Well Log and Production Based Analysis of Fractures in Karachaganak Field, Northwestern Kazakhstan*

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Abstract

Karachaganak Field, a super-giant retrograde gas condensate field located in northwestern Kazakhstan, contains significant reservoir volume where fractures are an important part of the permeability system. Both resistive (generally sealed), conductive (generally open), and effective (flowing fractures) fractures are found to occur in all investigated intervals (PV2 to P1). Field-wide amalgamations of data reveal weak strike preference toward NNE and E-W for resistive fractures, while conductive fractures show no preferred trend. However, trends in conductive fractures are apparent when the data are examined with respect to unit and to the mapped stratal horizons. In Devonian through Early-Visean units, fracture trends appear to align with respect to lineaments visible in structural surfaces. These structural lineaments are interpreted to be due to normal faulting of the platform top. Thus, Devonian and Early-Visean fractures formed in a tectonically-controlled stress environment, likely related to extension roughly perpendicular to the northern Pricaspian Basin margin. In contrast, fracture trends in Carboniferous through Permian units tend to align parallel and perpendicular to local platform margin orientations. Thus, fractures in these units are interpreted to be non-tectonic in origin and to have formed in a stress environment controlled by interaction of stratal geometry, sediment composition, and gravity forces.

Based on current understanding of existing data (primarily image and wireline logs, production logs, well tests, lost circulation zones), the majority of Karachaganak Field is classified as a Type 3 NFR (after Nelson, 2001), where fractures provide excess permeability above that of the background matrix system. A few wells are interpreted to exhibit Type 2 NFR behavior, where fractures provide essential permeability in a dominantly matrix storage system. It should be noted that, due to limitations in data availability, uncertainties remain regarding the exact magnitude of fracture-related flow effects. However, the fact that a significant number of

wells show some fracture influence at this early-stage in the field development suggests that the fracture influence might grow with time. Thus, the effects of fractures on future development scenarios should be considered.

Selected References

O'Hearn, T., S. Elliott, and A. Samsonov, 2003, Karachaganak Field, northern Pre-Caspian Basin, northwestern Kazakhstan: AAPG Memoir, v. 78, p. 237-250.

Ulmishek, G.F., 2001, Petroleum geology and resources of the Middle Caspian basin, former Soviet Union: USGS Bulletin, v. 2201-A, 42 p.

Well Log and Production Based Analysis of Fractures in Karachaganak Field, Northwestern Kazakhstan

or

Confounded by heterogeneity: *Integration of 'advanced technology' and 'fundamental models' to arrive at less-than-certain conclusions about a fractured reservoir*

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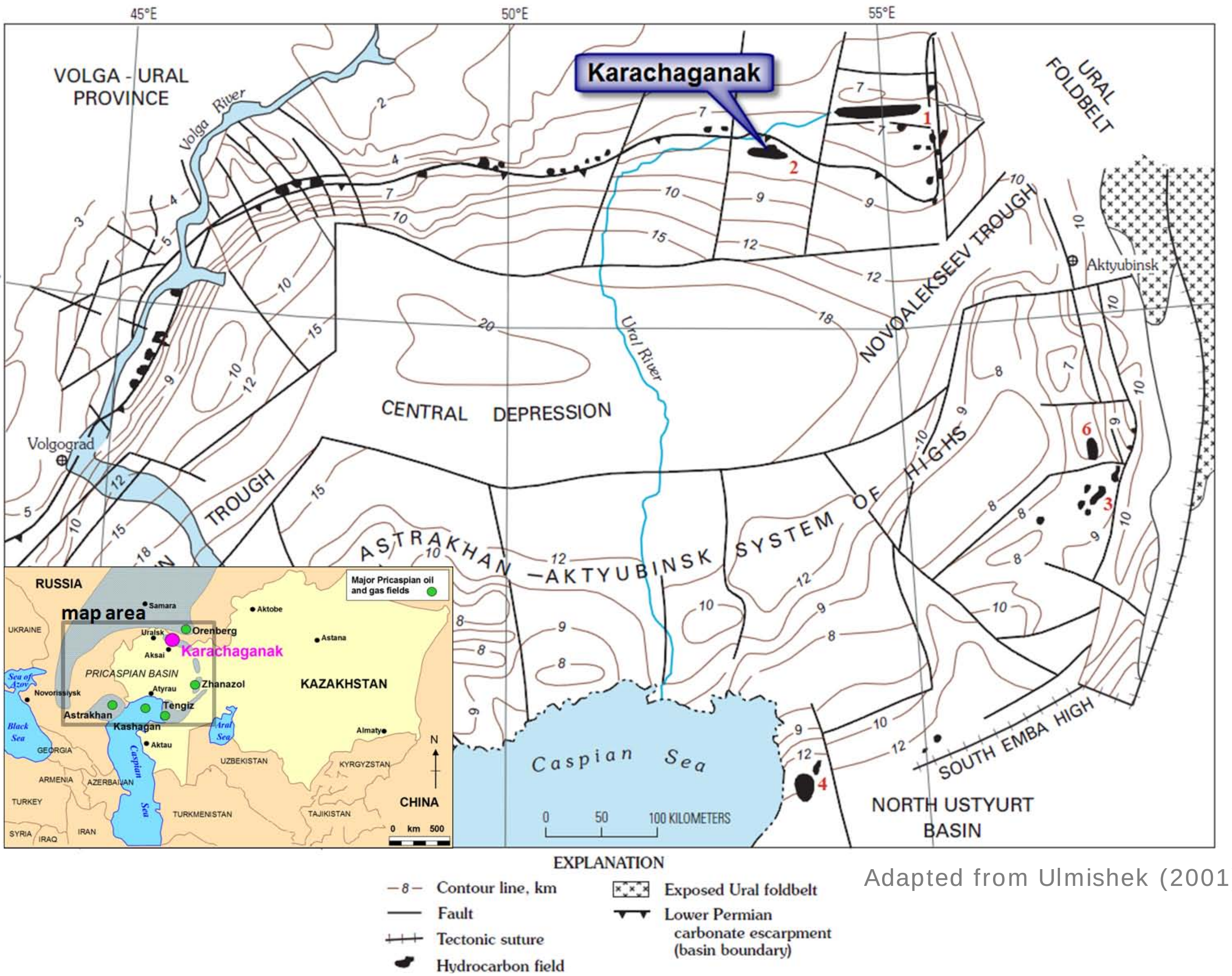
Outline

- Overview of Karachaganak geology
- Evidence for fractures
- Fracture controls and conceptual models
- Summary and Implications

Main discussion points

- **Karachaganak, an isolated steep margin carbonate platform, is a Type III fractured reservoir (terminology after Nelson, 2001)**
  - Fractures provide uplift to matrix permeability
  - A minority of wells suggest Type II behavior where fractures provide essential permeability
  - Permian wells thus far suggest no fracture influence
- **Fractures in Devonian and early Carboniferous units**
  - Fractures strike roughly parallel and perpendicular to underlying structural grain and are likely tectonic in origin
- **Fractures in Carboniferous and Permian units**
  - Fractures strike roughly parallel and perpendicular to margin and are likely non-tectonic in origin (differential compaction and gravity failure)
- **Data misalignment**
  - Despite >25 km of image log, >1 km modern core, >80 PLT, >100 well tests, and various wireline log suites, significant uncertainty remains as to the flow effectiveness of fractures identified in image log due to the fact complete data suites rarely overlap in space

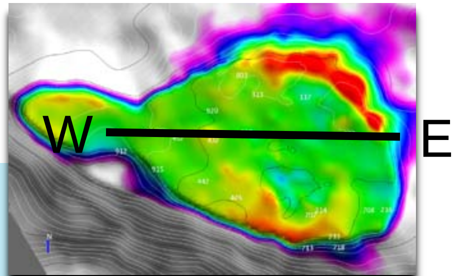
Pricaspian Basin and Karachaganak

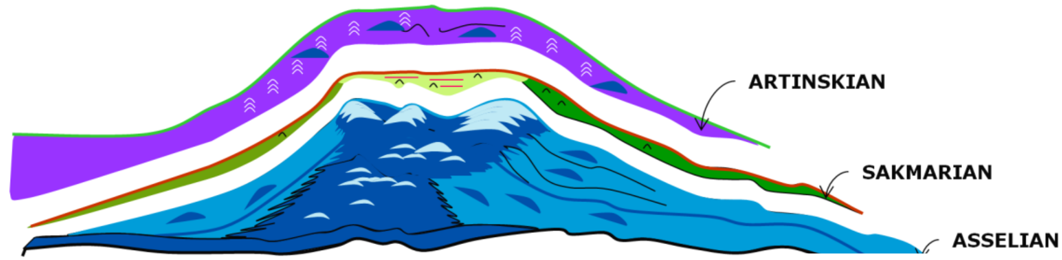


Adapted from Ulmishek (2001)

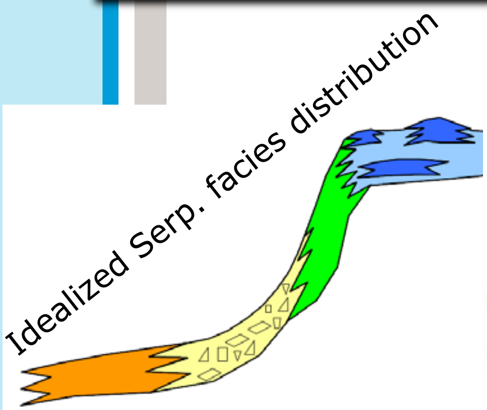
- Karachaganak located on north side of Pricaspian Basin
- Most basin development activity appears to be Devonian and earlier
- Thick, mobile salt section overlies Karachaganak

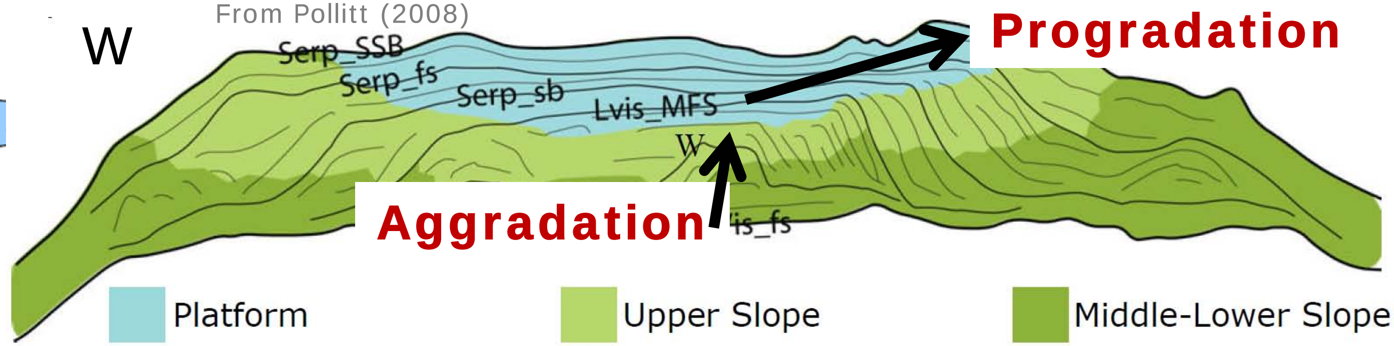
Karachaganak geology





From Pollitt (2008)





From Katz and Bergman (2009)

- F1 – Shallow Platform Interior (skeletal grainstones and packstones)
- F2 – Open/Deep Platform Interior (crinoidal-peloidal ps and ws)
- F3 – Upper Slope (algal and microbial boundstones and grainstones)
- F4 – Middle Slope (breccias of microbial boundstones)
- F5 – Distal Slope (redeposited grainstones and packstones)

From Bassant and Hsieh (2006)

1. Devonian broad shallow water platform
2. Early Carboniferous aggradation
3. Carboniferous progradation
   - characteristic steep-rimmed stratal profile
4. Permian pinnacle reefs and progradation

