Genetic Classification of Natural Fractures: A Key to Understand Flow in a Giant Carbonate Field*

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Abstract

Fractures are one of the main features that impact reservoir quality in carbonates. They record the history of the chemical and physical processes undergone by the reservoir from deposition through burial. These processes dictate the distribution and intensity of different fracture types and their effective flow properties. Understanding fractures from a genetic perspective helps develop better conceptual models that compensate for the often skewed distribution of wells, and the lack of uniformity in the data.

Three distinctive fracture generations can be distinguished in the Kashagan core. (1) During deposition processes associated with exposure and gravitational instability along the margin of the build-up result in early fracturing (Generation A). A-fractures are filled by carbonate, volcanic debris or early marine cements. (2) During burial fractures formed as a result of vertical loading and compaction (Generation B), and mostly in association with pressure dissolution surfaces (stylolites). Both types of structural features were effectively closed and unable to transmit fluids at the time of their formation. (3) During the reservoir charge, elevated fluid pressure led to breaching of the top seal. A fine network of small hairline fractures (Generation C) developed in the tightly cemented rocks, while existing fractures (A and B) were enhanced and in cases reactivated. Through integration of core and image logs a set of guiding principles is defined to identify fracture generations in wellbore images away from where there is core control. Interpretation results show that syndepositional fractures are more abundant along the rim, while burial fractures are ubiquitous in platform and rim. Core-to-log integration also proves that the resistivity signal of a fracture is no guarantee for its dynamic potential. Instead losses experienced while drilling are used as a proxy for excess permeability, in the absence of well test or production data. Lost circulation events and PLTs are evaluated using observations from core and image logs to determine the causes. Results suggest that A-Generation drives the large scale fracture permeability in the rim. In the platform, losses are mostly related to B-fractures. This provides a modeling approach more closely tied to geological processes and consistently integrated among data types. It can be used to distribute fractures based on the inferred spatial variability of causative processes within the reservoir over time.

References Cited

Collins, J., W. Narr, P.M. Harris, T. Playton, S. Jenkins, T. Tankersley, and J.A.M. Kenter, 2010, Lithofacies, depositional environments, burial diagenesis, and dynamic field behavior in a carboniferous slope reservoir, Tengiz Field (Republic of Kazakhstan), and comparison with outcrop analogs: SEPM Special Pub 105, p. 50-83.

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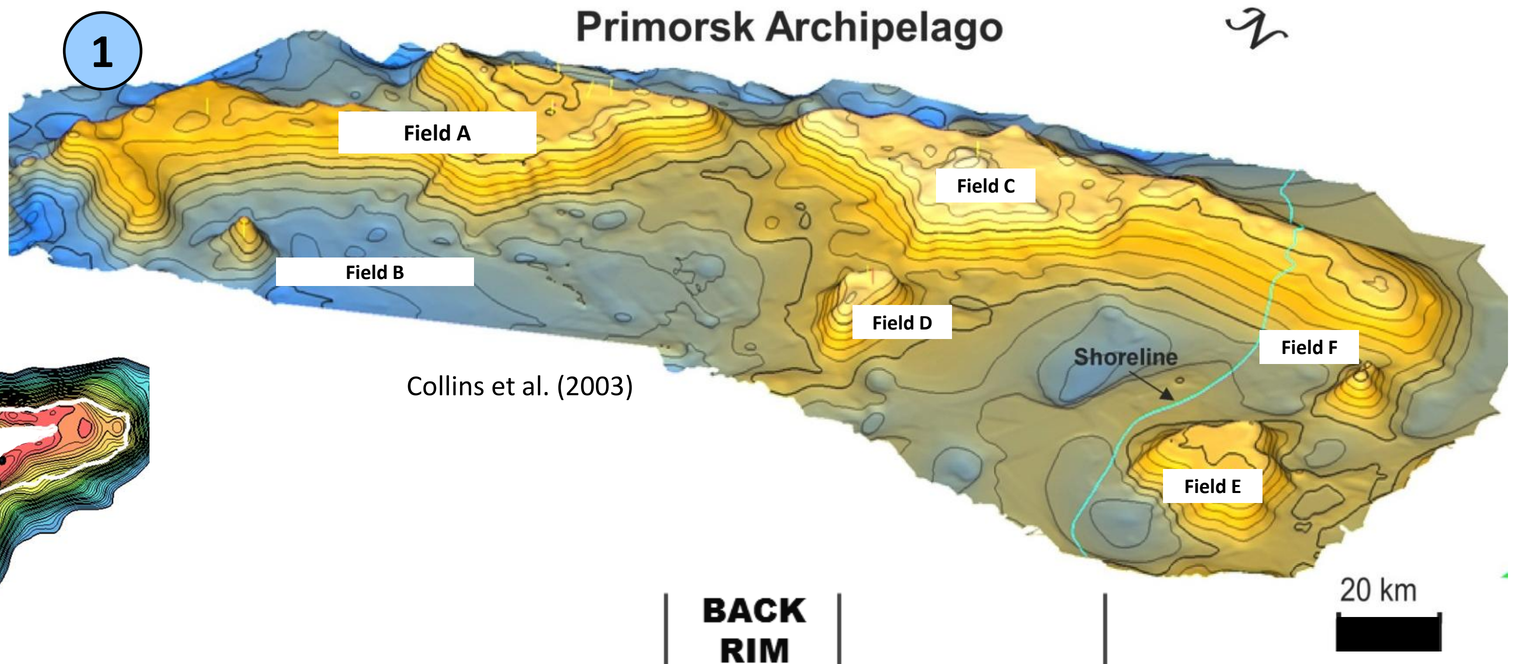
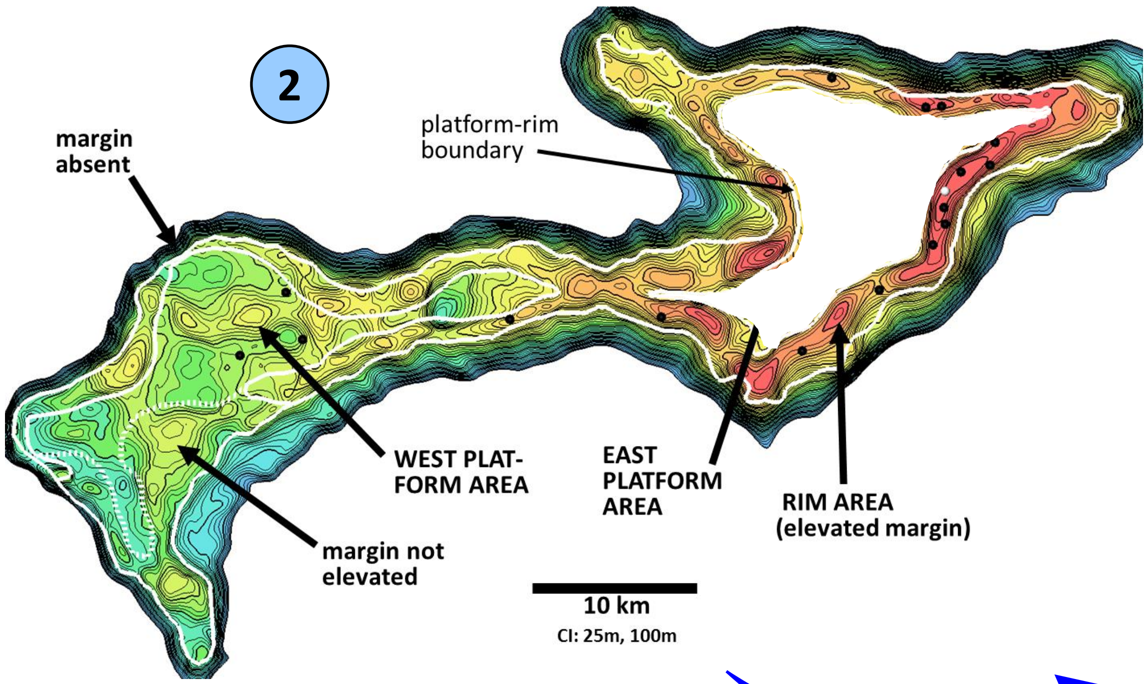
Introduction

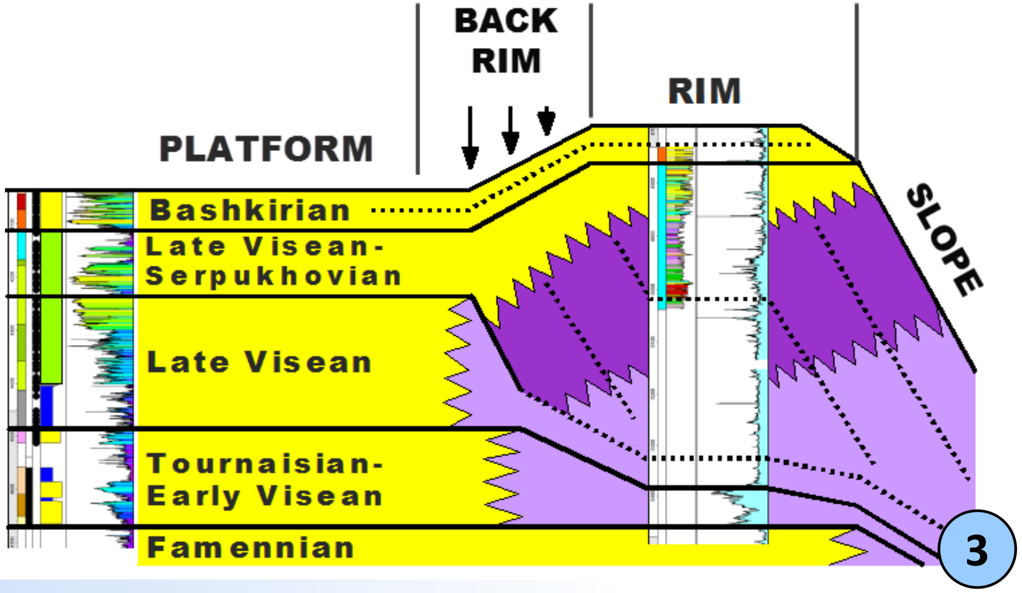
- **Not all fractures form the same**, so why do we then model them together?
- North Caspian reservoirs as an example of how a genetic characterization of natural fractures can **improve reservoir description and development of concepts** to predict fracture occurrence
- This is the result of a 3 year study involving 45+ wells with **core and/or wellbore image logs**
- All interpretations and conceptual models are **supported by core observations**

