SPE DISTINGUISHED LECTURER

Primary funding is provided by

The SPE Foundation through member donations and a contribution from Offshore Europe

The Society is grateful to those companies that allow their professionals to serve as lecturers

Additional support provided by AIME

SPE International

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

SPE DISTINGUISHED LECTURER

Perfecting In-situu Stress Calibration for Field Developments

Javier A. Franquet
Baker Hughes

Baker Hughes

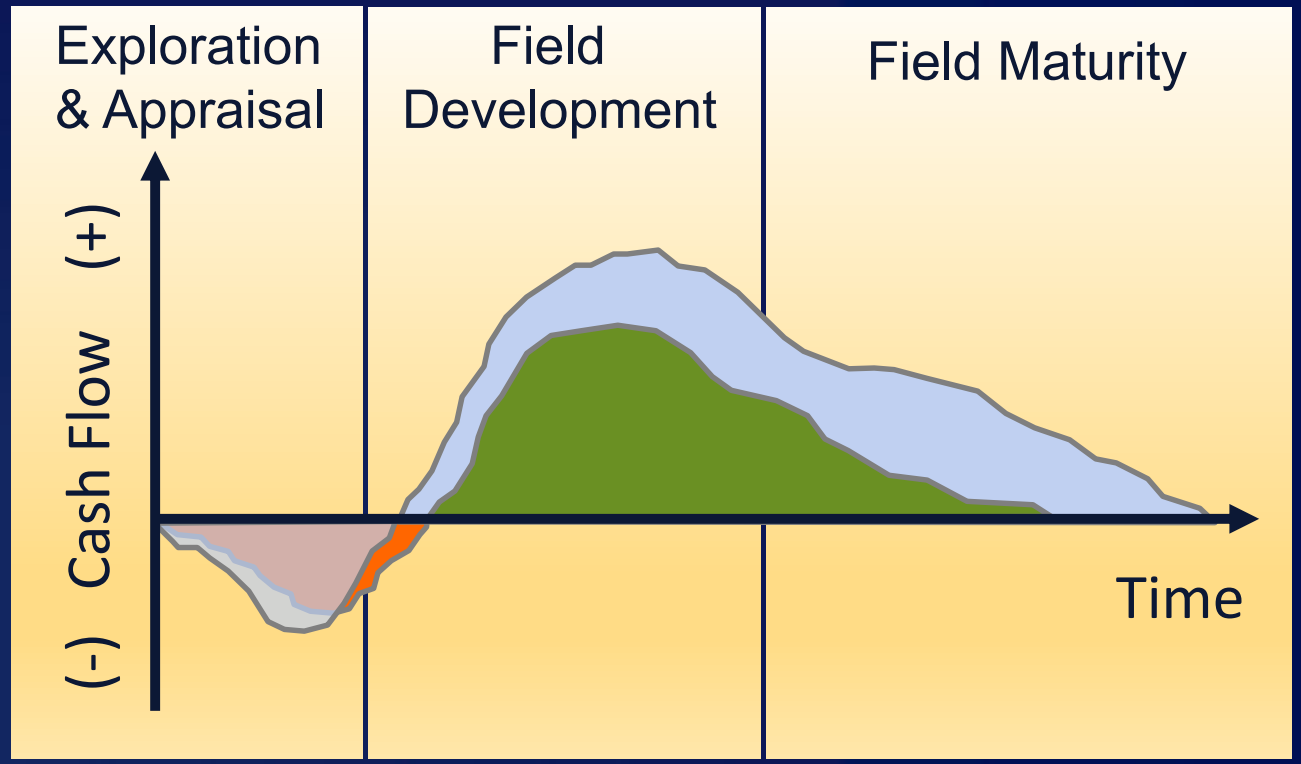
SPE International

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl

Why Stress Testing in Oilfield Operations?

SPE DISTINGUISHED LECTURER

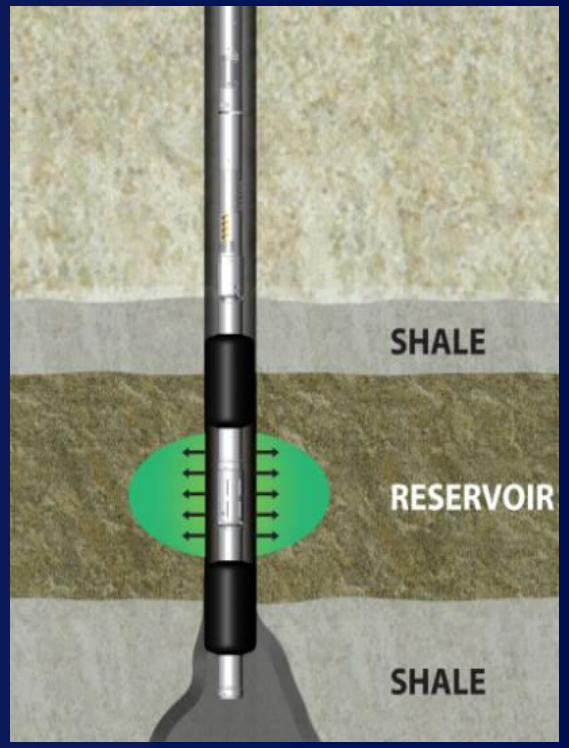
- Drilling wellbore stability
- Well casing design perforacion
- Solid production prediction
- Critically-stressed frac analysis
- Cap-rock integrity assessment
  - Enhanced recovery injector wells
  - Cutting re-injection wells
  - Underground gas storage
- Hydraulic fracturing containment
- Reservoir compaction / subsidence



Reduction of Tectonic Stress UNCERTAINTY → Accurate field Prediction & BETTER ROI

Outline

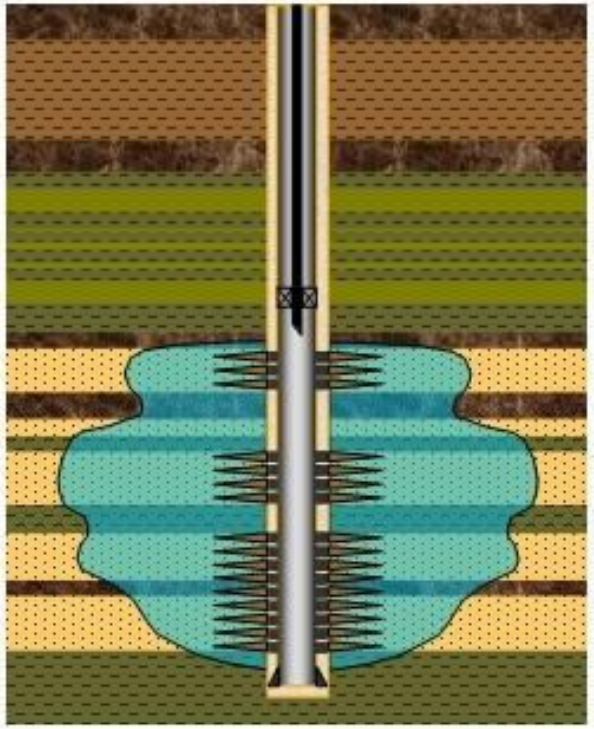
- What is microfrac stress testing
- Logs don’t measure stress
- Bad news – underutilized technology
  - History data, ops. challenges, and track record
- Good news – service improvement
  - Upgraded tool capabilities and enhanced workflow
- Case studies and applications
- Take away message