<u>Resource est. (*from O'Hearn et al., 2003*)</u>

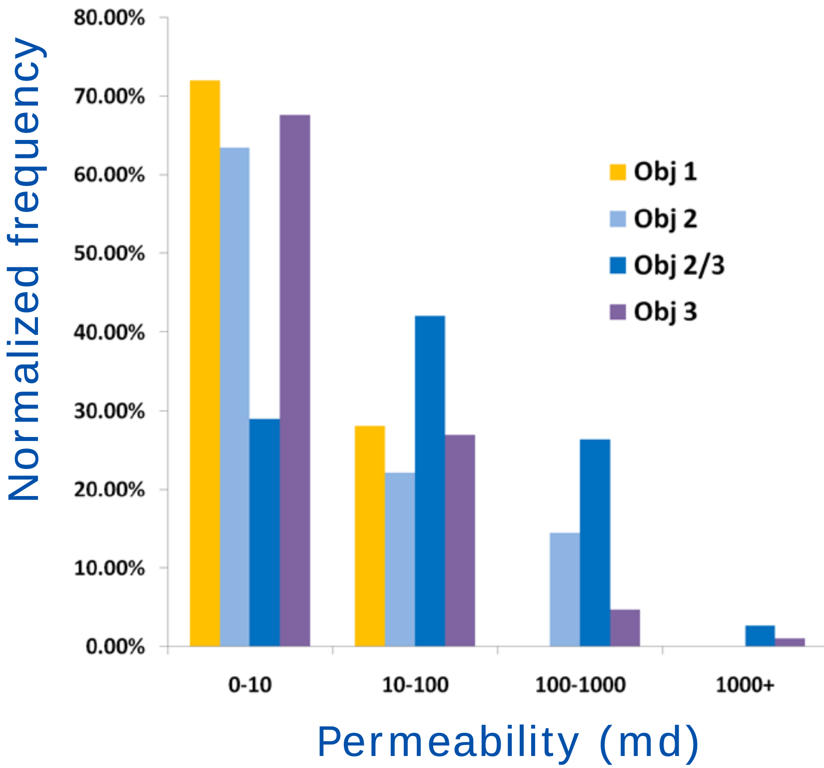
- Retrograde gas condensate field with 200 m oil rim (~1.7 km total column)
- Original in-place resource: 48 TCF gas & 10 MMBBL

Data analysis for fracture flow influence

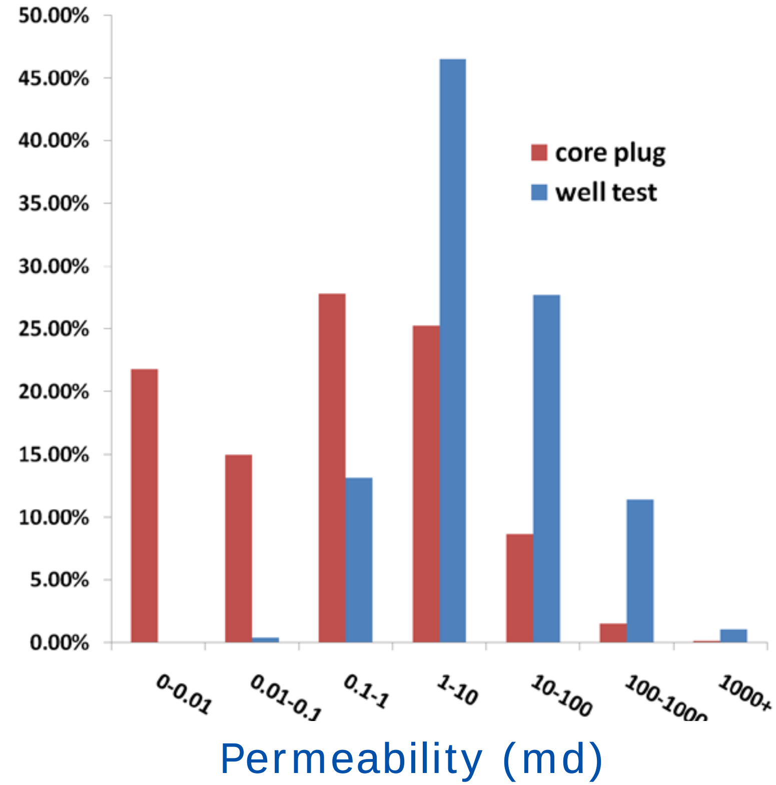
- Core plug permeability
- Well tests
- Lost circulation
- Core
- Image logs and PLT

Analysis of permeability data

Well test permeability

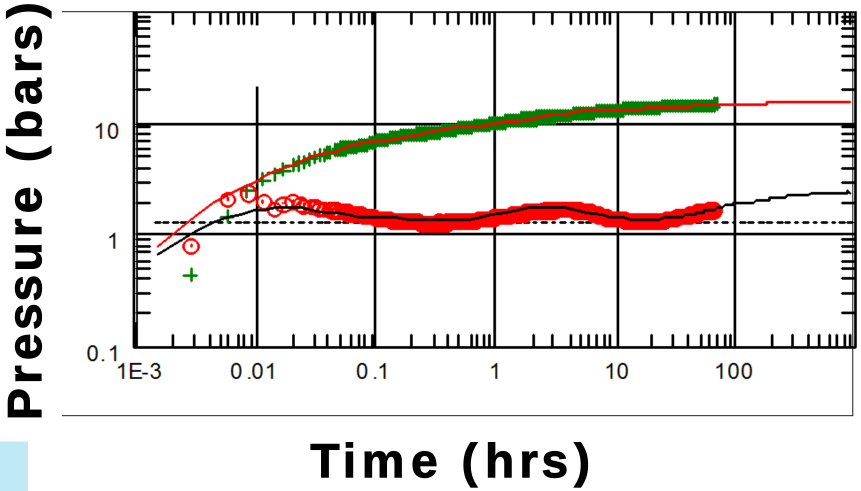


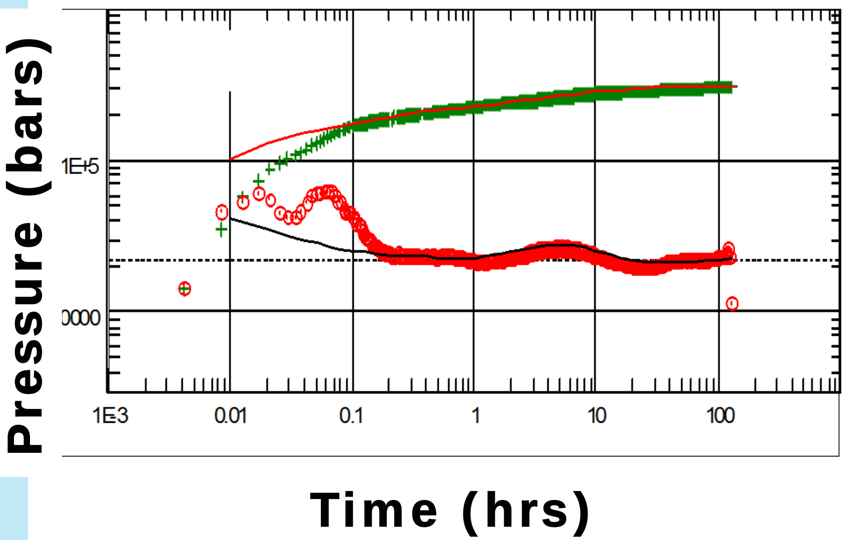
Core plug vs. well test



- Well test perms are strongly skewed (approx. log-normal with high value)
- Significant mismatch between well test and core plug perms (core plugs underestimate perm)
- Both plots suggest significant heterogeneity

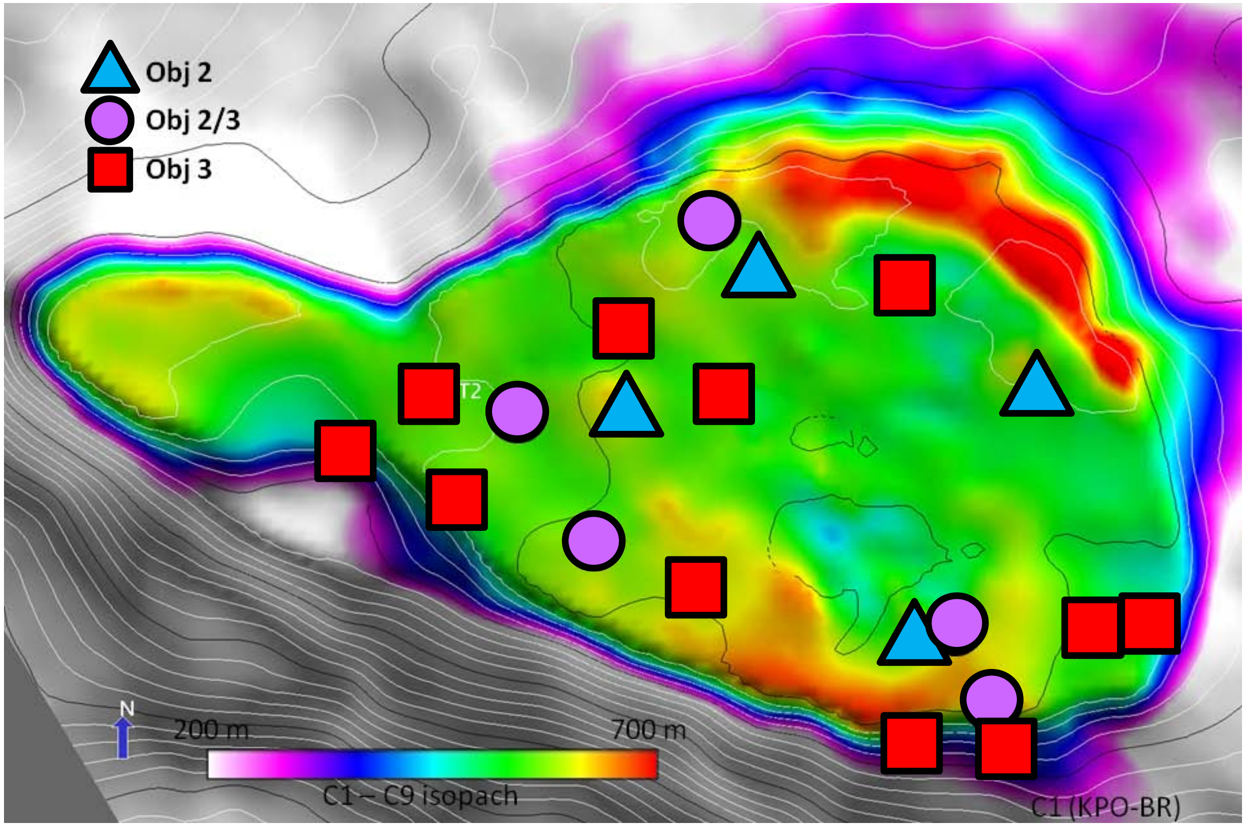
Well test signature





- A few well tests suggest a multi-porosity system (e.g. fractures + matrix)
  - Two best examples shown
  - Both cases are also well fit by a multi-layer radial flow model
- Pulse-tests generally do not show significant anisotropy (some exceptions)

