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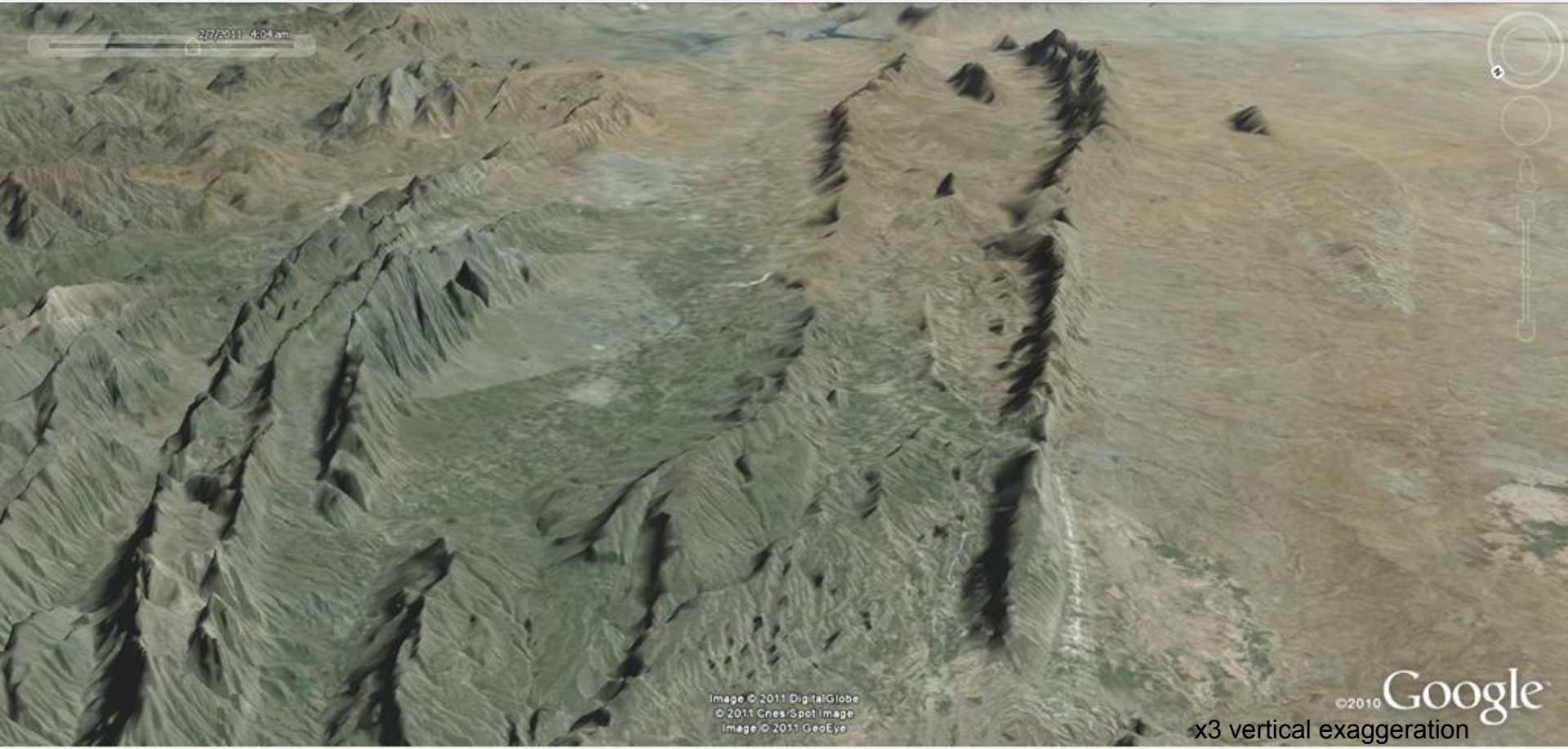
Defining Zagros structural domains in the Kurdistan region of northern Iraq



x3 vertical exaggeration

Graham Banks, PhD

Presented to the CSPG Structural Geology Division, Calgary, February 4, 2011

ACKNOWLEDGEMENTS

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

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

AIMS AND CONTENTS

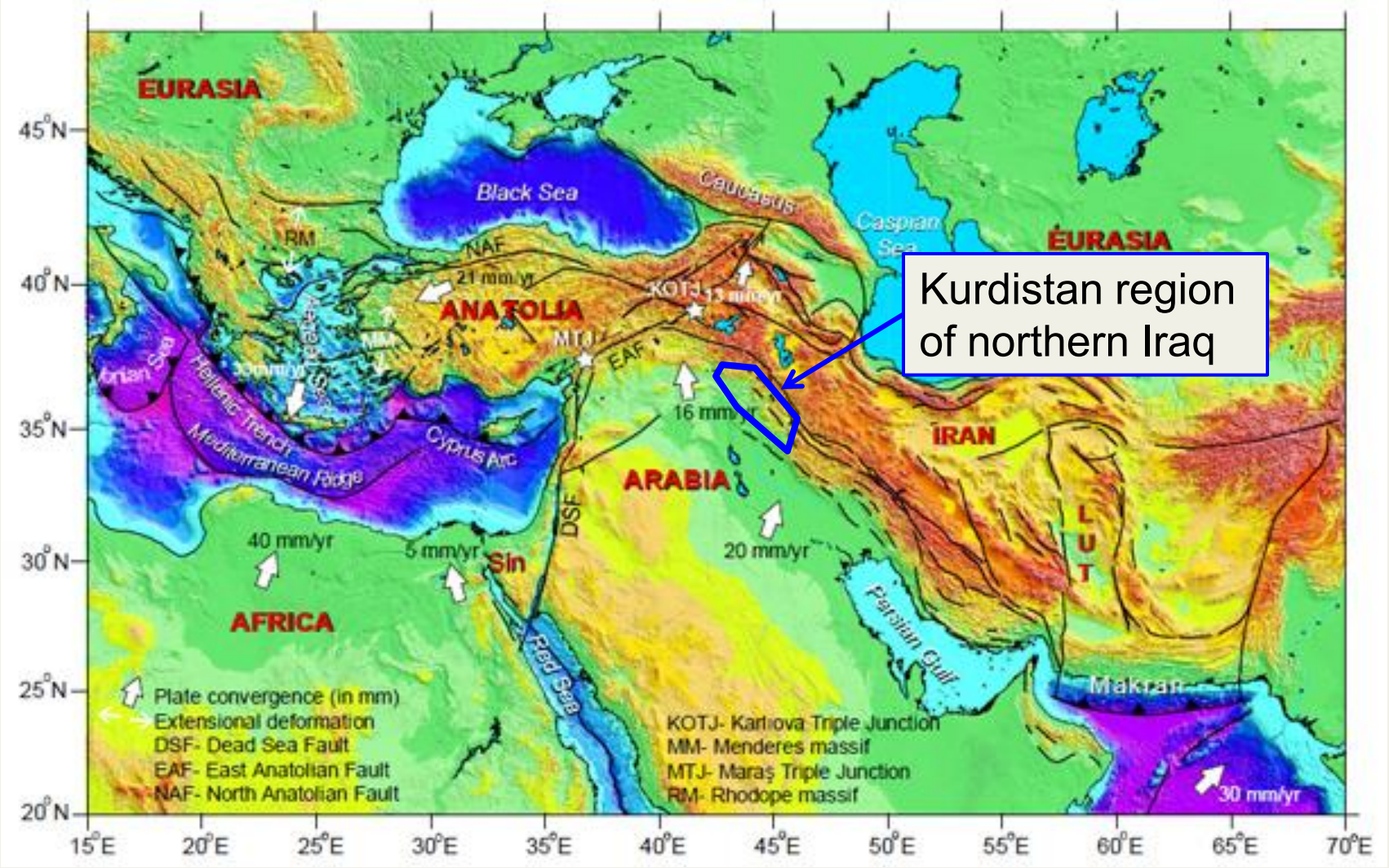
Principal aims

- 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



AGU blogosphere, 2010

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

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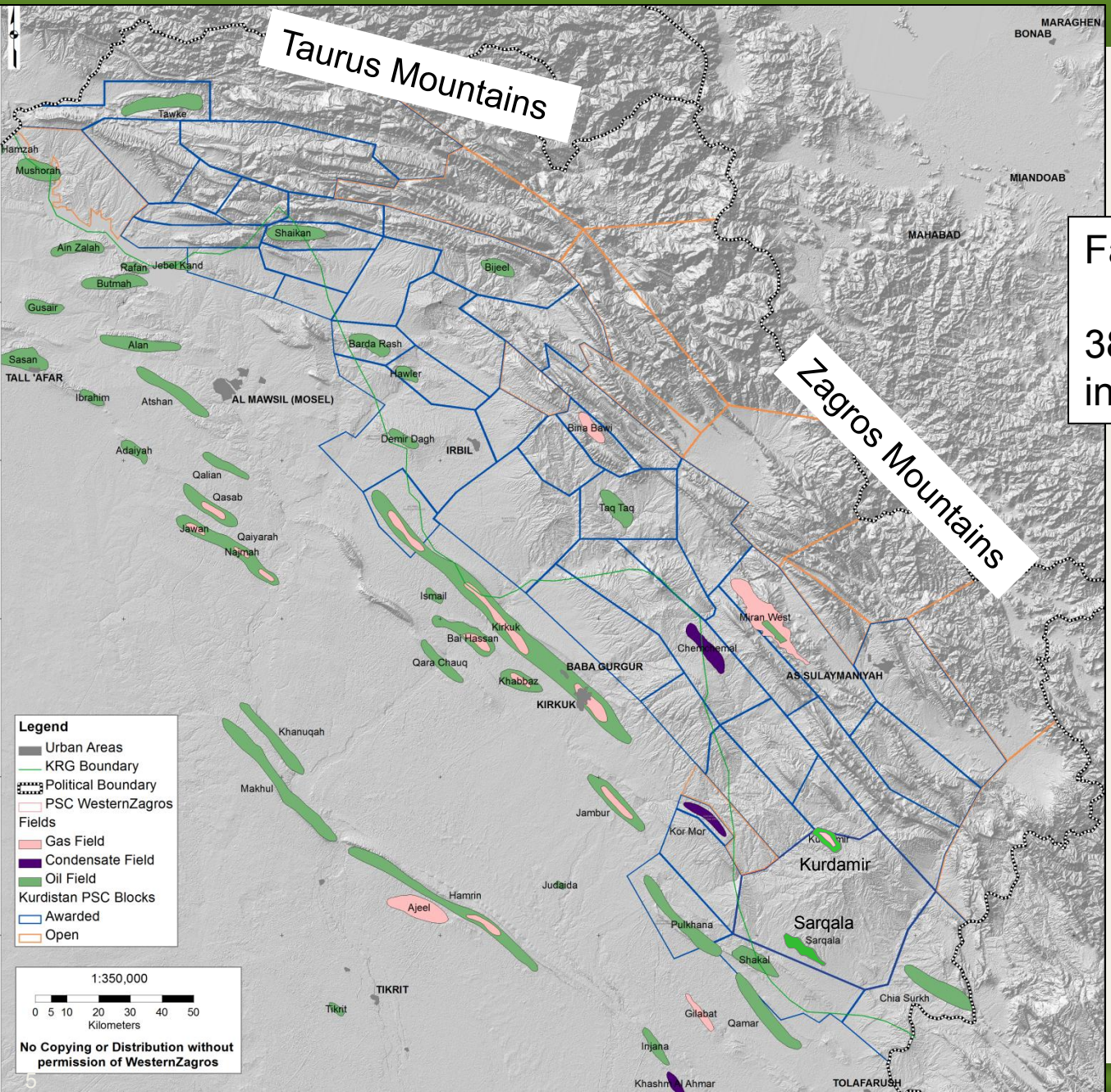
CURRENT HYDROCARBON EXPLORATION