Minifrac / Microfrac Clarifications

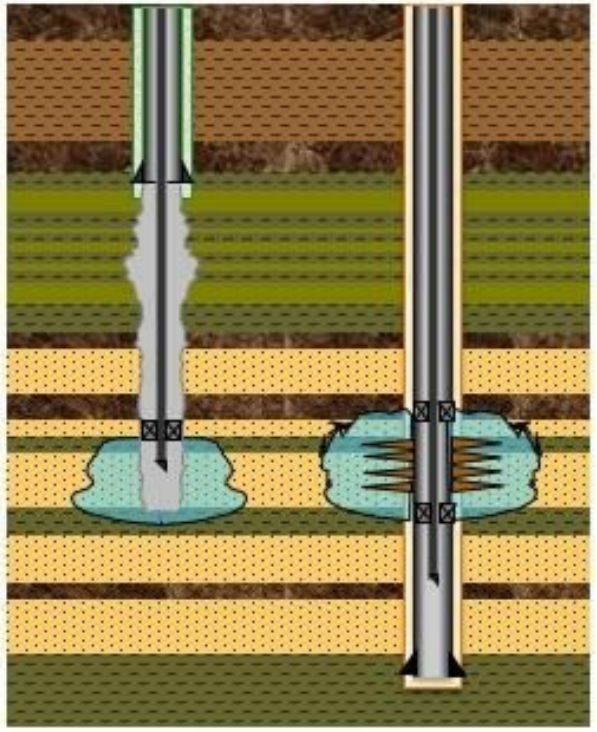
SPE DISTINGUISHED LECTURER

Surface Minifrac



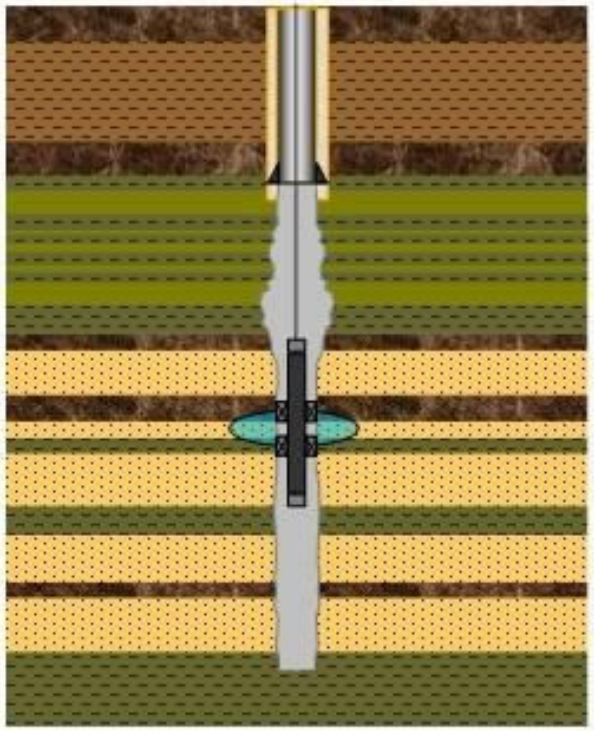
* Cased-hole / Surface pumping
* Test interval [20 - 100 ft]
* Very high rate [2 - 10 bpm]
* Injection vol. [10 - 100 bbl]

Surface MicroFrac



* CH or OH / Surface pumping
* Test interval [10 - 20 ft]
* High flow rate [5 - 25 gpm]
* Injection vol. [20 - 200 gal]

Downhole MicroFrac



* Open-hole / Downhole pumping
* Test interval [3 - 5 ft]
* Very low rate [0.1 - 2 lpm]
* Injection vol. [7 - 30 liters]

Technology Advantages

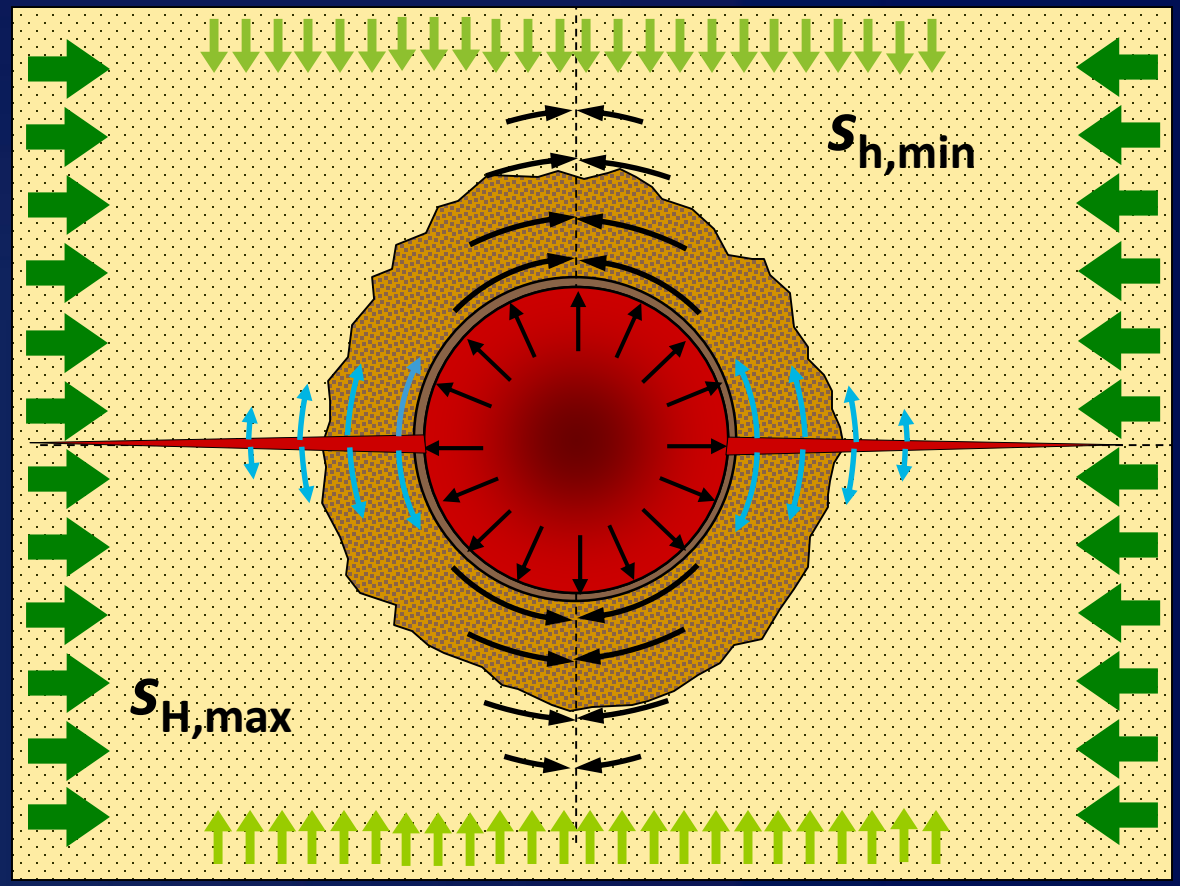
Straddle Packer Microfrac Testing

1) Stress contrast between pay and non-pay zones
- Multiple testing intervals

2) Less poro-elastic effects in reopening and closure
- Small volume fracture
- Low injection rate

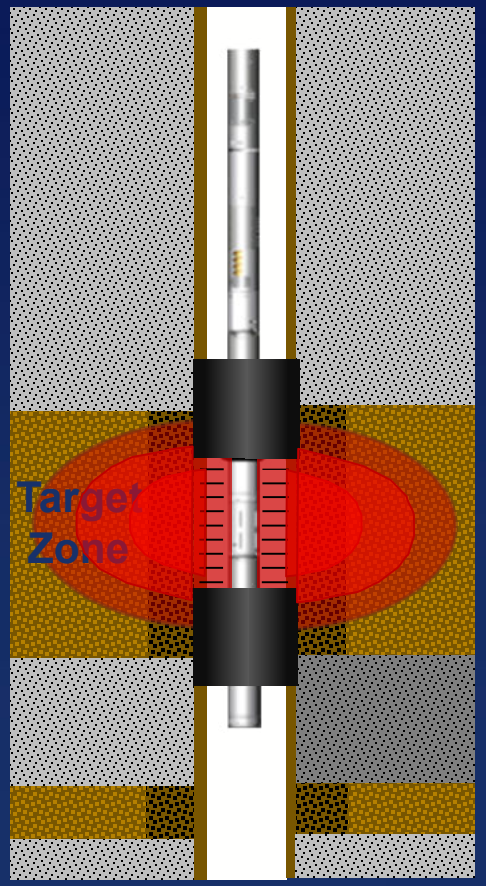
3) Accurate measurements
- Downhole injection
- No borehole effects
- In-situ pressure gauges