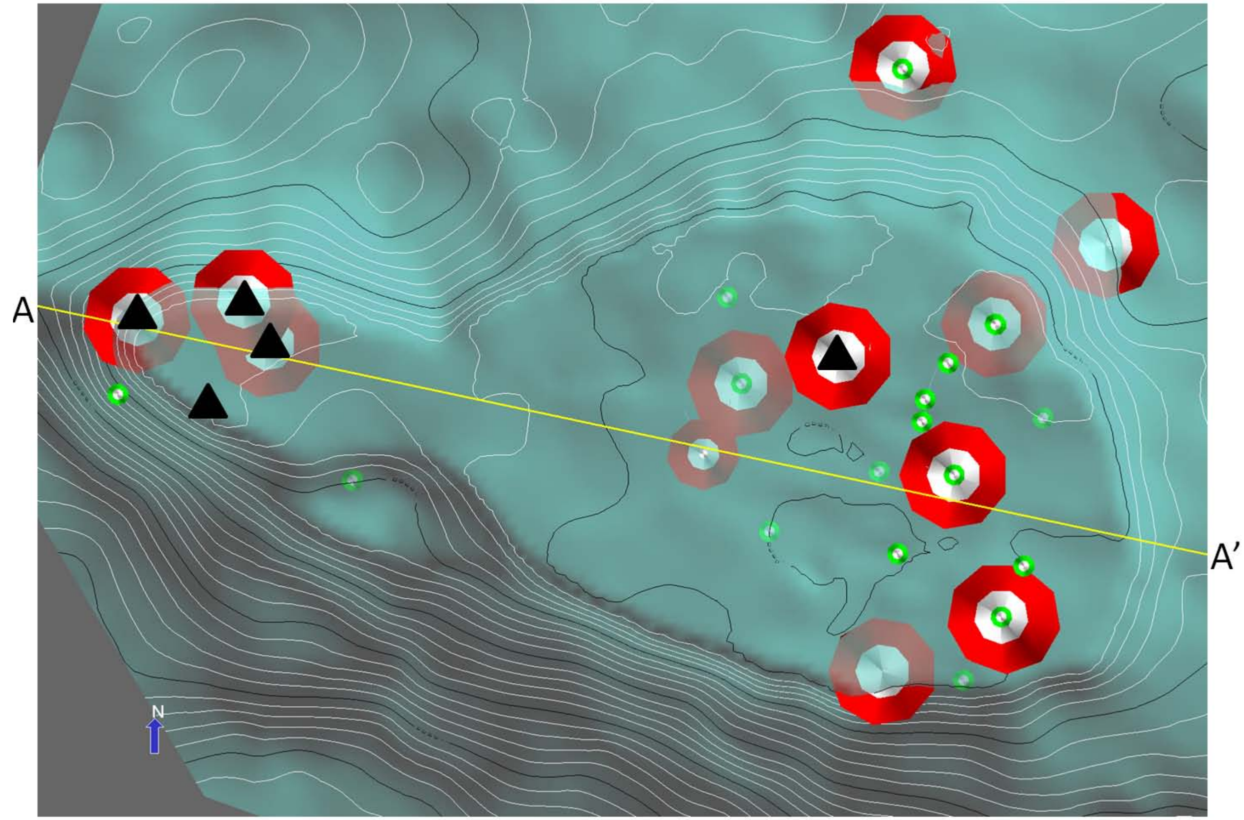
Well test interpretations suggesting fractures

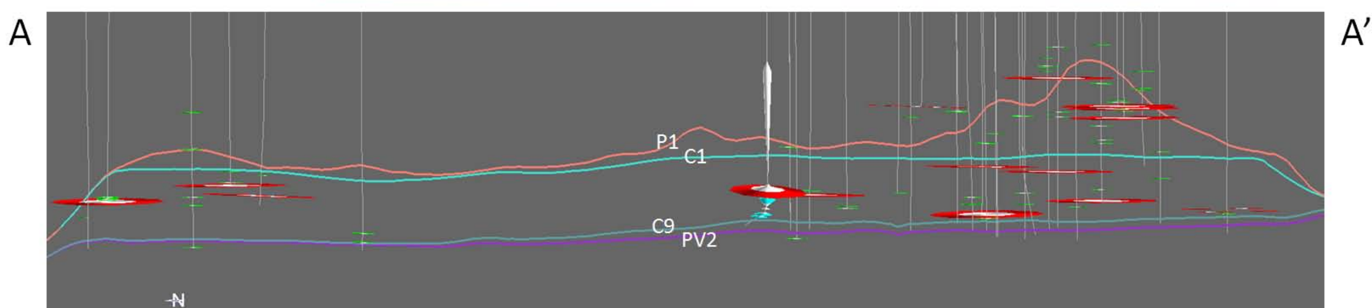


- Twenty different well tests were interpreted to have, at least in part, a multi-porosity signature
- Wells tests suggesting some fracture influence tend to occur around margin
- Note that wells with known effective fractures do not show up in the map and vice versa

Spatial distribution of lost circulation

- Red circles indicate severe LCZ event (> 3 m^3/hr)
- Black triangles indicate total losses (P&A)
- No apparent stratigraphic control on loss events
- Ubiquitous loss of fluid circulation in far-west satellite

