# Fractures in Steep-rimmed Carbonate Platforms: Comparison of Tengiz Reservoir, Kazakhstan, and Outcrops in Canning Basin, NW Australia*

**Wayne Narr[1] and Eric Flodin[2]**

Search and Discovery Article #20161 (2012)**
Posted August 6, 2012

*Adapted from an oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012


[1]Chevron Energy Technology Co., San Ramon, CA (wnarr@chevron.com)
[2]TengizChevroil, Atyrau, Kazakhstan

## Abstract

Natural fractures bear significant influence on productivity in Tengiz field, which is one of several giant light-oil accumulations trapped in isolated carbonate platforms in the Pricaspian Basin of Kazakhstan. Outcrop analogs are particularly important for understanding reservoir fracture systems because many aspects of fracture character (e.g., height, length) are impossible to measure with subsurface data.

The Devonian margin of the Canning Basin in NW Australia presents a well exposed outcrop analog for steep margin and slope deposits of Tengiz field. Fracture data gathered from Tengiz core and image logs suggest affinity to fractures in the Canning outcrops in terms of origin, orientation, and range of density. Inclusion of additional information - gained through outcrop study - into reservoir fracture description leads to improved understanding of stratigraphic influence on their occurrence and character.

Shallow-burial fractures - those formed in carbonate strata prior to significant burial, including neptunian fractures - are most important for reservoir productivity at Tengiz field. These fractures dip steeply and strike dominantly parallel and/or normal to the local orientation of the depositional margin. They are most well developed in brittle, boundstone-dominant facies of the outer-platform to upper slope environment. Dissolution by corrosive fluids following burial led to enlargement of fracture apertures, which range from small to cavernous. In Tengiz field, cavernous fractures pose both high lost-circulation risk, as well as the reward of highly productive wells.

Outcrop data from the Canning Basin show fractures in the mid- to upper-slope facies and reef core that are, on average, not limited by bedding and hence much taller than fractures in the reef flat and outer platform areas. Fracture size cumulative distributions are mainly exponential, and they differ between stratigraphic settings. We expect such size differences will have important effects on fracture connectivity and permeability in a reservoir. Fracture density, which is measured routinely in the Tengiz reservoir, was measured with long pseudowells (i.e., scanlines) “drilled” along Canning outcrops. Fracture density shows significantly less variation among facies than does

fracture height. Thus, outcrop-based data can add substantially to our understanding of key fracture system characteristics that are unavailable from well data alone.

## References


Exxon Production Research Company: World Mapping Project (compilers), 1985, Tectonic map of the World: Exxon Production Research Company, Houston, Texas, 20 maps on 17 sheets.

Kenter, J.A.M., O. Vizika, E. Rosenberg, M. Skalinski, P.M. Harris, and M. Buoniconti, 2007, Assessment of permeability and porosity using high resolution CT and NMR; an example from the central Tengiz Platform reservoir, Pricaspian Basin, Kazakhstan: AAPG Annual Meeting Abstracts, p. 75.

Playford, P.E., R.M. Hocking, and A.E. Cockbain, 2009, Devonian Reef Complexes of the Canning Basin, Western Australia: Geological Survey of Western Australia Bulletin, Report # 145.

Playton, T.E., 2008, Characterization, variations, and controls of reef-rimmed carbonate foreslopes: Ph.D. dissertation, The University of Texas at Austin, Austin, Texas, 283 p.

Weber, L.J., B.P. Francis, P.M. Harris, and M. Clark, 2003, Stratigraphy, lithofacies, and reservoir distribution, Tengiz Field, Kazakhstan, *in* W.M. Ahr, P.M. Harris, W.A. Morgan, and I.D. Somerville, (eds.), Permo-Carboniferous Carbonate Platforms and Reefs: SEPM Special Publication 78/AAPG Memoir 83, p. 351-394.

# Fractures in Steep-rimmed Carbonate Platforms:

## *Comparison of Tengiz Reservoir, Kazakhstan, and Outcrops in Canning Basin, NW Australia*

**Wayne Narr** *Chevron Energy Technology Company*
*San Ramon, CA*

**Eric Flodin** *TengizChevroil*
*Atyrau, Kazakhstan*

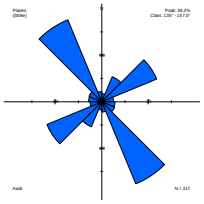
AAPG Long Beach, CA
24 April 2012

# Objective of Outcrop Analog Study

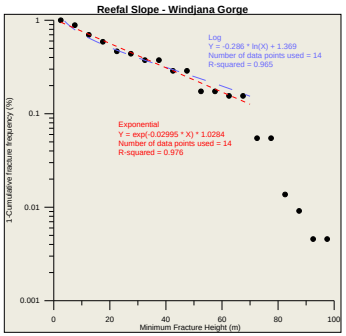
- Improve understanding of fractures for reservoir model construction in steep-margin carbonates.

- Evaluate **fracture characteristics**…

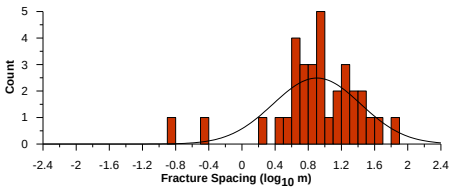
Orientation



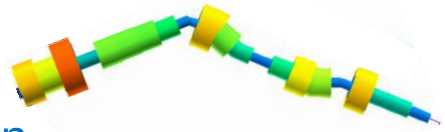
Size distribution




Spacing distribution




Density distribution



…as a function of **stratigraphic facies**

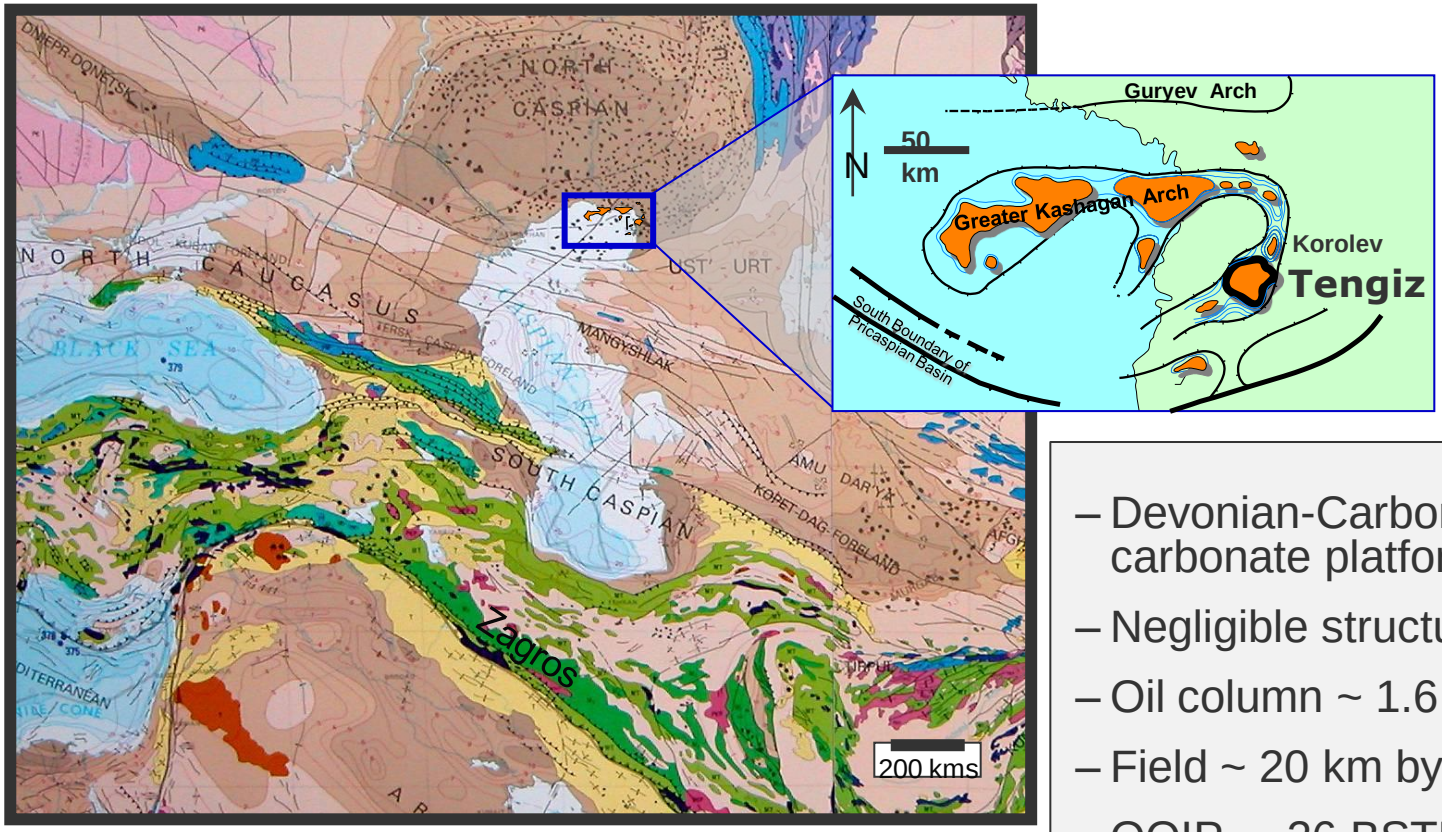
# Outline of Presentation

- Geology & fracture characteristics of Tengiz oil field, Republic of Kazakhstan.
- Geology & fracture characteristics of outcrop analog in Canning Basin, N.W. Australia.
- Compare:
  - *Timing of fracture genesis.*
  - *Fracture geometry.*
  - *Stratigraphic distribution of fractures.*
- Discuss fracture size & density distributions with respect to stratigraphy.
  - *Factors not determinable from reservoir data → value of analog study.*

# Geologic setting of Tengiz field

## NE Caspian Sea, Pricaspian Basin, Republic of Kazakhstan

### Tectonic map of Caspian region




Isolated Carbonate Platforms / Organic Buildups



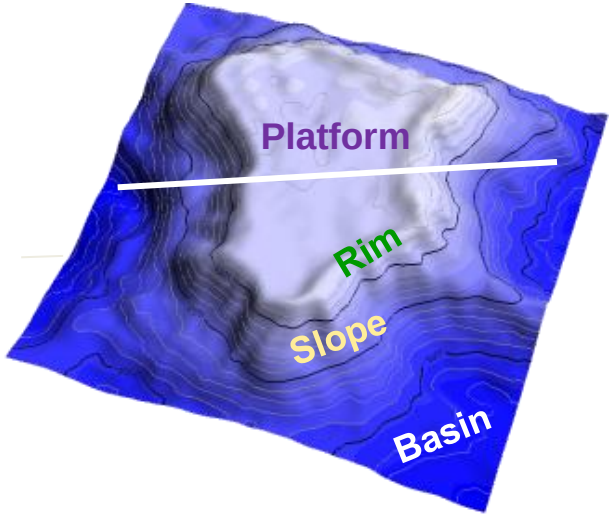
*After Kenter et al., 2007, Late Visean to Bashkirian Platform Cyclicity…..: Core Workshop, Giant Oil Fields, AAPG Ann. Mtg., Long Beach.*

*from Patterson et al., 1985, Tectonic Map of the World, 1st ed., Exxon Production Research Co., AAPG Foundation*



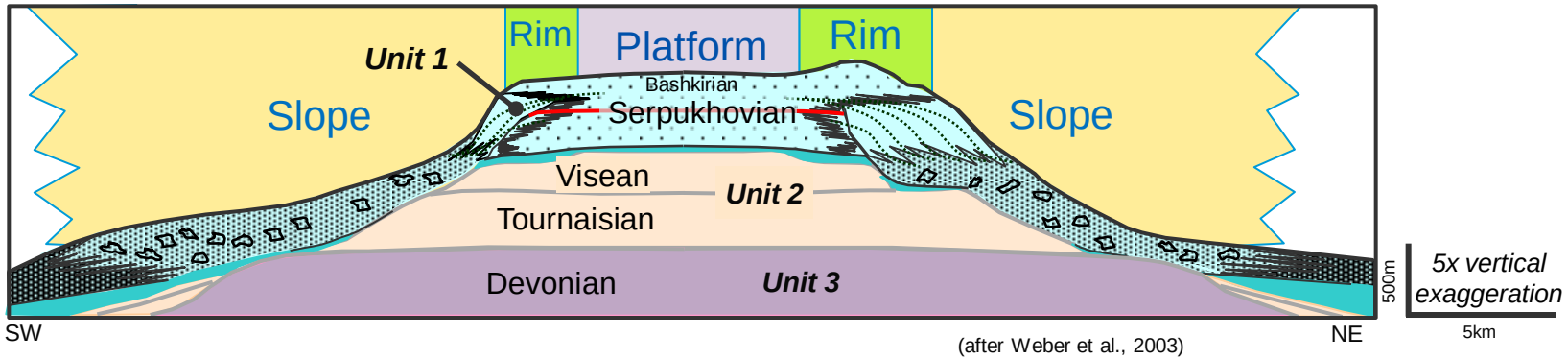
- Devonian-Carboniferous isolated carbonate platform
- Negligible structural deformation
- Oil column ~ 1.6 km thick
- Field ~ 20 km by 22 km
- OOIP ~ 26 BSTBO
- Porosity: ~3%, Matrix Perm: ~1 mD
- Tengiz production >500,000 BO/day.
- **Fractures** important to productivity.