Geological Setting





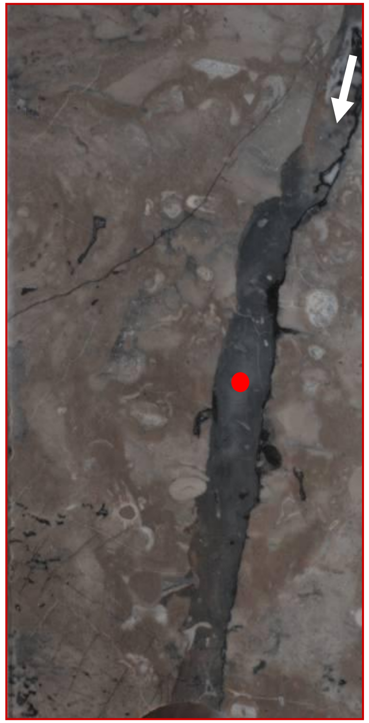
CHCD wells mostly in the rim



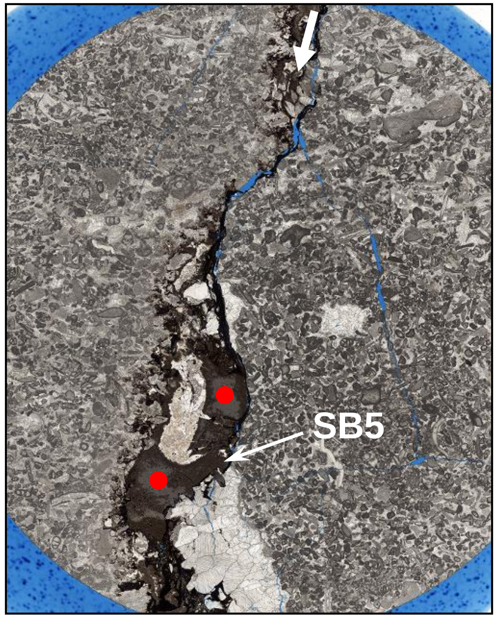
A-Generation Fractures: Syn-depositional

Characteristics

- **Opening mode** dip slip; sinuous to irregular
- Dip > 60^{o}; **width to 80 mm, variable**; non-matching walls
- Analog data suggest 90+ m height, and m-km scale lengths
- Partially filled with **clay, carbonate debris or early marine cements**
- Abundant near **exposure surfaces** and **outer platform to slope transition**
- **Pre-date** all other structures



- Clay / Debris Bitumen
- Carbonate Micrite



PST GST

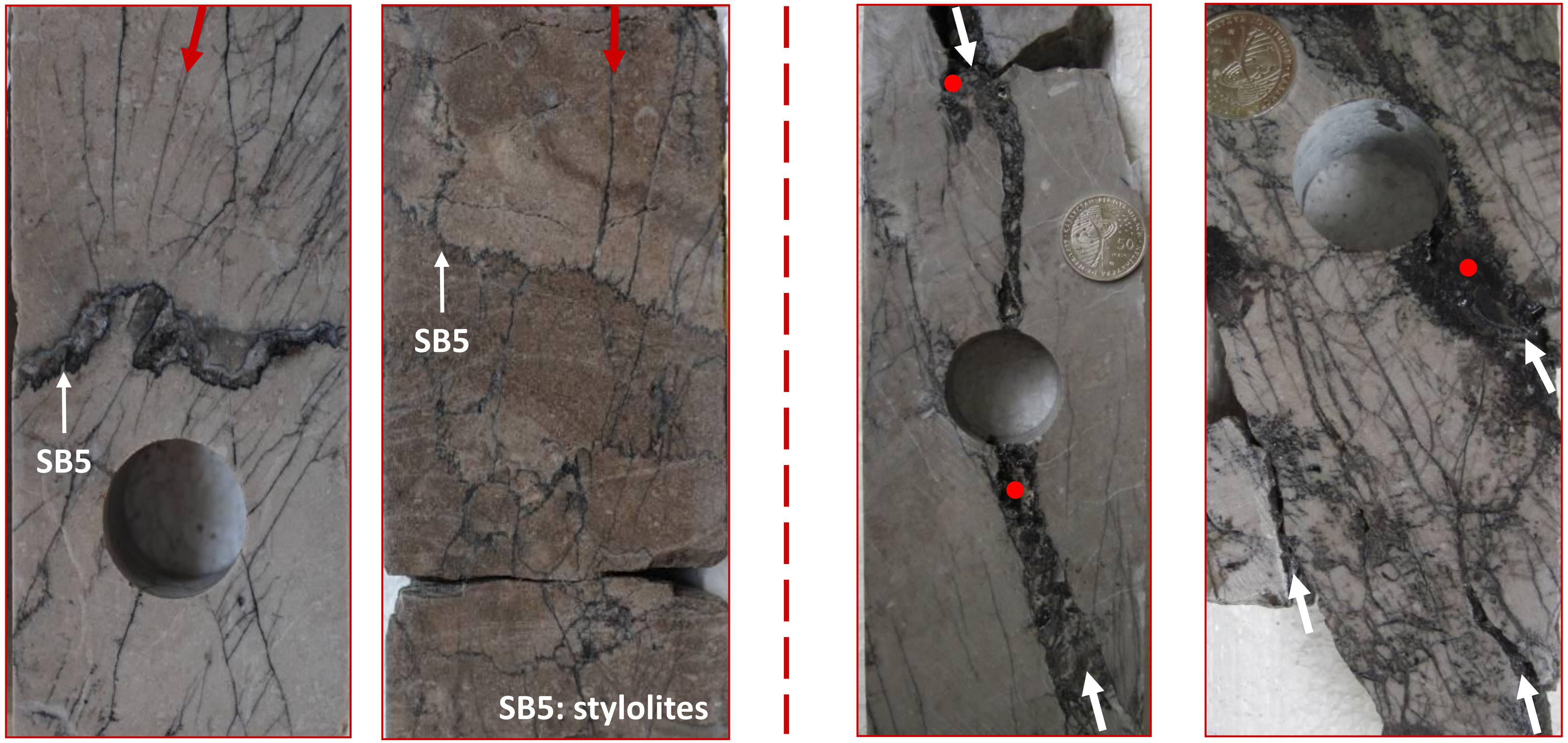
SB5: stylolites

B-Generation Fractures: Burial Related

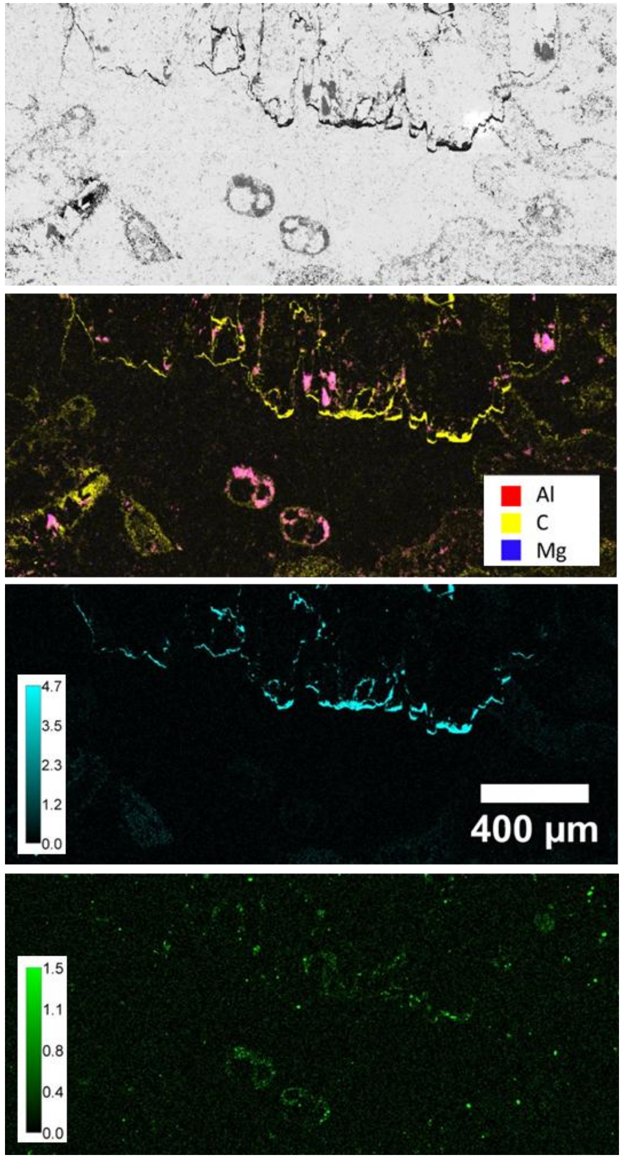
Characteristics

- **Opening mode** dip slip; irregular, branched to crossing networks
- Dip > 60^{o}; **width to 30 mm**, high L:W ratio
- Mostly filled with **blocky calcite, bitumen**; late dissolution
- Medium to high abundance **in swarms**
- **Post-date Gen A joints**; **pre-date / coeval with stylolites**