Favourable PSCs

38 operating companies, including NOCs

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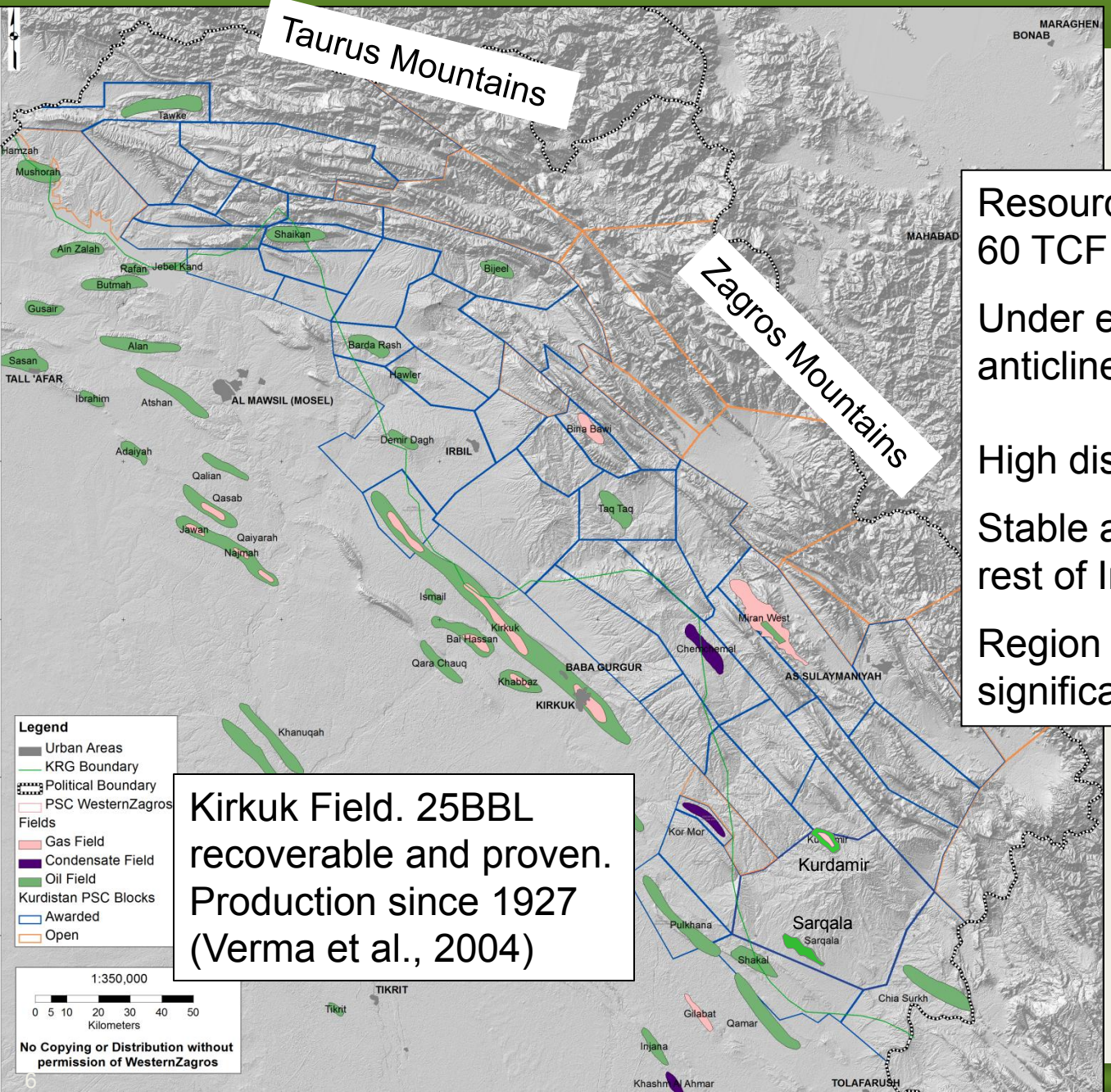
CURRENT HYDROCARBON EXPLORATION