# Stratigraphic Framework of Tengiz Oil Field




- Isolated Carbonate Platform
- Dominantly limestone
- Platform growth
  1. Retrogradational→ Aggradational: Devonian to Late Visean (Miss.)
  2. Progradational: Serpukhovian (Miss.)
  3. to Aggradational: Bashkirian (Penn.)

*Unit 1 - Main reservoir*



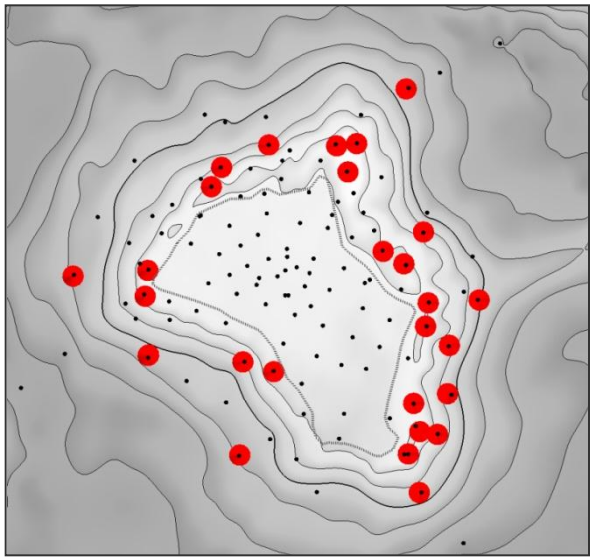

(after Weber et al., 2003)

*Permission of AAPG and SEPM is required for further use*

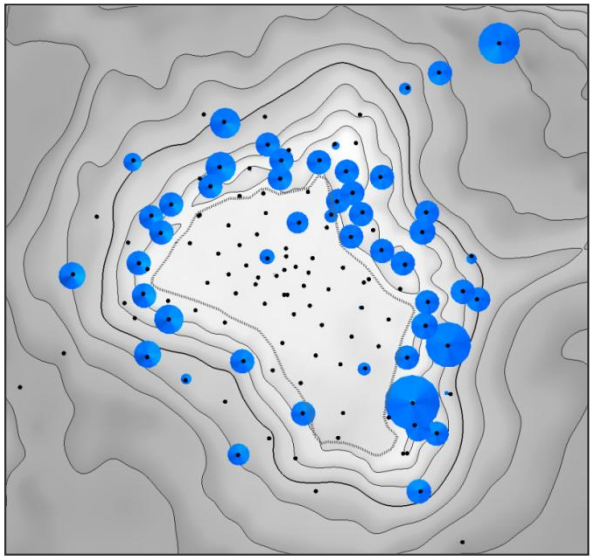
*Weber, L.J., Francis, B.P., Harris, P.M., and Clark, M., 2003, Stratigraphy, lithofacies, and reservoir distribution, Tengiz Field, Kazakhstan, in Ahr, W.M., Harris, P.M., Morgan, W.A., and Somerville, I.D., eds., Permo-Carboniferous Carbonate Platforms and Reefs: Society for Sedimentary Geology Special Publication 78 / AAPG Memoir 83, p. 351-394.*

# Evidence of fractures from operational data

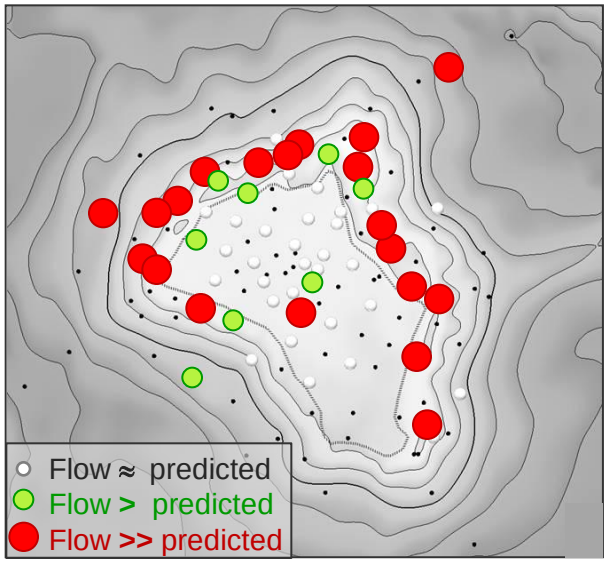
**Bit drop**



**Lost Circulation Zones**



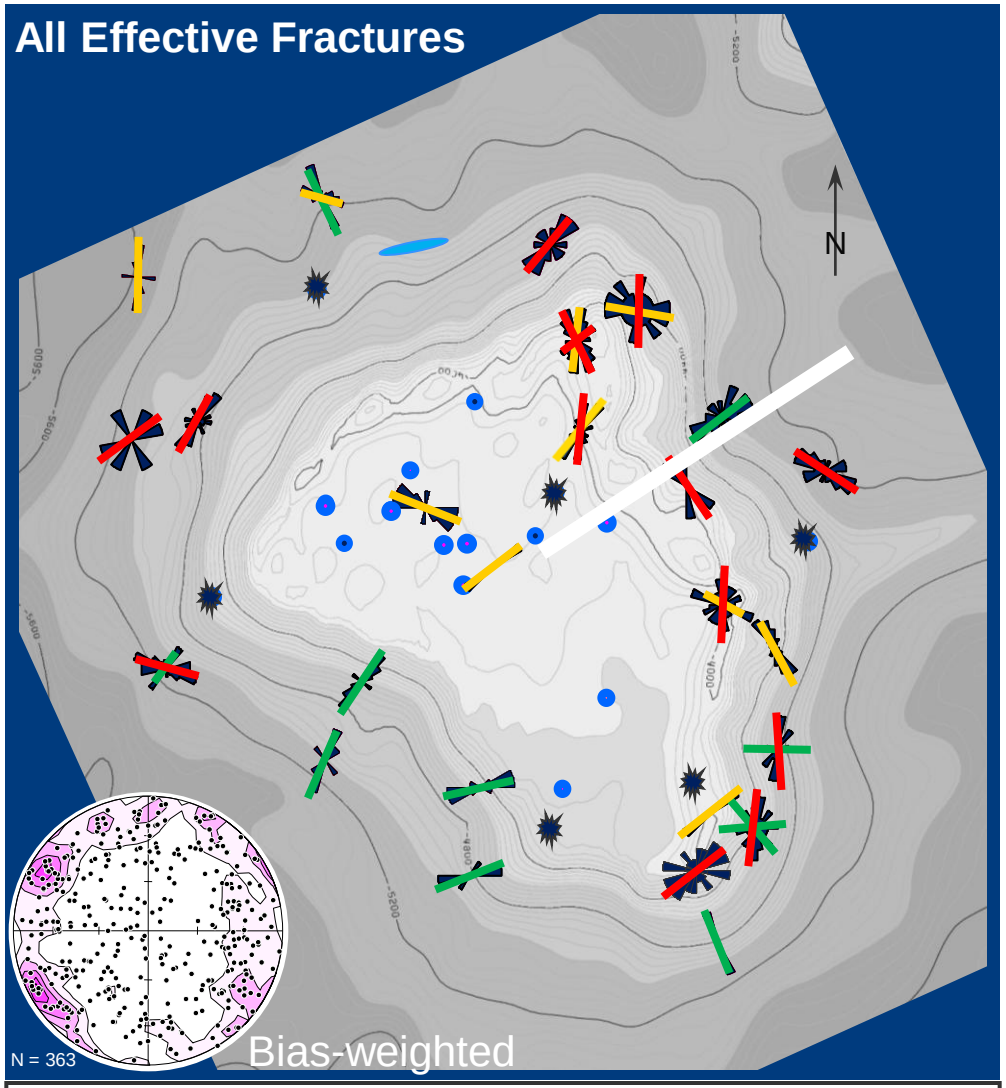
**Flow Capacity Index**




$$FCI = \frac{\text{Observed performance}}{\text{Predicted performance}}$$

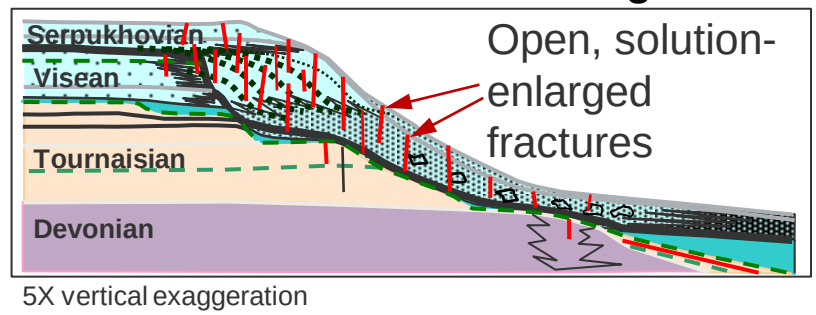
- Effective fractures are concentrated in Unit 1 **rim** & **slope**.
- Depositional setting is significant in location of fractures.

# Effective Fractures at Tengiz




Effective fractures occur mainly in the rim & slope.

Dominant fracture strike is commonly parallel or normal to the deposition margin.

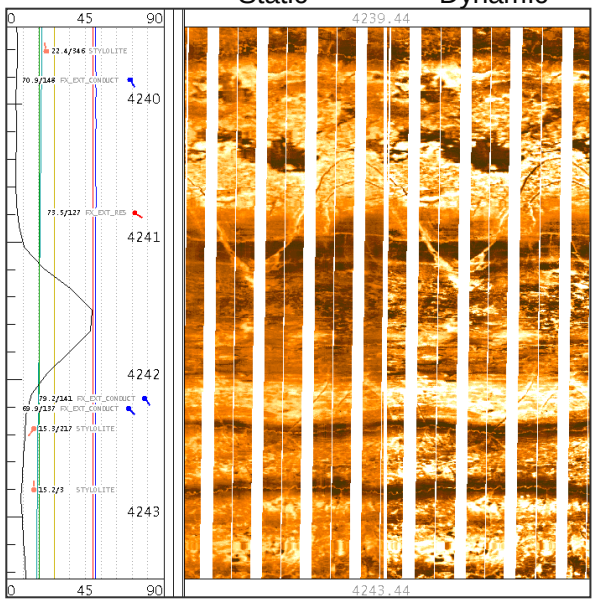



Fractures are concentrated in prograding Serpukhovian & Bashkirian (Miss. & Penn.) section of rim and slope.