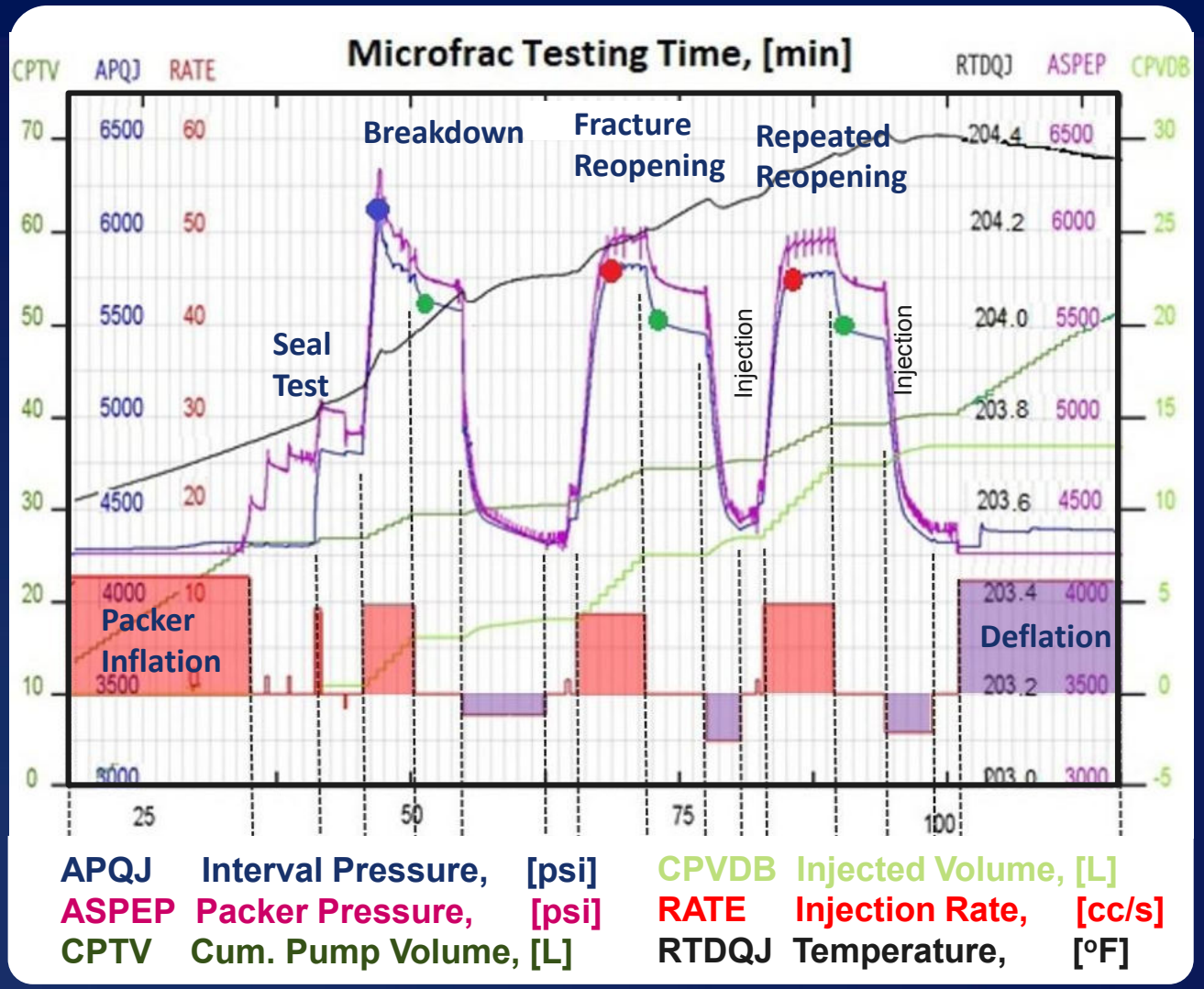
Cross-section



Plane-view

Microfrac Stress Testing Data

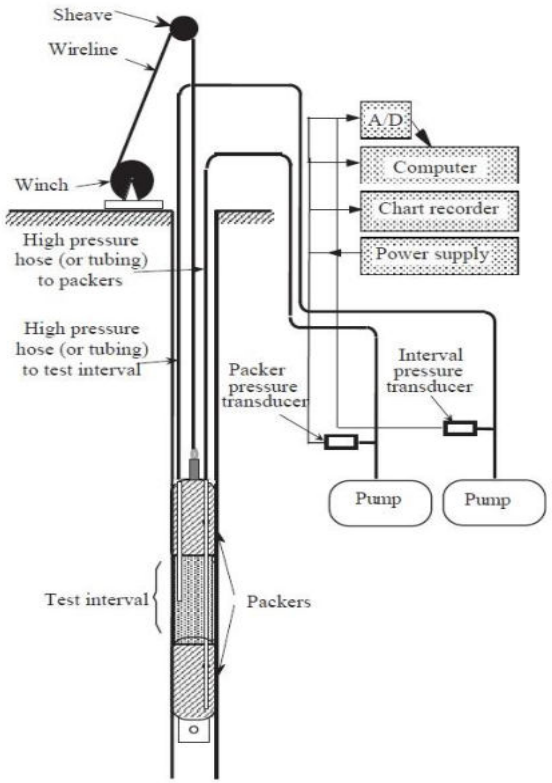




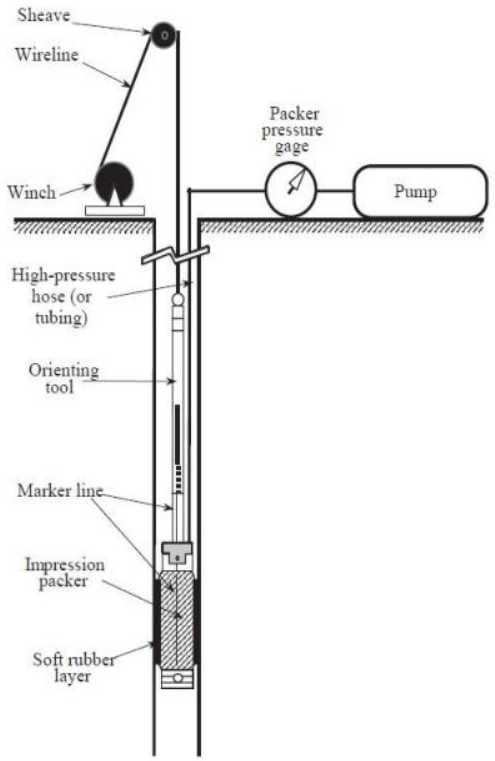
- Formation breakdown pressure
- Fracture Reopening & propagation
- Fracture closure pressure

Franquet *et al.* (2018) SPE-193004-MS

Dual-Packer Sleeve Frac



Dual-Packer Microfrac



Single-Packer Microfrac

Haimson and Cornet (2003) ISRM Suggested Methods for Rock Stress Estimation

Logs Don't Measure Stress

SPE DISTINGUISHED LECTURER

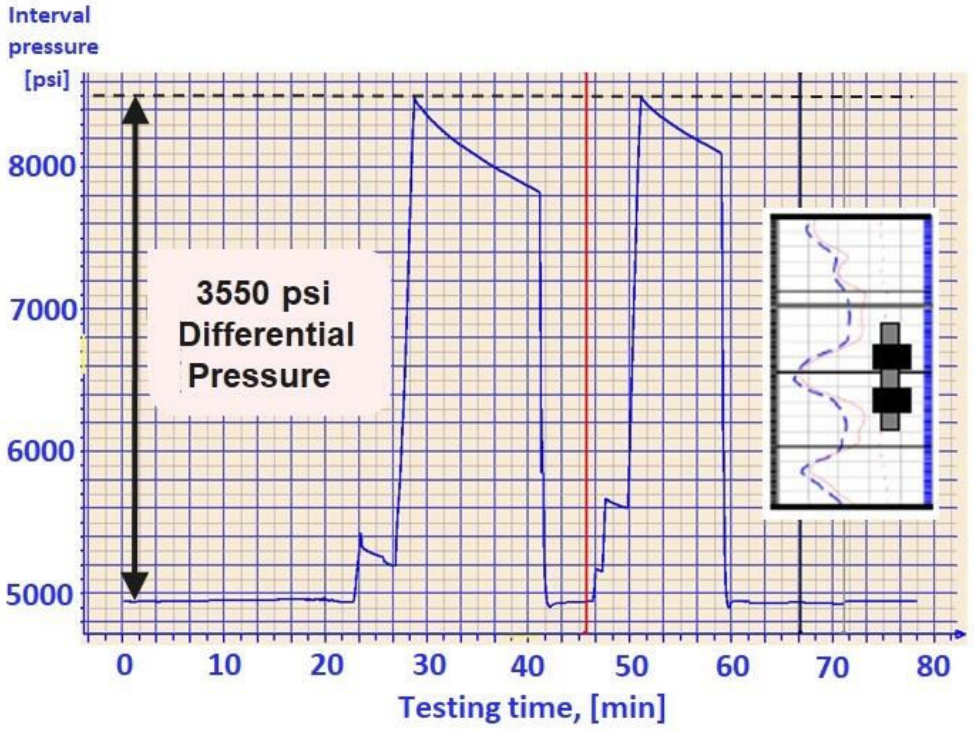
Logs ONLY measure consequences of stress:

- Changes in porosity, density, slowness, and rock stiffness
- Borehole failure evidences

ONLY Microfrac testing measure stress directly

Microfrac Testing: Underutilized Technology

- Straddle Packer Microfrac Underutilization
  - Insufficient tool capability and packer performance



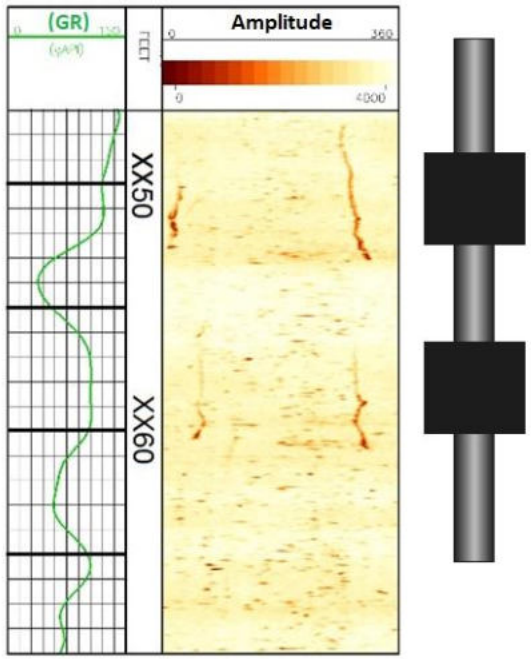
Microfrac testing unable to achieve formation breakdown

Packer rupture

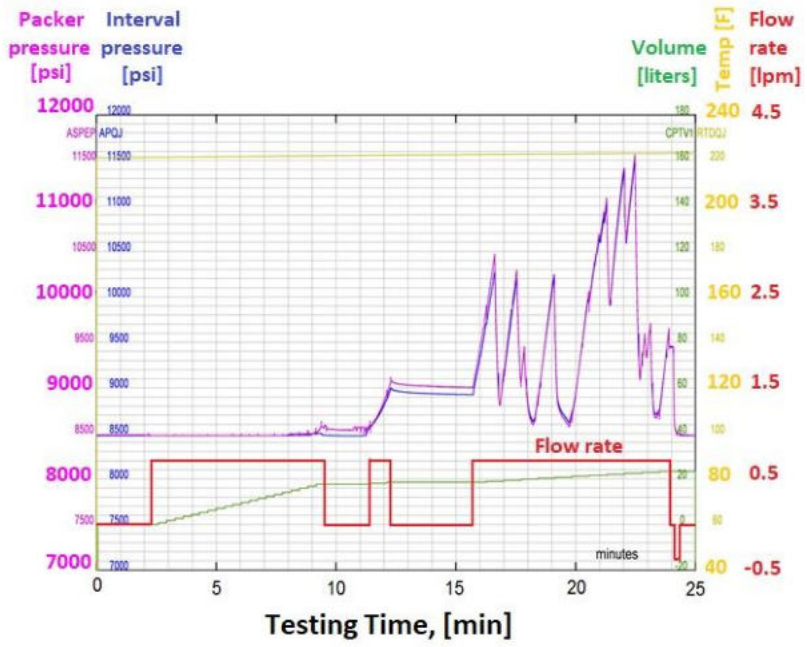
Permanent deformation

Microfrac Testing: Underutilized Technology

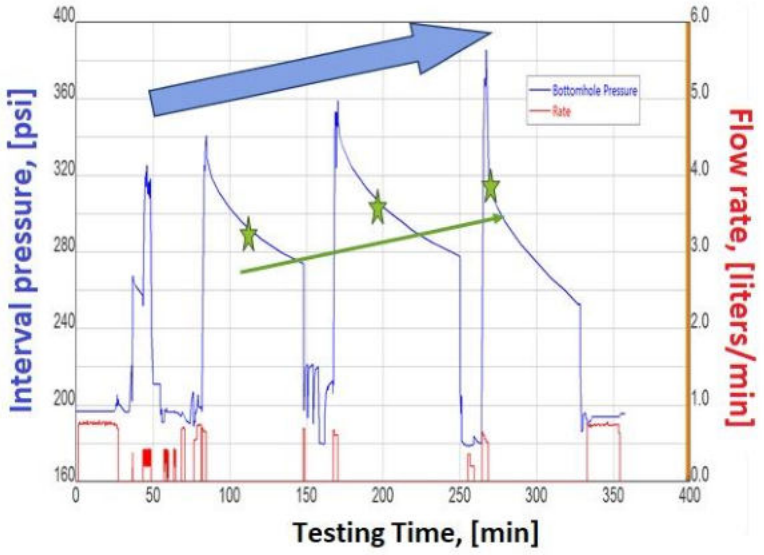
- Straddle Packer Microfrac Underutilization
  - Insufficient tool capability and packer performance
  - Deficient Service Deployment (interval selection)



Unintentional sleeve fracturing



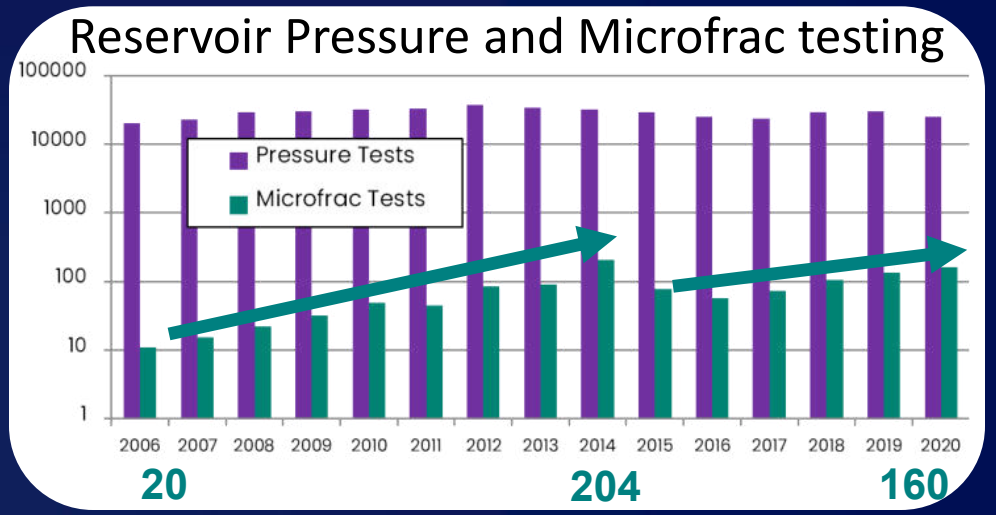
Poor interval isolation and packer sealing