Smaller, Filled Joints *Large, Partially Open Joints*



● Late Corrosion

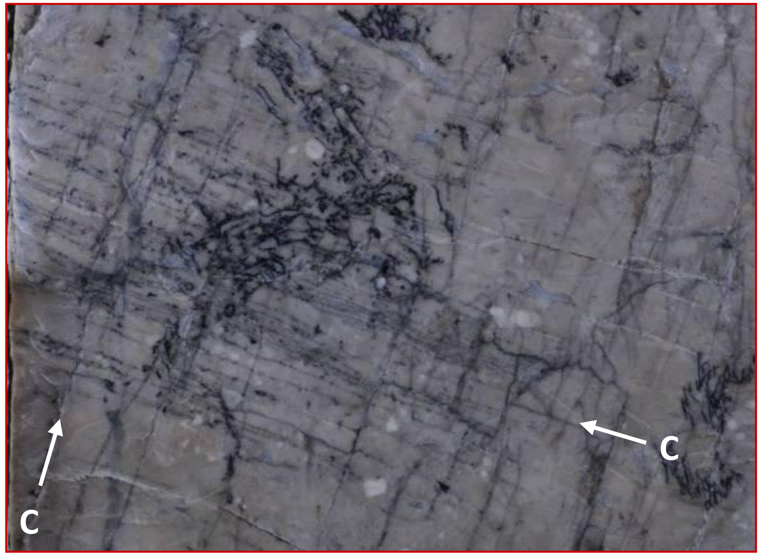


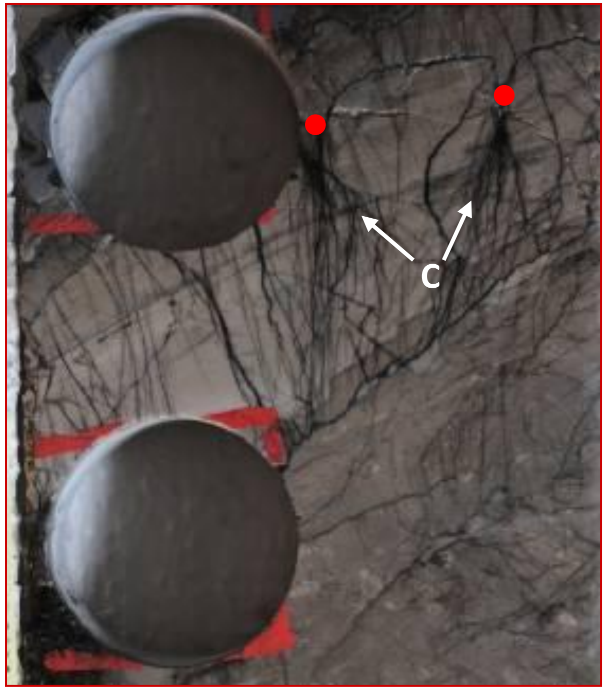
C-Generation Fractures: Overpressure

Characteristics

- **Opening mode**; ~ planar, sub-mm to cm scale spacing
- Dip > 75^o or < 15^o; **width < 0.1 mm**; high L:W ratio, <20 cm long
- **Stained dark brown**; locally pitted along trace
- Abundant in **boundstones** and tightly **cemented** grainy lithofacies
- **Post-date most structures**; may pre-date minor late stylolites

● **Branching**





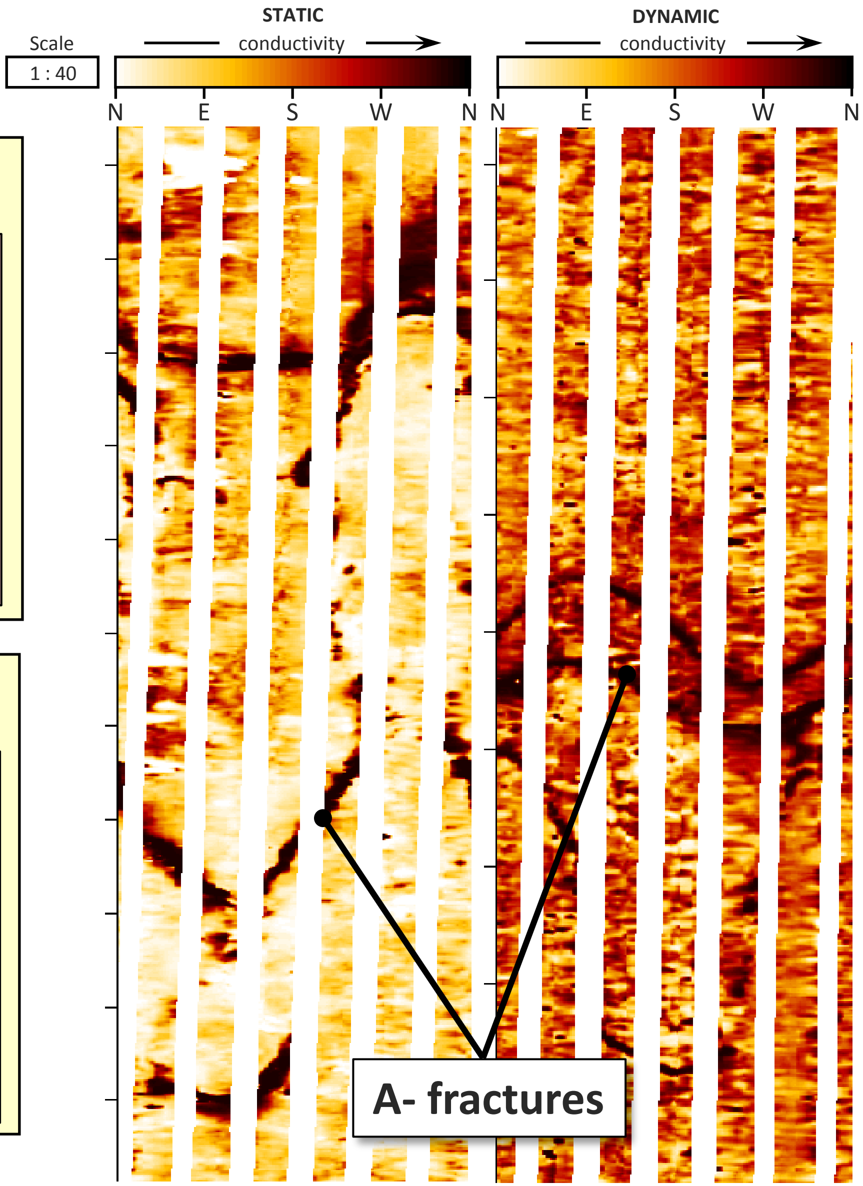
Log-without-Core Fracture ID Criteria

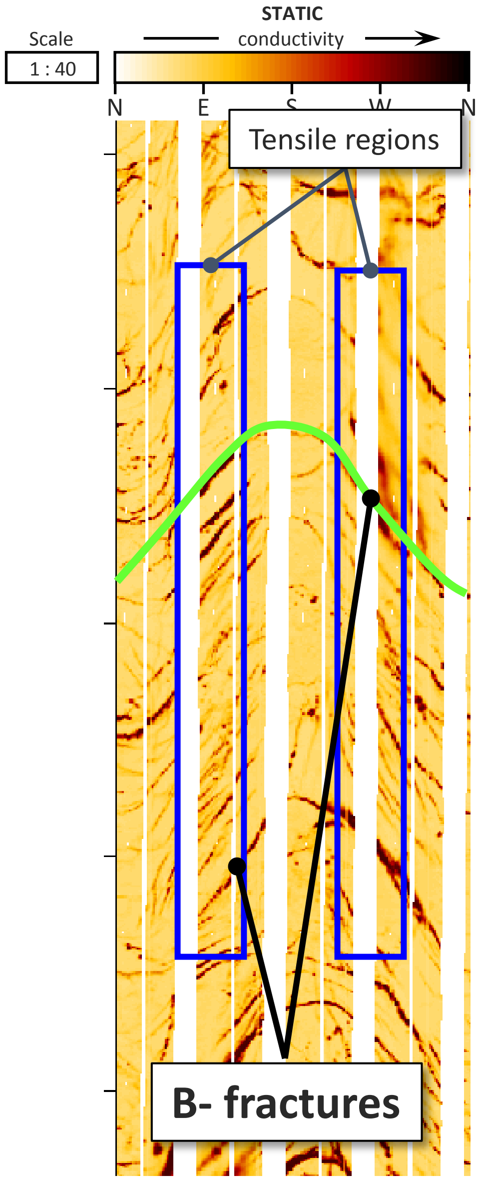
A - Fractures

- Continuous to q-continuous sinusoids
- Strong resistivity signal (cond / res)
- Not associated with DITFs
- Below and near sequence boundaries
- Non-planar surface geometry
- Below and near clay seams