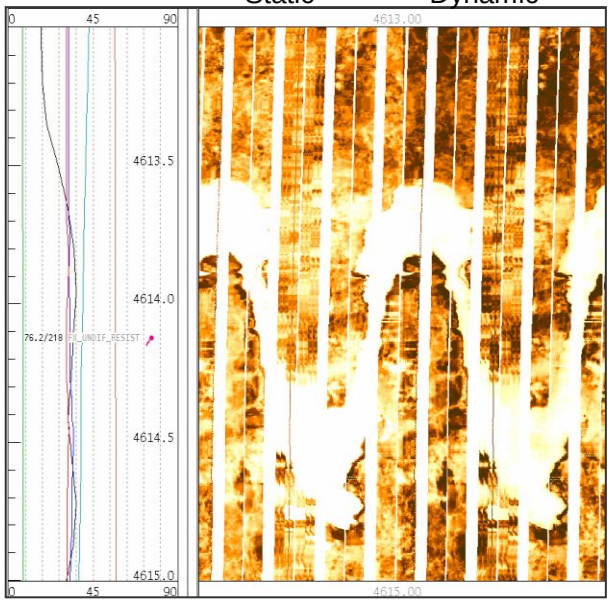
# Fractures in Tengiz Reservoir

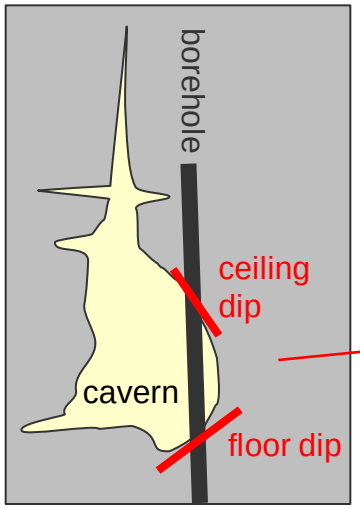
- *Conventional FMI, oil-based mud. Open fractures are resistive.*
- *Fractures range from narrow-aperture opening-mode to significant caverns.*

## Healed fracture



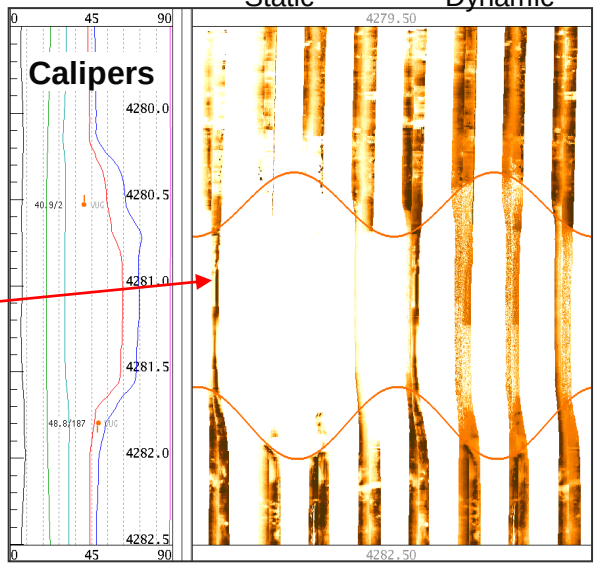

## Solution enlarged



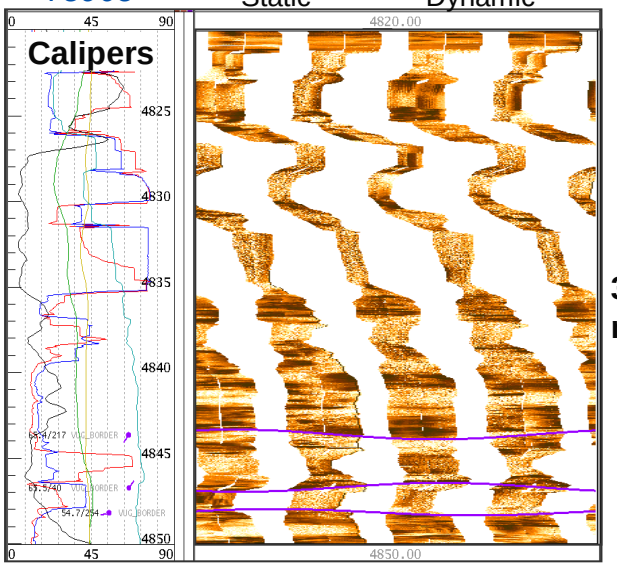

## Cavern

*T5454*




## Cavernous interval

*T5963*




**30 meters**

# Fractures formed early (syndeposition to early burial)

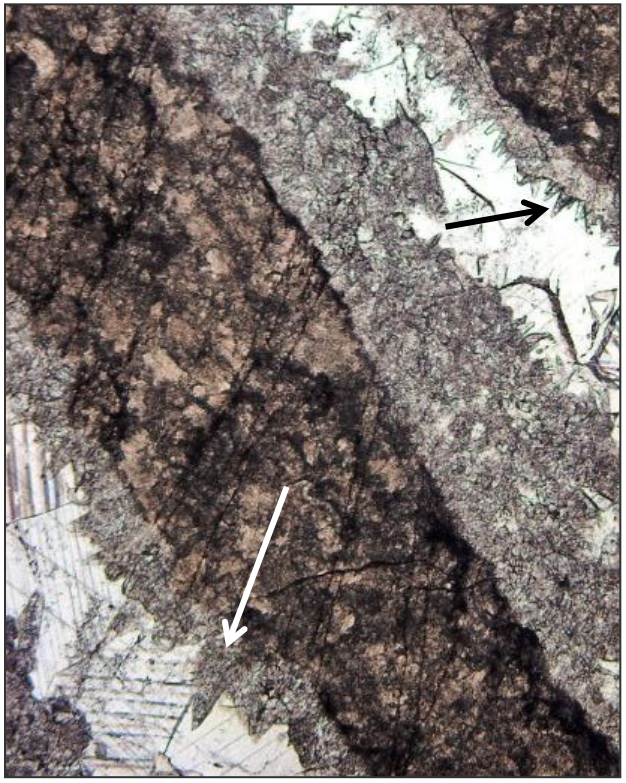
Scalenohedral (early burial) cement commonly lines fracture walls.

Blocky calcite was deposited later.