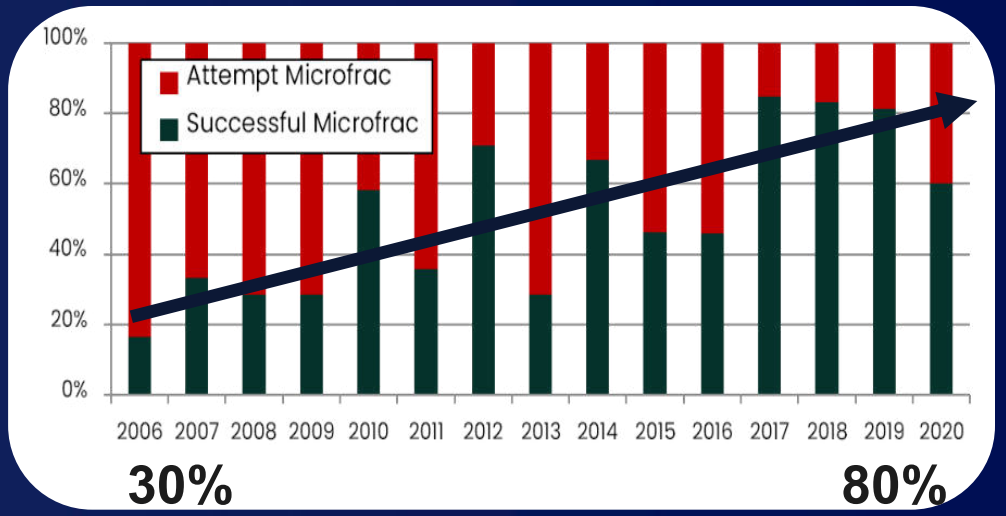


Near wellbore poro-elastic effects

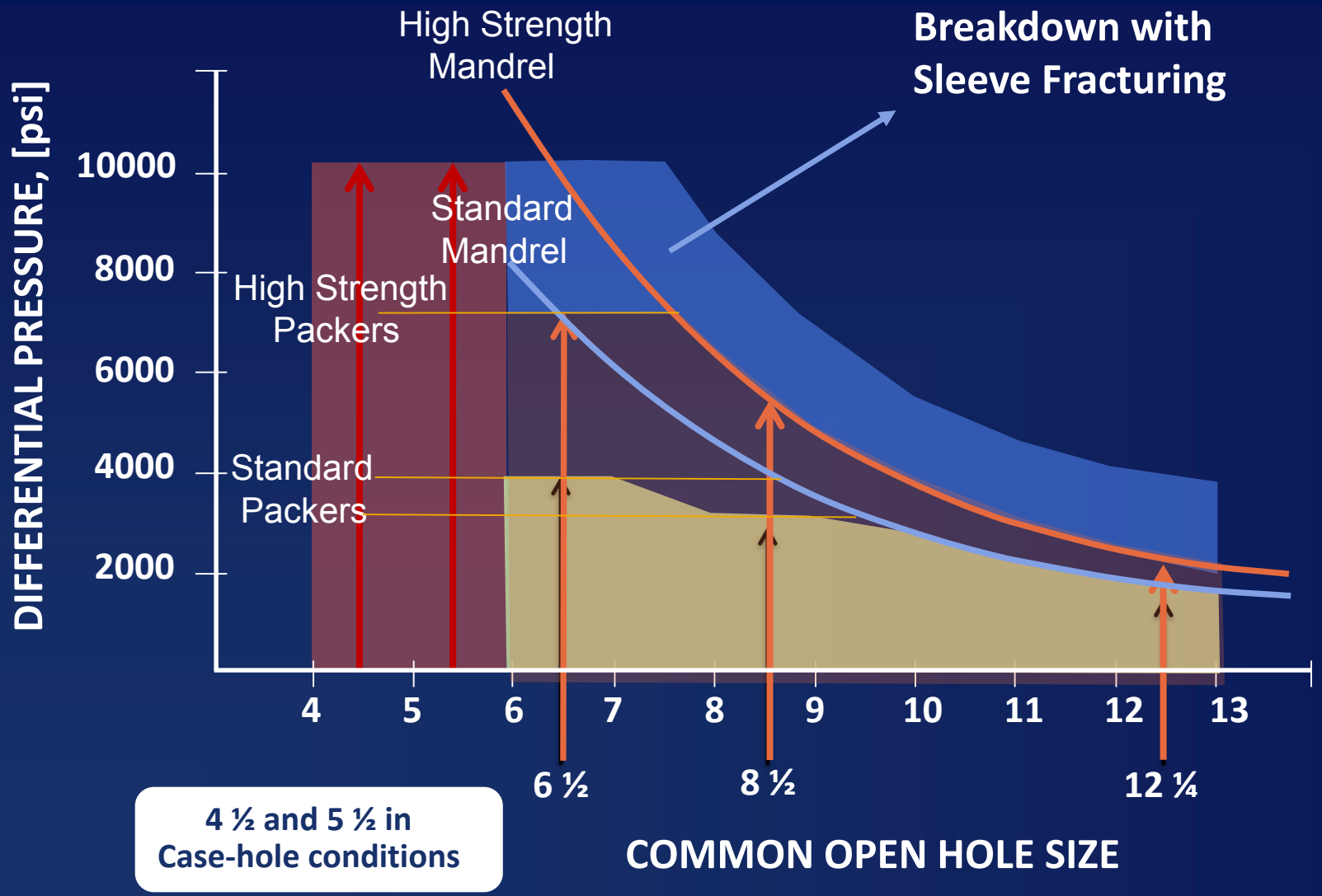
Microfrac Testing: Underutilize Technology

- Straddle Packer Microfrac Underutilization
  - Insufficient tool capability and packer performance
  - Deficient Service Deployment
    - Tool Plugging (high solid content in the mud)
    - Differential sticking (high overbalance)
- Microfrac Performance Improvement
  - Upgraded tool capabilities (Mandrel & Packer)
  - Enhanced microfrac service workflow
  - Improved operational practices





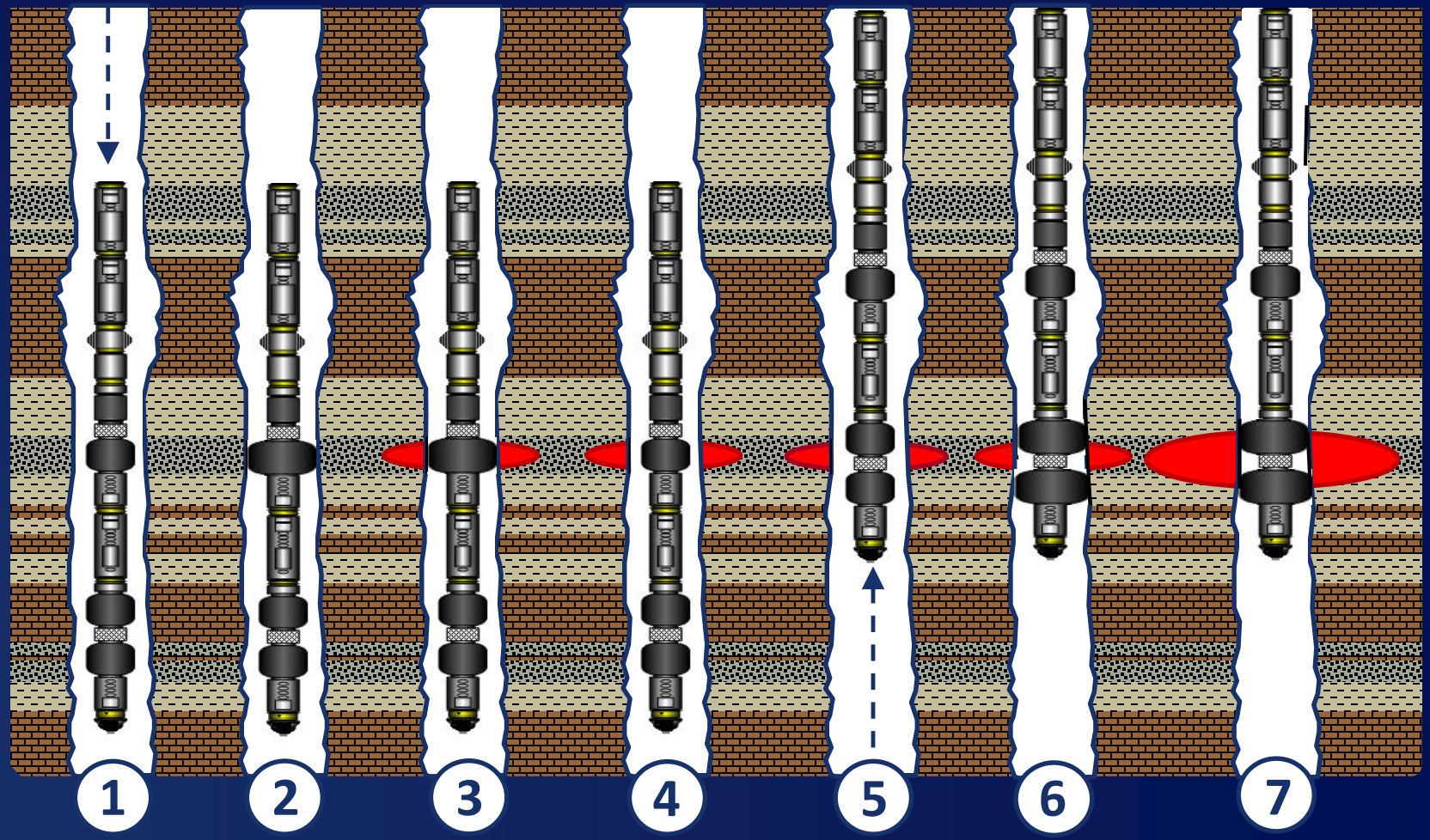
Upgraded Straddle Packer Capabilities



4 ½ and 5 ½ in Case-hole conditions

Sleeve Fracturing Alternative Testing

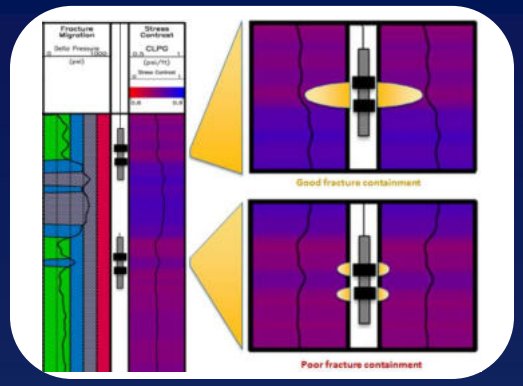
1. Position single packer at testing interval
2. Inflate single packer
3. Sleeve Fracture
4. Deflate single packer
5. Position straddle Packer at interval
6. Inflate straddle packer
7. Perform straddle packer microfrac testing