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

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PETROLEUM SYSTEMS OVERVIEW

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

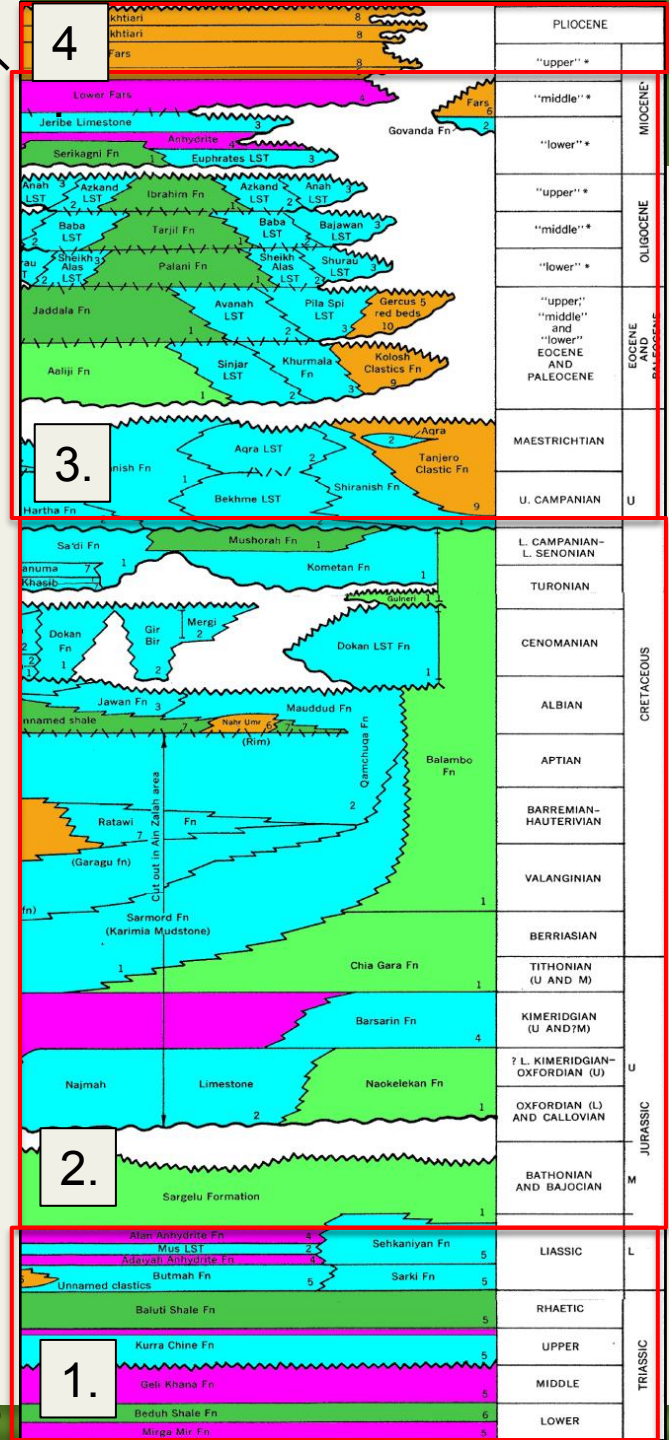


Figure modified after PGA, 2006

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

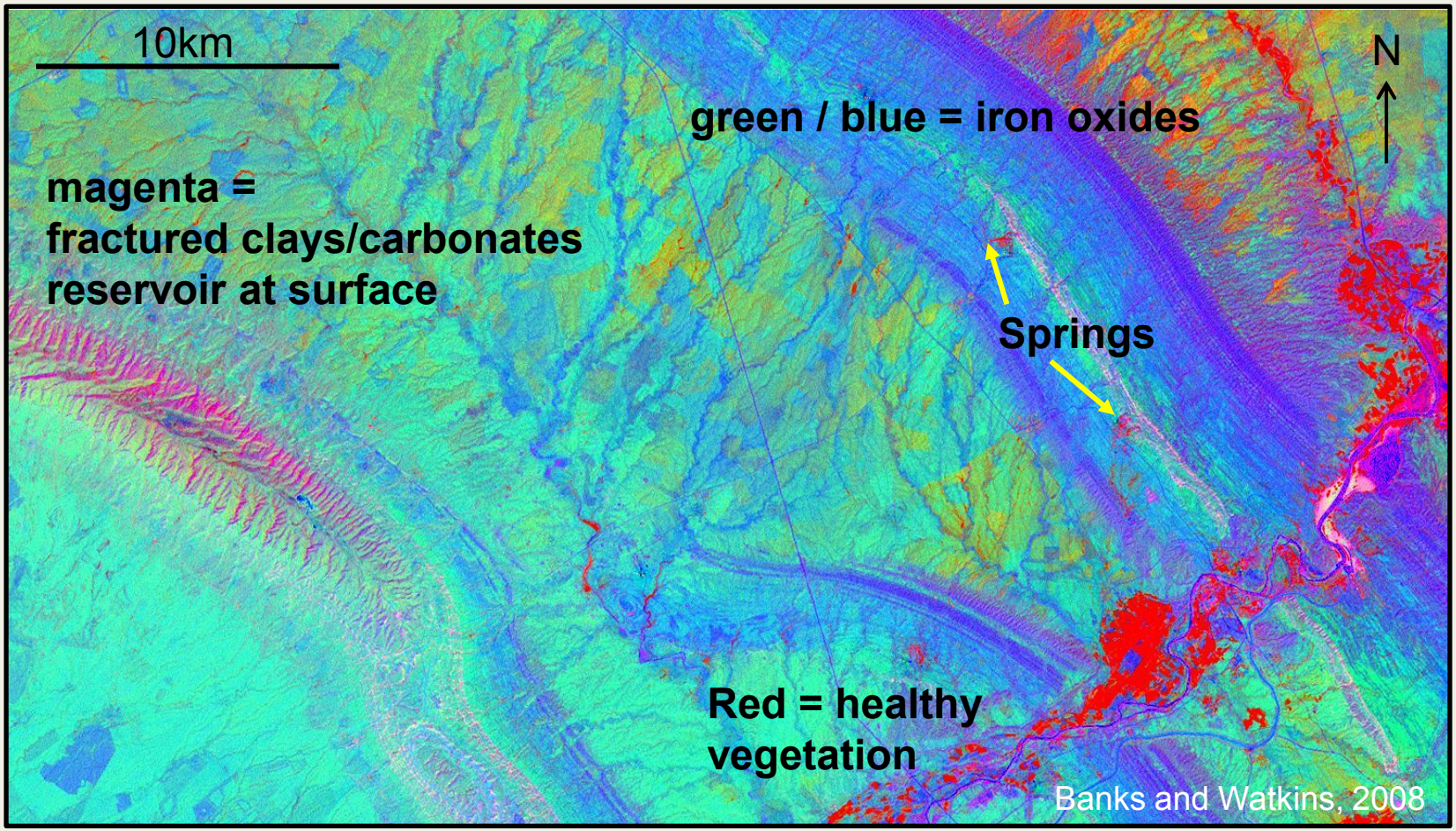
Exploration and Operations

- 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

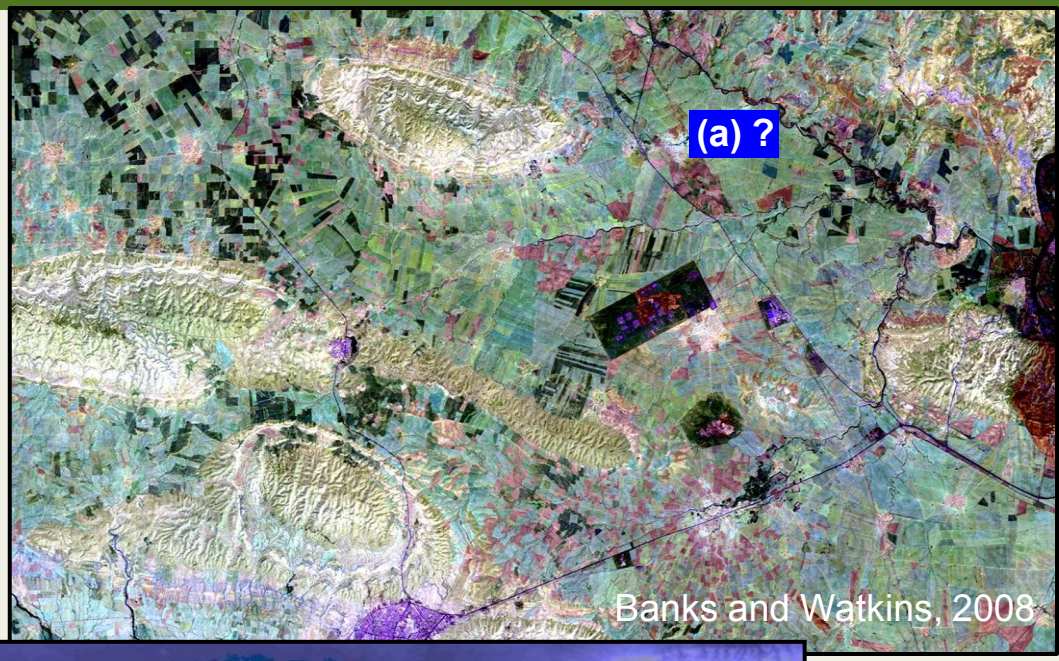
NEW VENTURE EXPLORATION TOOLS

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

- The structural trend appears to be WNW-ESE

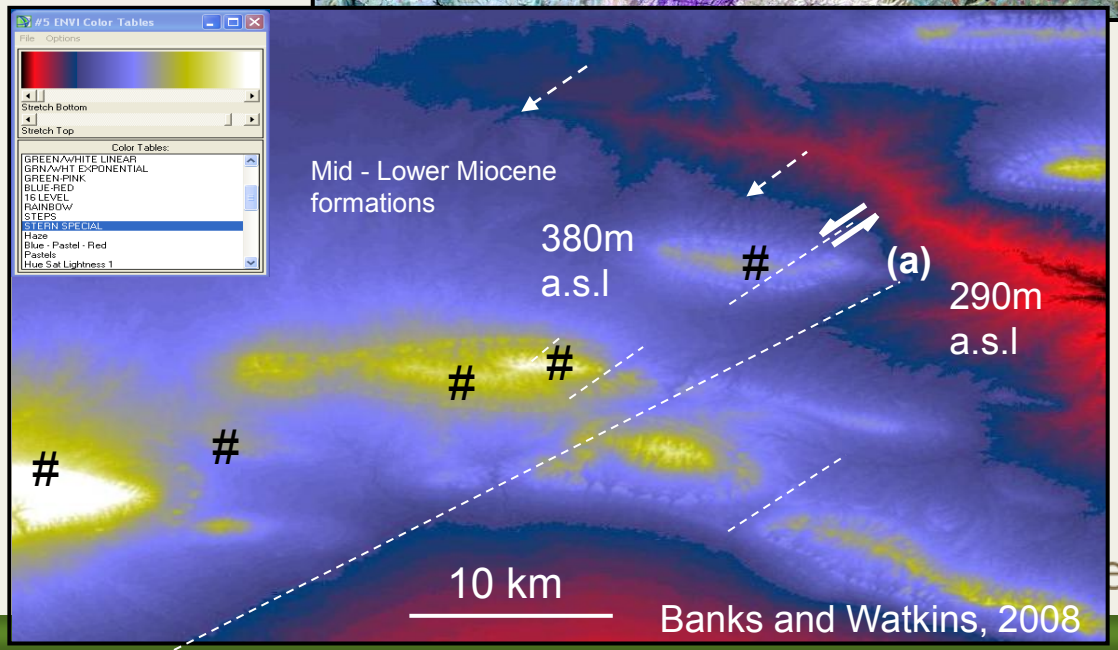
- Minor NE-SW strike slip

- No major lineament (a) visible

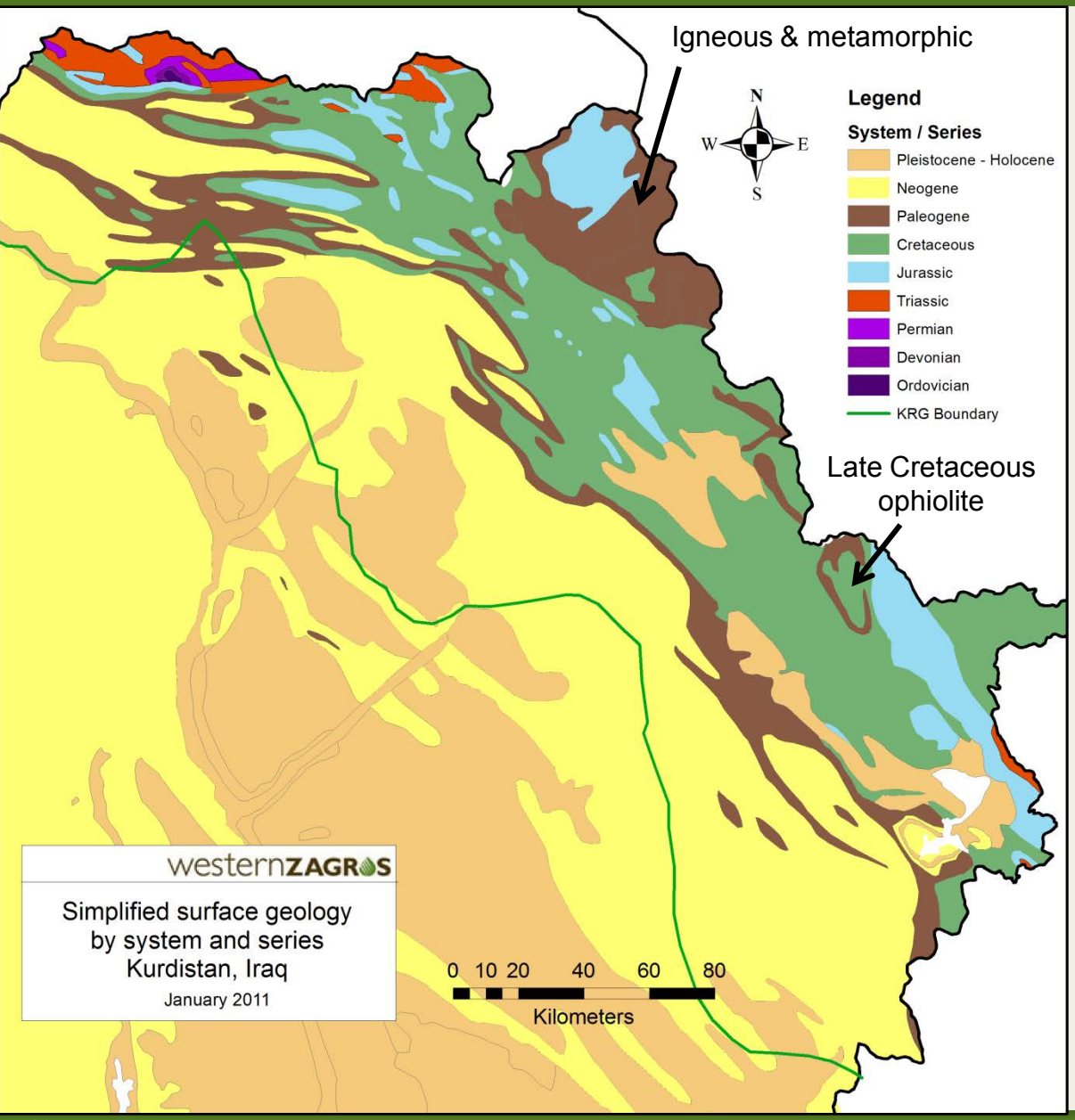


Major NE-SW lineaments show syn- / post-Mid Miocene reactivation

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



SCHEMATIC SURFACE GEOLOGY MAP



- 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

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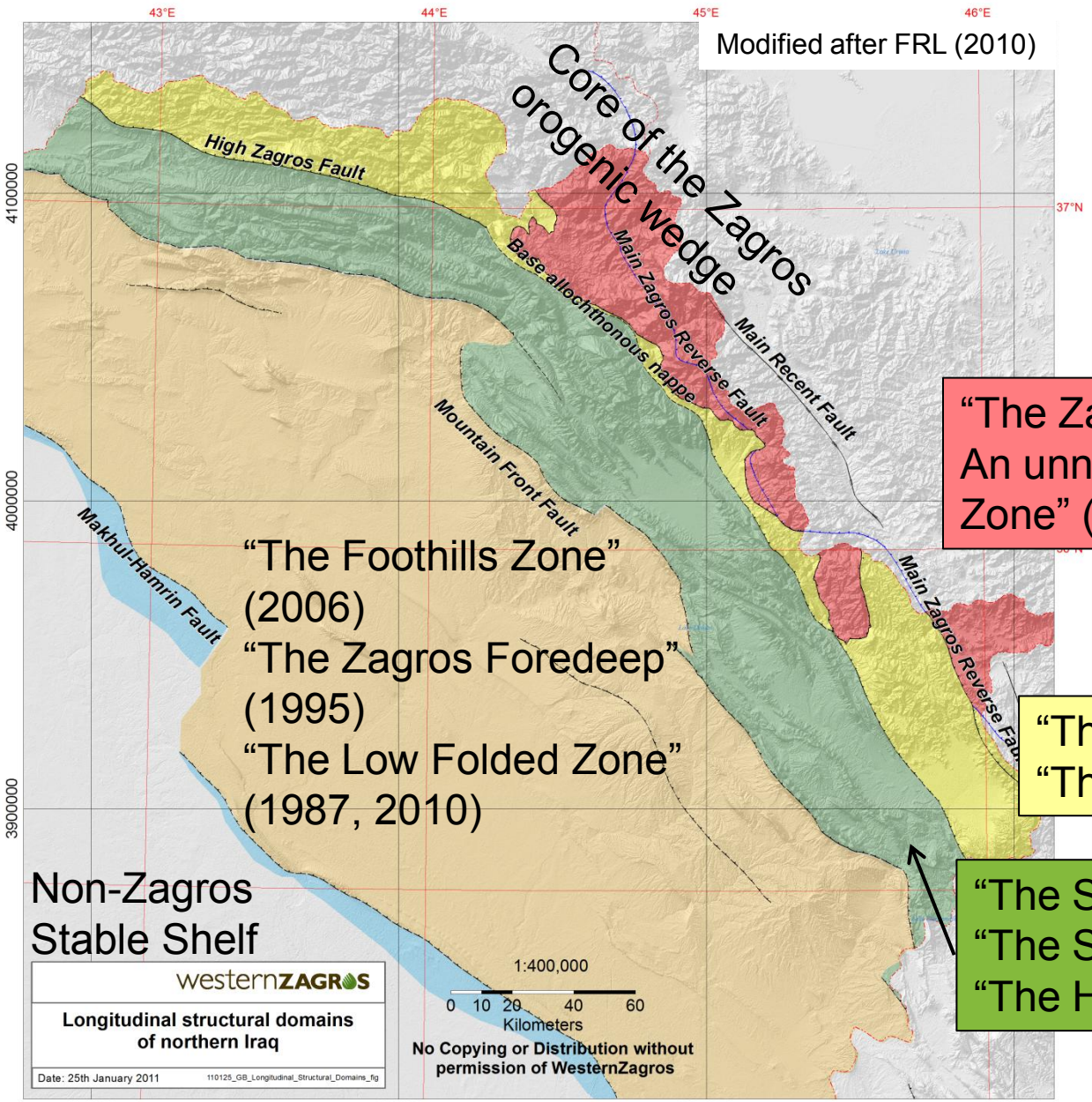
PUBLISHED STRUCTURAL DOMAIN NAMES



- 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 Thrust Zone" (1987, 2010)
"The Imbricated Zones" (2006)

"The Simple Fold Belt" (1995)
"The Simply Folded Zone" (2008)
"The High Folded Zone" (1987, 2010)