Corrosion of fracture walls predates blocky calcite cement

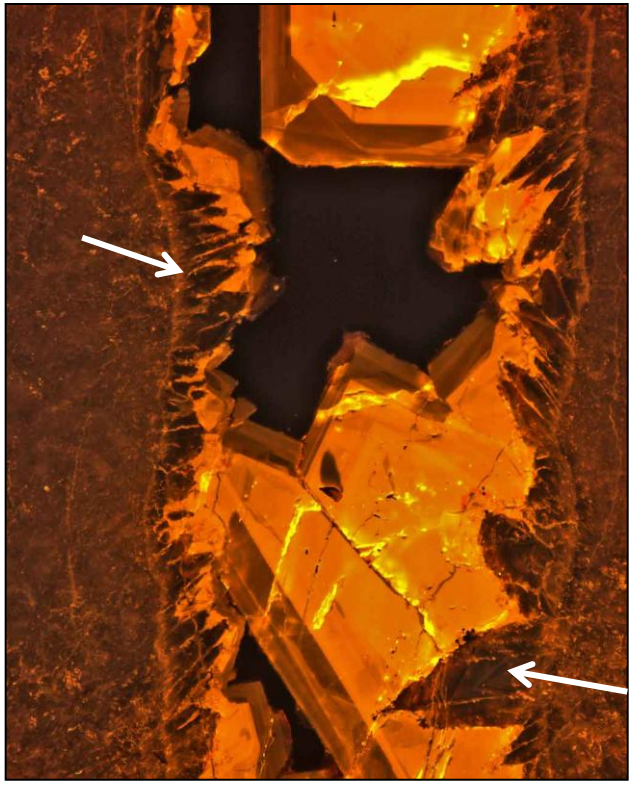
- early cement may have been removed

*Plane light*



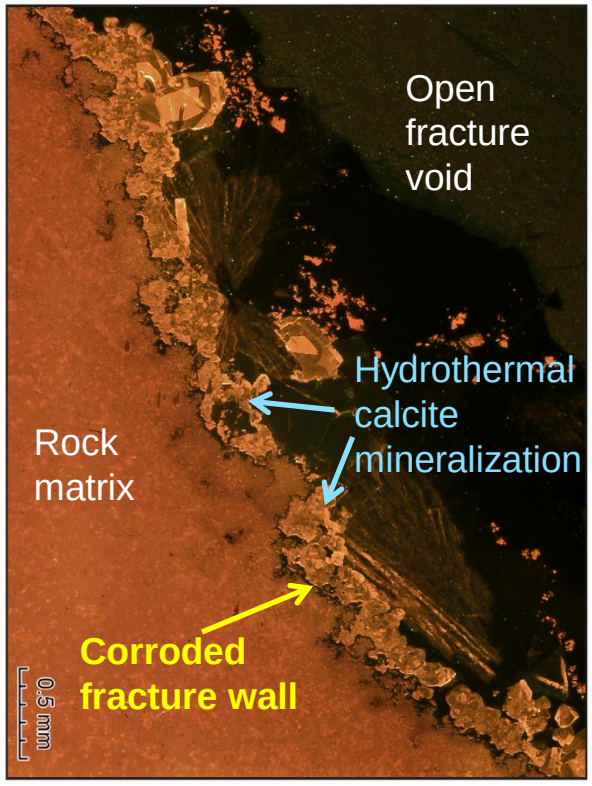
1 mm

*Cathodoluminescence*



1 mm

*Cathodoluminescence*




1 mm

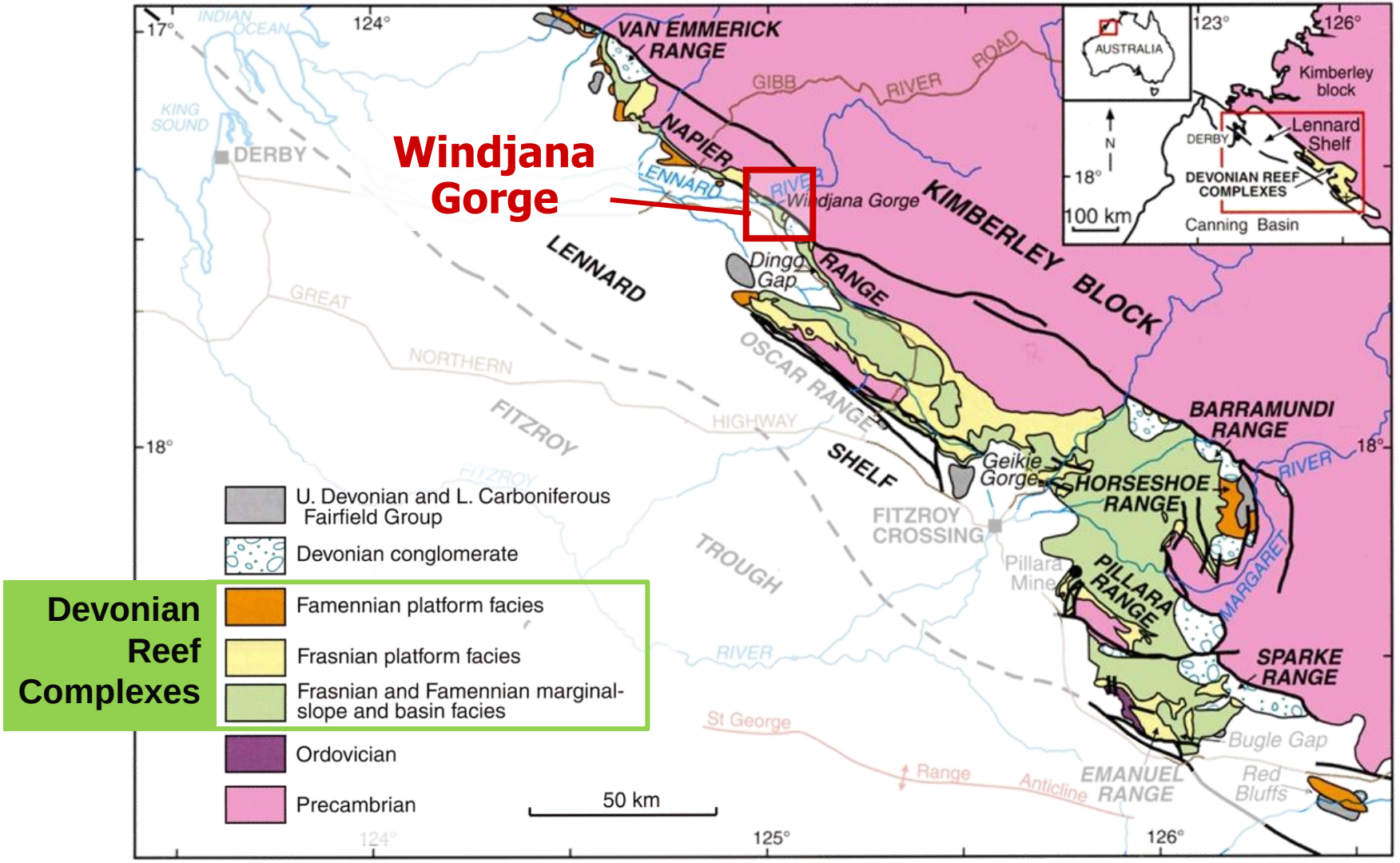
# Let's move from the Steppe…

…to the Outback

# Let's move from the Steppe…

…to the Outback

# Geologic index map of Lennard Shelf (NE margin) of Canning Basin

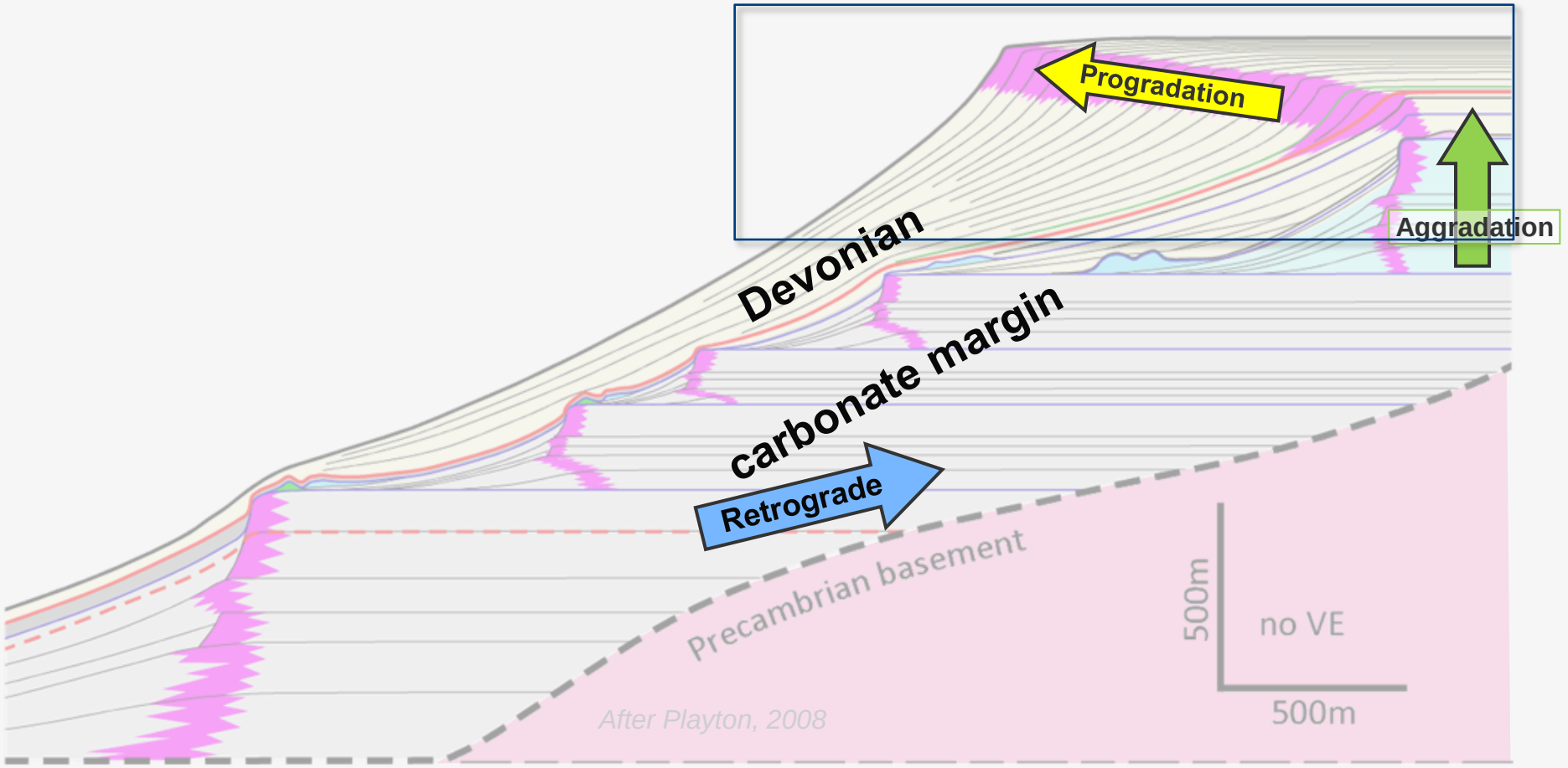



*From Playford et al., 2009*



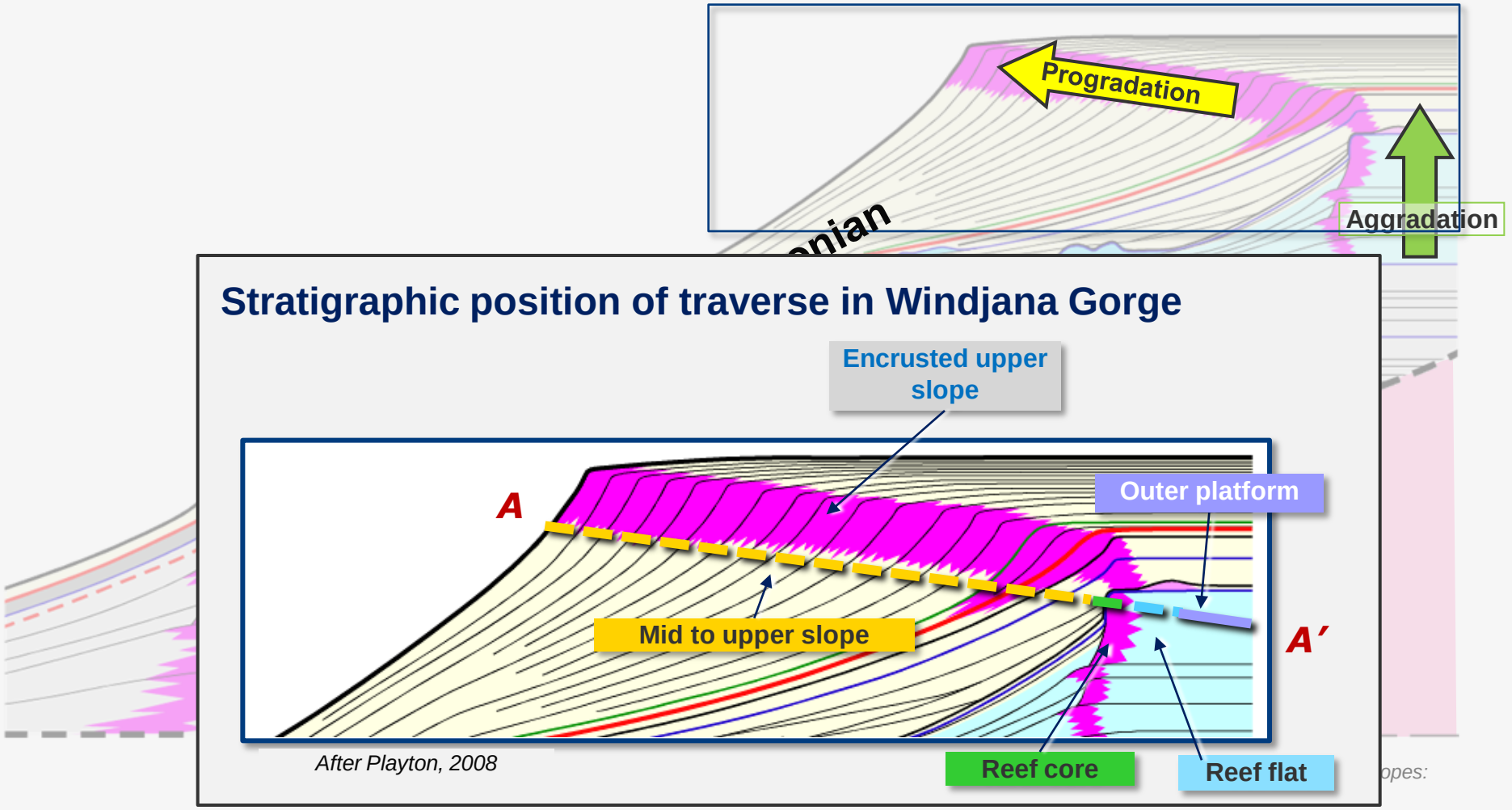
*Playford, P. E., Hocking, R. M., and Cockbain, A. E., 2009, Devonian Reef Complexes of the Canning Basin, Western Australia: Geological Survey of Western Australia Bull. 145.*

# Stratigraphic Setting of Canning Basin Study Site

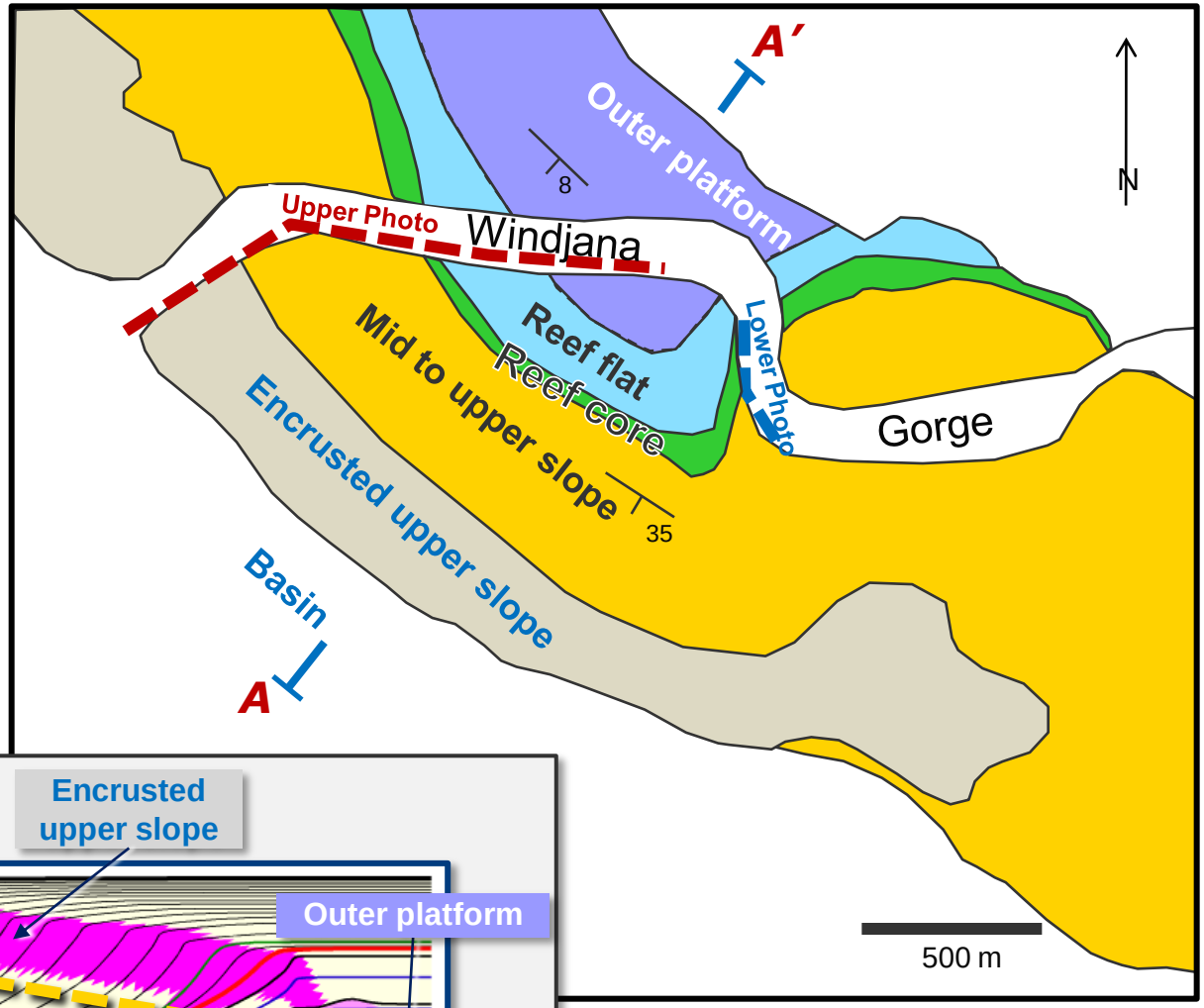



*Playton, T.E., 2008, Characterization, variations, and controls of reef-rimmed carbonate foreslopes: unpub. Ph.D. dissertation, The University of Texas at Austin, Austin, Texas, 283 p.*