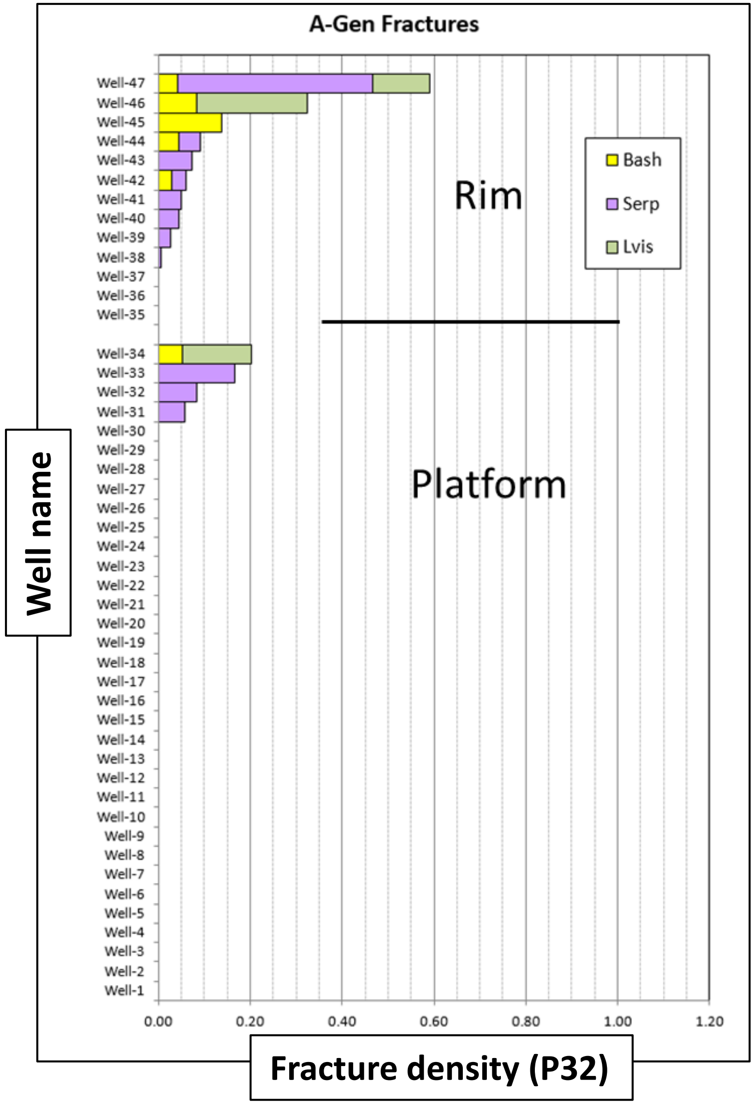
B - Fractures

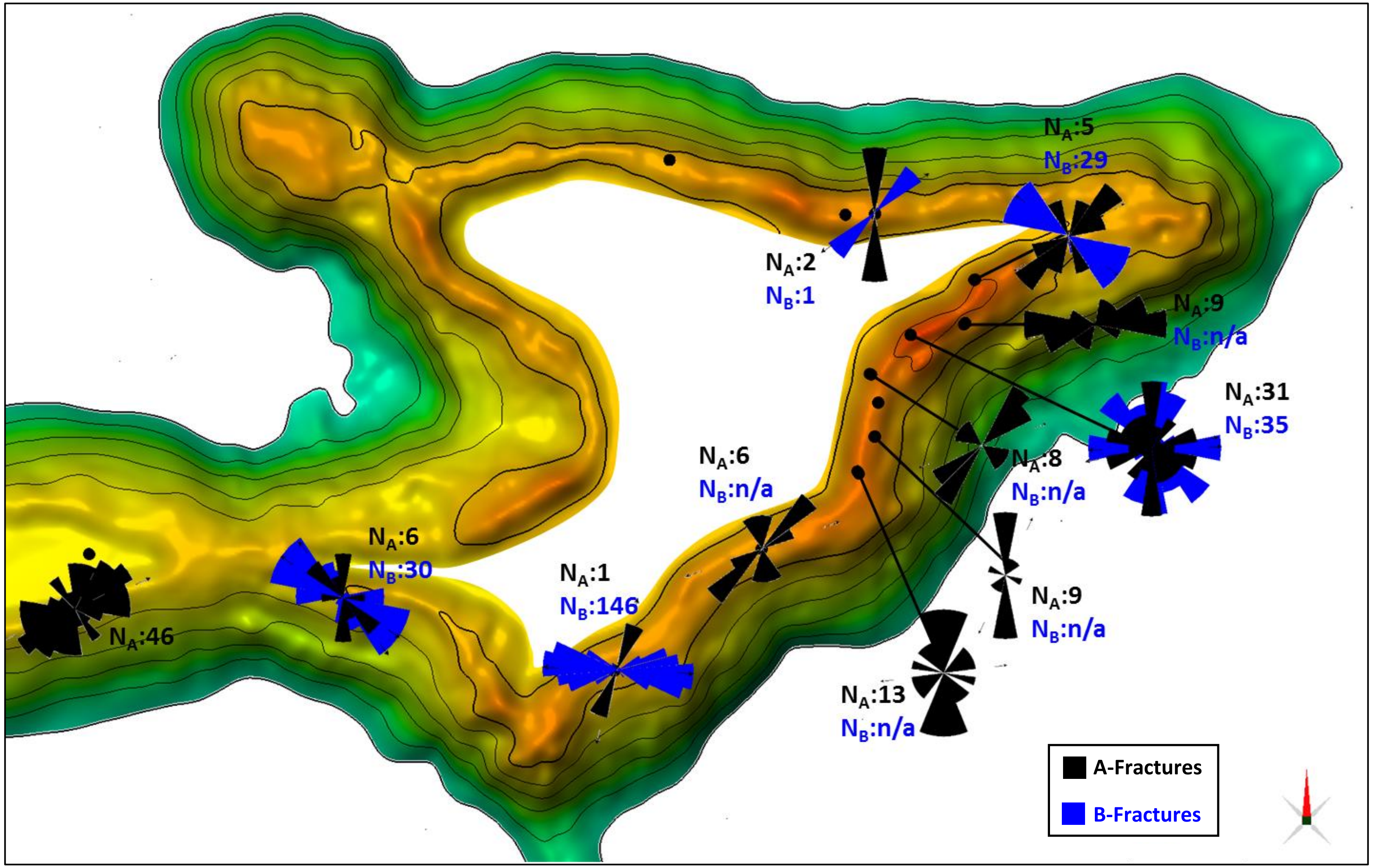
- Enhanced in tensile wellbore regions
- Sub-parallel to S_{Hmax}
- Form clusters along the wellbore
- Low dispersion in orientation
- Mostly semi-continuous
- Bounded by stylolites



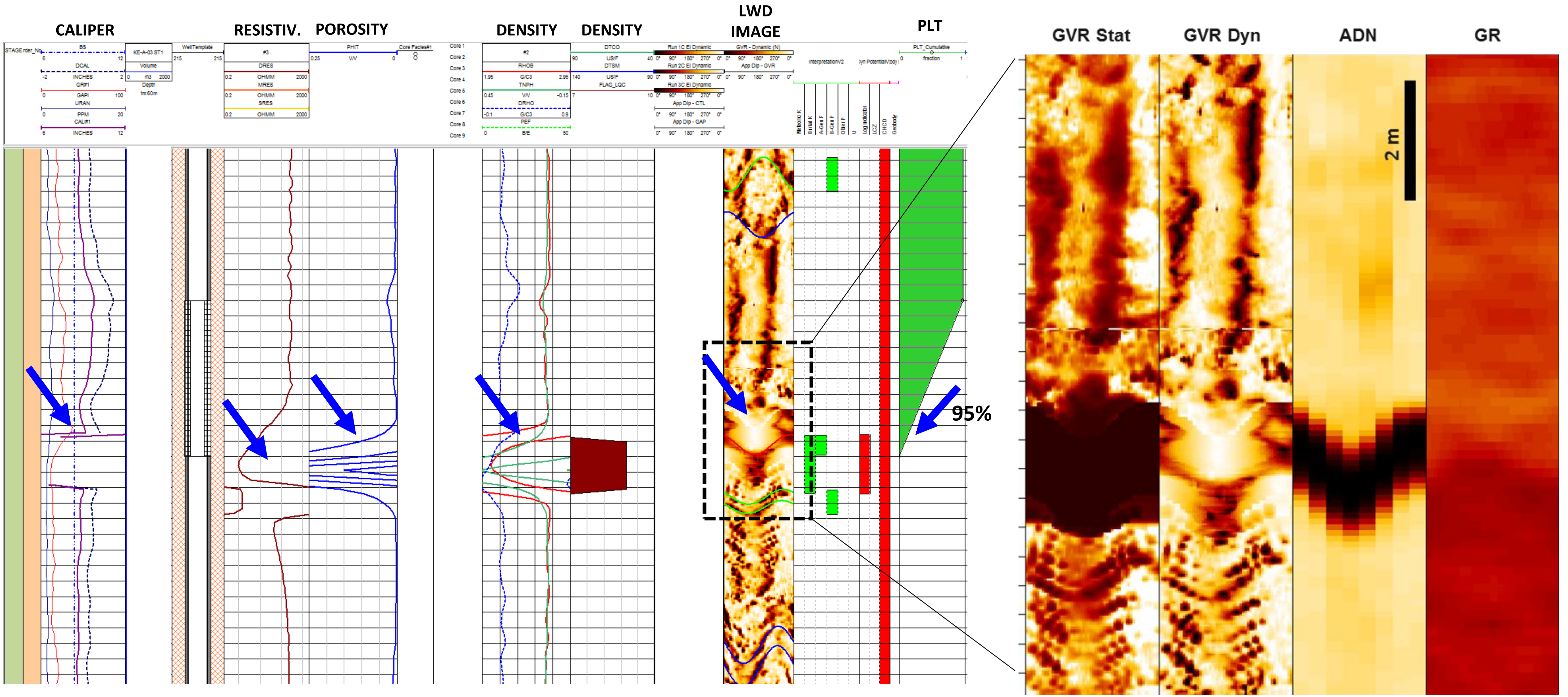


A-Generation Fractures: Orientation and Abundance

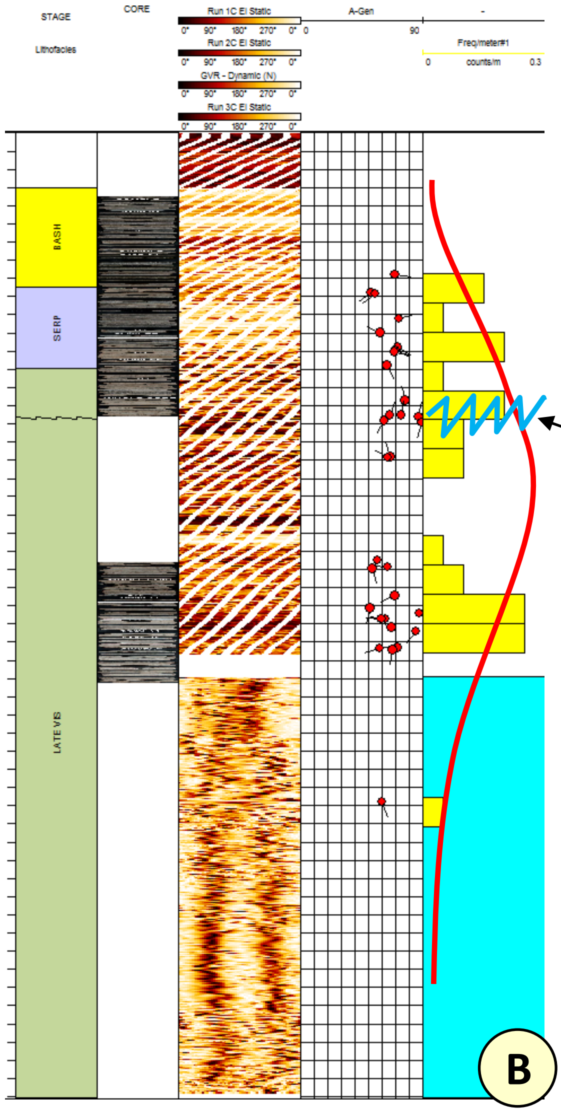




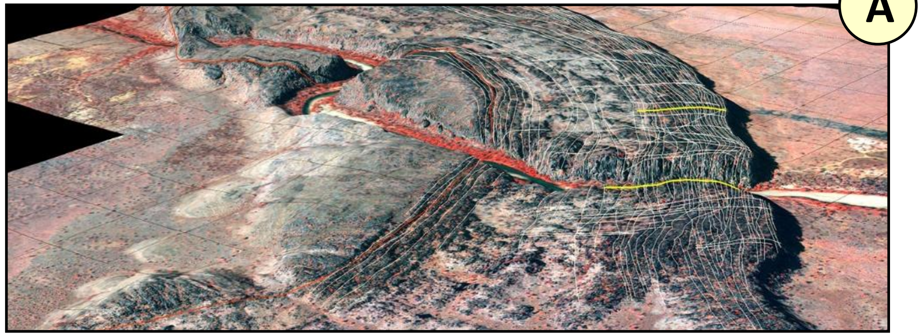
Dynamic Potential of A-Generation Fractures