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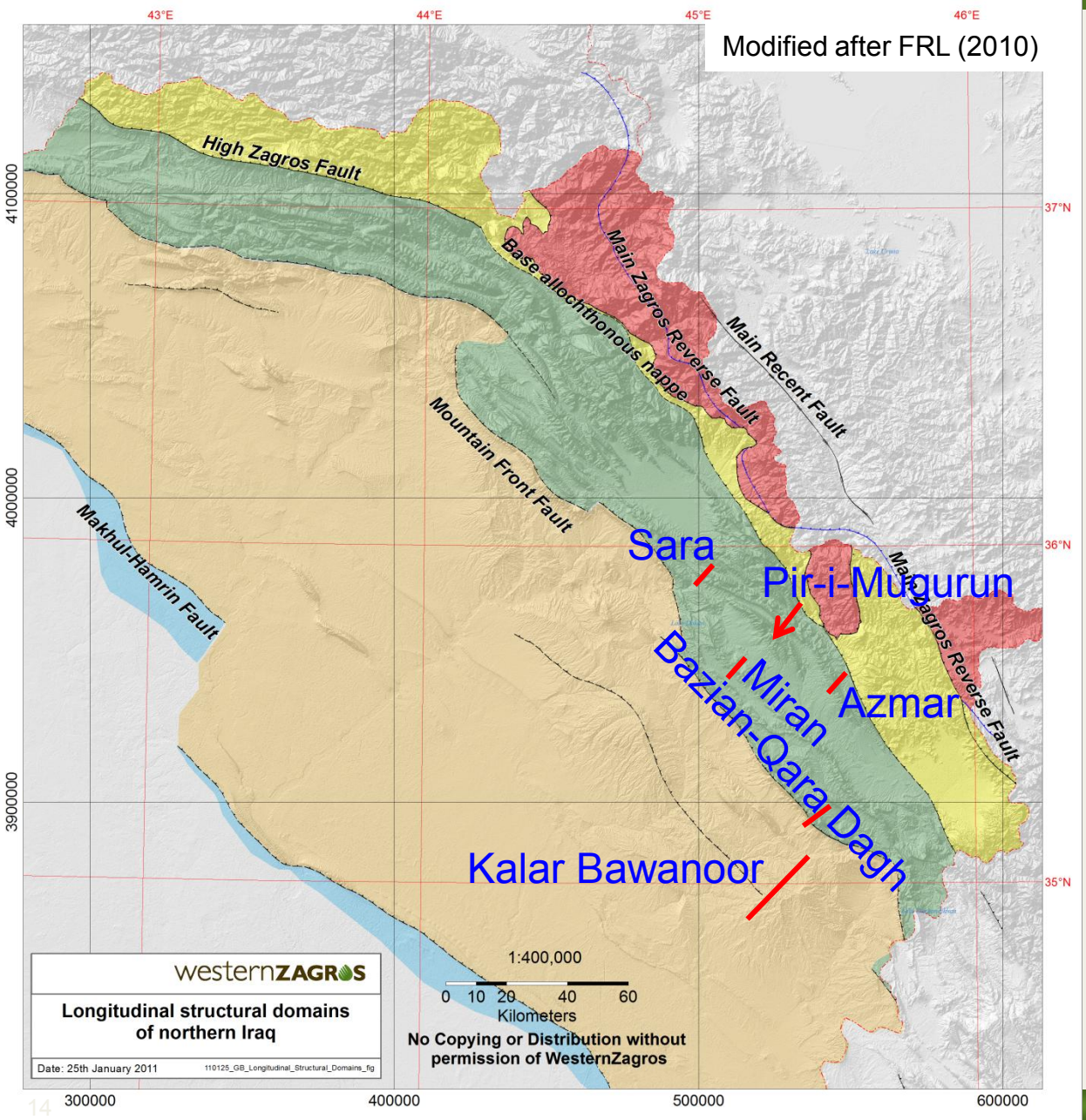
PUBLISHED STRUCTURAL DOMAINS



- 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

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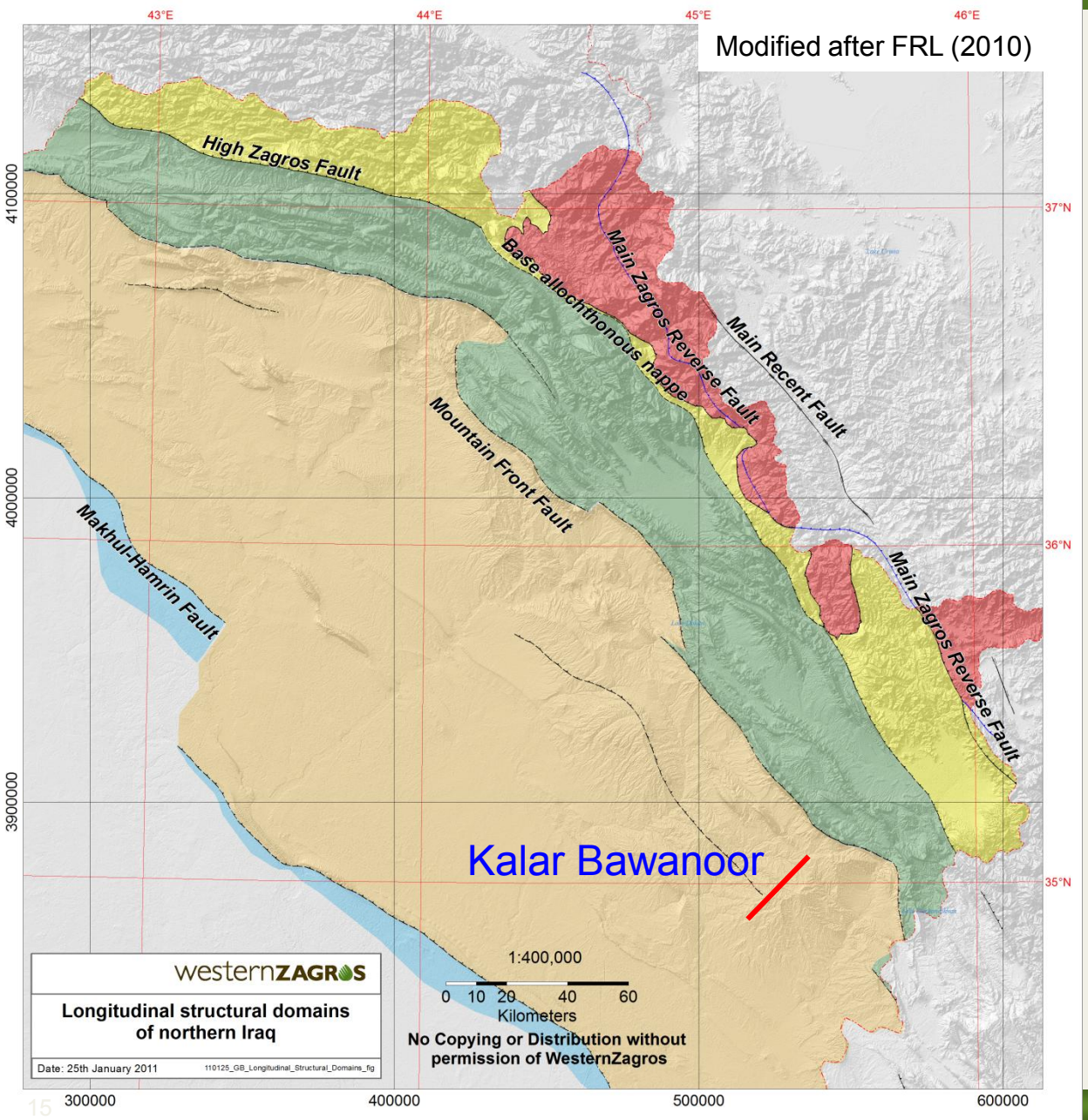
“THE FOOTHILLS / LOW FOLDED ZONE”



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

“THE FOOTHILLS / LOW FOLDED ZONE”

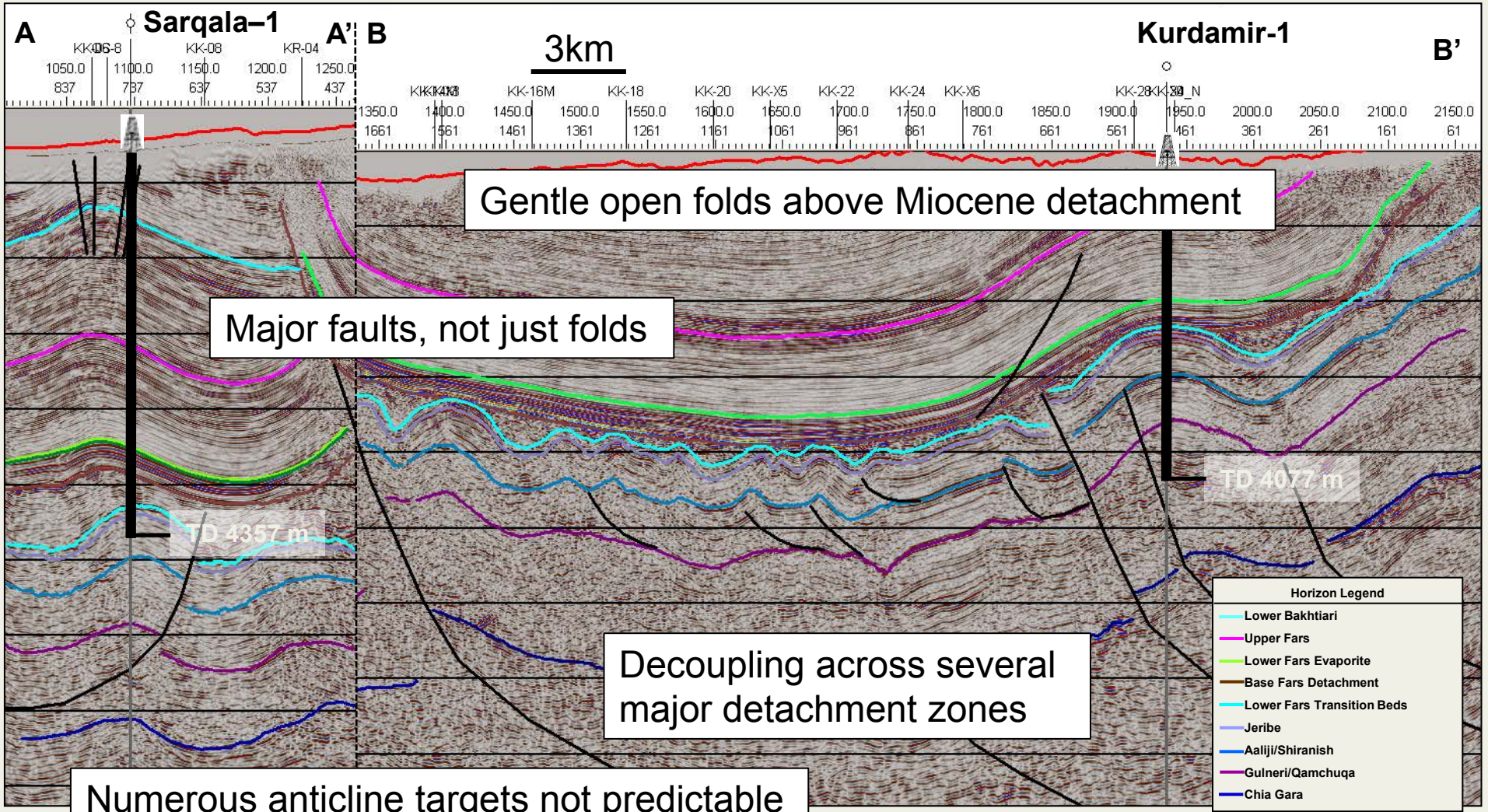
Shakal Thrust from 30,000ft. Looking ~SE

- 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”