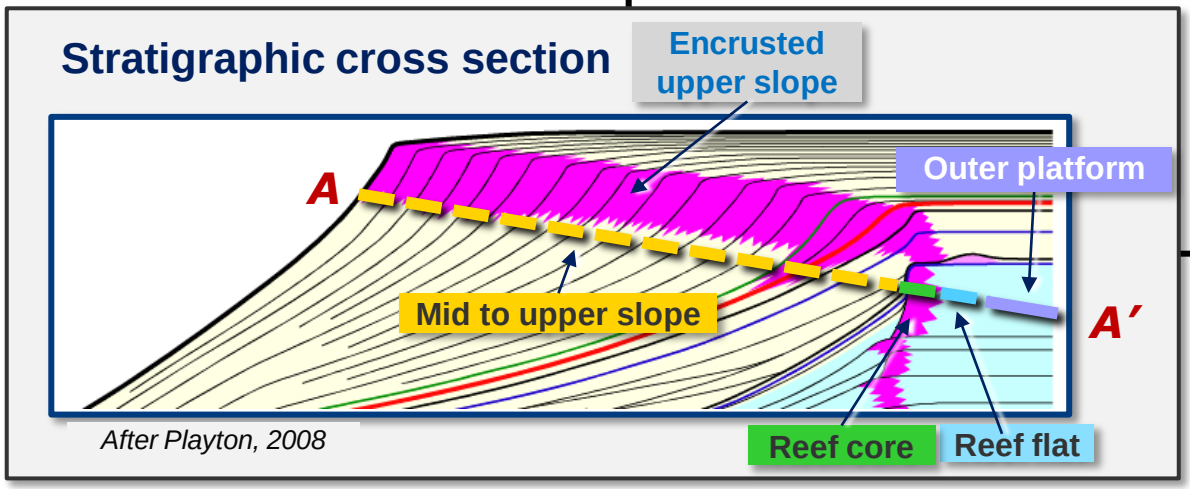
# Stratigraphic Setting of Canning Basin Study Site



# Geologic map of Windjana Gorge




## Stratigraphic position of scan line in gorge



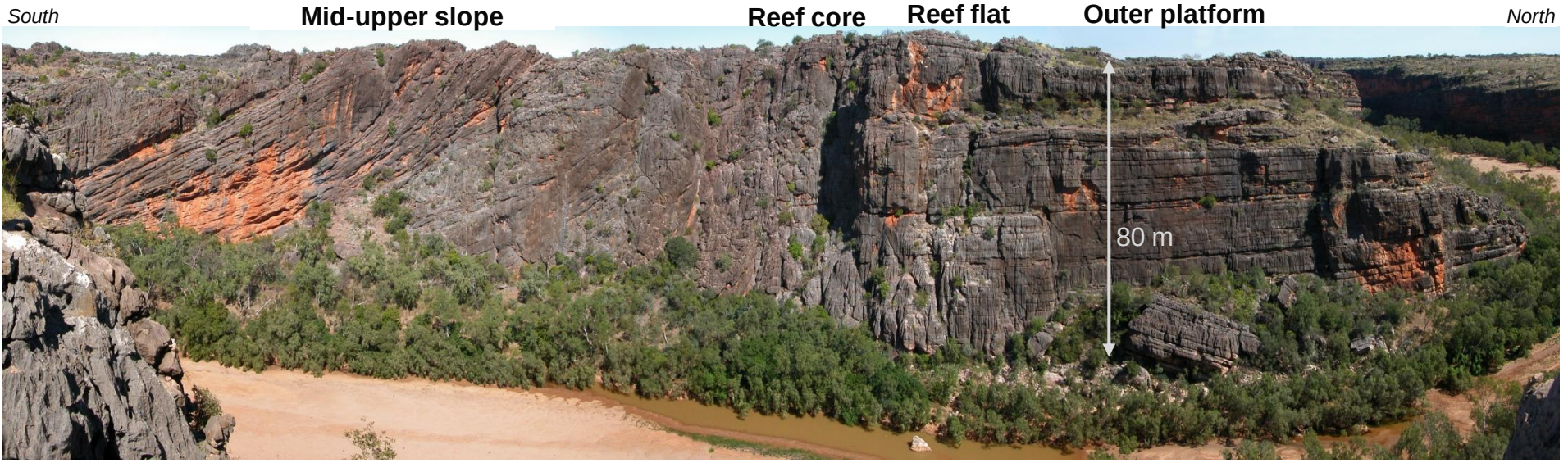

After Playton, 2008

After Playford et al., 2009

*Playford, P. E., Hocking, R. M., and Cockbain, A. E., 2009, Devonian Reef Complexes of the Canning Basin, Western Australia: Geological Survey of Western Australia Bull. 145.*

# Windjana Gorge – Near-complete exposure along traverse, outcrop quality superb

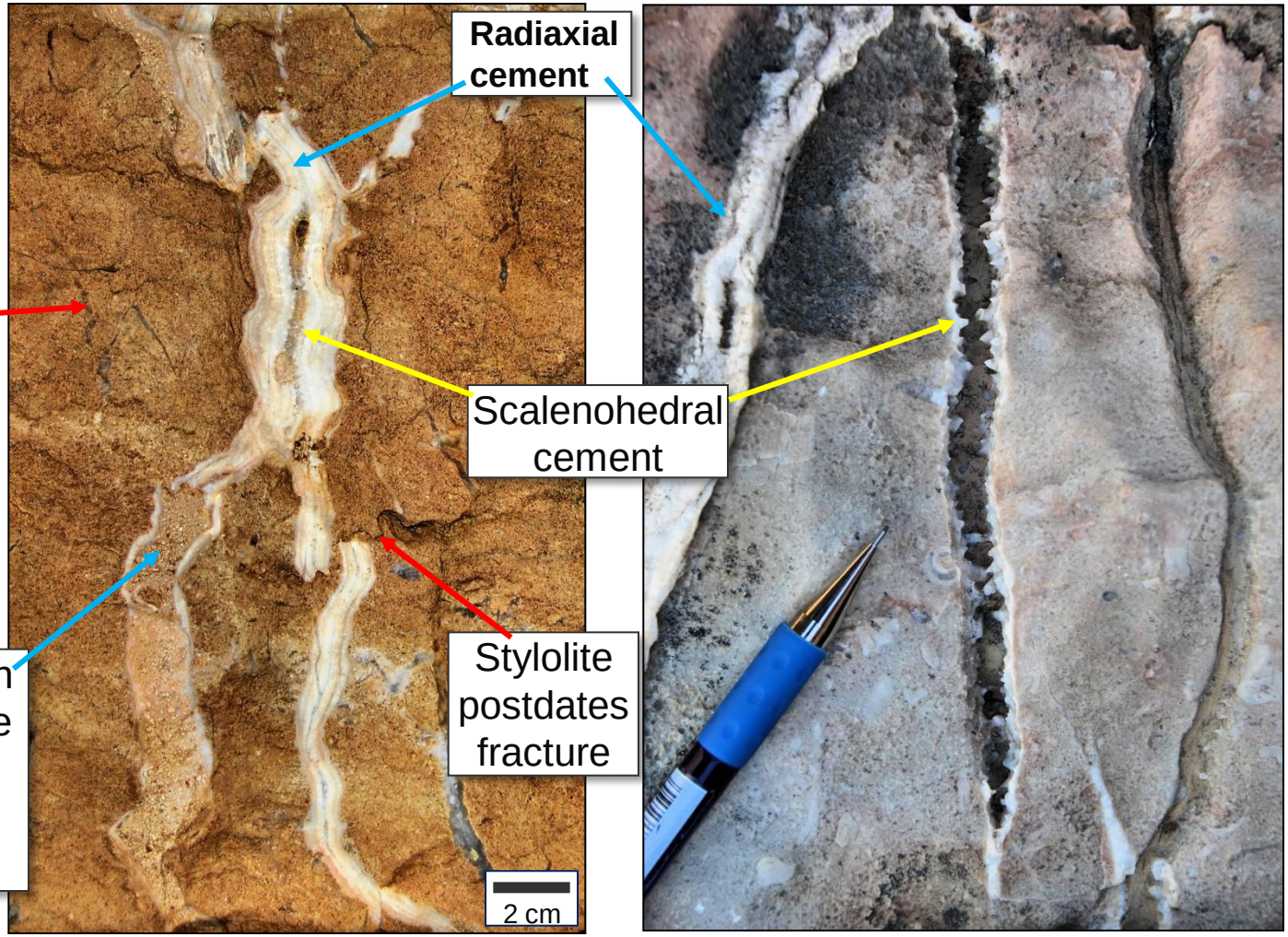

South wall of Windjana Gorge extending from outer platform to encrusted upper slope.



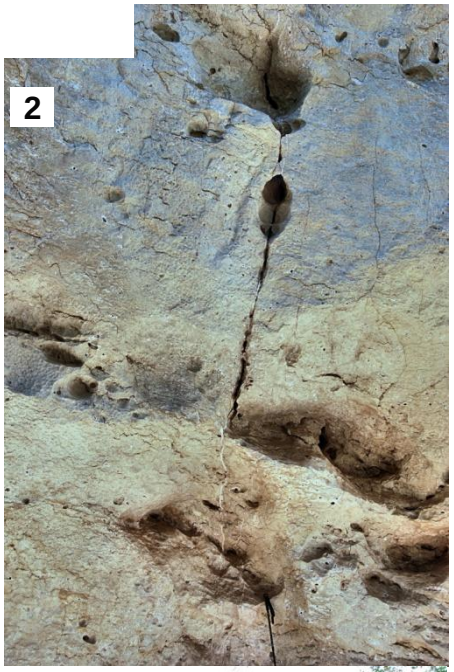

The “classic face” at Windjana Gorge

# History of early fracture cements – Windjana Gorge

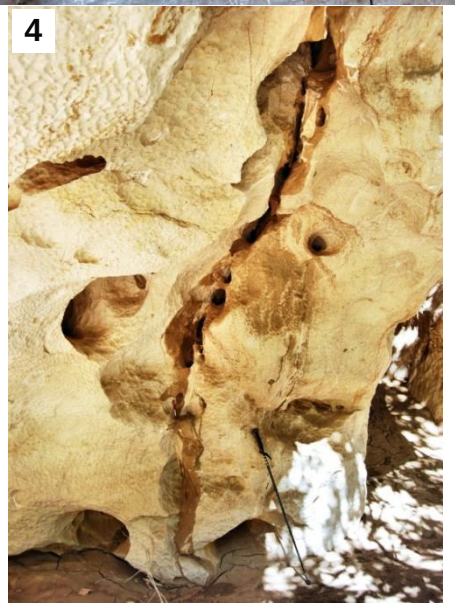
1. Neptunian debris & radiaxial calcite – ***marine water***
2. Scalenohedral cement – ***restricted marine; early burial***
3. Blocky calcite fractures – ***deeper burial; not studied***