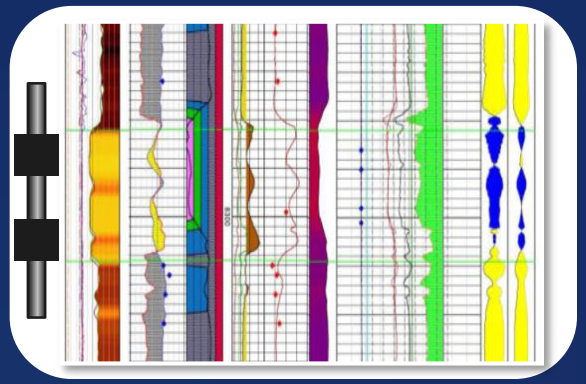
Enhanced Microfrac Testing Workflow

SPE DISTINGUISHED LECTURER

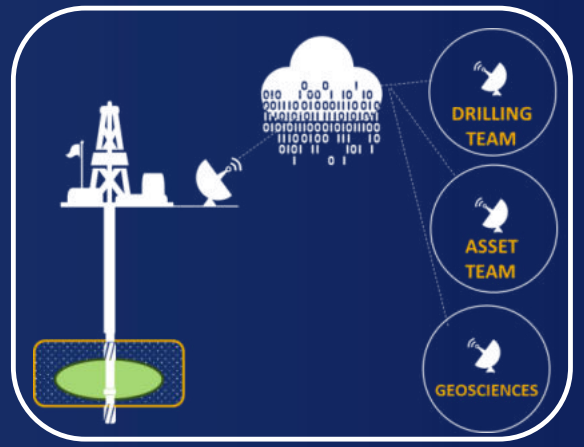
PRE-JOB ASSESSMENT



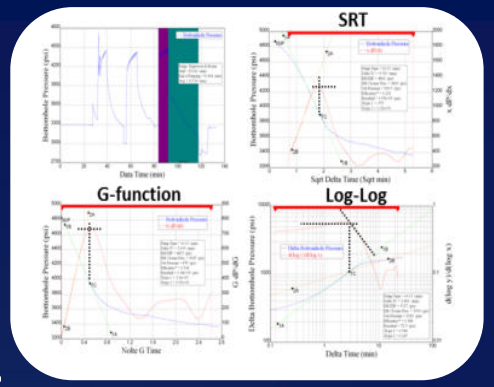
INTERVAL SELECTION



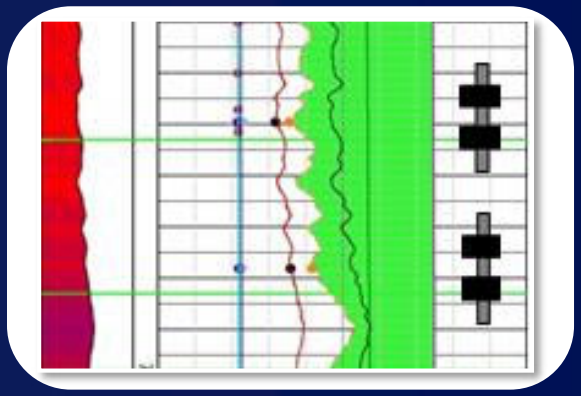
REAL TIME MONITORING



POST-ACQUISITION ANALYSIS

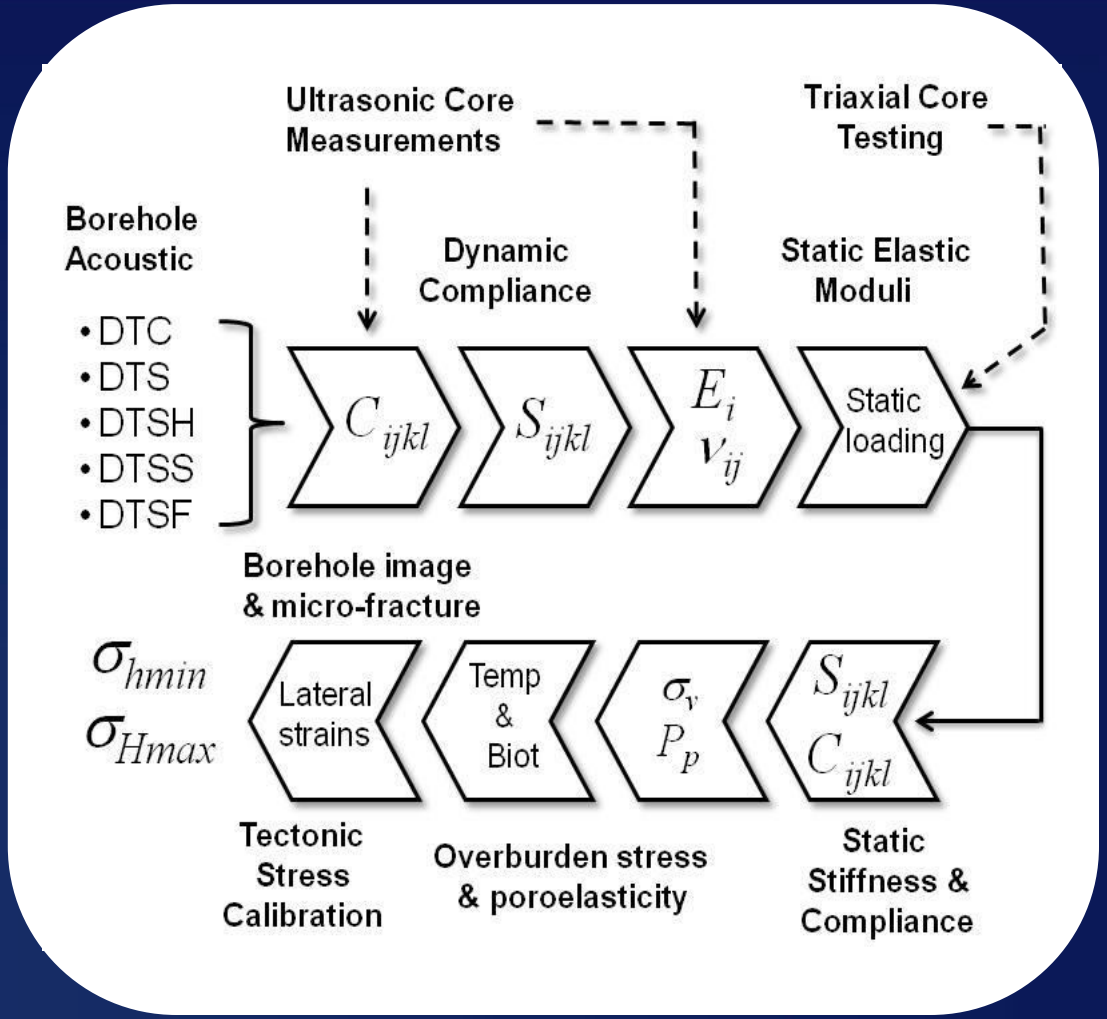


TECTONIC STRAIN CALIBRATION



Prejob Microfrac Assessment

- Estimation of formation mechanical properties
- Estimation of stresses
  - Overburden stress and pore pressure profile
  - Minimum and maximum horizontal stresses
- Prediction of formation breakdown pressure
- Maximum tool pressure capability