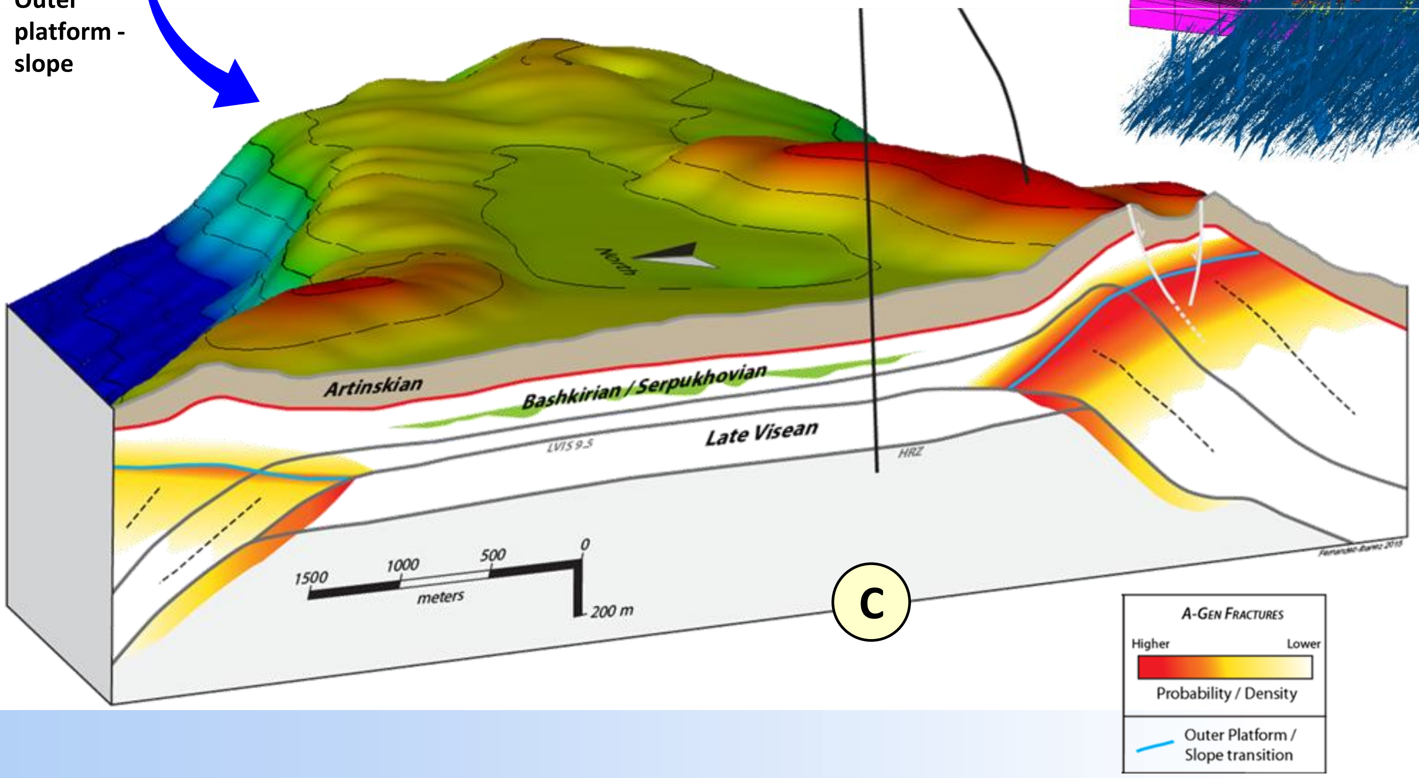
Syn-depositional (A-Gen) Fractures Conceptual Model

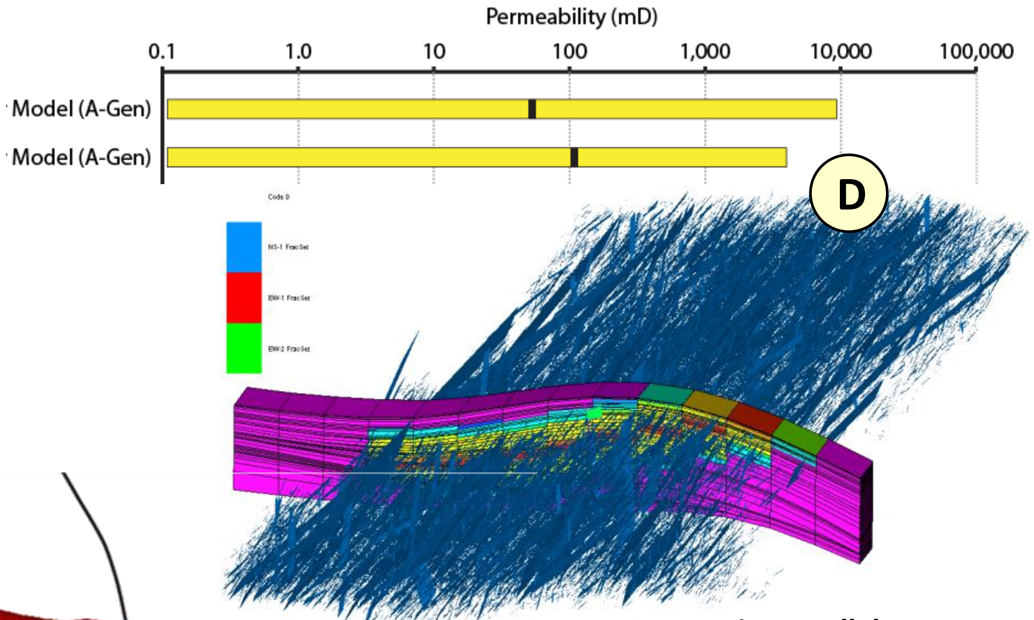


Outer platform - slope



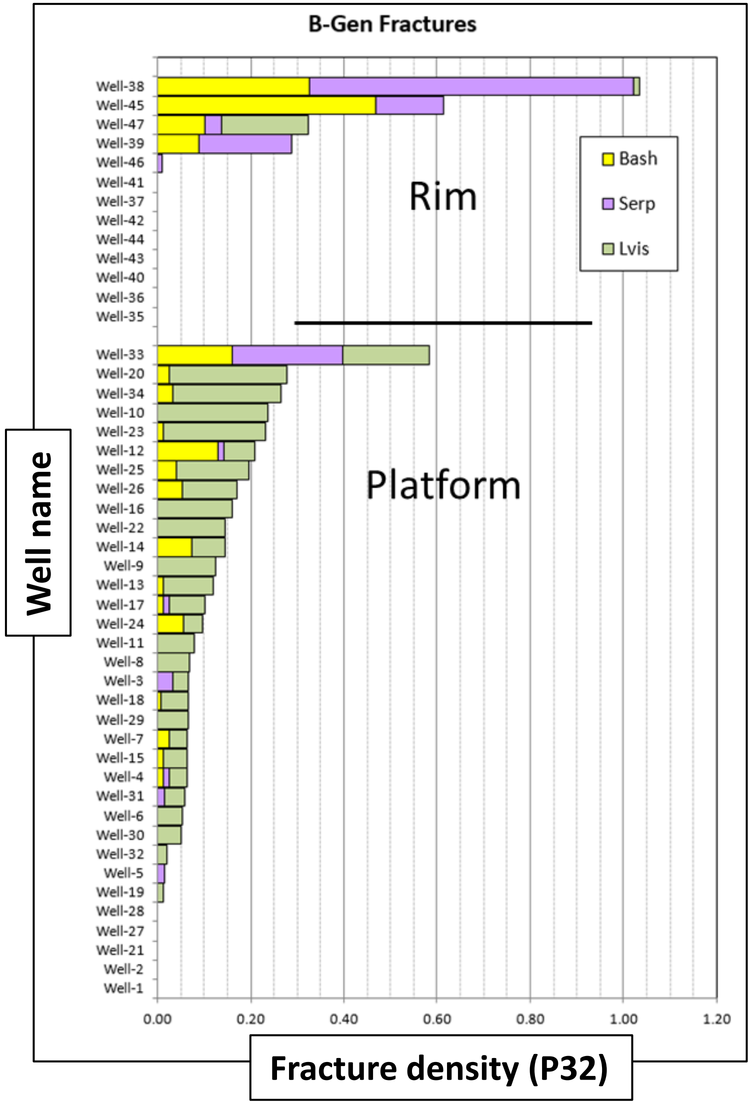
Canning Basin (WA) - Courtesy of Ned Frost