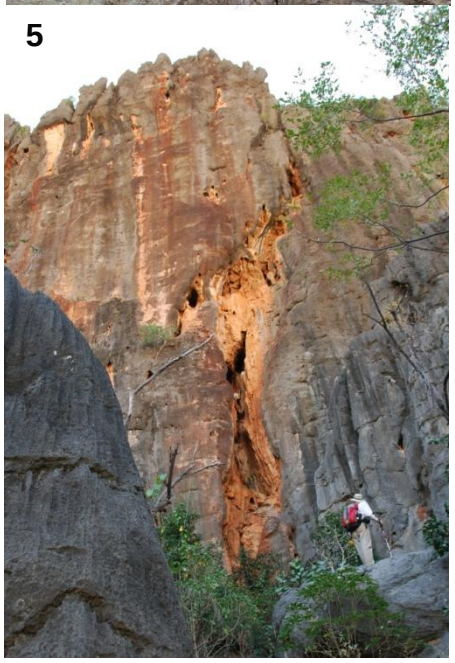


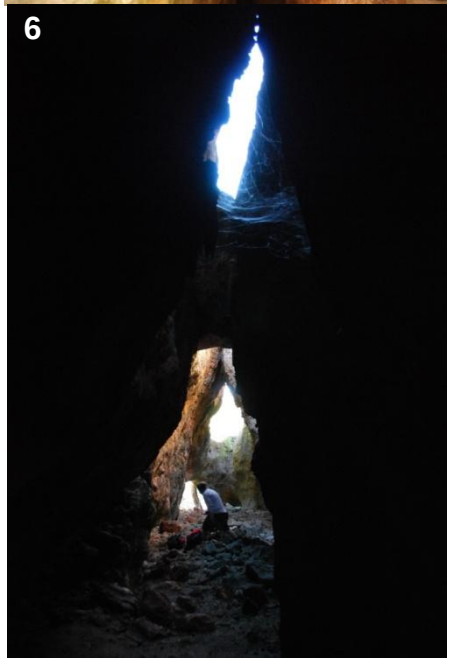
# Worm-tube flow in fractures can coalesce to form caverns



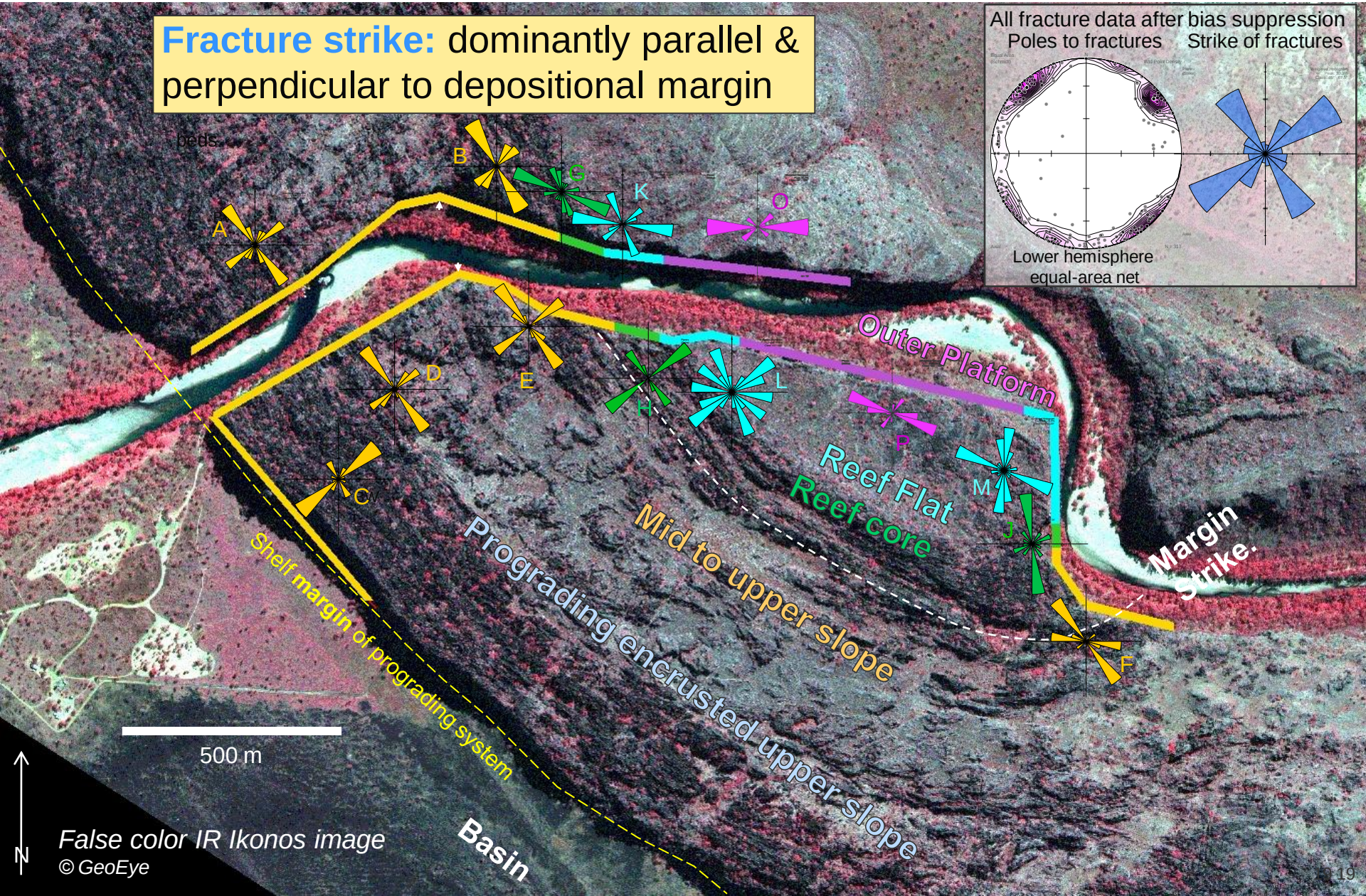



Fractures are more soluble, or more permeable, than matrix

# Strike of all fractures measured along traverses, weighted to suppress sampling bias.



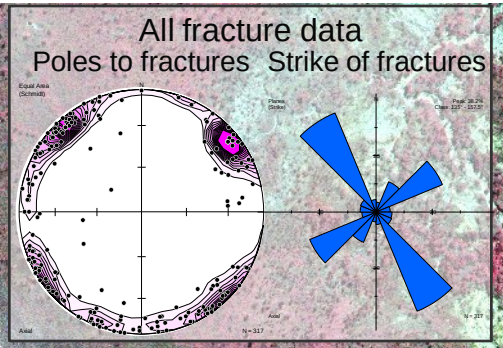
# Fracture Density Along Scanlines - “horizontal wells”

## *- Stratigraphic influence*

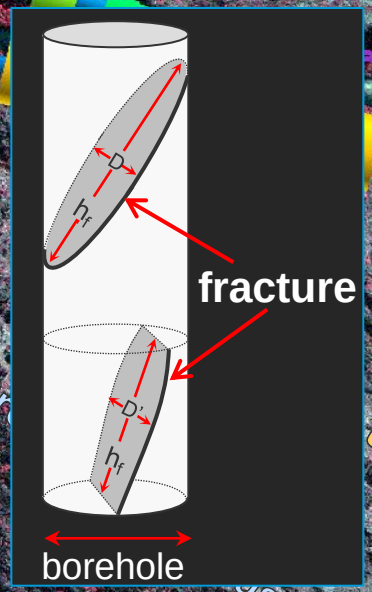
**Fracture density:**

- Slope ≈ reef core ≈ reef flat > outer platform.
- High variability within same facies → high heterogeneity at scale of 75m bin size.

fracture surface area / borehole volume




Fracture density scanlines




- Fractures are weighted according to size.
- Implicitly corrects orientation-based sampling bias.

upper slope

usted upper slope

500 m

0 — 0.5

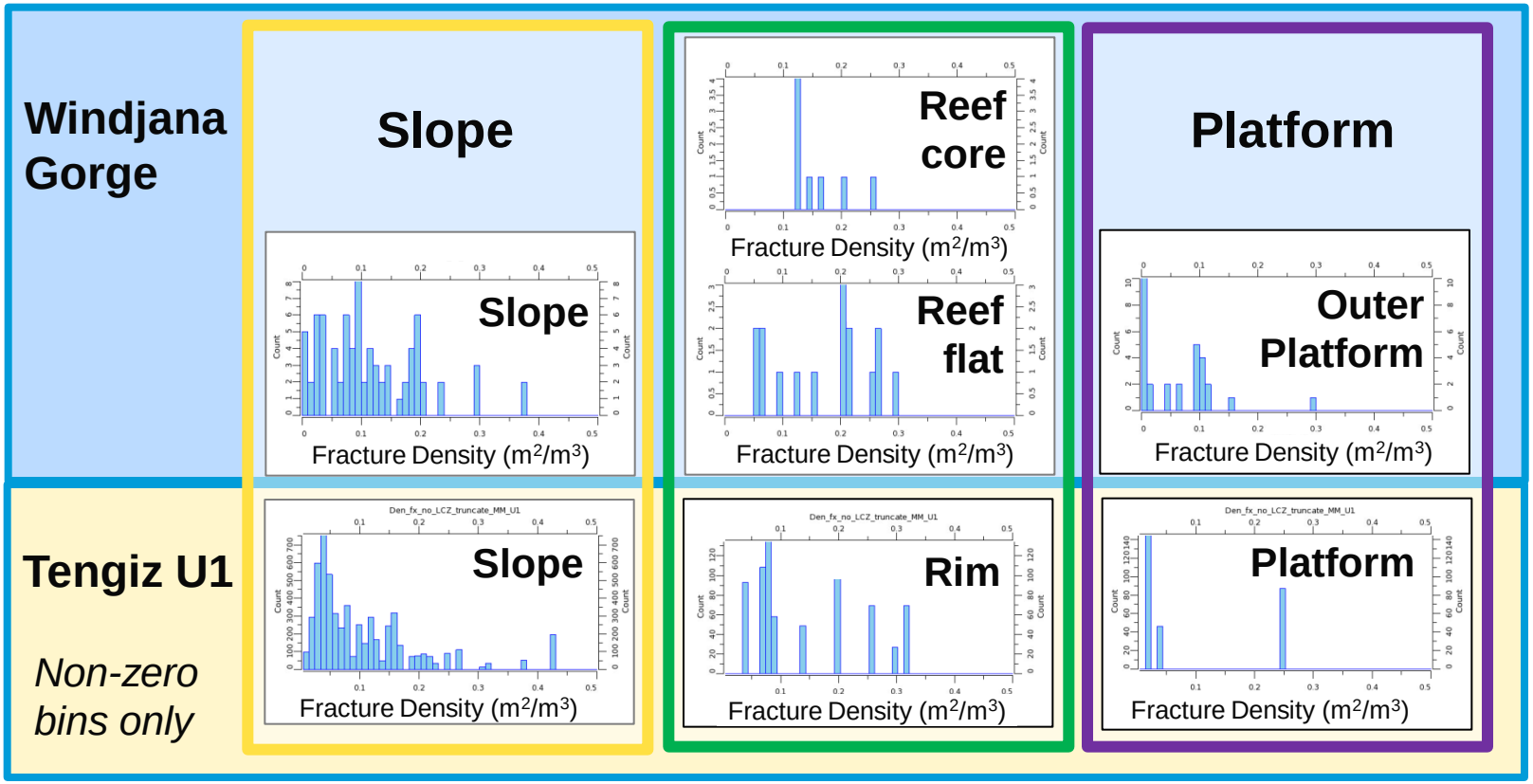
Fracture density ($m^2/m^3$)

*False color IR Ikonos image*
*© GeoEye*

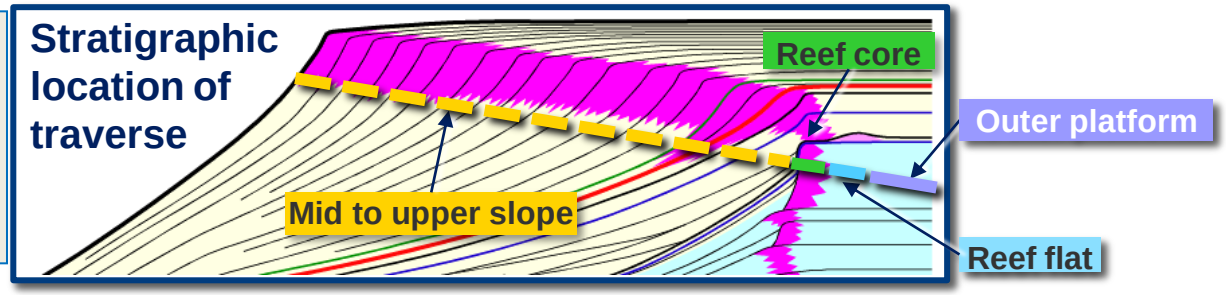
# Summary - Similarities of Tengiz Unit 1 reservoir and Devonian carbonates of Canning Basin

- Stratigraphy – Steep-sided, limestone-dominated carbonate margin
  - Retrograde → aggradation, then → progradation.
- Fractures –
  - Syndepositional &/or early burial.
  - Occurrence and orientation strongly influenced by stratigraphy.
  - Solution-enlargement led to cavernous fractures.