Composite cross-section through Kalar-Bawanoor Block

SW NE



Numerous anticline targets not predictable from surface structural geology

Modified after WZ Corporate Presentation 2008

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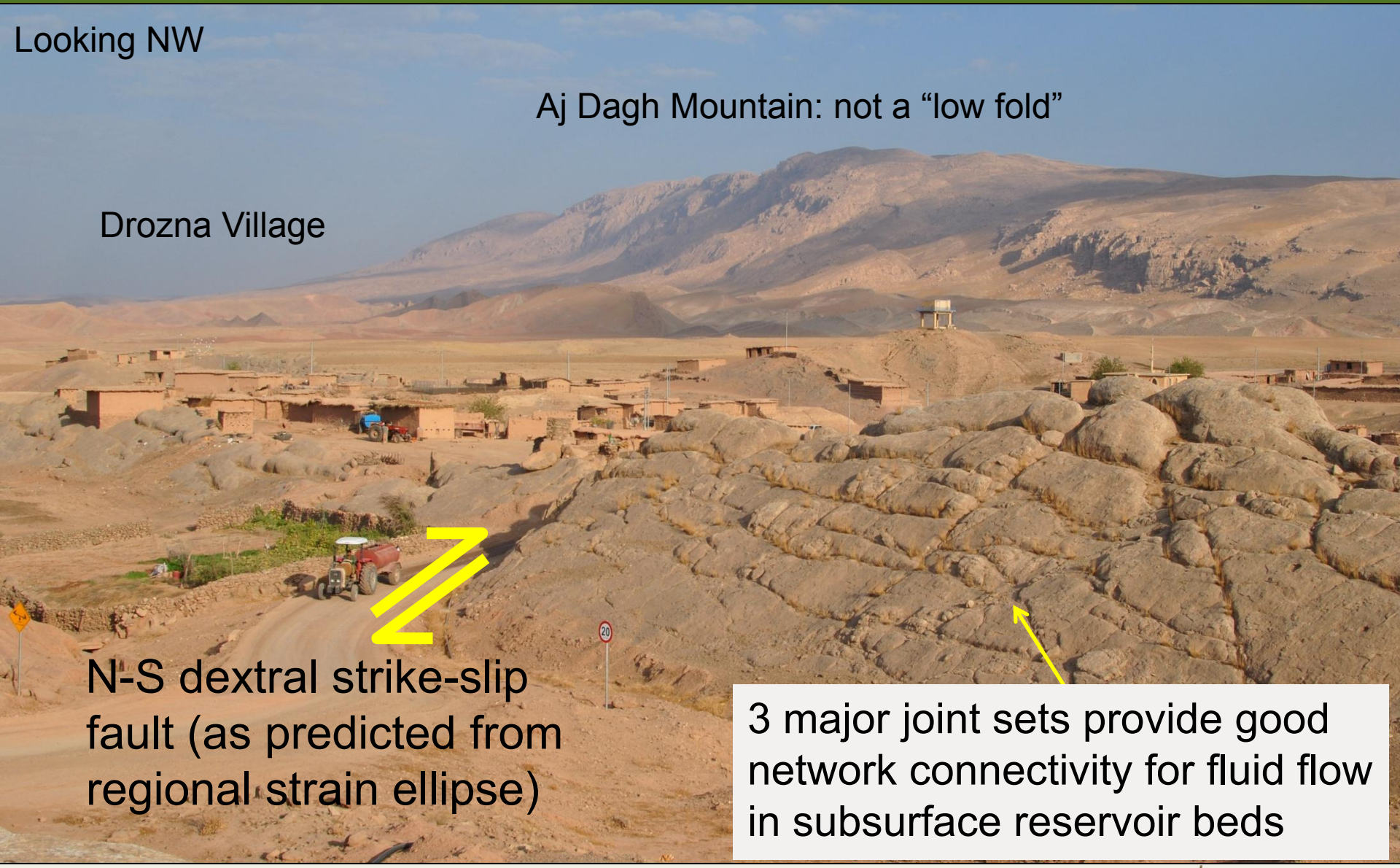
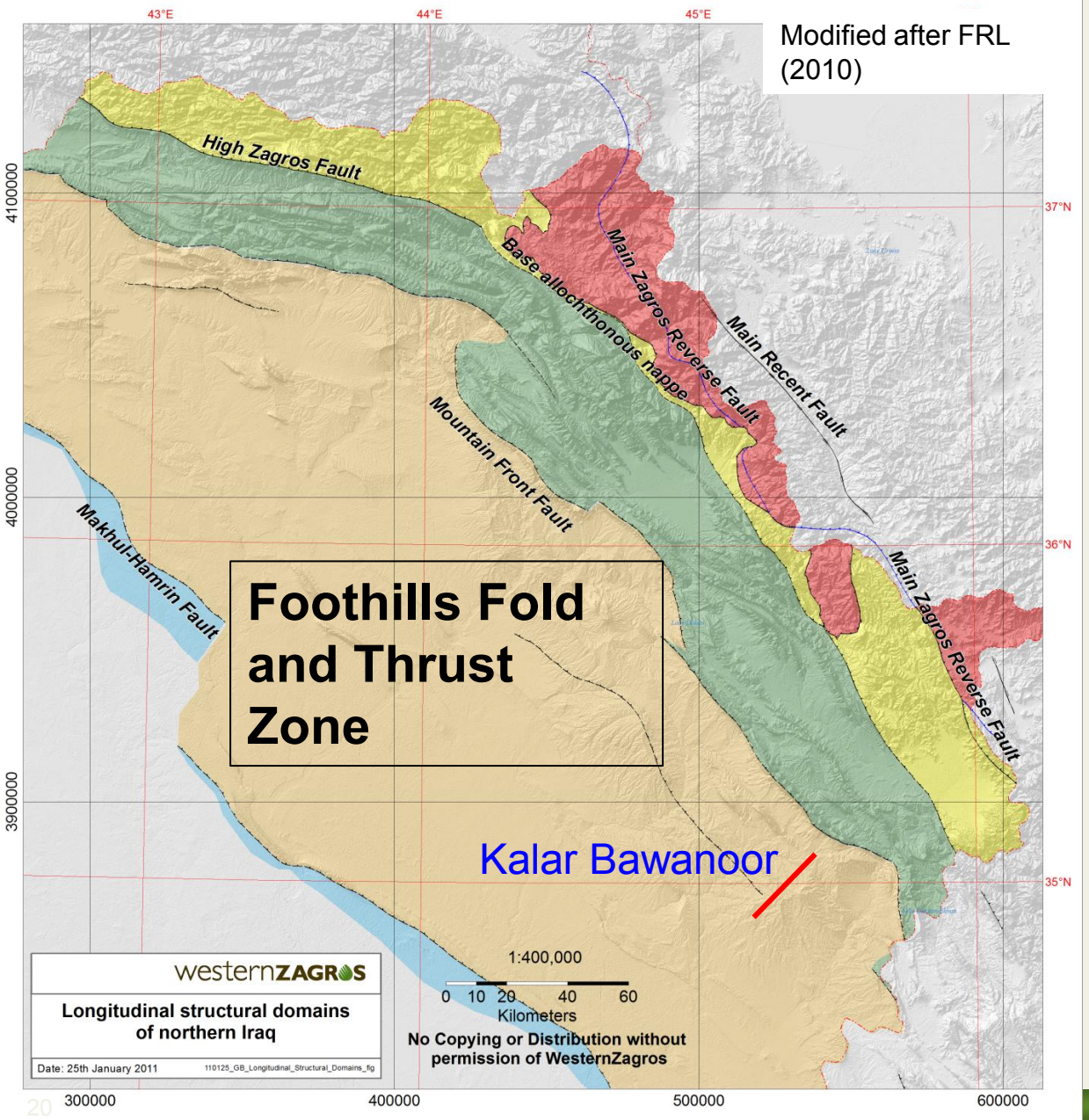
“THE FOOTHILLS / LOW FOLDED ZONE”



FOOTHILLS FOLD AND THRUST ZONE



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

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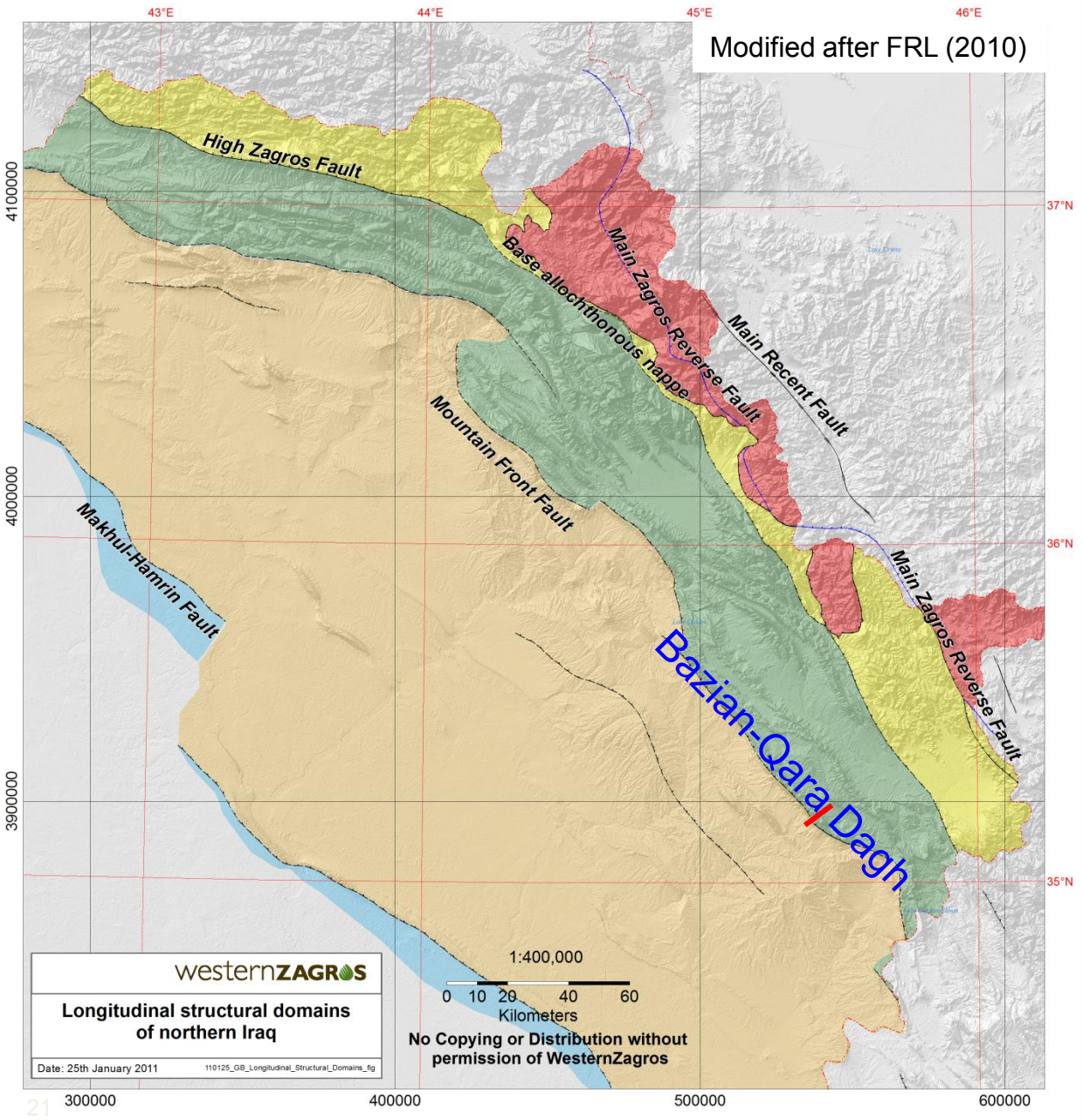
“THE MOUNTAIN FRONT FAULT”