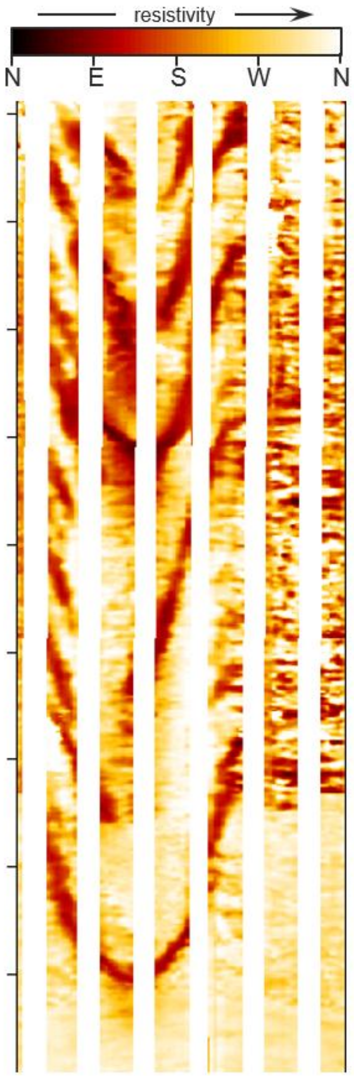


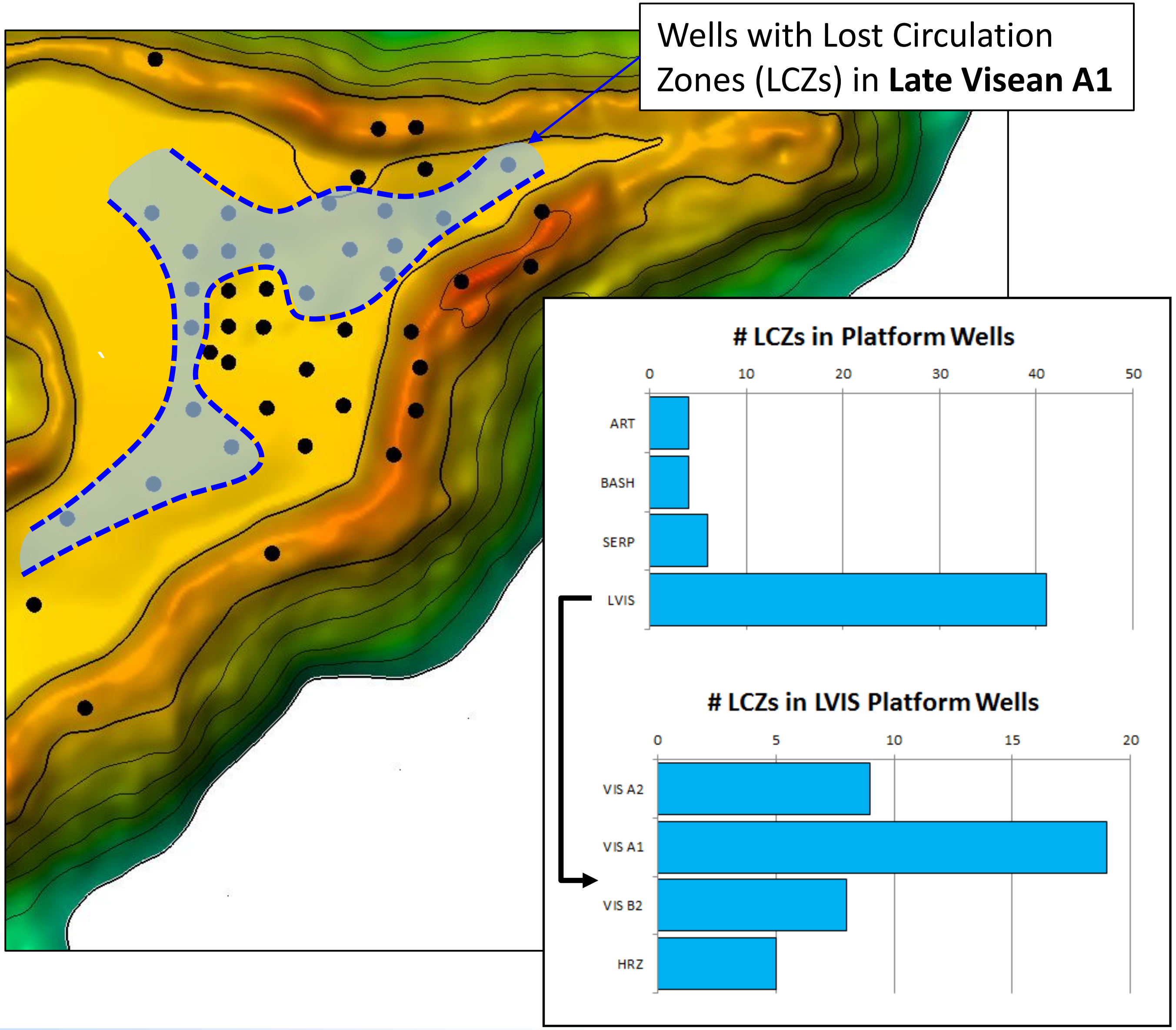


Gen A, Rim-Parallel Fractures

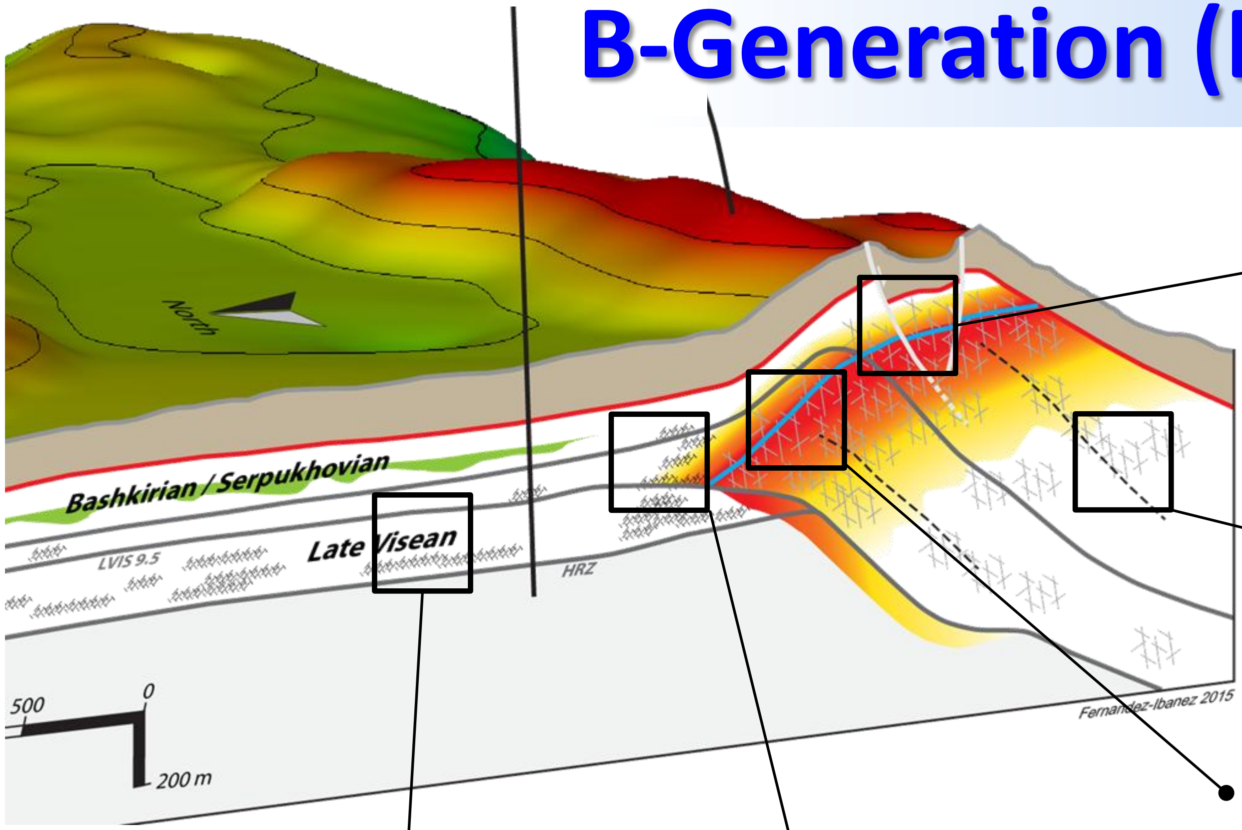
B-Generation Fractures: Abundance & Dynamic Potential







B-Generation (Burial) Characteristic Regions



1 B-Gen in **fault damage zones**

Highest fracture densities observed
Fractures mostly open with strong dissolution overprint
One of the main drivers of massive losses and CHCD
Depth extend is uncertain due to lack of reflectivity in boundstones

2 B-Gen in the **slope**

Not well characterized as well are drilled in CHCD mode
Potentially cemented so lower effective fracture density
Late dissolution may enhance fracture properties

3 B-Gen **within A-Gen region**

High fracture density
Mostly filled fractures with bitumen and calcite
Flow contribution mostly overwhelmed by A-Gen
Different scale between A and B represents modelling challenge

4 B-Gen in the **back rim**

Conceptually related to compaction bend
Medium-High fracture density
Often plugged with bitumen

5 B-Gen in the **platform**

Moderate fracture density
Mostly open fractures
Develop as clusters within certain stratigraphic intervals