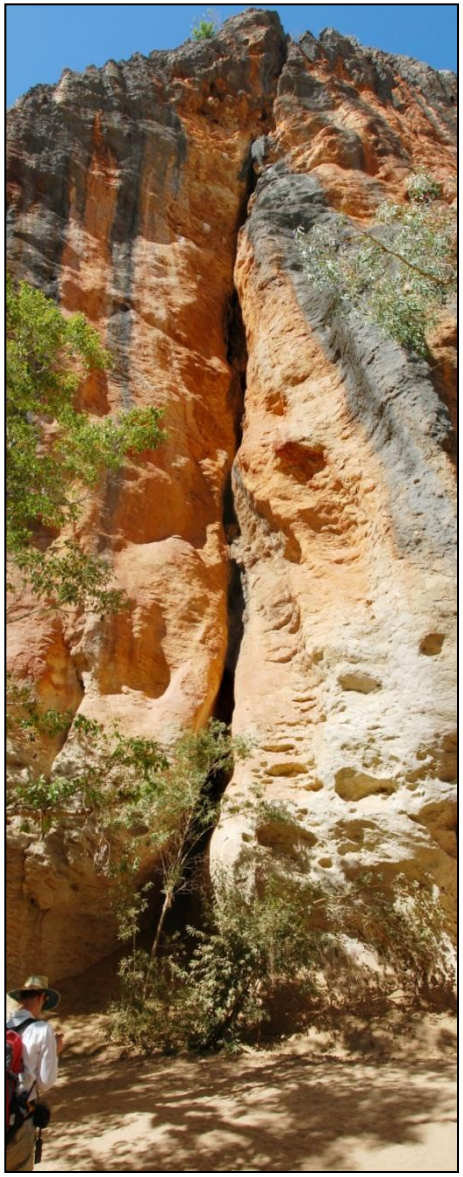
# Fracture Density Comparison by Facies: Windjana Gorge & Tengiz Unit 1

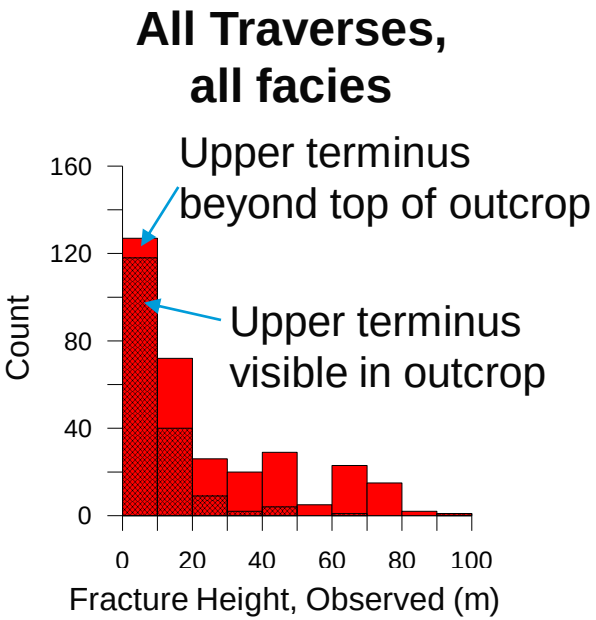


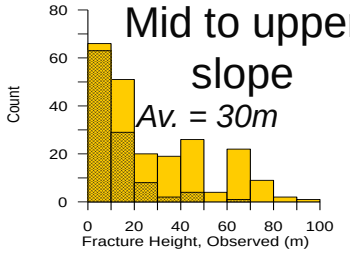

- Ranges of distributions are similar.
- Shape of non-zero distributions is compatible.

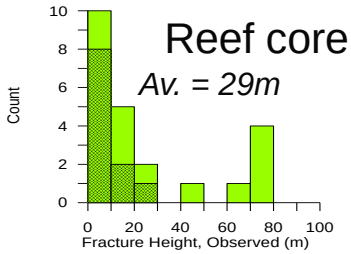


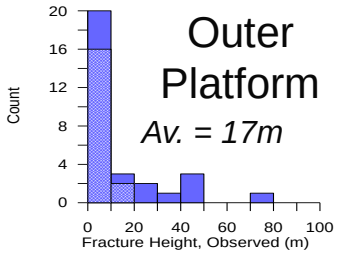
# Fracture height distribution by facies