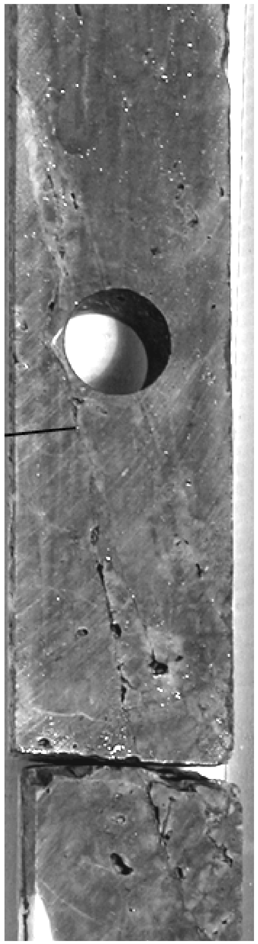




Fractures in core

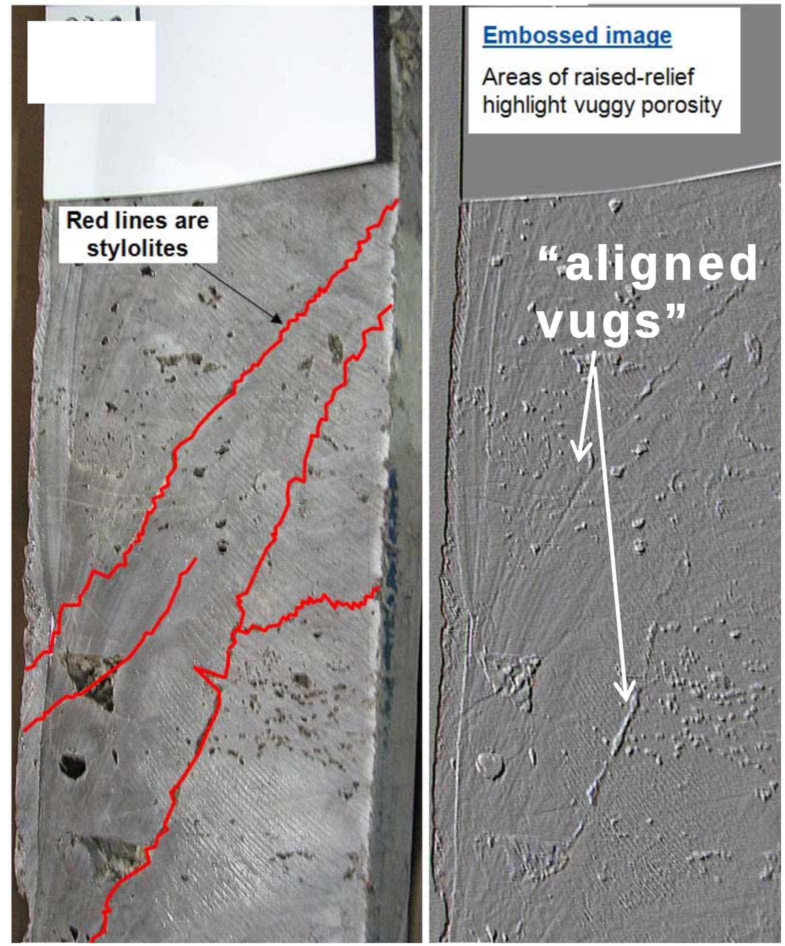
Well A

Well B



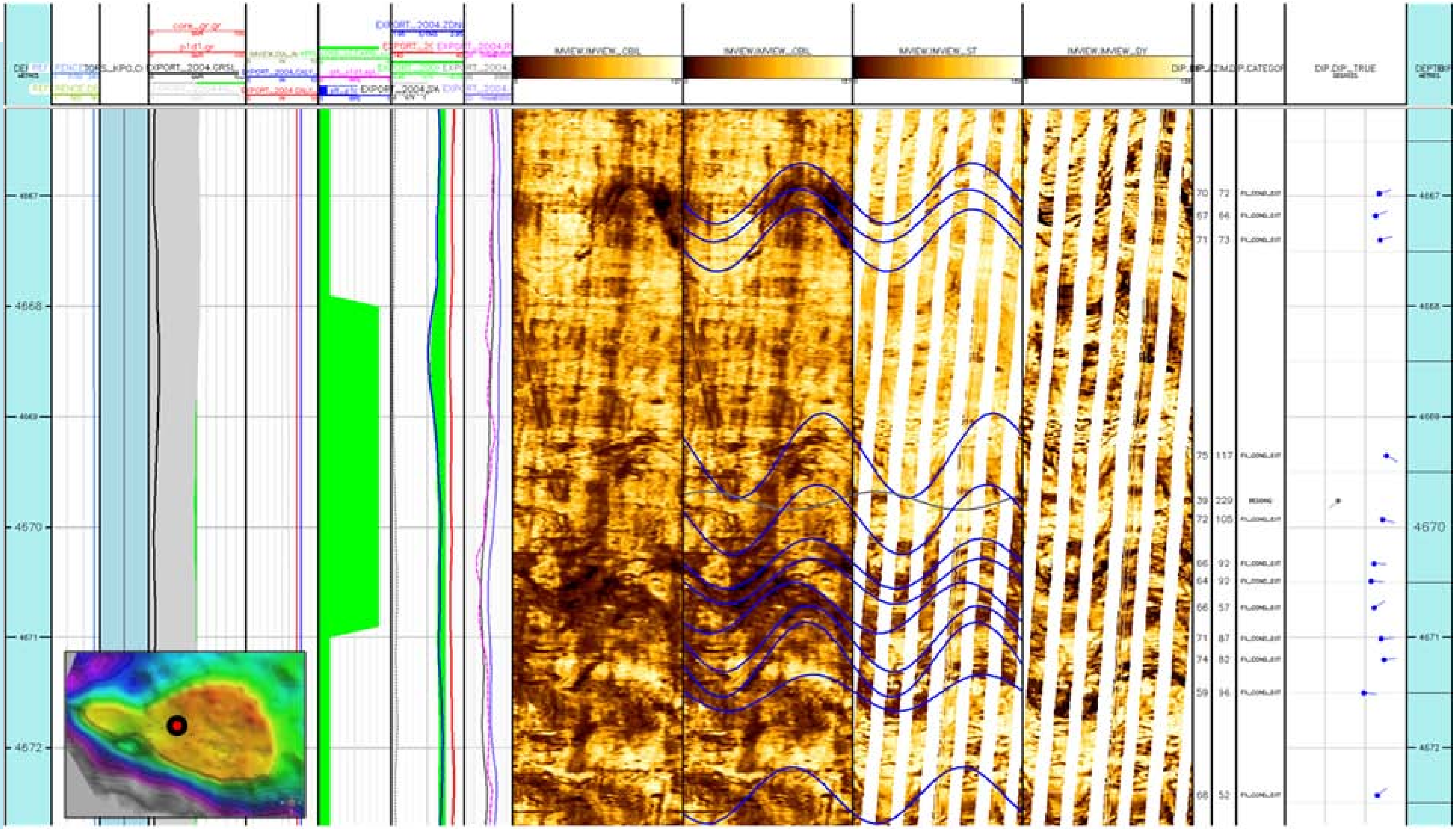
Well C

Well D



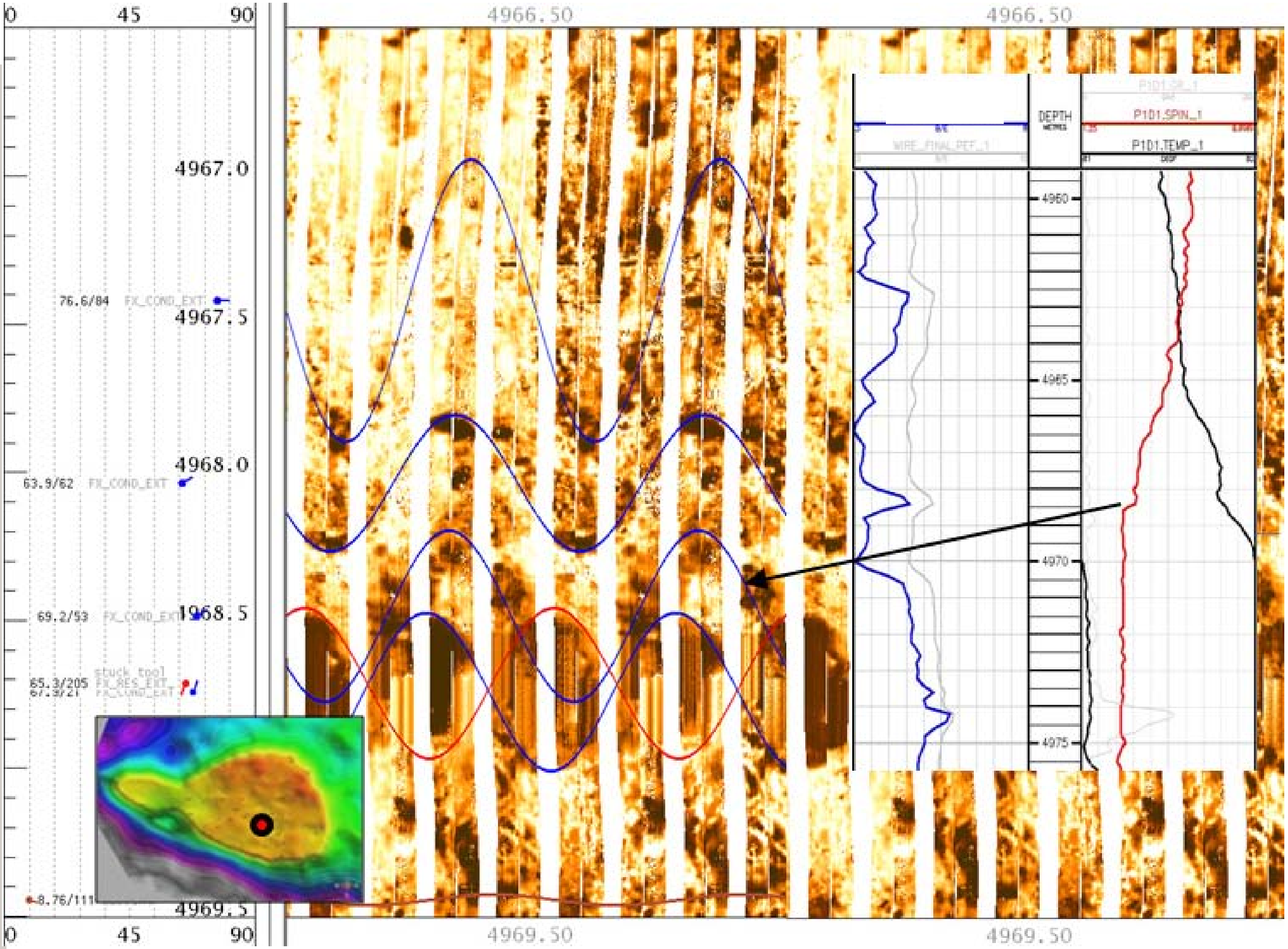
- Fractures present in core, but correlable to in-flow in only one case
- Interesting relationship between stylolites and aligned vugs

Effective fractures in image log (Carboniferous)



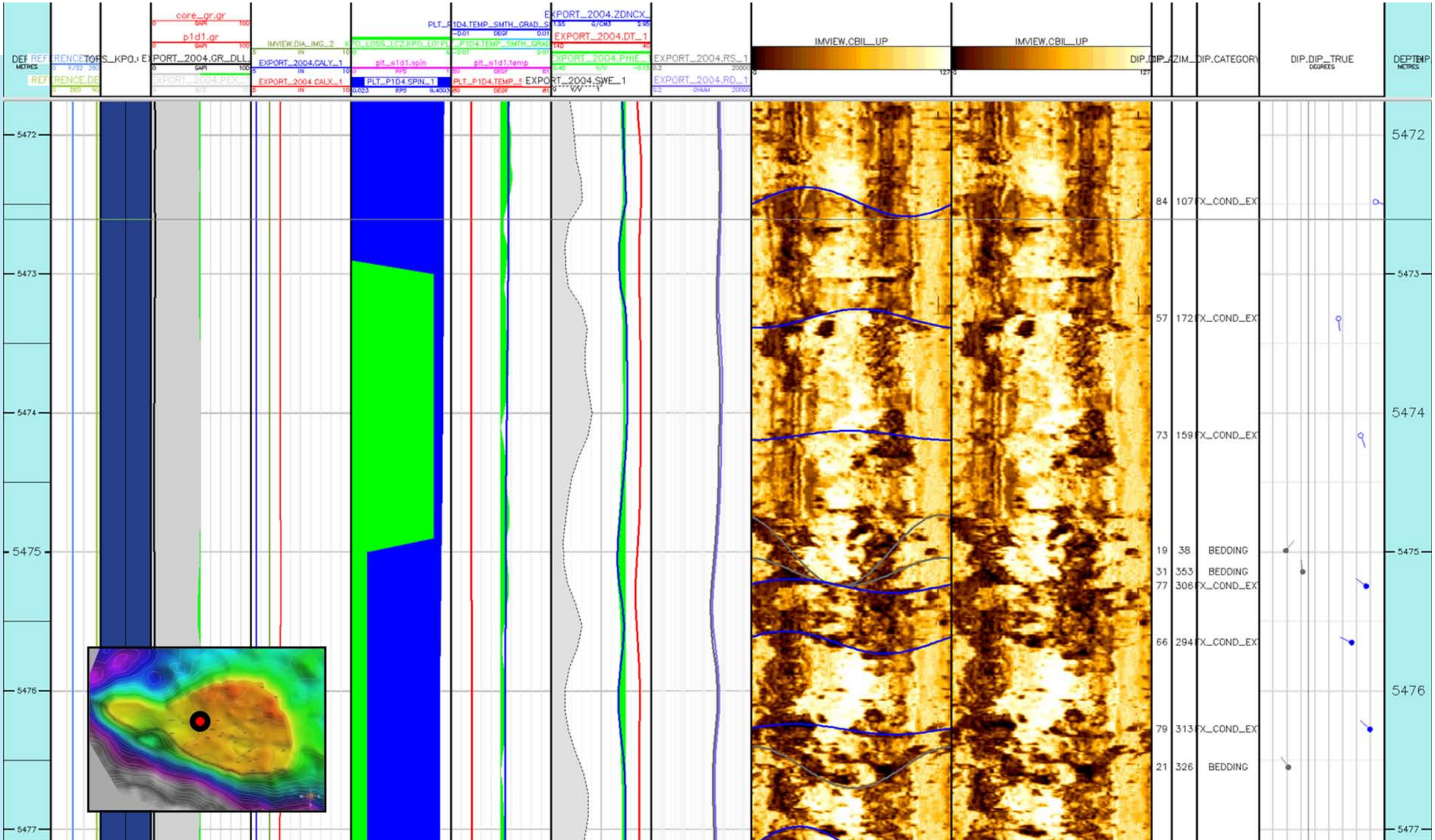
- Severe LCZ corresponds in depth with open fractures

Effective fractures in image log (Carboniferous)



- Modest PLT signal corresponds in depth with open fractures

Plugged fractures? (Carboniferous)

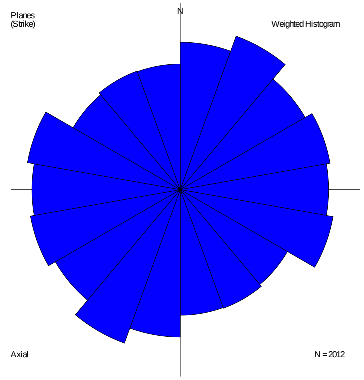


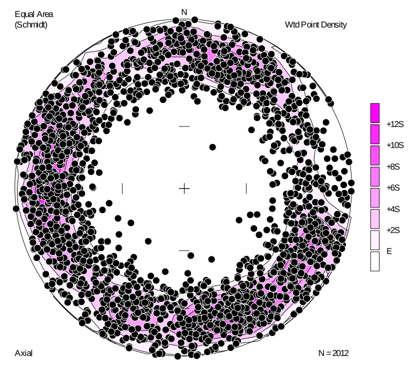
- Severe LCZ corresponds in depth with open fractures. However, subsequent PLT pass does not detect inflow.

Fracture Trends

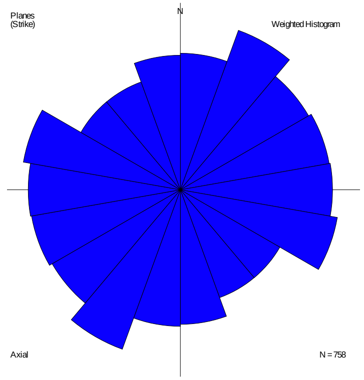
Conductive fractures – All wells, all units