B-Gen Fractures

Areas of increased density in platform

Areas of increased density in slope/margin

A-Gen Fractures

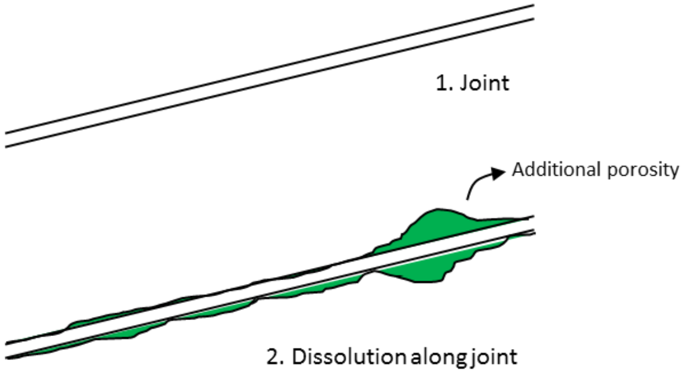
Higher — Lower

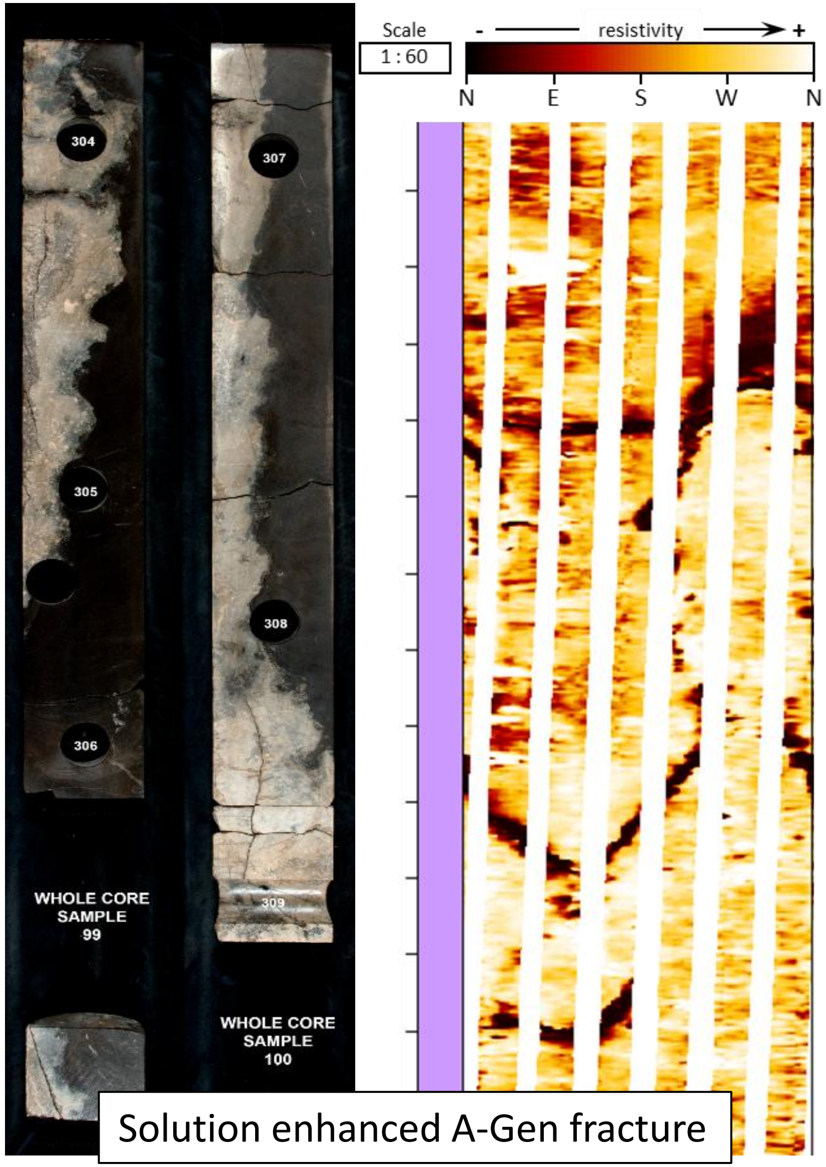
Probability / Density

Outer Platform / Slope transition

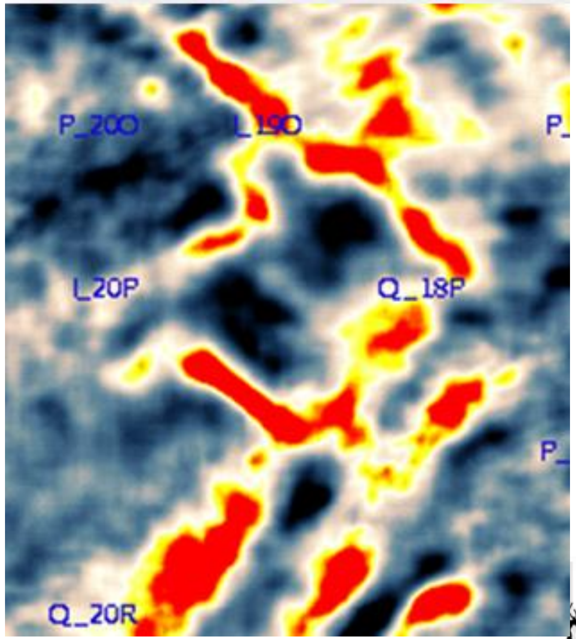
Dissolution and the Non-Matrix Continuum Dilemma

Solution enhanced B-Gen fracture

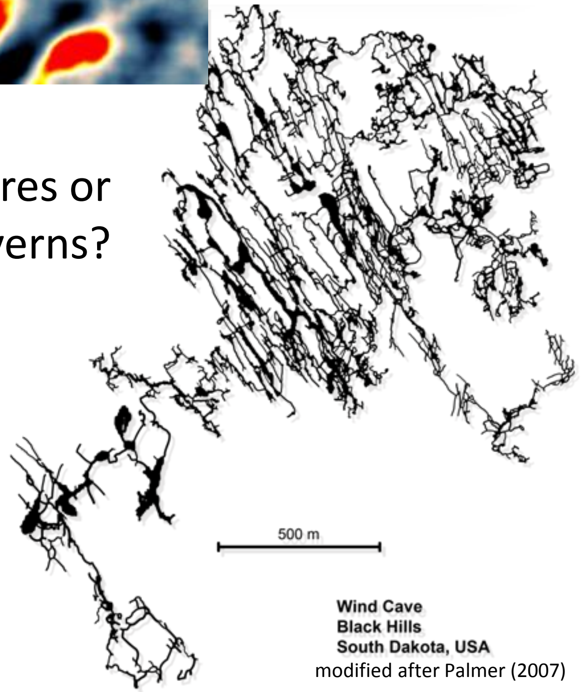




Solution enhanced A-Gen fracture



Large fractures or caverns?



modified after Palmer (2007)

Summary

- **Genetic fracture characterization**, although time intensive, allows development of **robust geologic concepts** for reservoir modelling
- A **process-based modelling** strategy is used in this example:
    - A-Gen (**syn-depostional**) fractures. Related to gravitational instability around the outer-platform/slope transition. Likely to **control large scale flow** along the rim
    - B-Gen (**burial-compaction**) fractures. Ubiquitous, high density but smaller than A-Gen. Diagenetic overprint results in **characteristic regions** that need to be modelled separately
- All fracture generations are affected by **late dissolution processes** which makes challenging to:
    - Estimate **fracture porosity** and effective properties
    - Establish the boundary between **enhanced fractures and karts**
- In the absence of reliable PLT/production data, **Lost Circulation Zones** can provide valuable information on the **permeability structure** of the fracture network

Acknowledgements

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www.kmg.kz

www.eni.it

www.inpex.co.jp

NCOC
NORTH CASPIAN OPERATING COMPANY

www.shell.com

CNPC
www.cnpc.com.cn/en/

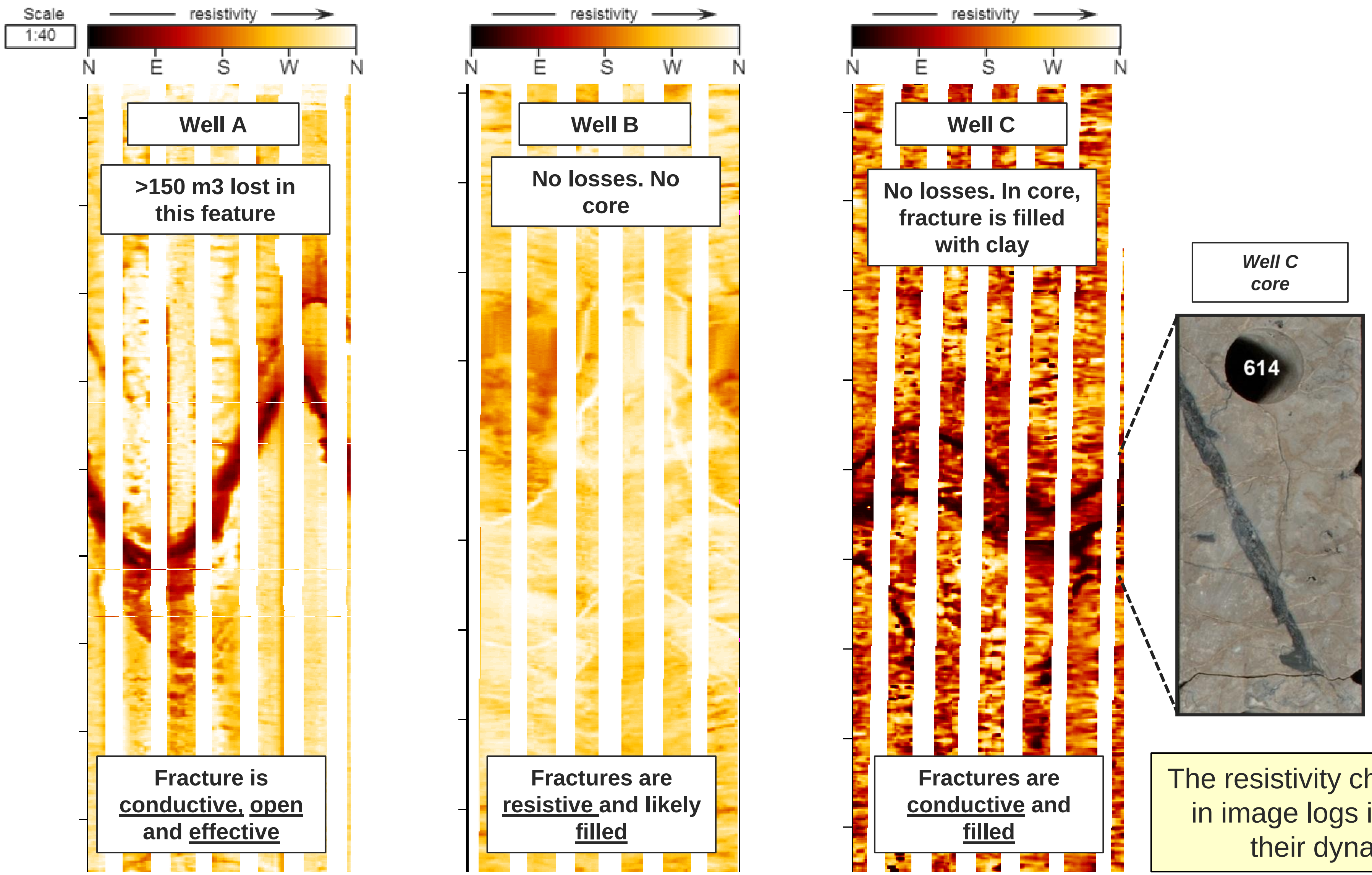
ExxonMobil
www.exxonmobil.com

TOTAL
www.total.com

Thank you!