Franquet et al. (2012) ARMA 12-644

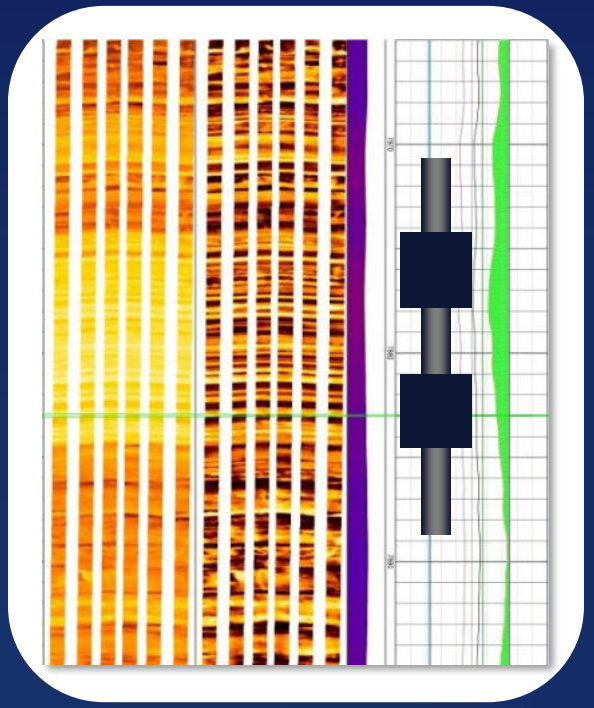
MICROFRAC TESTING

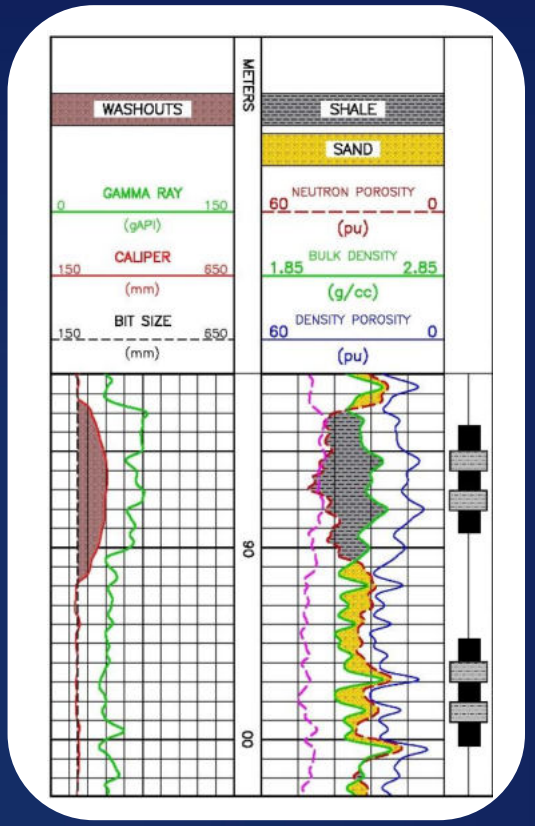
- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- Post Acquisition Interpretation
- Hstress Tectonic Calibration

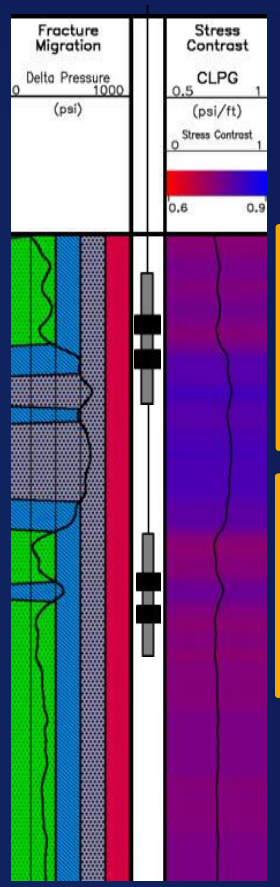
FINAL STRESS MODEL

Real-Time Interval Selection

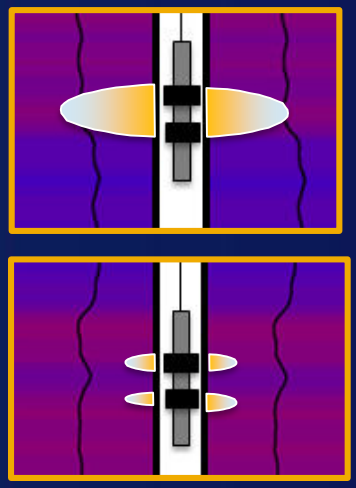
- Rush borehole acoustic processing (DTc and DTs)
- Borehole Image assessment (Breakouts / Fractures)
- Hole caliper quality (Washouts)
- Stress contrast







GOOD FRACTURE CONTAINMENT



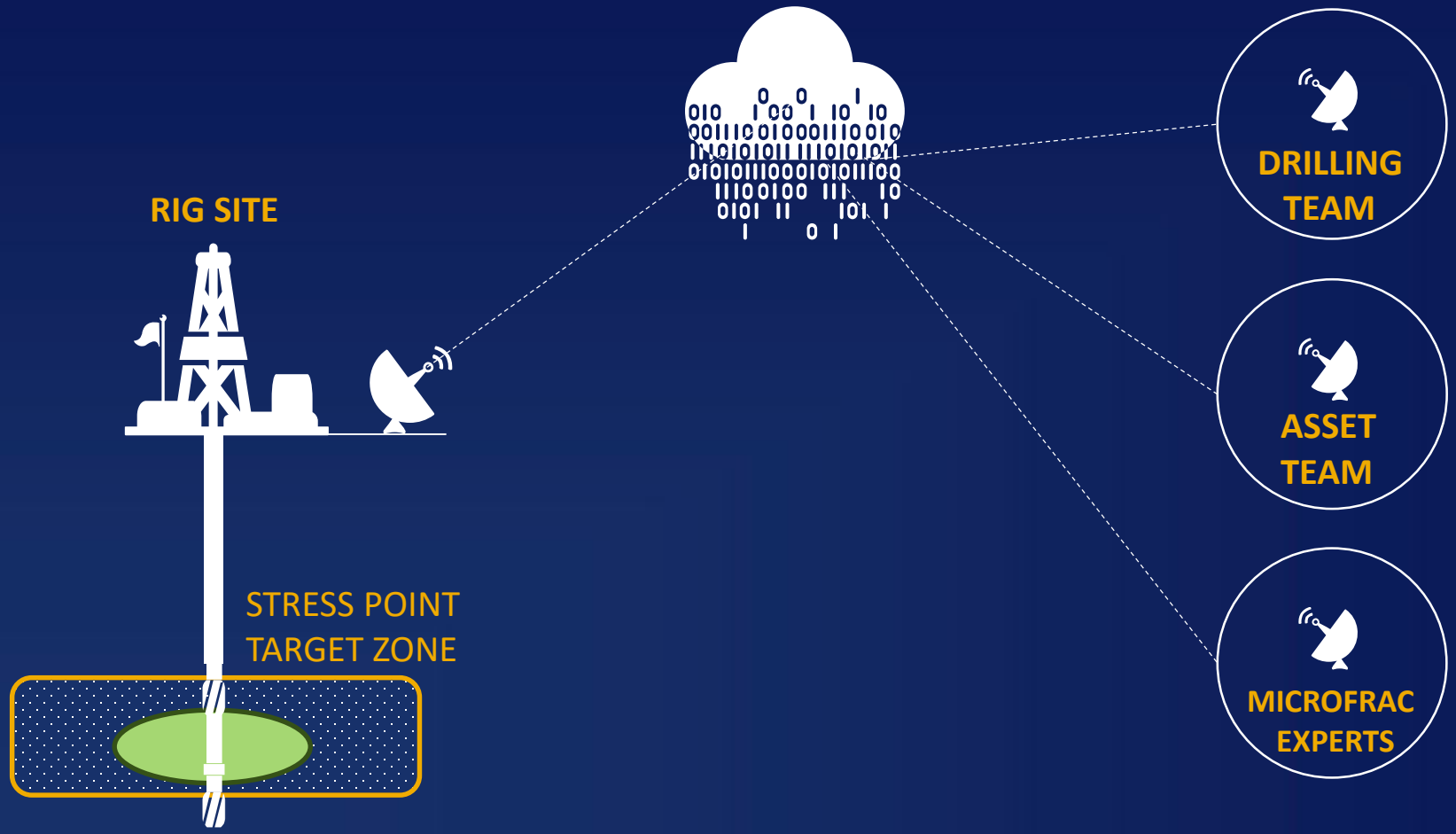
POOR FRACTURE CONTAINMENT

MICROFRAC TESTING

- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- Post Acquisition Interpretation
- Hstress Tectonic Calibration