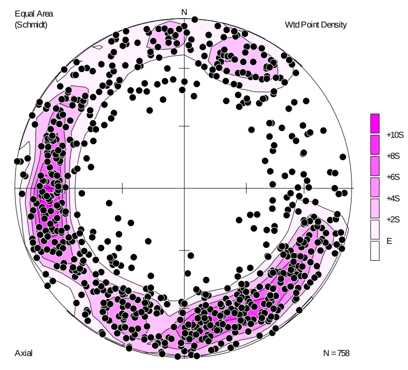
Moderate & High confidence picks



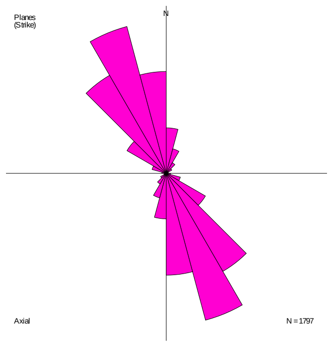


High confidence picks



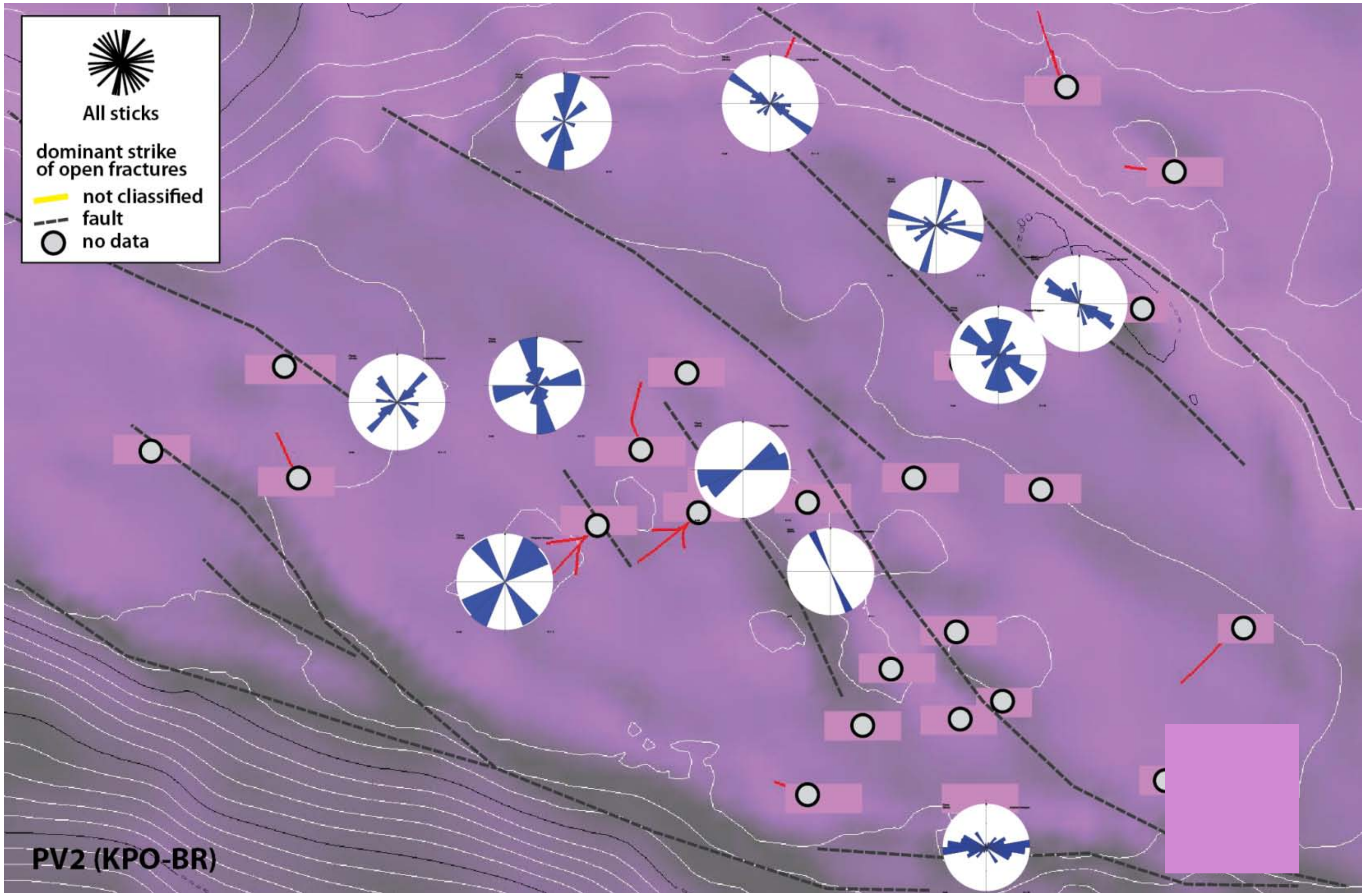


Max Horizontal Stress Direction



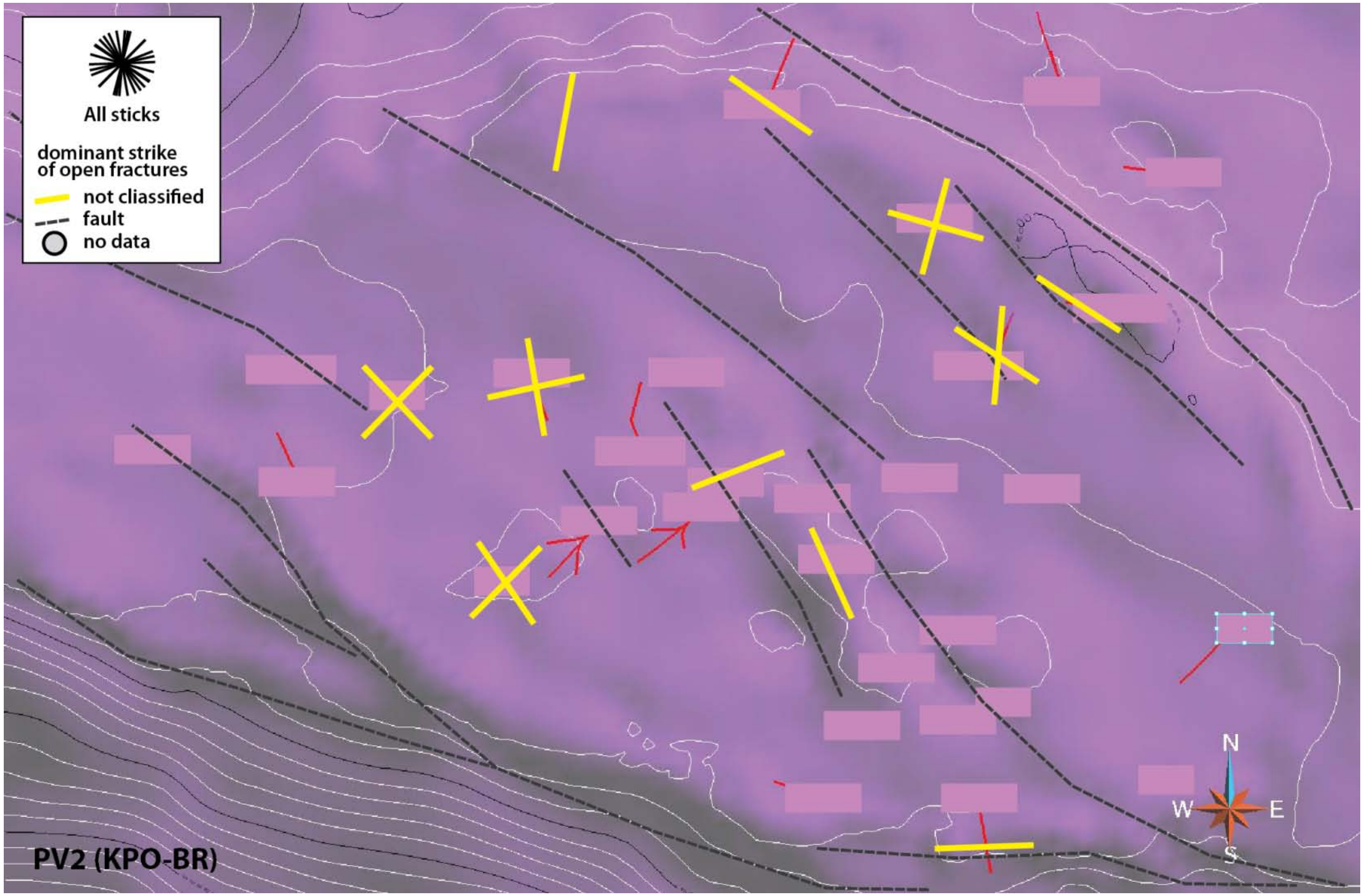
- Data suggest NO field-wide trend in fracture orientation, as is common for fractures formed under tectonic load
- Lack of regional trend suggests formation in local (gravity) stress field
- Note strong preference for NE dip direction
    - Suggests fractures formed prior to regional tilting
- No relation to modern stress state

Open fracture trends – early Carb. & Devonian



- **Fractures show two dominant trends NE and NW**
- **Fractures align with lineaments (likely faults) in base platform surface**

Open fracture trends – early Carb. & Devonian



- Fractures show two dominant trends NE and NW
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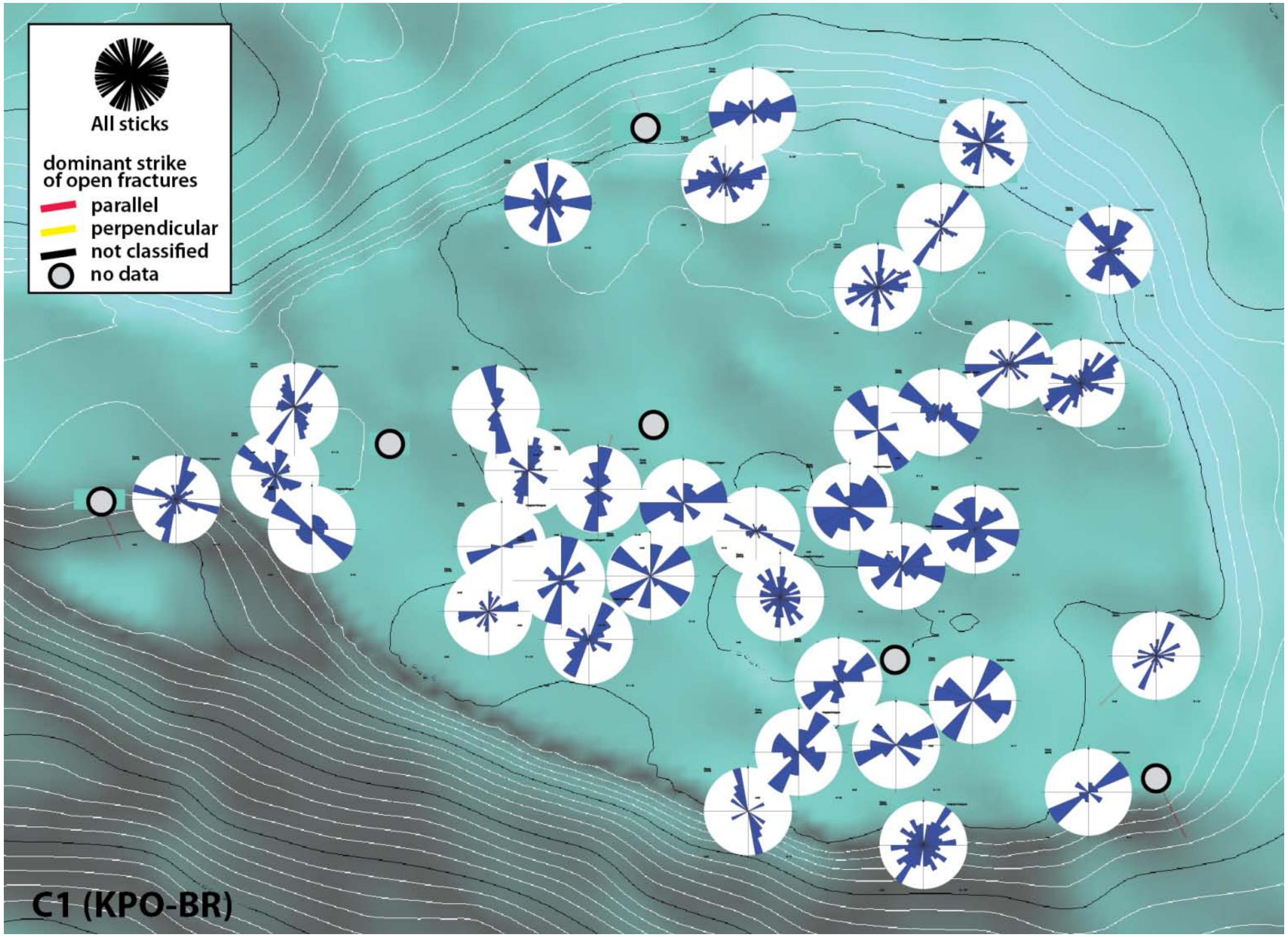
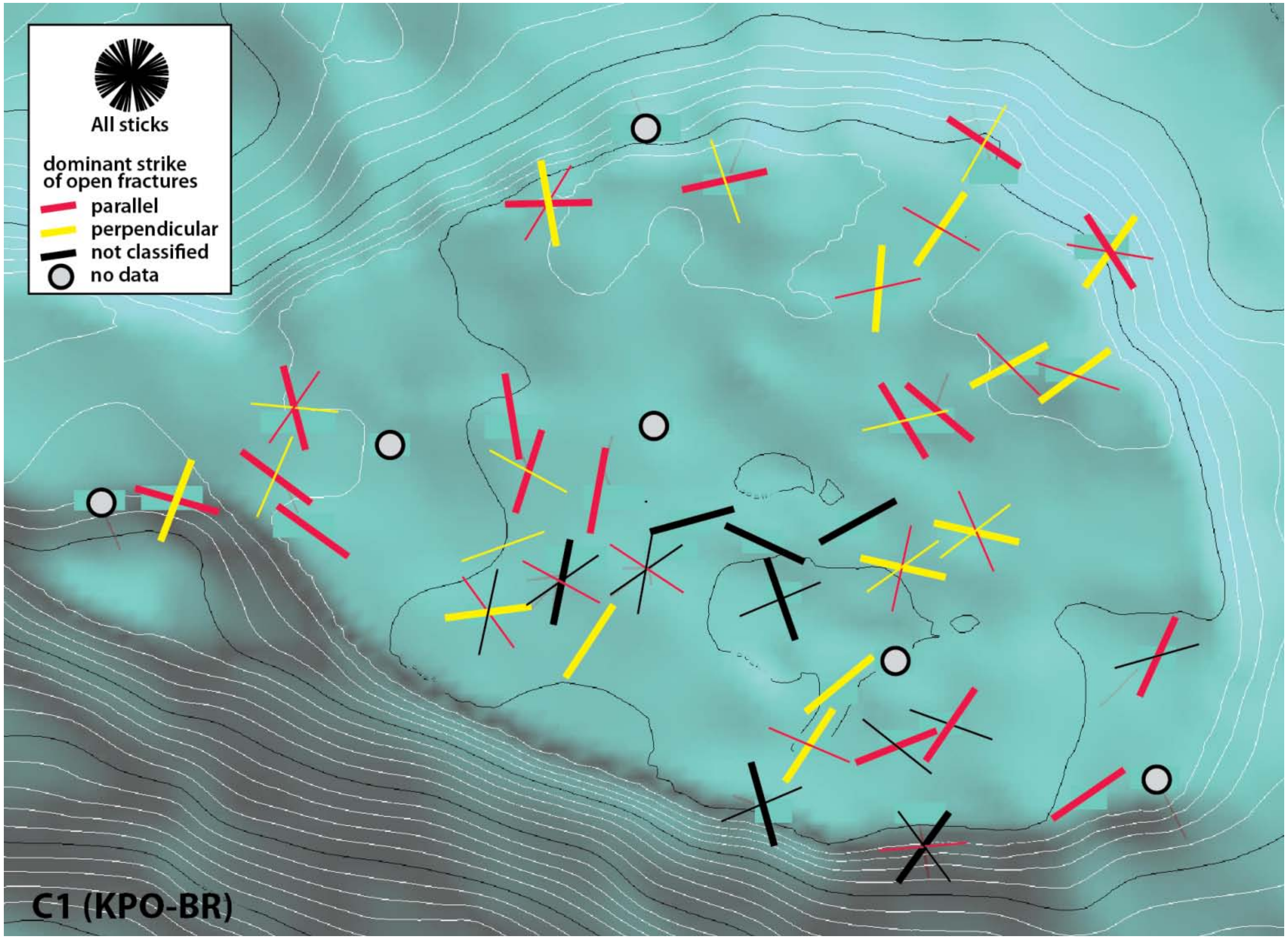
Open fracture trends – Carboniferous



