neogene sediments cover folds and now actively deforming

Abrupt change from Neogene- to Mesozoic-aged rocks at surface northeastwards across the mountain front

Structural domains are generally parallel the orogenic belts, with promontories and embayments
PUBLISHED STRUCTURAL DOMAIN NAMES

4 Zagros domains are currently defined

Published names are subjective and misleading

“The Zagros Suture Zones” (2006)
An unnamed part of “The Thrust Zone” (2010)

“The Foothills Zone” (2006)
“The Zagros Foredeep” (1995)

“The Thrust Zone” (1987, 2010)
“The Imbricated Zones” (2006)

“The Simply Folded Zone” (2008)
“The High Folded Zone” (1987, 2010)

Non-Zagros Stable Shelf

Longitudinal structural domains of northern Iraq

Date: 25th January 2011

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There appear to be 5 not 4 Zagros structural domains

Require more appropriate, objective names that better describe the observed deformation

Section of finer-scale study
What does the published definition “Low Folded” refer to:
- Low amplitude?
- Low altitude?
- Low frequency?
- Low intensity?

Definition clarity is valuable for exploration.
“THE FOOTHILLS / LOW FOLDED ZONE”

- ~500m amsl and currently undergoing tilting and uplift
- Thick Pliocene molasse of conglomerates, sandstones and siltstones

Looking WSW

Quiljan Sarhad village
Shakal Thrust from 30,000ft. Looking ~SE

- Thrust has 10s metres surface topography and is 10 to >50 kms long
- Mid-Miocene rocks being thrust SW-wards above Pliocene rocks
- Largest structures are thrust faults, not folds

“THE FOOTHILLS / LOW FOLDED ZONE”
"THE FOOTHILLS / LOW FOLDED ZONE"

Composite cross-section through Kalar-Bawanoor Block

Modified after WZ Corporate Presentation 2008
“THE FOOTHILLS / LOW FOLDED ZONE”

Looking NW

Aj Dagh Mountain: not a “low fold”

Drozna Village

N-S dextral strike-slip fault (as predicted from regional strain ellipse)

3 major joint sets provide good network connectivity for fluid flow in subsurface reservoir beds
It is suggested this currently deforming foreland basin, with long thrusts and folds at surface be named **Foothills Fold and Thrust Zone**.

It is the preferred Zagros zone for hydrocarbon exploration:
- In front of the main mountain ranges
- Well-sealed Tertiary and Cretaceous reservoirs
- Current oil generation into large anticlines
- Close to infrastructure
Moving NE, this is the first major mountain range encountered

Misleading name: not a major fault at surface for the vast majority of its length

It strikes from Syria to SE Iran

In Iraq there are 9 exploration blocks along it. Several are currently / imminently being drilled
Part of Qara Dagh license block from 20,000ft. Looking ~SE
No major fault visible at surface; it is a box fold
"THE MOUNTAIN FRONT FAULT"

Overturned backlimb of Qara Dagh Anticline, looking south into partly eroded fold core

Most of the MFFZ I’ve seen has no major fault at surface
“THE MOUNTAIN FRONT FAULT”

Forelimb of Bazian Anticline: a tall fold

Here a segment of a regional monocline: “Alpine geowarping” (Ameen 1991)

450m high
The Mountain Front Fold Zone

- A distinct structural domain: anticline chain, in places a monocline
- An accurate name is Mountain Front Fold Zone
- A challenging structural domain for exploration:
  - Thickened seals
  - Hinge lines decoupled between surface and reservoir level anticlines
  - Tough seismic acquisition and imaging
  - Often karstified reservoir carbonates at surface
In the outer Zagros Mountain belt

Only some of the license blocks awarded to date

Dominantly at seismic acquisition and wildcat drilling stage of exploration

Are “Simply Folded” and “High Folded” names accurate?

What does “High” Folded refer to?
"THE SIMPLE / SIMPLY / HIGH FOLDED ZONE"

Heritage Oil seismic dip line

Reverse-reactivated normal faults

Major detachments, probably Triassic evaporites and muds

Heritage Oil corporate presentation, 2008
"THE SIMPLE / SIMPLY / HIGH FOLDED ZONE"

Apparent sheath fold in Tanjero Fm

Mountain Front Monocline dipping to the SW: into the page

Hinge line folded into SW transport direction

Not simple folding!

* Modified after http://ic.ucsc.edu/~casey/eart150/Lectures/ShearZones/15shearZns.htm
Anticlines are tall, asymmetric and have steep to overturned limbs.

Region’s conventional Cretaceous reservoirs exposed at surface: type section for the prolific Qamchuqa Fm.
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

Shiranish Formation

- Seeps from exposed reservoir units, e.g. Along this NNE-SSW strike-slip fault
- Oil on all fracture sets here
- Oil lubricating faults?
"THE SIMPLE / SIMPLY / HIGH FOLDED ZONE"

Kometan Formation

Seeps in exposed reservoir units, e.g. along NW-SE strike-slip faults
There are significant faults as well as folds. Note the width of the fault zone and the potential for fluids to pass through shaly units.
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

Pir-i-Mugurun Gorge
Looking NW

Folding of the competent Qamchuqa Formation
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

- Complex, tight deformation in Lower Cretaceous in fold cores
- Reservoir potential in highly fractured, calcareous units

Core of Azmar Anticline

Looking E
The more apt **High Amplitude Fold Zone** name is suggested.

Folds dominate with few thrusts. Most faults observed are normal and strike-slip: pre-Neogene extension and recent transpression?

A challenging domain for hydrocarbon exploration:

- Huge folds = tough seismic acquisition programmes
- Region’s main reservoirs at surface or eroded
- Deep gas targets?
Five structural domains rather than four

The 3 new domain names suggested here more accurately and objectively describe the deformation styles

This assists New Ventures assessment of hydrocarbon prospectivity in the Iraqi Zagros
KURDISTAN REGIONAL CONCLUSIONS

- Much hydrocarbon potential
- Lower risk in the Foothills Fold and Thrust Zone
- More challenging and higher risk towards the orogenic core

- Kurdistan Zagros deformation is not as simple as current NW-SE folding and SW-directed contraction

- Complex deformation and potential fluid flow observed in all formations, including the Upper Pliocene

- Normal, strike-slip and reverse faults are common, striking: N-S, E-W, NW-SE. More normal and strike-slip faults have been seen at surface than thrusts

- Folding is complex, e.g. monoclinic, overturned, sheath, and needs to be understood for each formation