- 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

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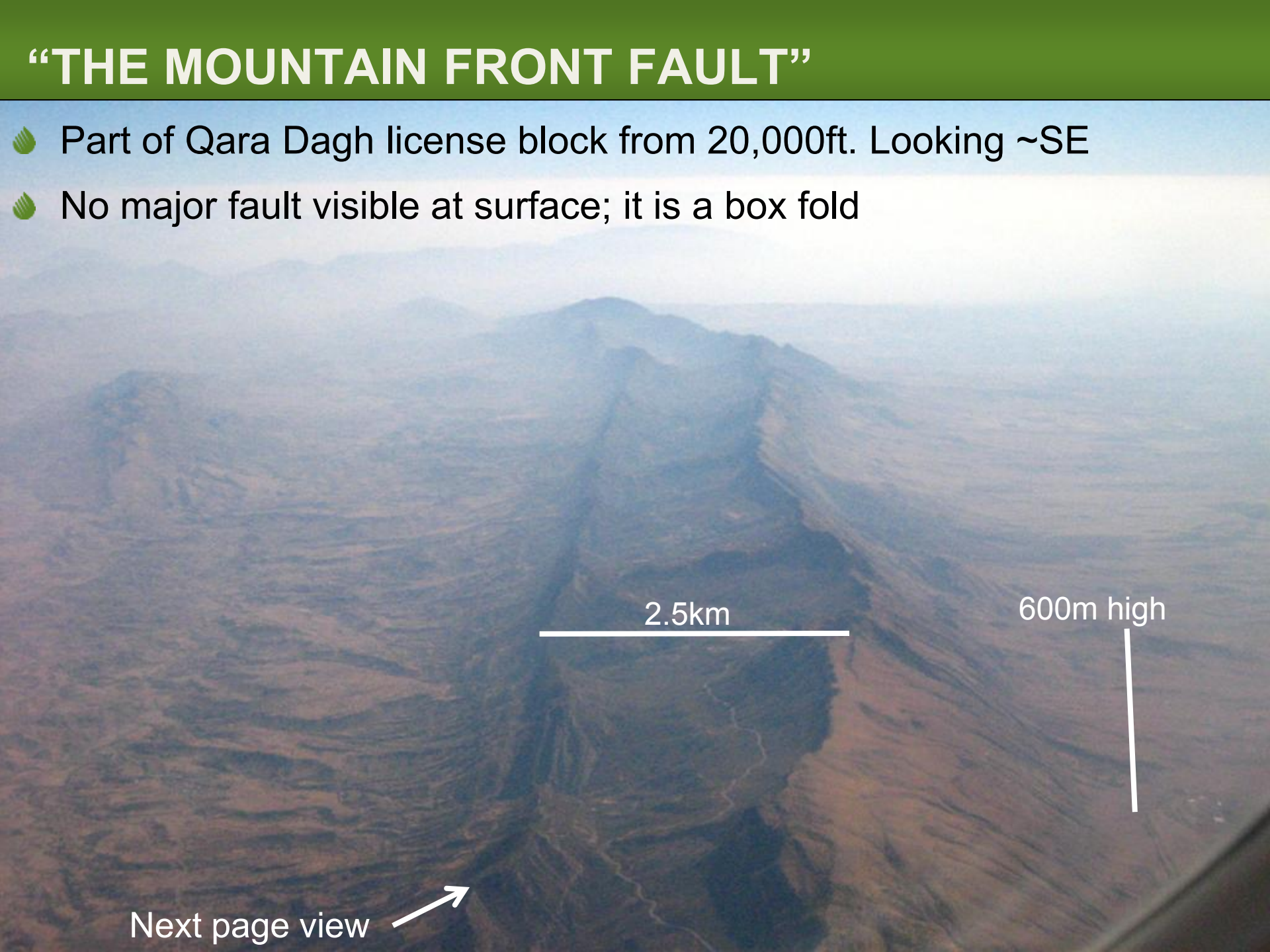
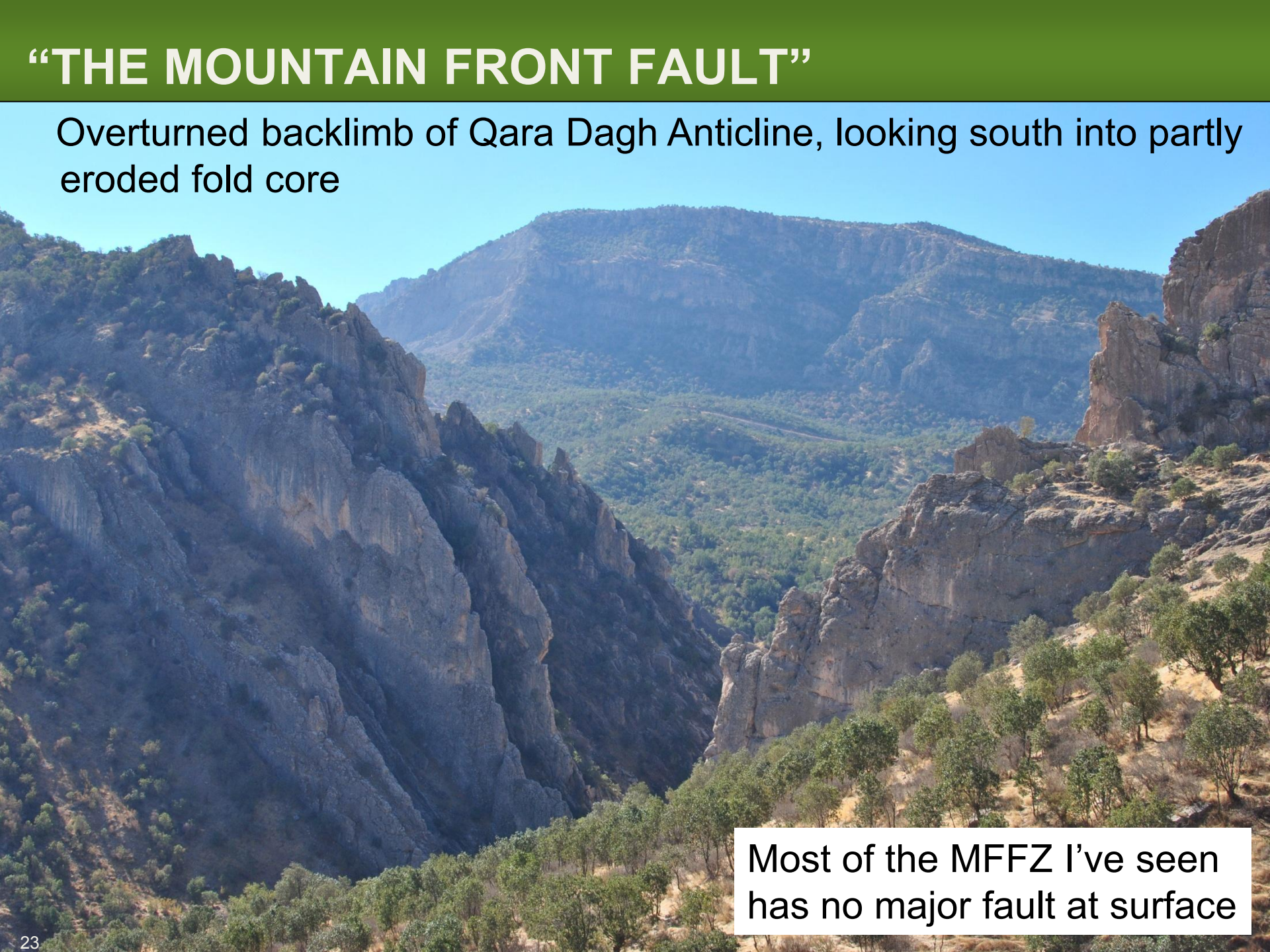
“THE MOUNTAIN FRONT FAULT”

- 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

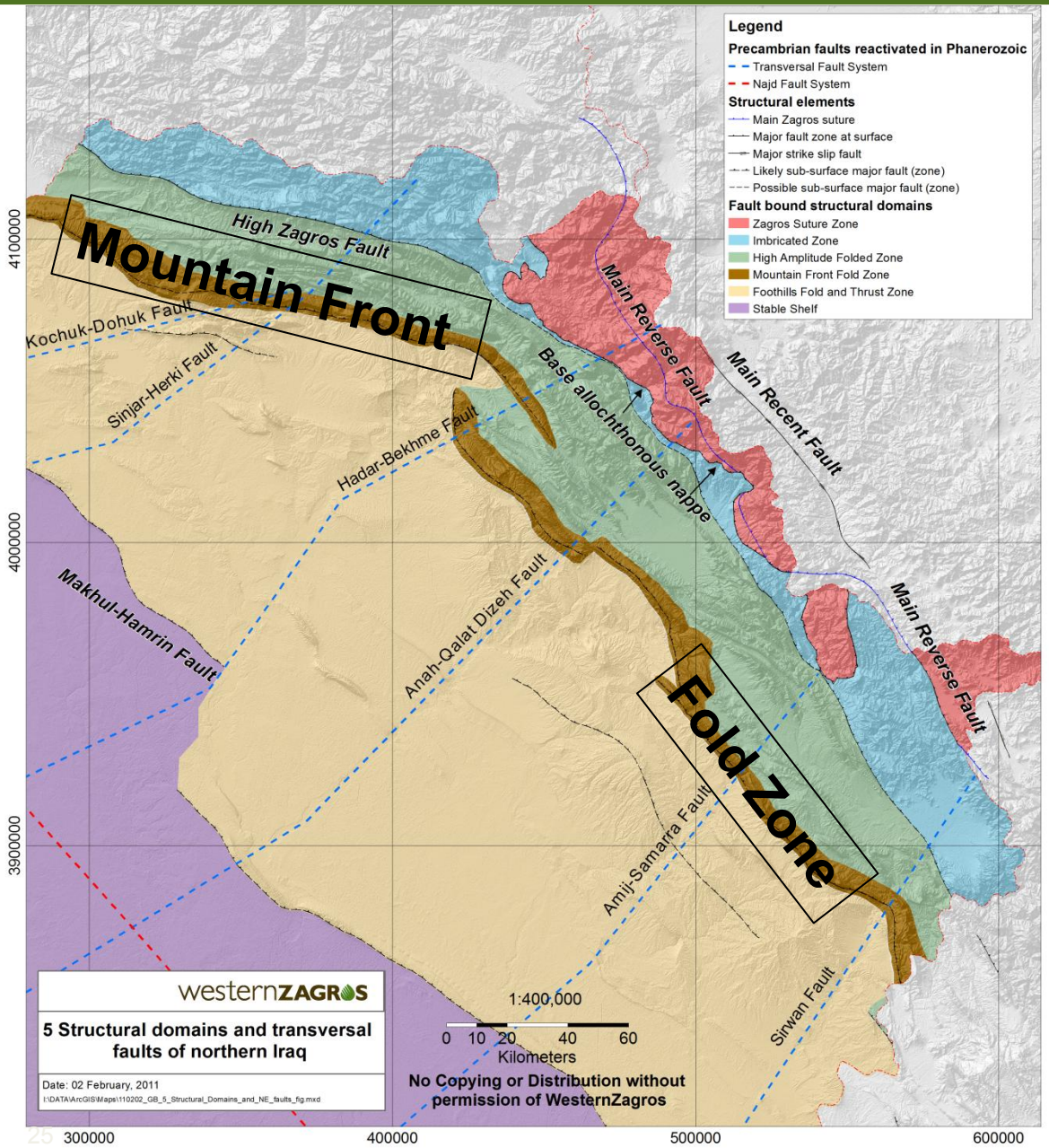


Most of the MFFZ I’ve seen has no major fault at surface

“THE MOUNTAIN FRONT FAULT”

- Forelimb of Bazian Anticline: a tall fold
- Here a segment of a regional monocline: “Alpine geowarping” (Ameen 1991)