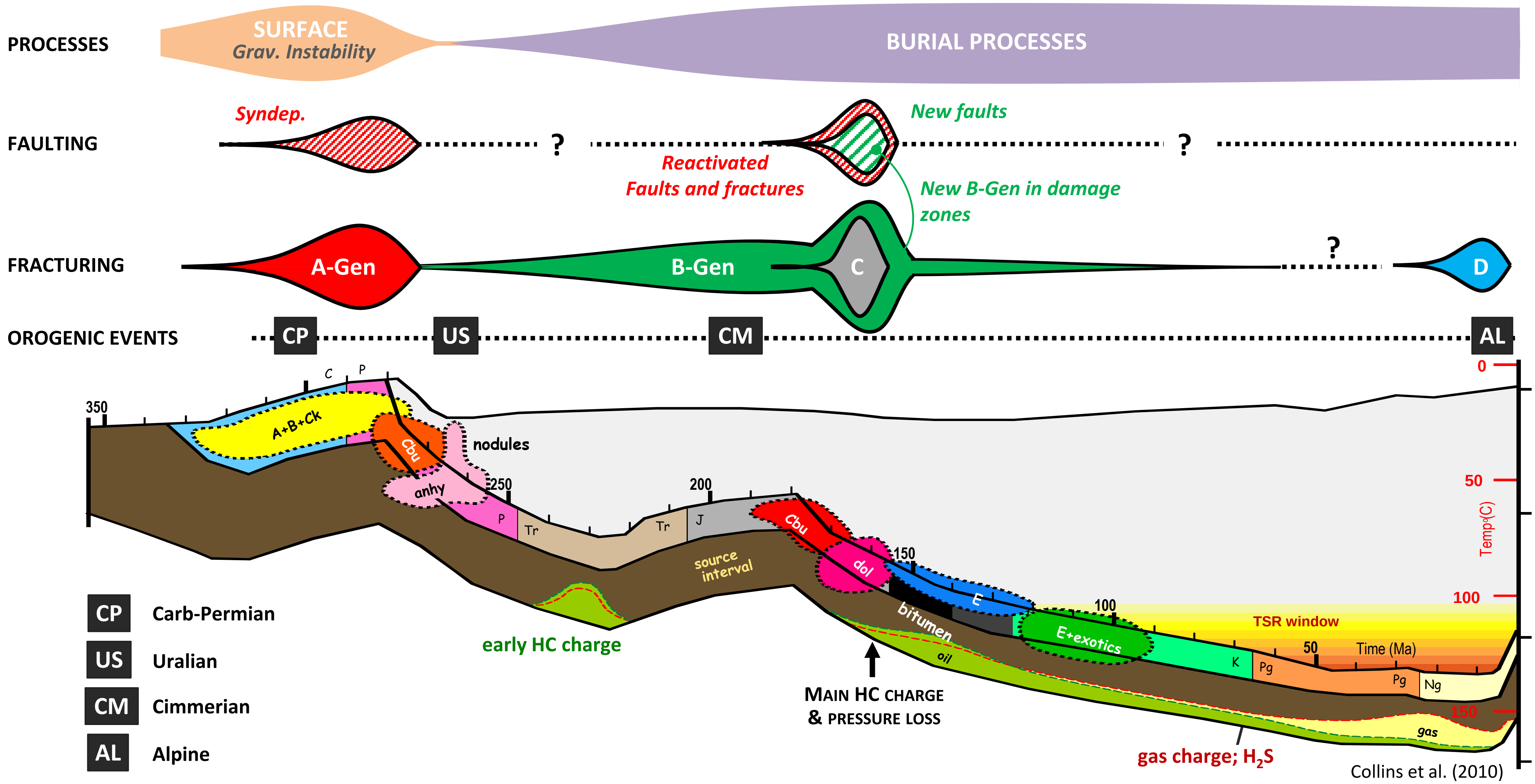
Supporting Slides

Open, Effective and Conductive Fractures

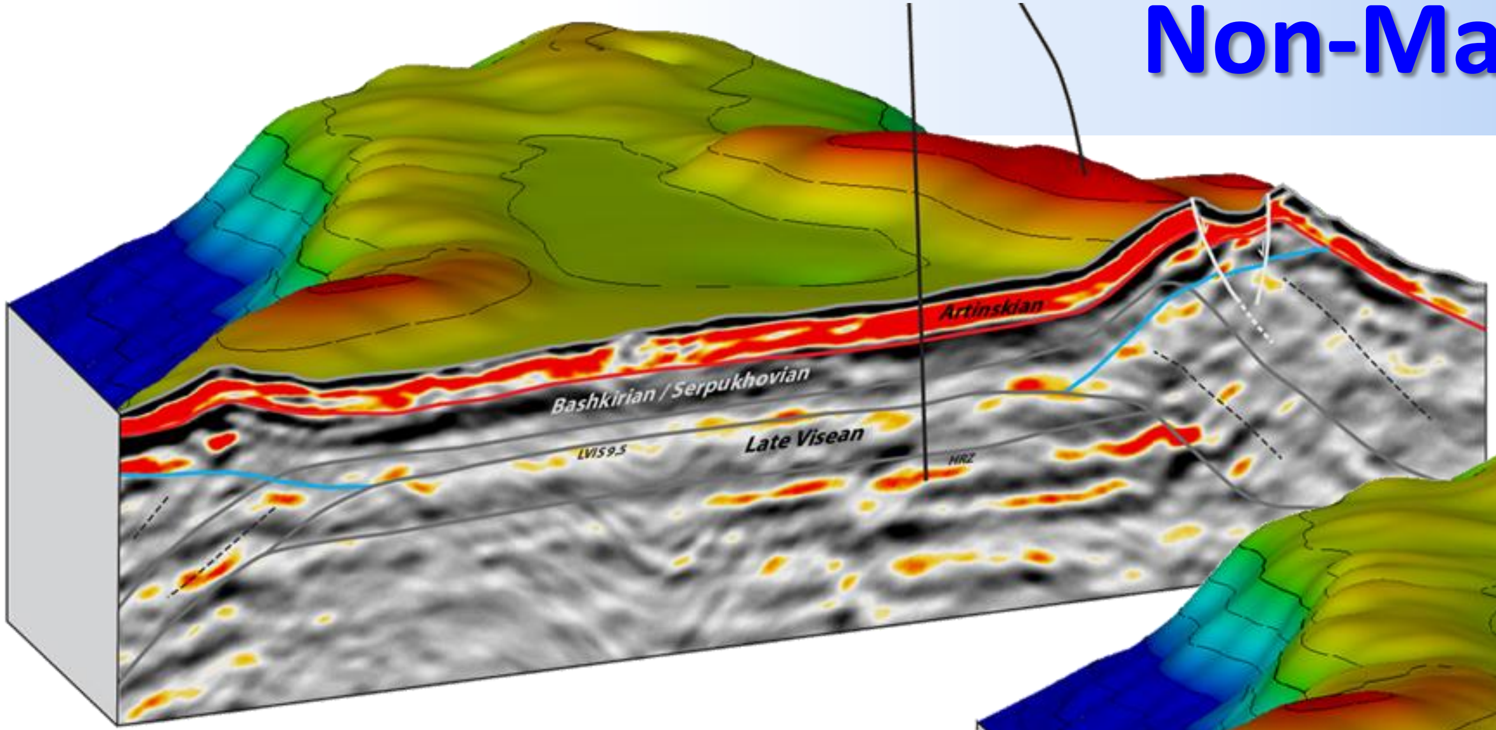


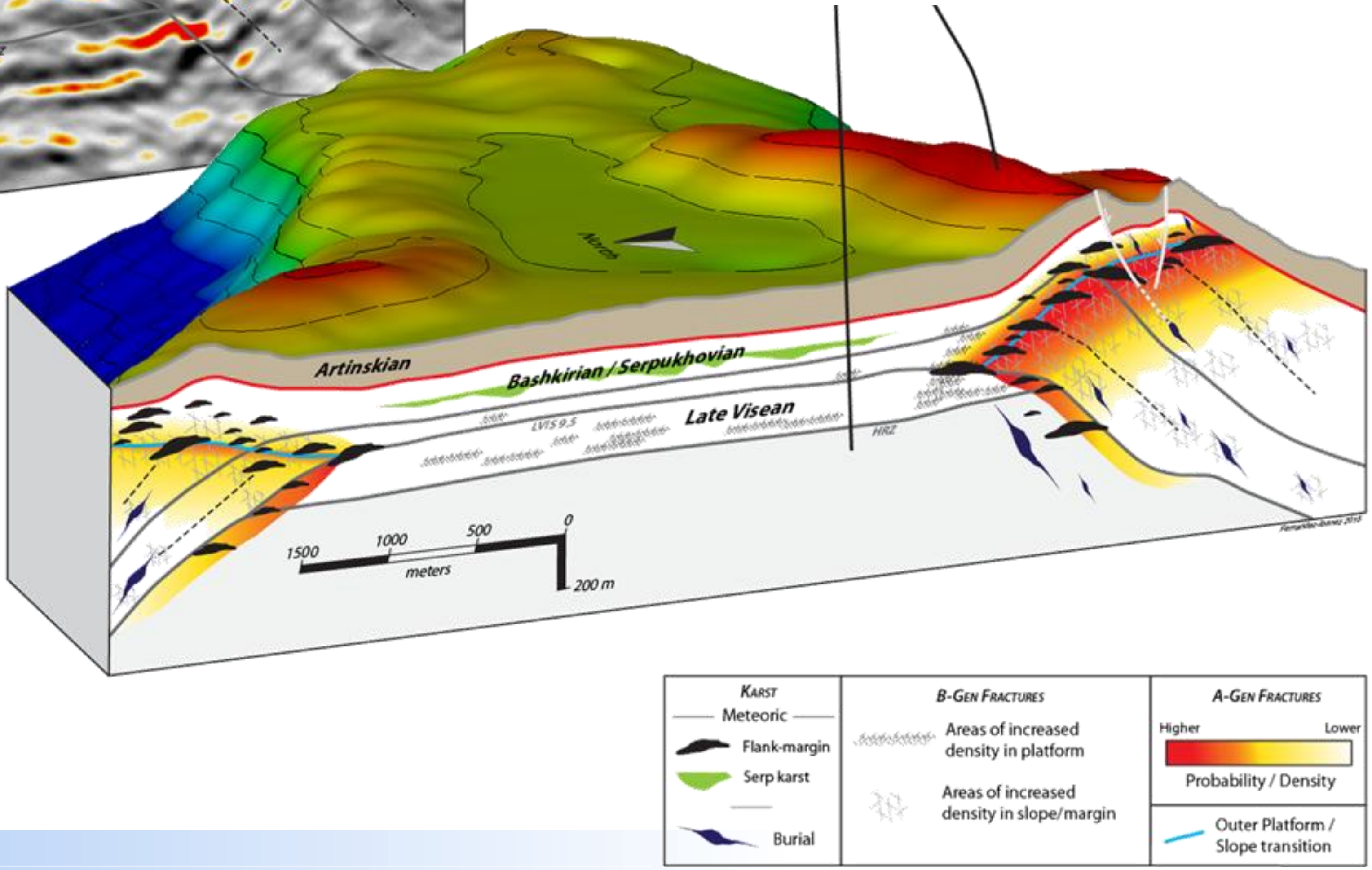
The resistivity character of fractures in image logs is no guarantee of their dynamic potential

Fracture Genetic Styles and Burial History



Non-Matrix Conceptual Model





Faulting along the Rim