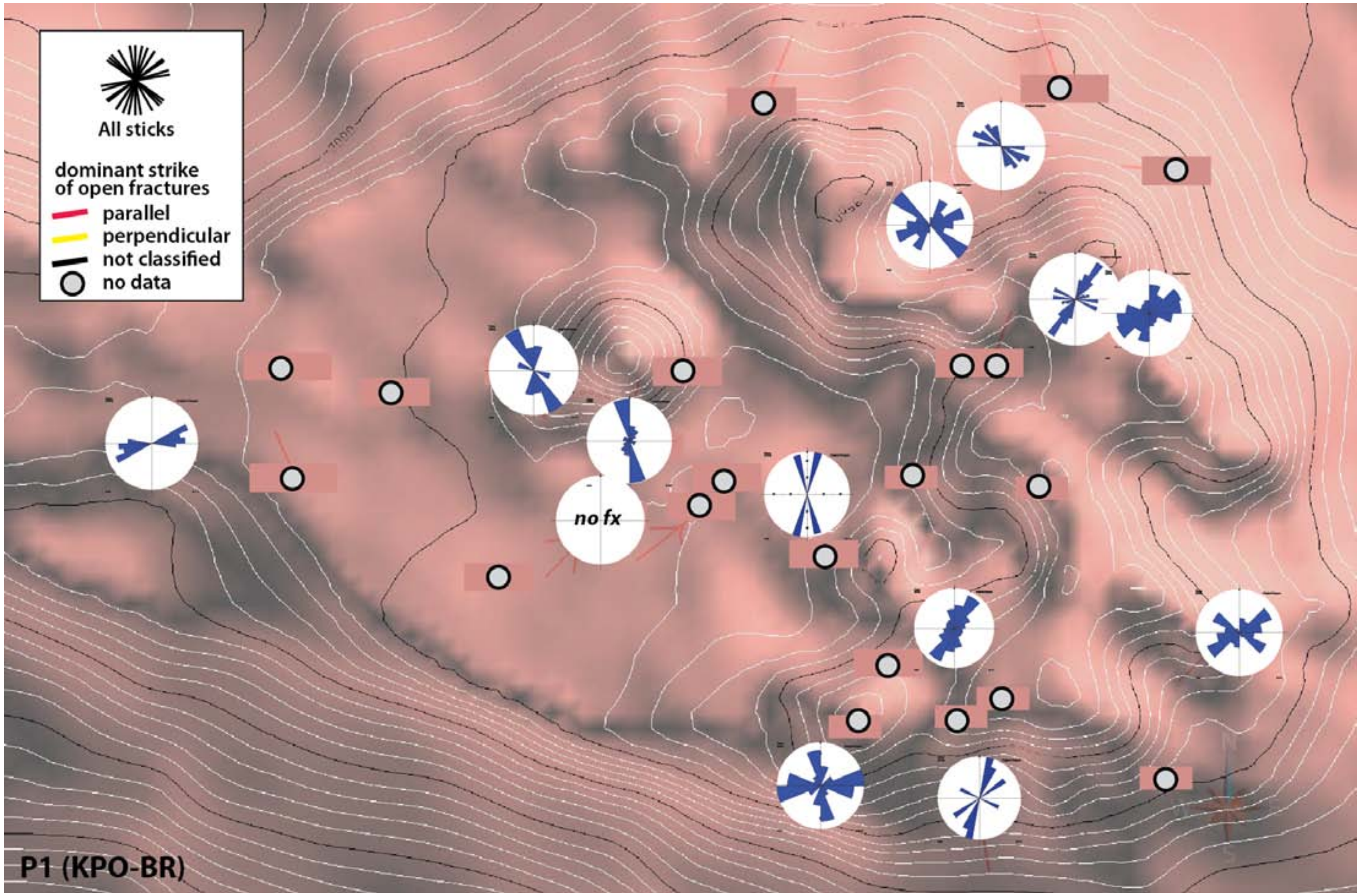
- Fractures show no dominant field-wide trend
- Fractures generally align parallel and perpendicular with local margin

Open fracture trends – Carboniferous



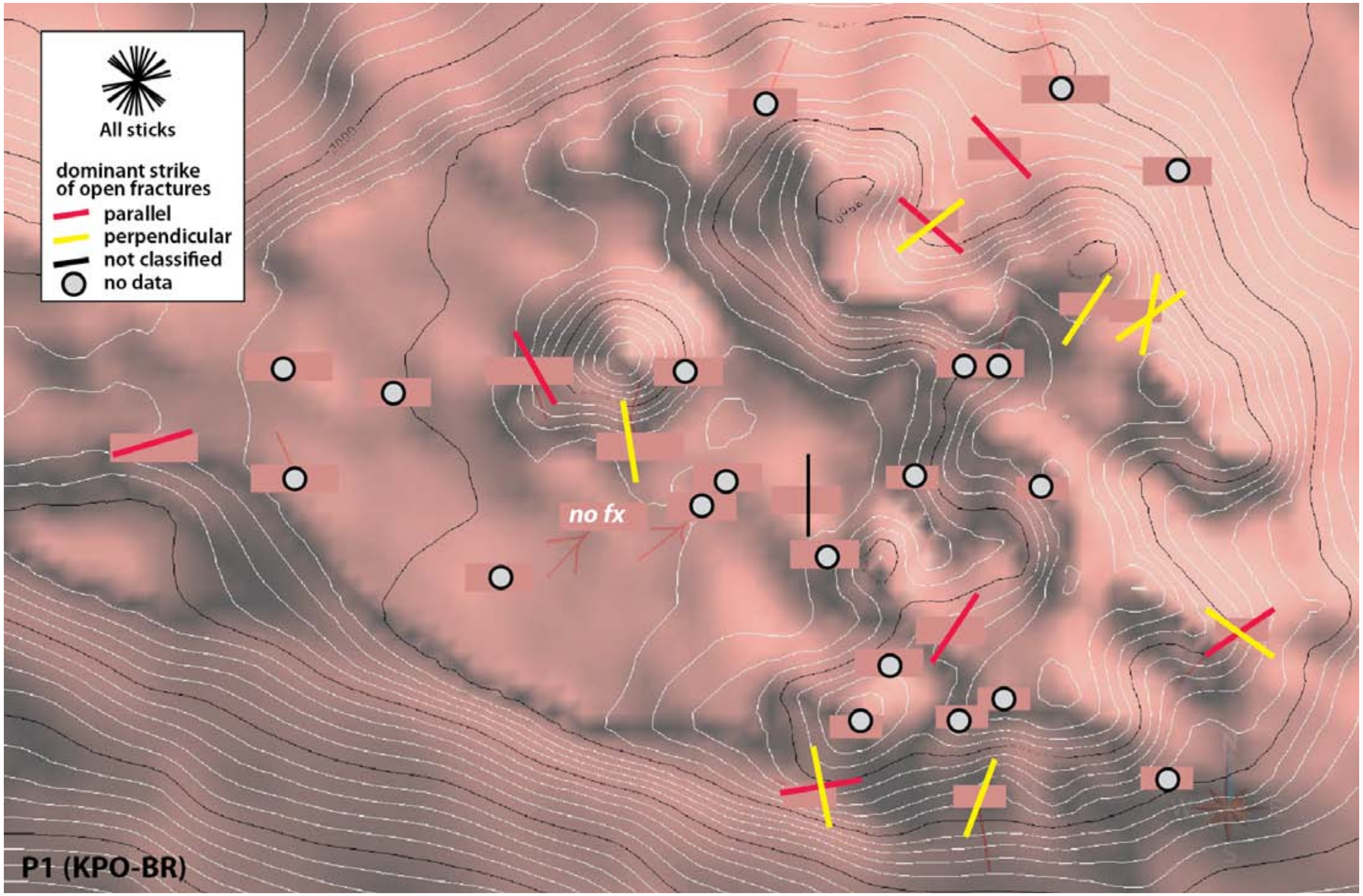
- Fractures show no dominant field-wide trend
- Fractures generally align parallel and perpendicular with local margin

Open fracture trends – Permian



- **Fractures show no dominant field-wide trend**
- **Fractures align parallel and perpendicular with local margin**