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

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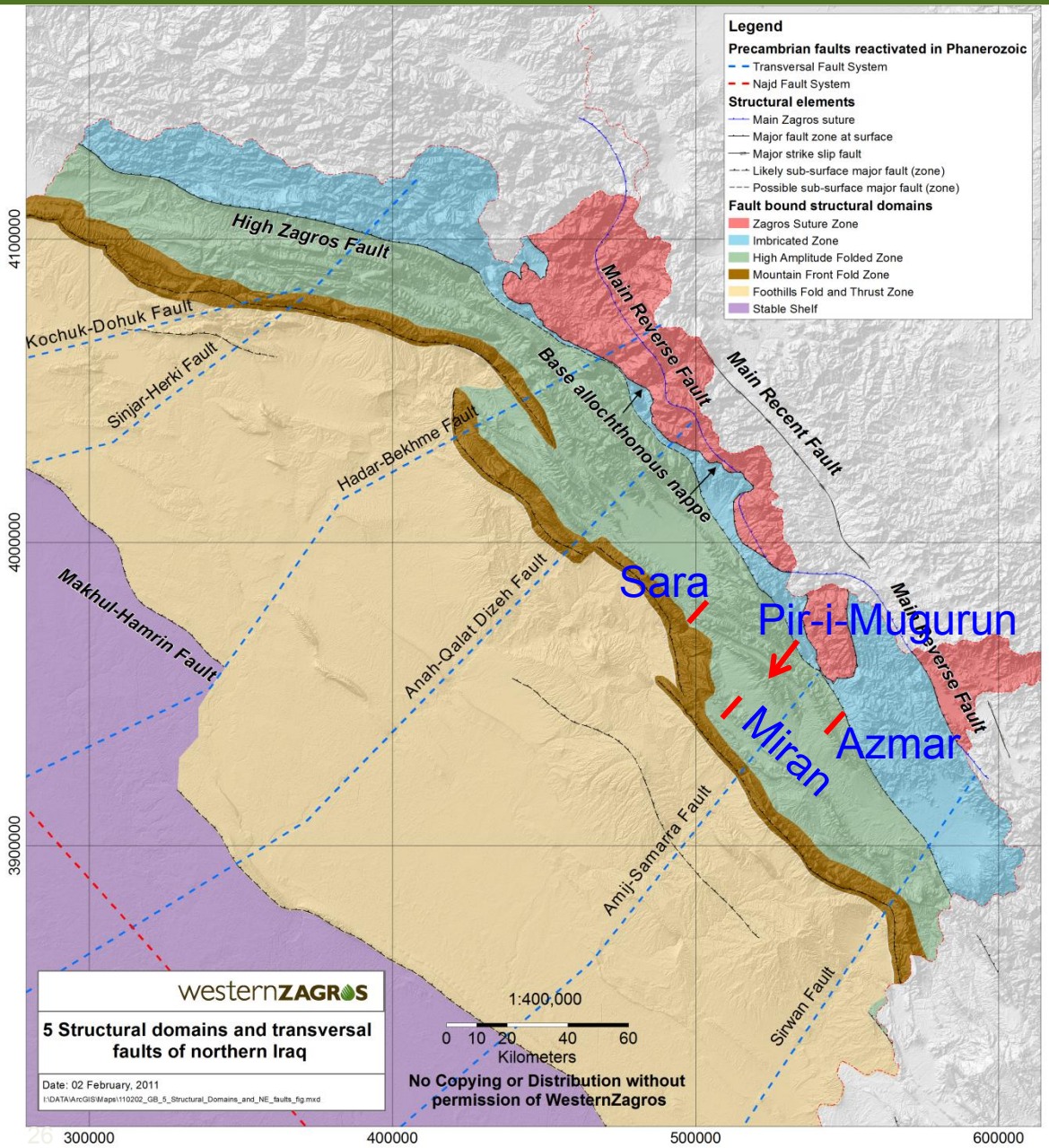
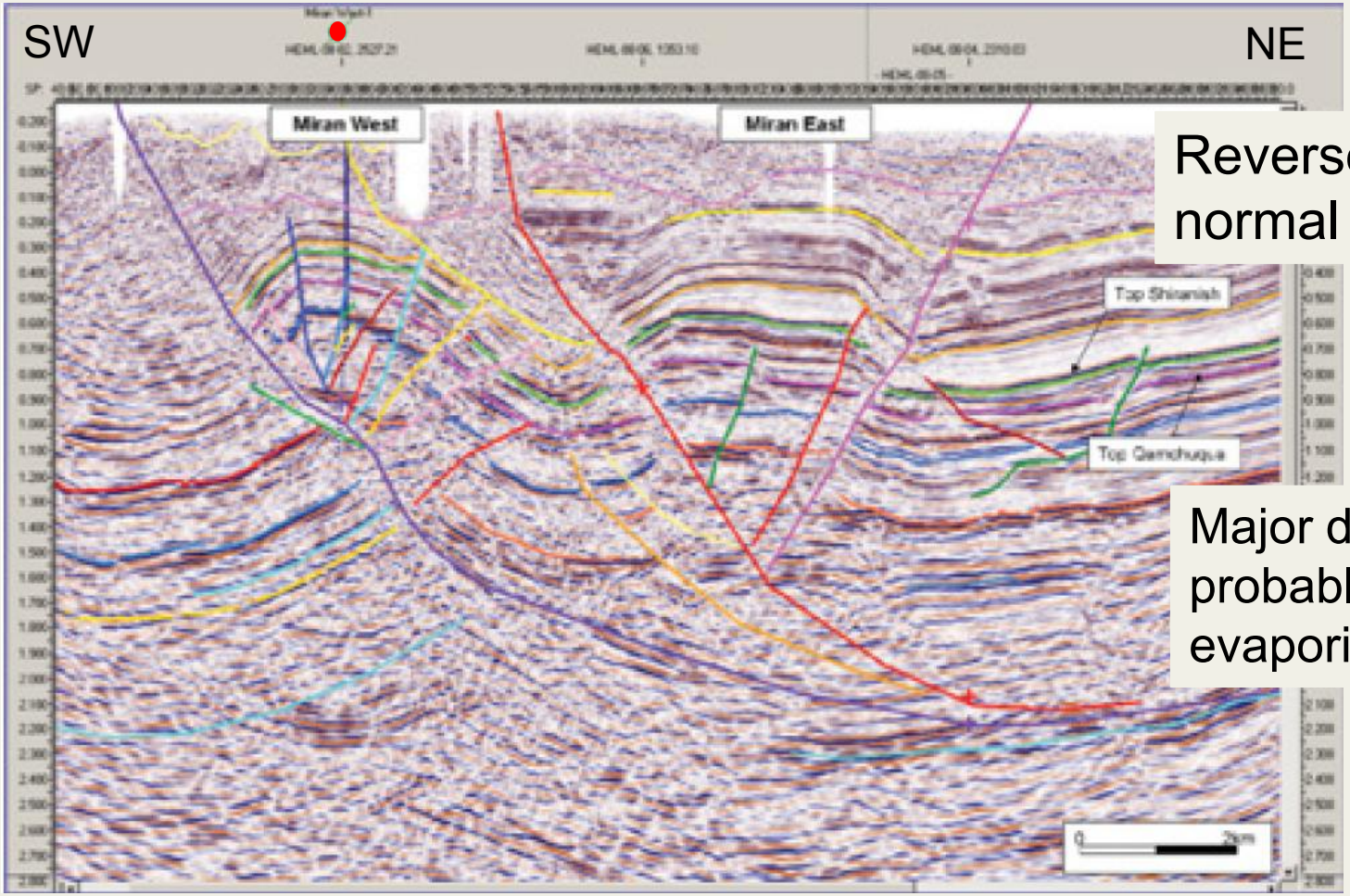
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”



- 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 acurate?
- What does “High” Folded refer to?

“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

Heritage Oil seismic dip line



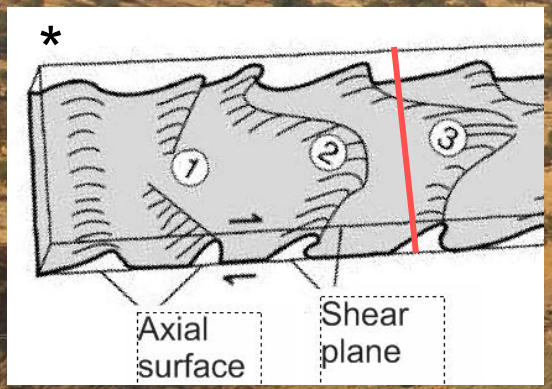
Reverse-reactivated normal faults

Major detachments, probably Triassic evaporites and muds

Heritage Oil corporate presentation, 2008

“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

Mountain Front Monocline dipping to the SW: into the page



Castle

Apparent sheath fold in Tanjero Fm

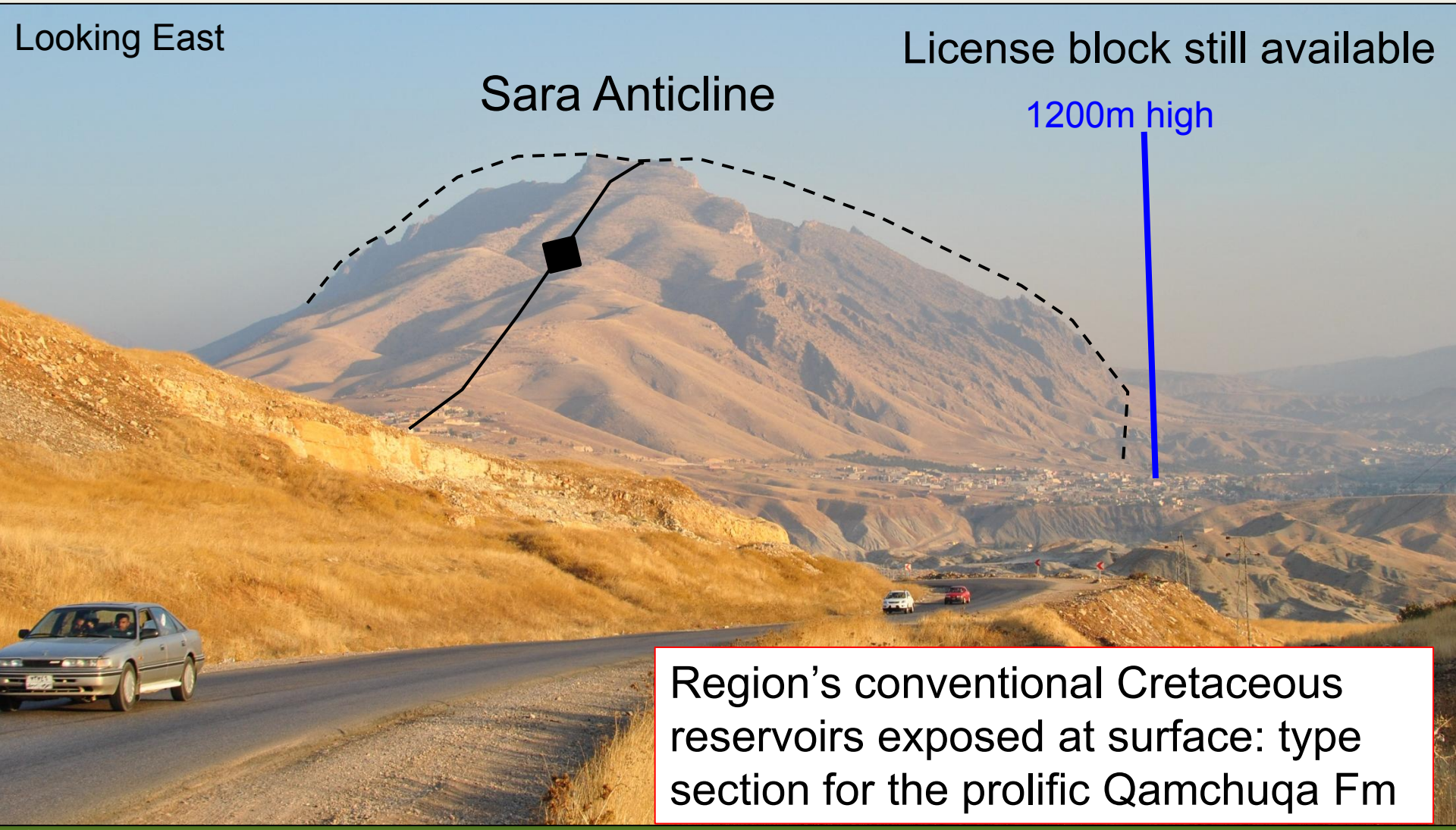
Hinge line folded into SW transport direction

Not simple folding!

* Modified after http://ic.ucsc.edu/~casey/eart 150/Lectures/ShearZones/15shearZns.htm

“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

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”