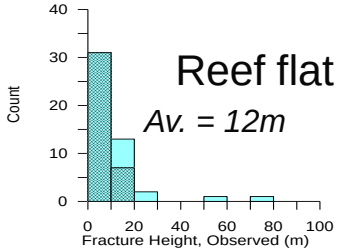


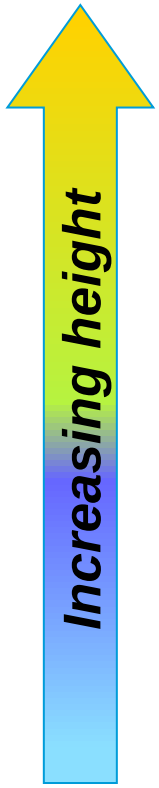


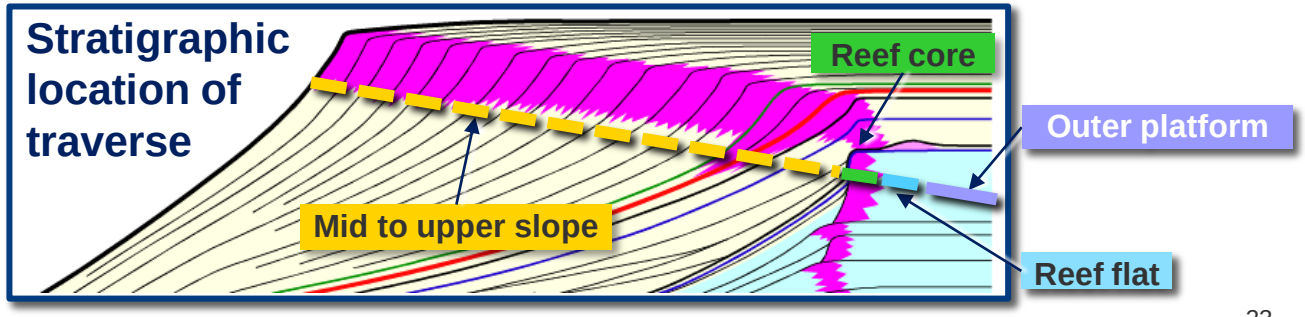



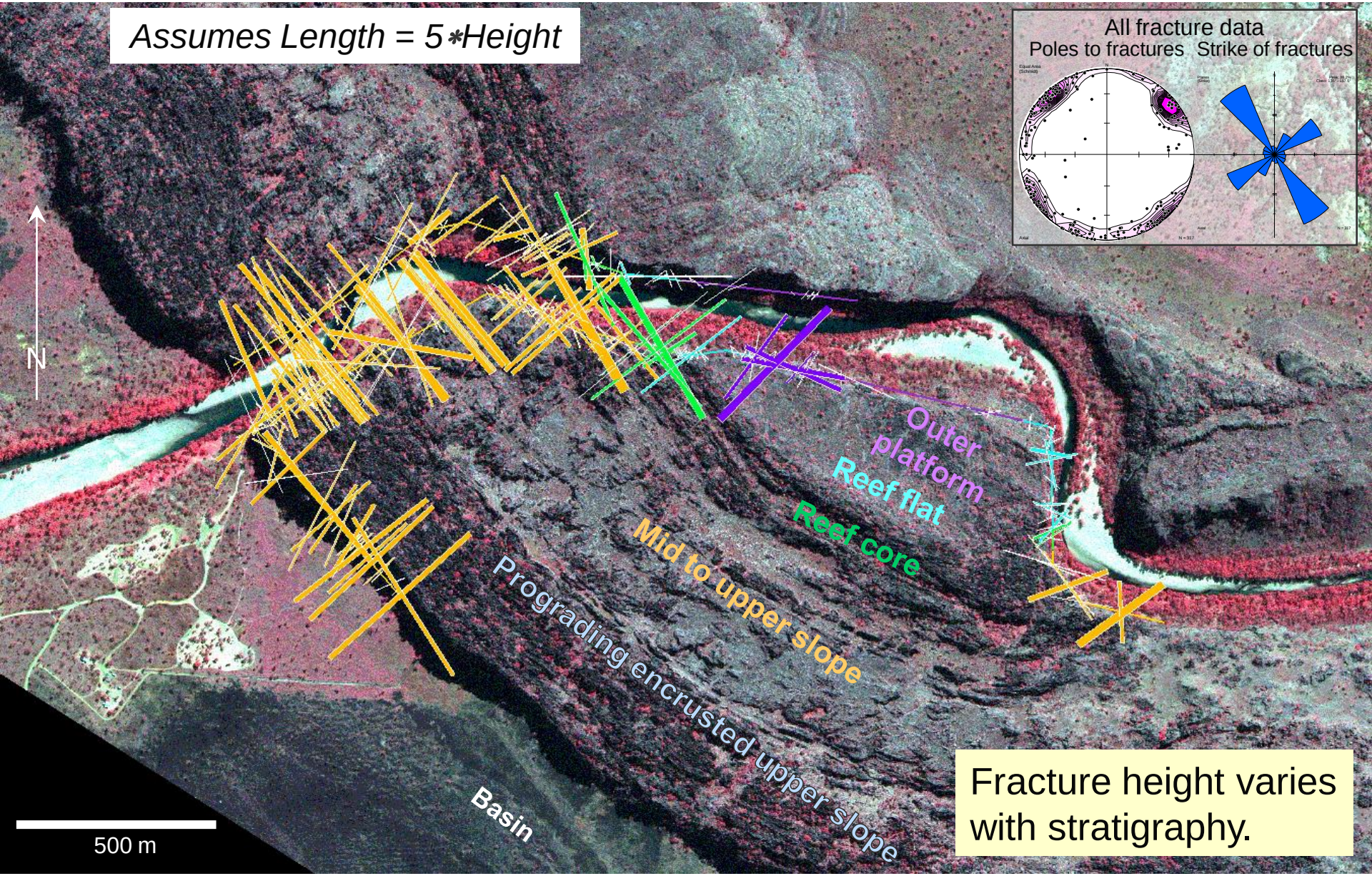



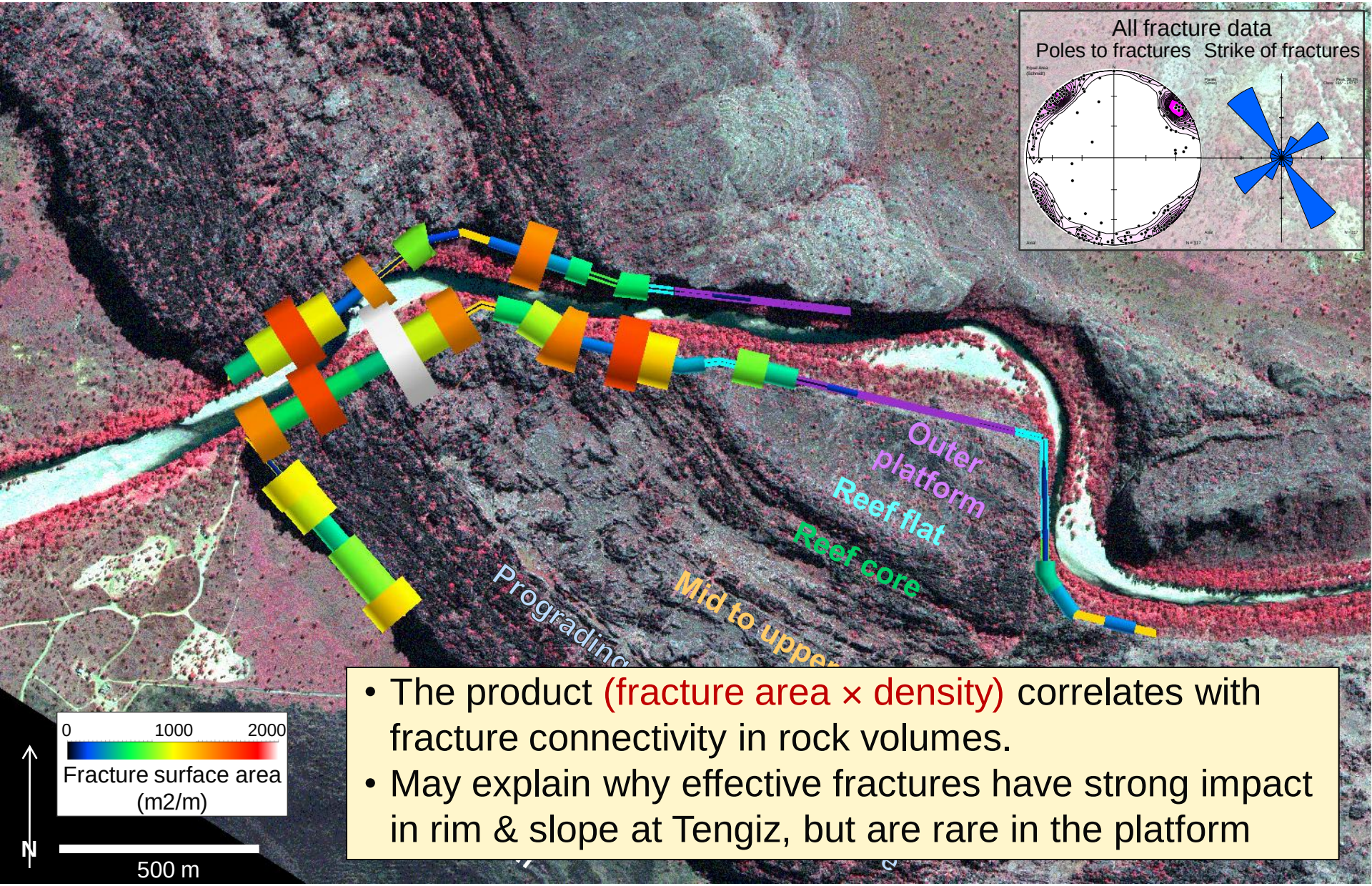
# Discrete Fracture Objects, Based on Measured Height






*False color IR Ikonos image © GeoEye*

# Logs of intersected-fracture surface area




- The product (fracture area × density) correlates with fracture connectivity in rock volumes.
- May explain why effective fractures have strong impact in rim & slope at Tengiz, but are rare in the platform



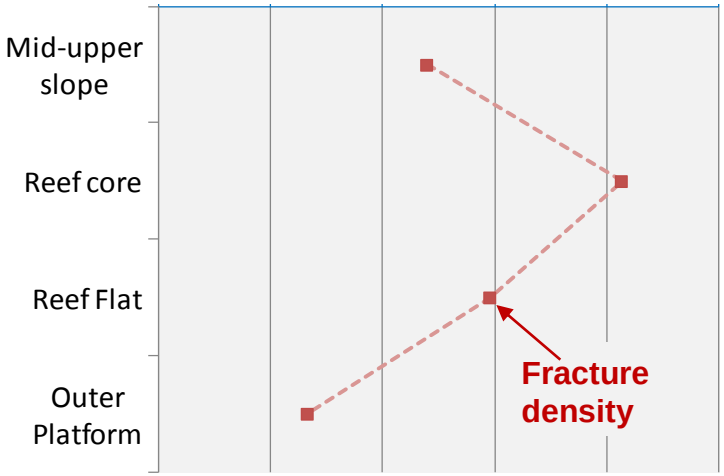
*False color IR Ikonos image © GeoEye*

# Intersected-fracture surface area predicts flow potential

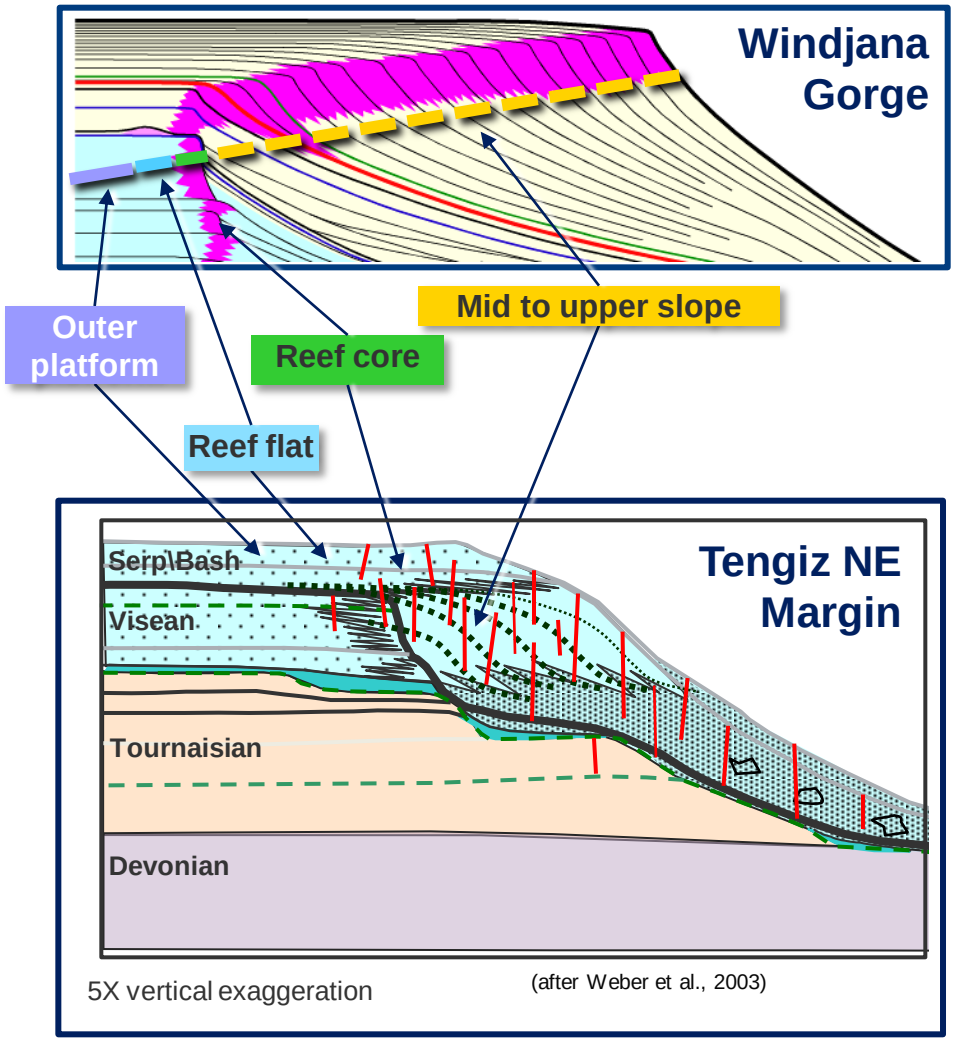
**As function of stratigraphy**

- **Fracture Density** varies moderately (factor of ~3) & does not correlate well with areas of known fracture impact at Tengiz.
  - *Borehole view*.
- **Intersected fracture surface area** varies strongly and is consistent with areas of strong fracture impact at Tengiz.
  - *Evident only at outcrop analog.*

**Windjana Gorge**




**Stratigraphic cross section**

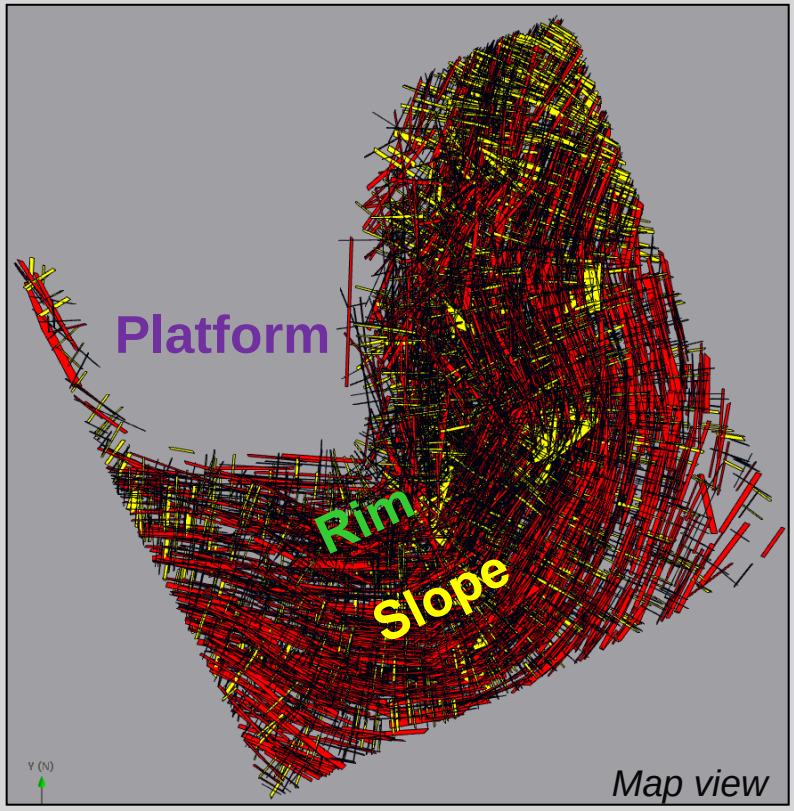


# Conclusions

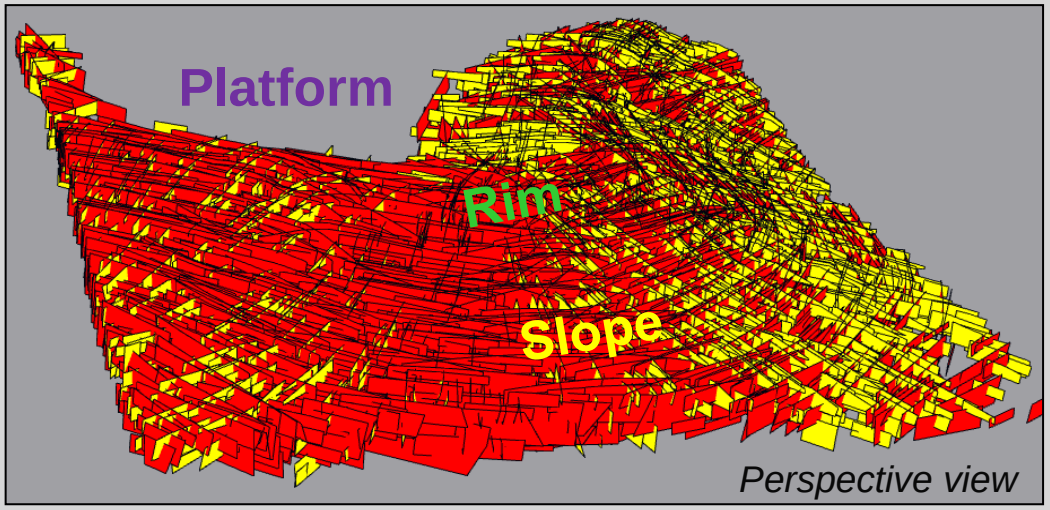
- In comparable facies of the Tengiz reservoir & Canning Basin Devonian carbonates, fractures are analogous in origin, occurrence, & character.
- Stratigraphy influences size & density (spacing) of fractures.
- The occurrence of **effective** fractures at Tengiz corresponds with facies that have large intersected-fracture surface area at Windjana Gorge.
  - *Postulate:* fracture "effectiveness" relates to hydraulic connectivity, and is a consequence of intersected-fracture surface area.
- This analog study provides understanding of fracture characteristics that cannot be derived from subsurface data alone.

# Application of fracture analog study:

*- Basis for discrete fracture models for flow simulation*




**Tengiz DFN model - southern sector**



# Acknowledgements:


For assistance & guidance about Canning Basin:
**Ted Playton** (Chevron ETC)
**Ned Frost** (U.Texas / RCRL Consortium)

For permitting us to share information about Tengiz Field:
**Republic of Kazakhstan**
**KazMunayGas**
**ExxonMobil**
**Lukarco**
**Chevron**

For ongoing encouragement, ideas, & support:
**TCO Reservoir Management Team, Atyrau, Kazakhstan**