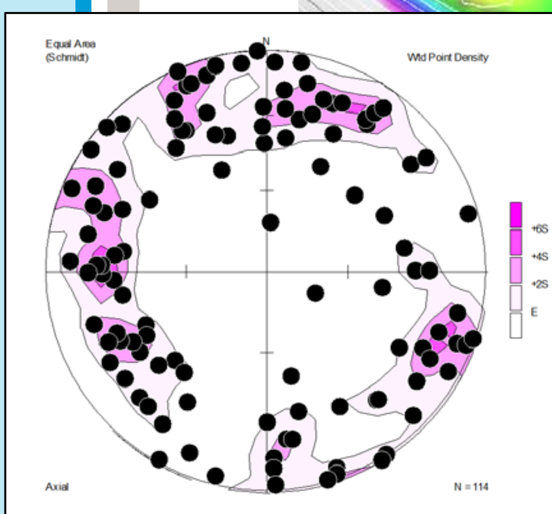
Open fracture trends – Permian

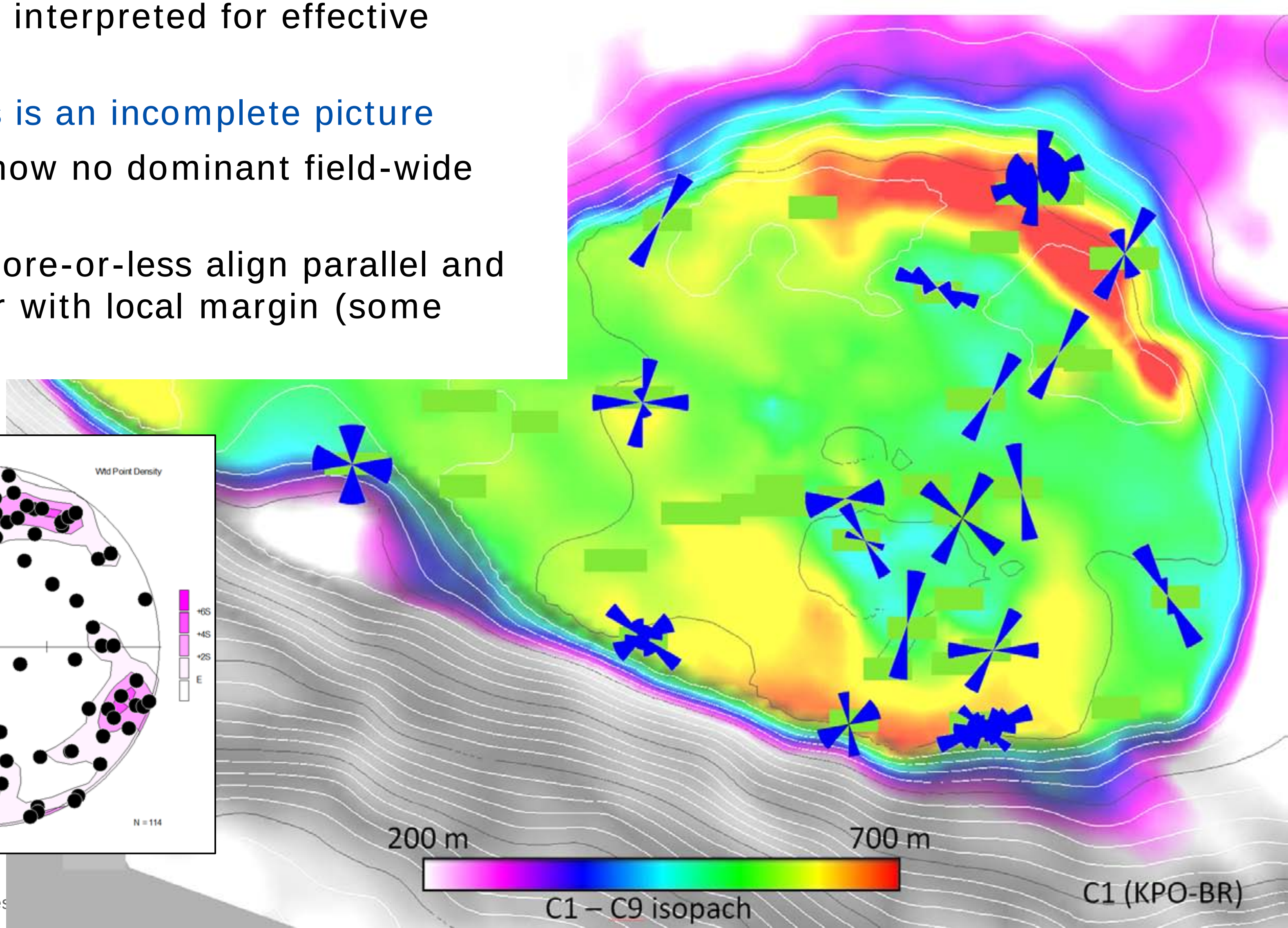


- **Fractures show no dominant field-wide trend**
- **Fractures align parallel and perpendicular with local margin**

Effective fracture trends

- Only portions of wells with both image log and PLT were interpreted for effective fractures
    - i.e. this is an incomplete picture
- Fractures show no dominant field-wide trend
- Fractures more-or-less align parallel and perpendicular with local margin (some exceptions)





Conceptual models for Karachaganak deformation

Era dominated by external forces (tectonic forces)

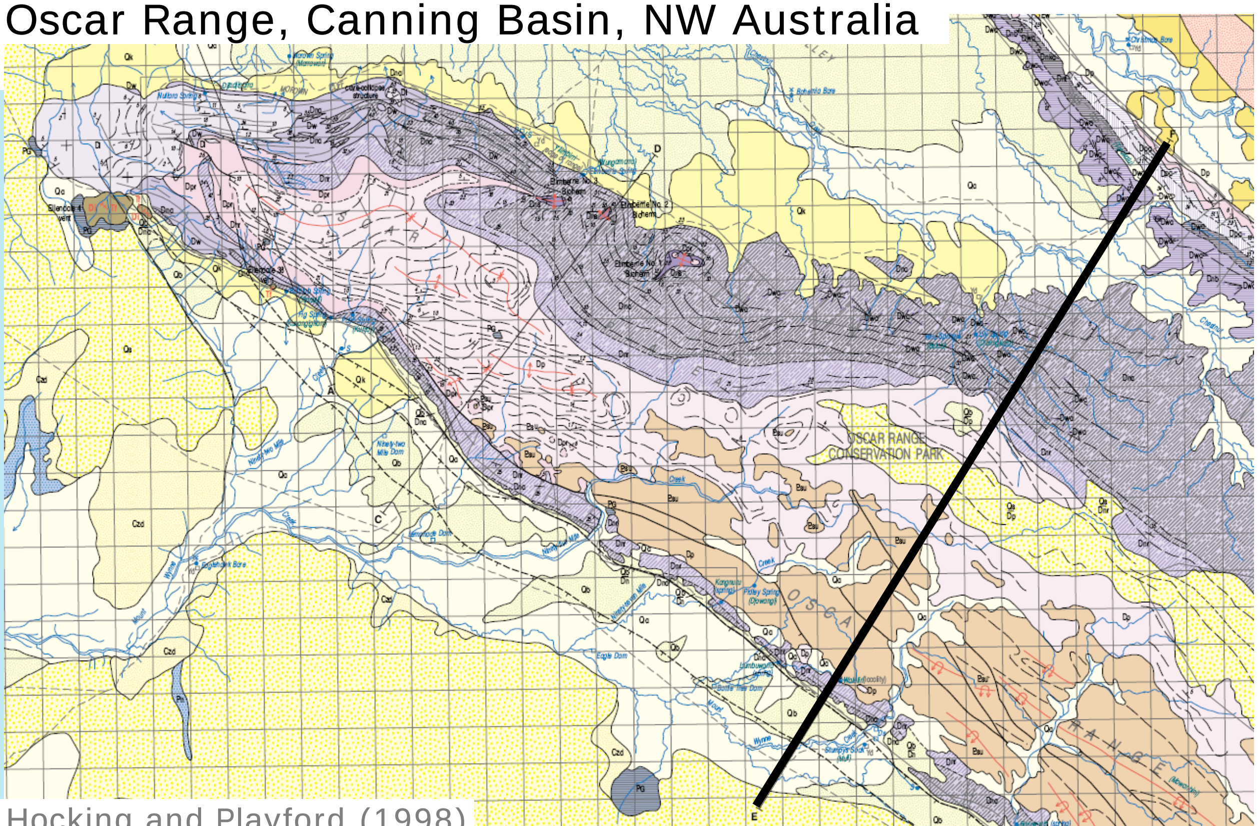
- Devonian to Early Carboniferous
  - SSW to NNE directed extension (approx perpendicular to Pricaspian basin boundary)
  - Activity wanes with time
    - Minor activity of deep seated faults

Era dominated by internal forces (gravitational forces)

- Carboniferous to Permian
  - Deformation result of intrinsic processes (i.e. differential compaction and slope failure)

Tectonic model for Devonian to Early Carboniferous development

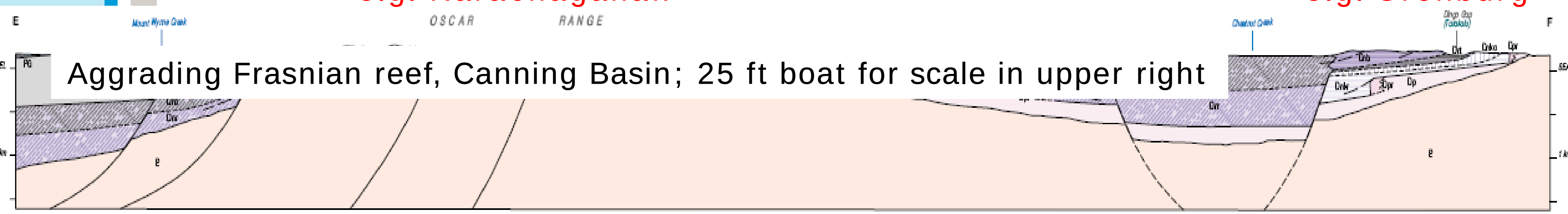
Oscar Range, Canning Basin, NW Australia



Hocking and Playford (1998)