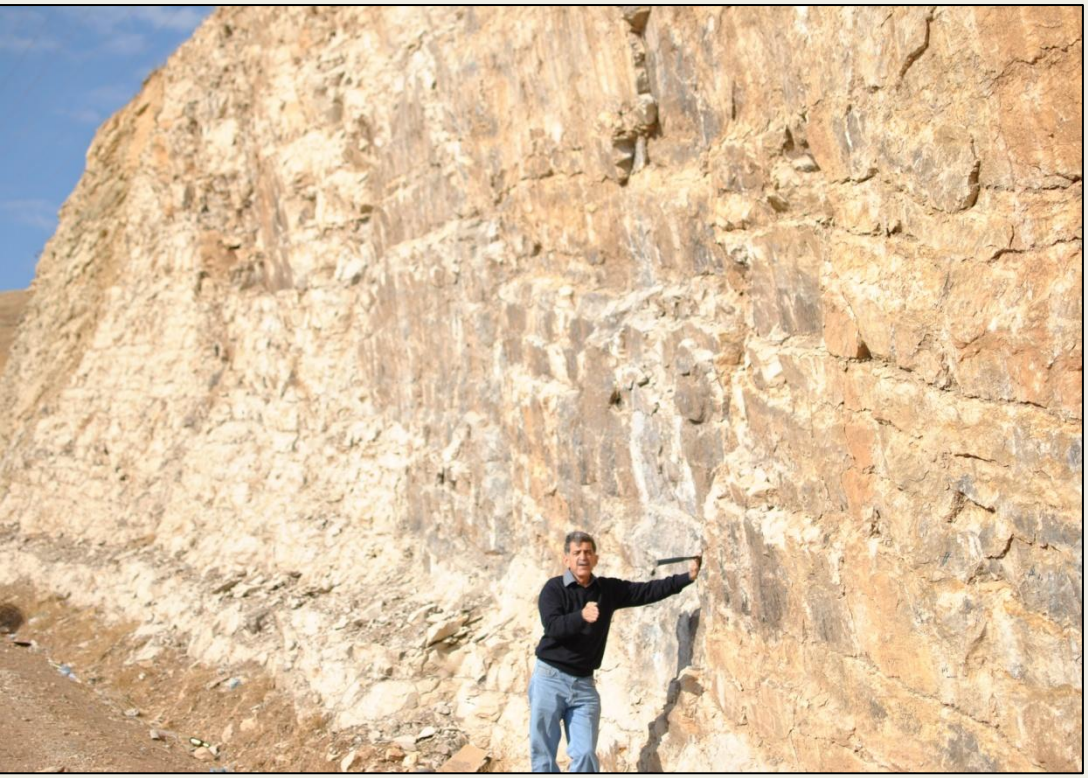
Shiranish Formation

- 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



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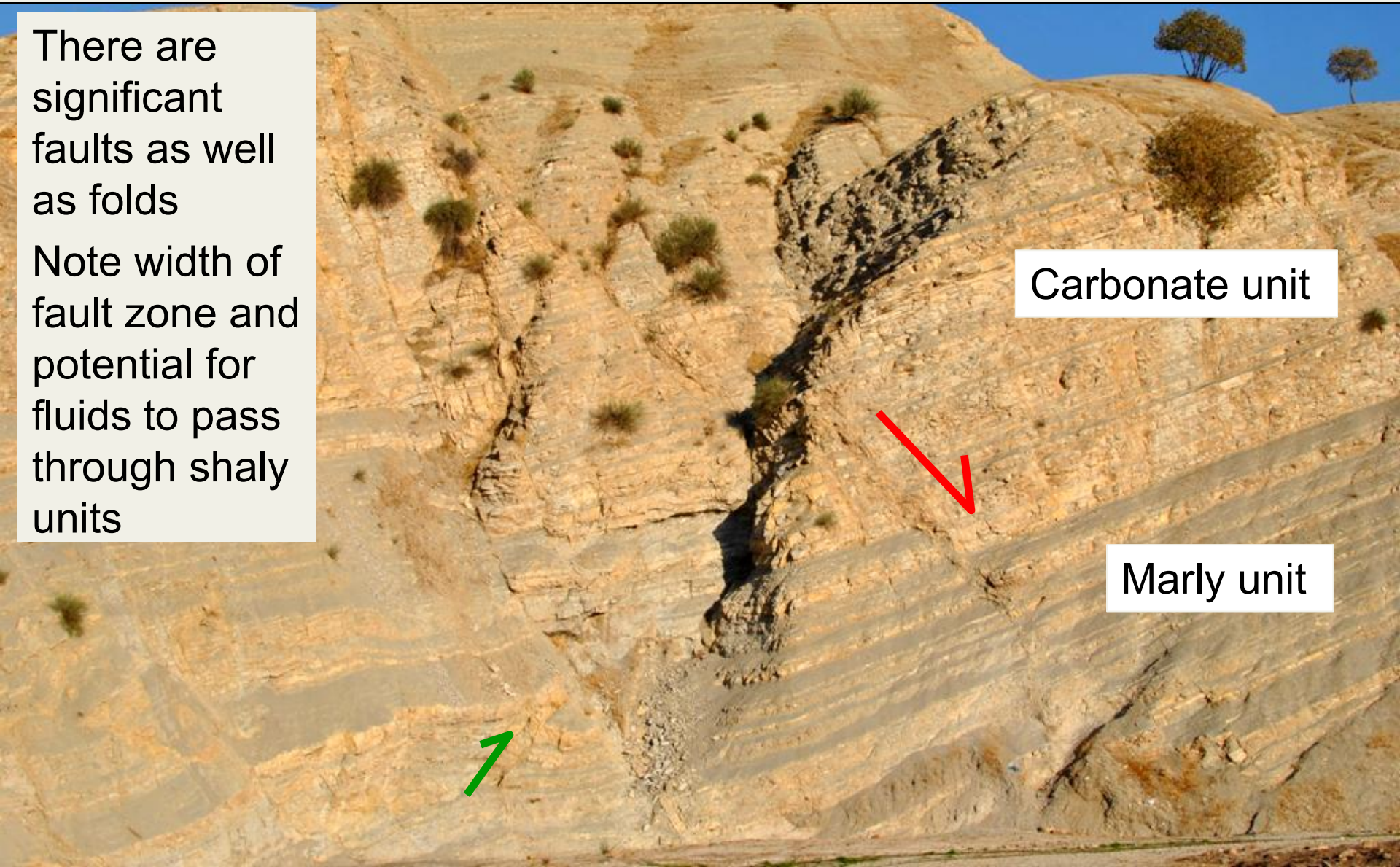
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

Shiranish Formation

Looking ENE

There are significant faults as well as folds

Note width of fault zone and 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

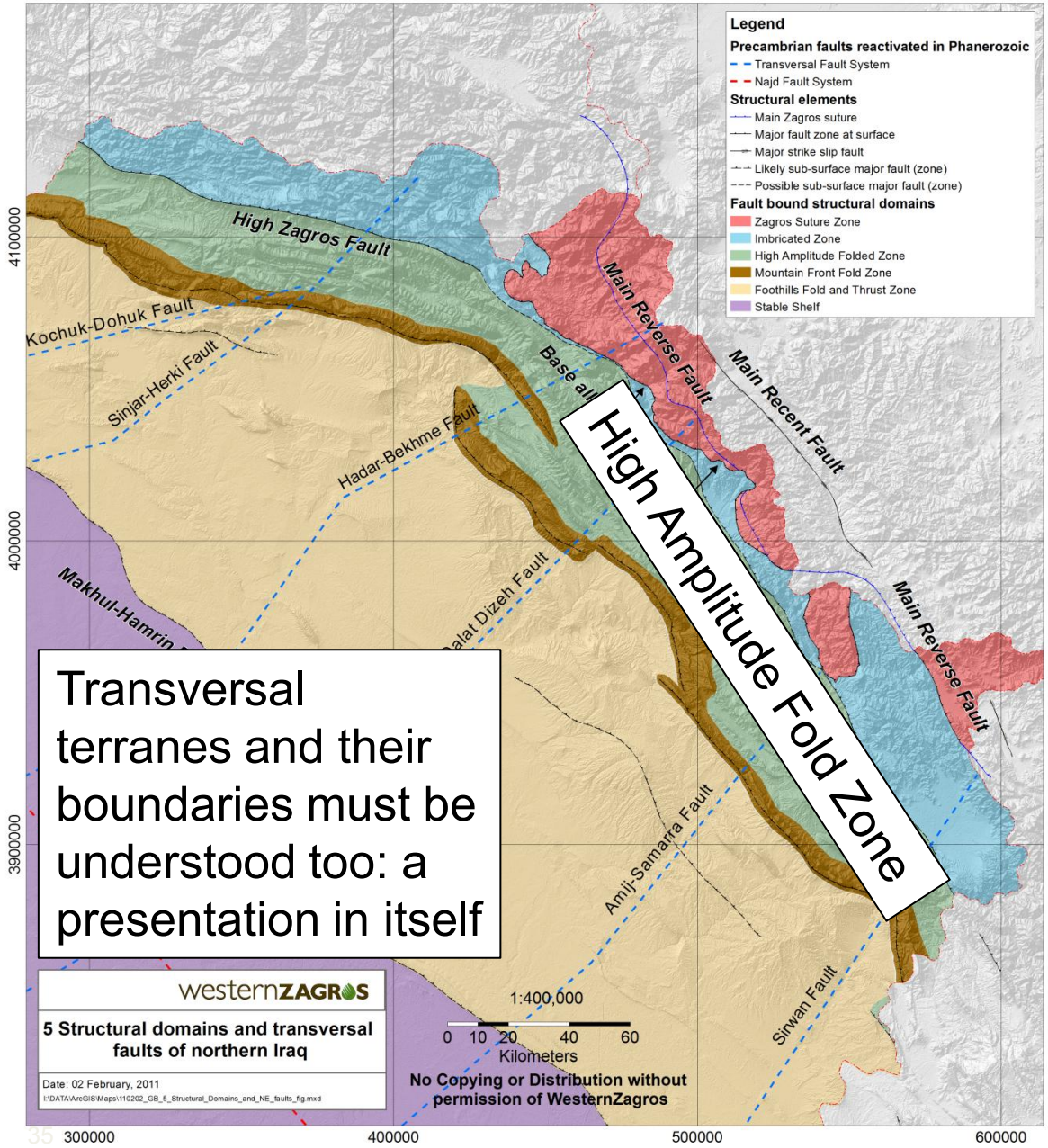
“THE SIMPLE / SIMPLY / HIGH FOLDED ZONE”

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

Core of Azmar Anticline

Looking E

THE HIGH AMPLITUDE FOLDED ZONE



- 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?

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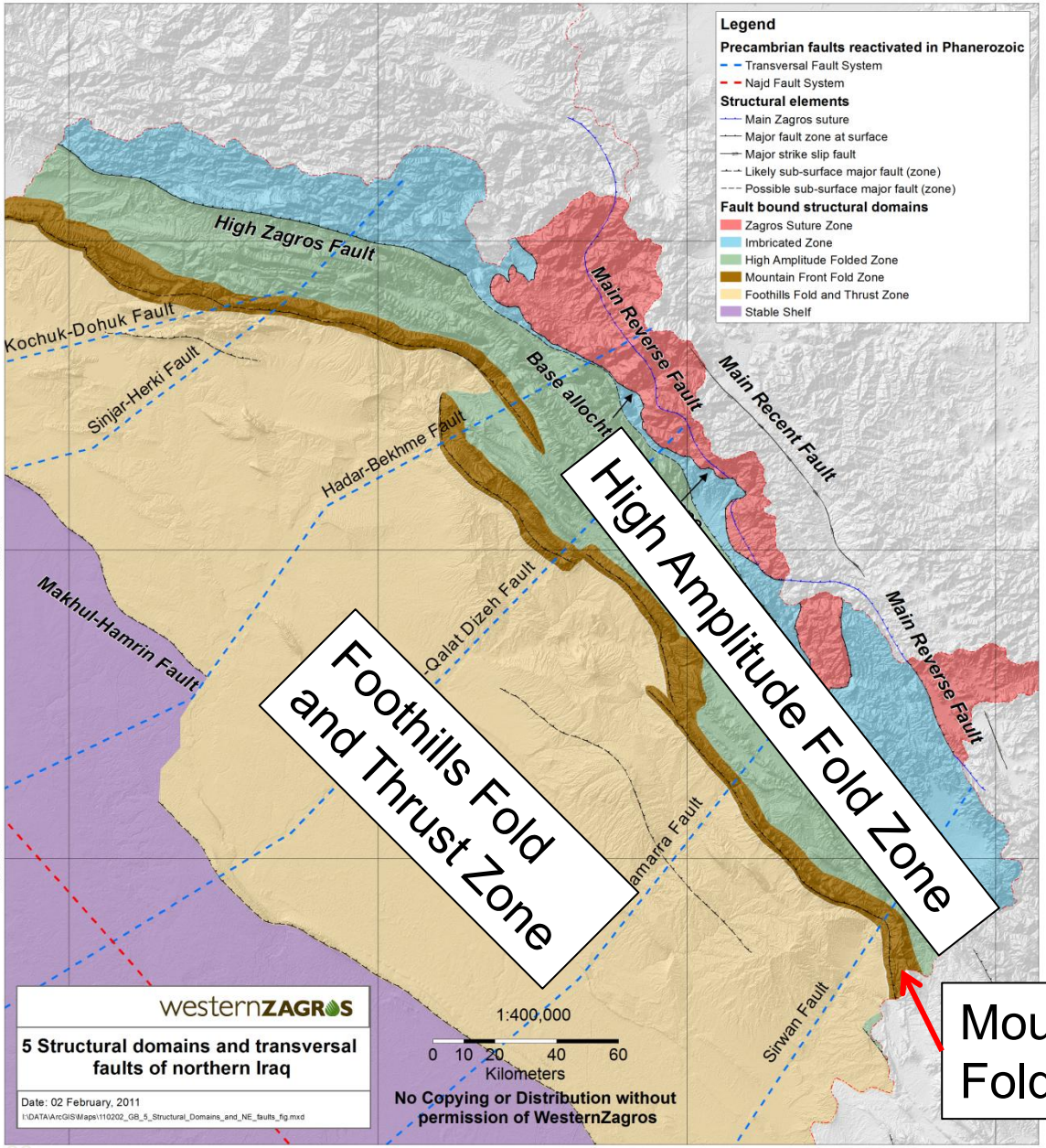
STRUCTURAL DOMAIN CONCLUSIONS



- 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

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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

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