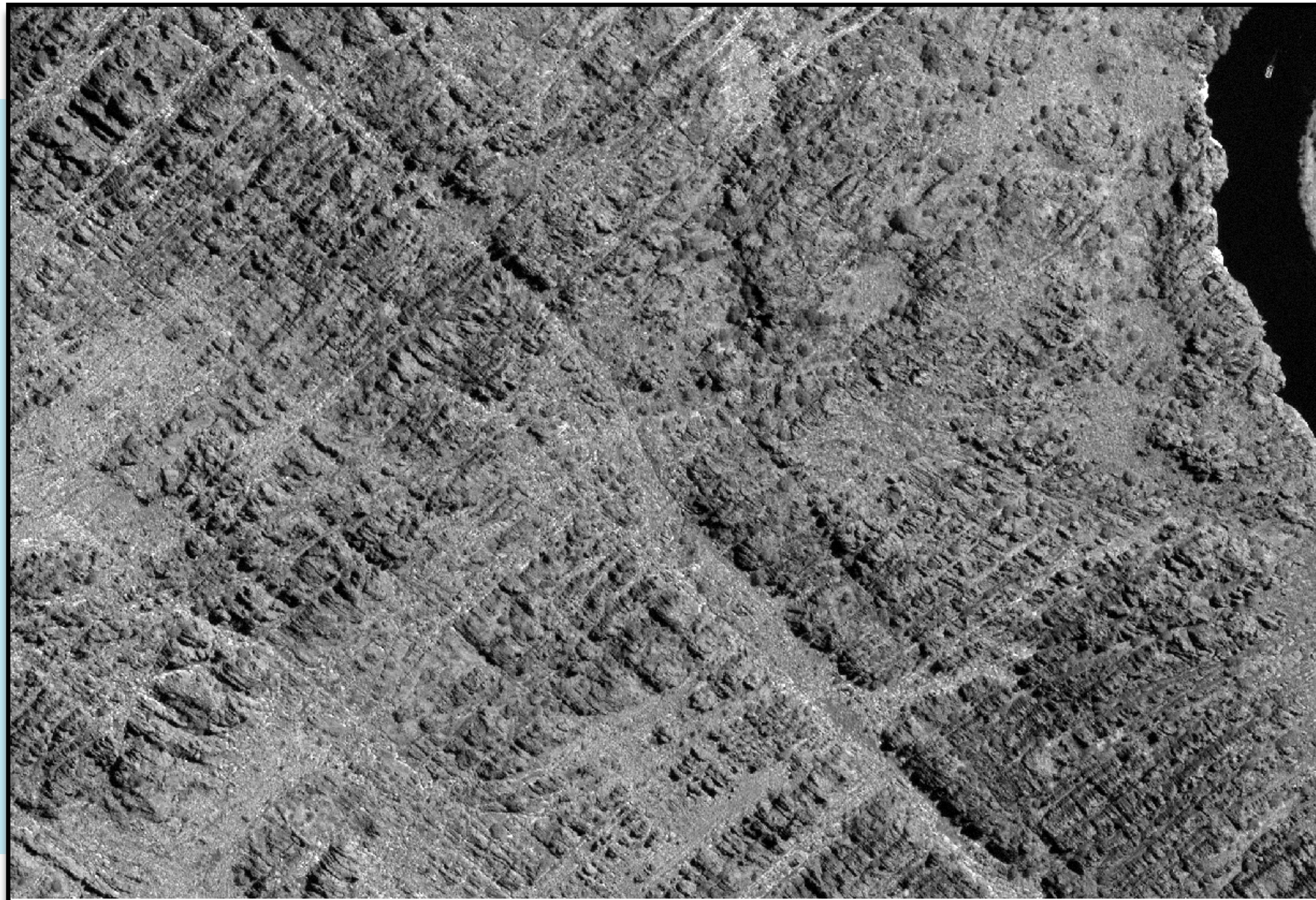
e.g. Karachaganak

e.g. Orenburg



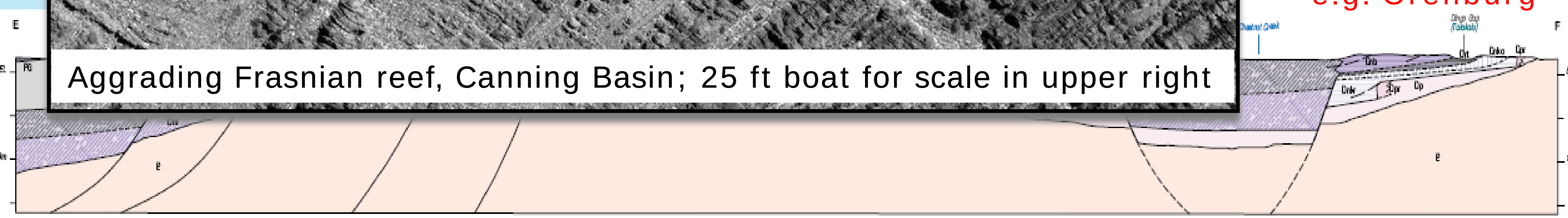
Aggrading Frasnian reef, Canning Basin; 25 ft boat for scale in upper right

Tectonic model for Devonian to Early Carboniferous development



Aggrading Frasnian reef, Canning Basin; 25 ft boat for scale in upper right

e.g. Orenburg



Gravity-driven model for Carboniferous to Permian development

McKittric Prograding Famennian reef, Canning Basin; Field of view ~ 1 km

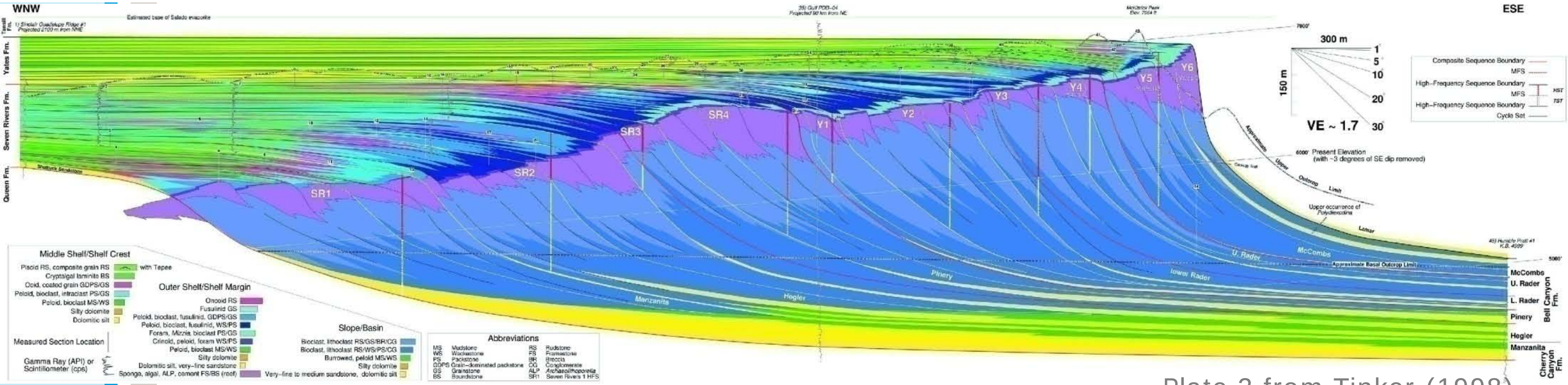
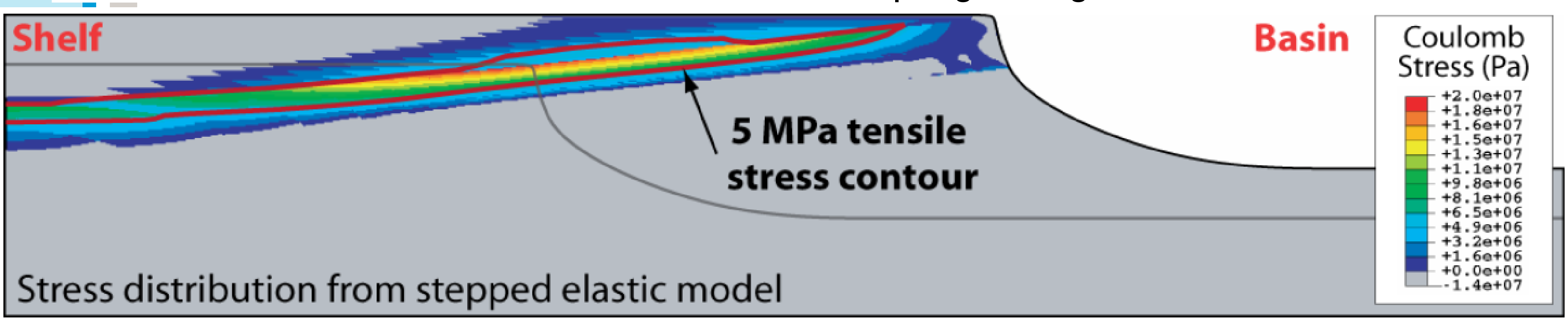
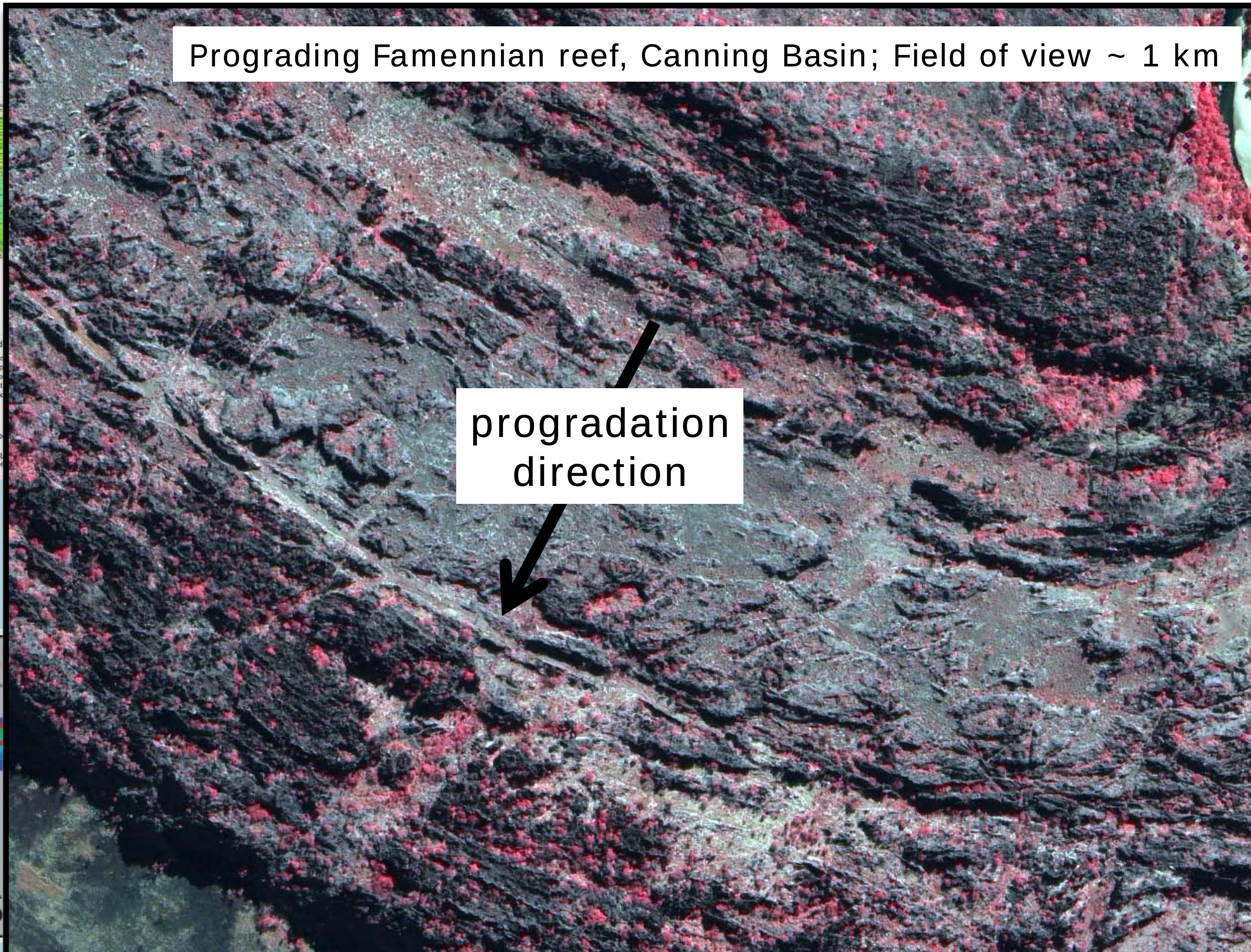


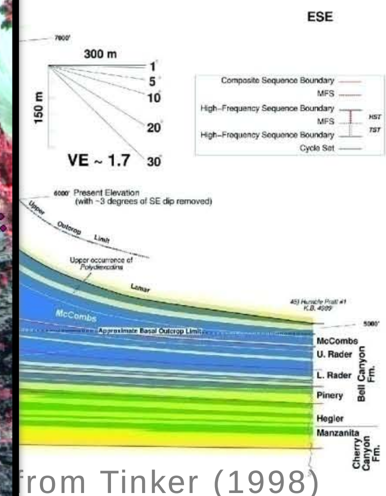
Plate 2 from Tinker (1998)

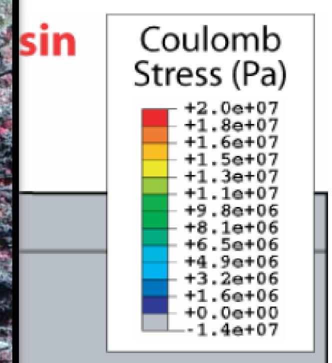
Geomechanical model of Coulomb stress in a prograding reef



Gravity-driven model for Carboniferous to Permian development







Summary and Conclusions

What is the nature of fractures at Karachaganak

- **Devonian to Early Carboniferous**
  - Fractures exhibit field-wide directional trends in Devonian to early Carboniferous
    - Fracture orientations appear to relate to underlying structural grain, suggesting that they are controlled by tectonic processes
- **Carboniferous to Permian**
  - Fractures do not exhibit field-wide directional trends
  - Fractures exhibit regional directional trends that roughly relate to local reef margin trend (parallel and perpendicular to margin)
    - Distribution and orientation suggest fractures are stratigraphically controlled and are likely related to differential compaction / slope-failure

Summary and Conclusions

Do fractures impart influence on reservoir flow?

- **Permian:** [perhaps] NO. Image log and PLT observations suggest the presence of horizontal barriers/baffles(?) → low Kv/Kh
  - Data are sparse; Only one well has both PLT and image log
- **Carboniferous**: YES. Clear examples of open fractures in Carboniferous. However, many intervals lack sufficient data to confidently interpret flow effectiveness of fractures
- **Devonian**: MAYBE. Some wells show high fracture density, but flow data for these wells are lacking
- **In all, data thus far suggest Karachaganak is a Type 3 NFR**
  - **Fractures enhance matrix flow system**