FINAL STRESS MODEL

MicroFrac Real-Time Data Monitoring

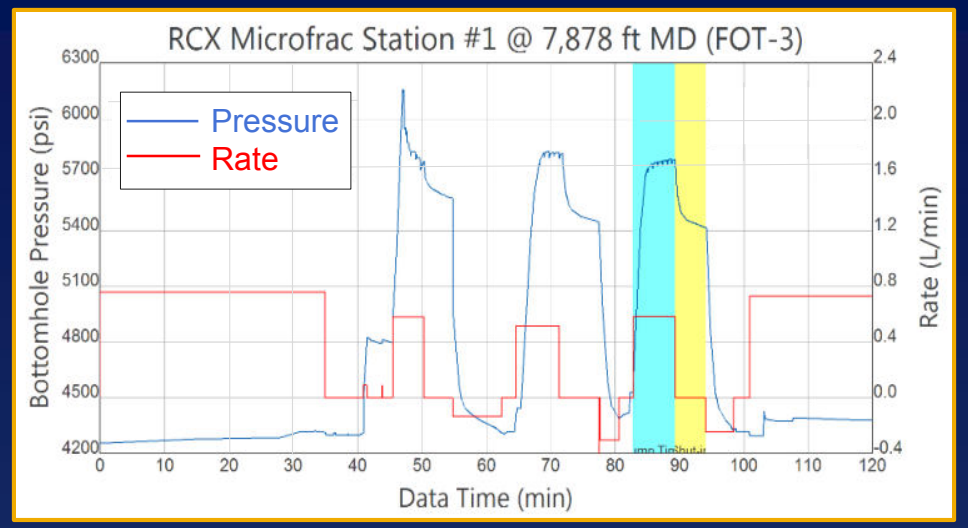


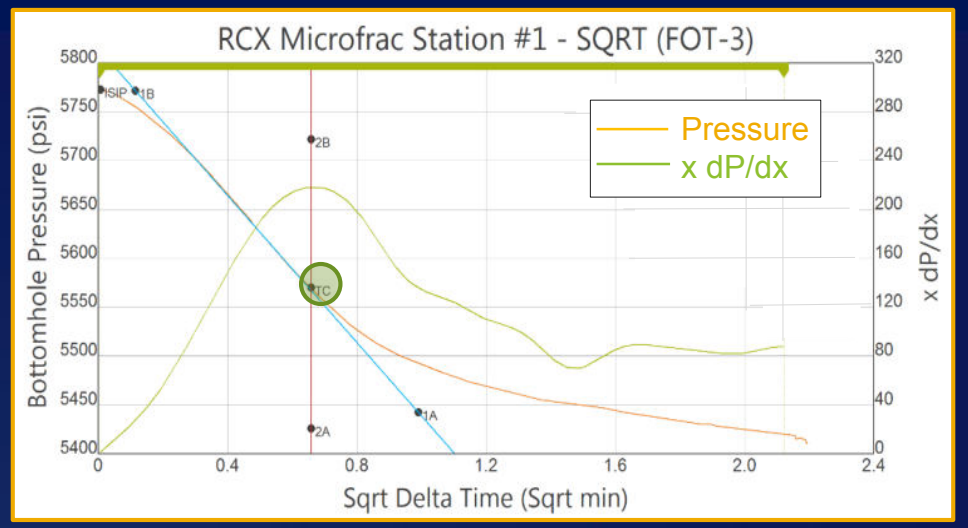
MICROFRAC TEST

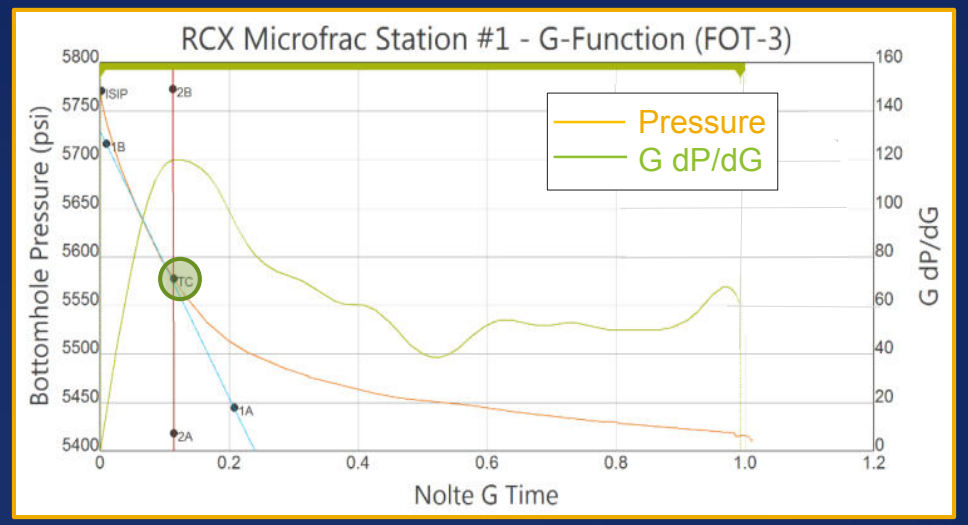
- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- Post Acquisition Interpretation
- Hstress Tectonic Calibration

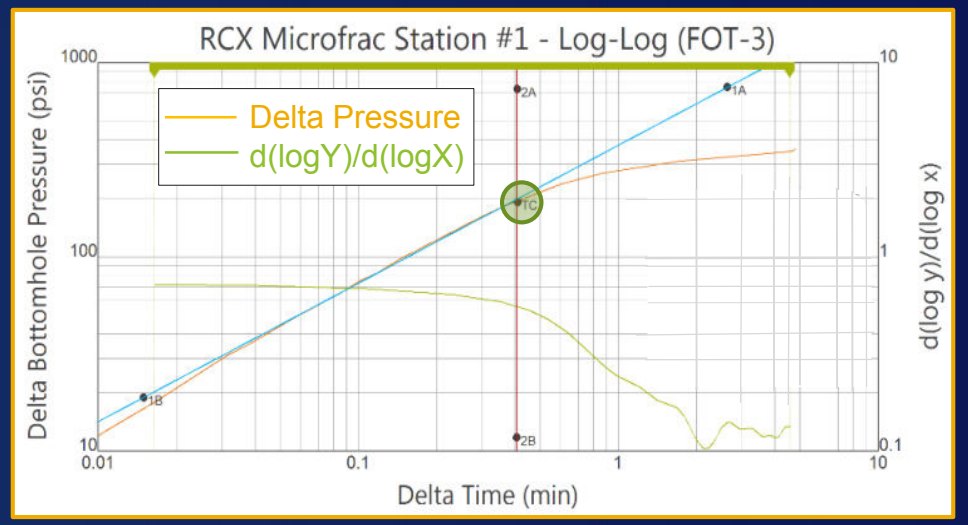
FINAL REPORT

Post Acquisition Interpretation (Reservoir)









MICROFRAC TEST

- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- **Post Acquisition Interpretation**
- Hstress Tectonic Calibration

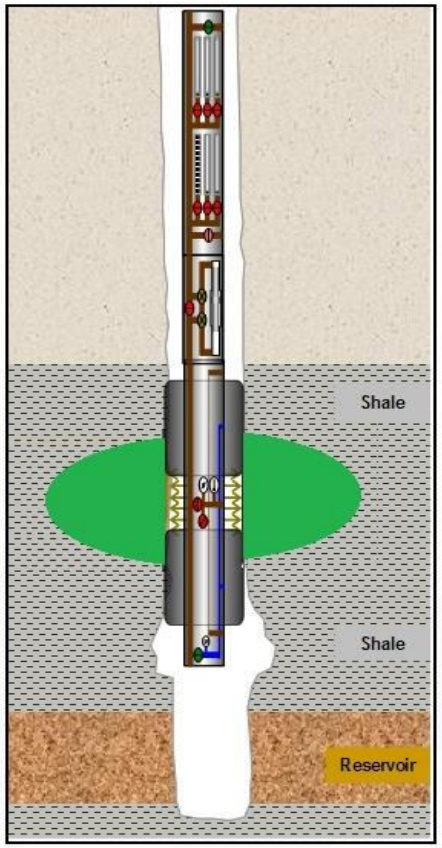
FINAL REPORT

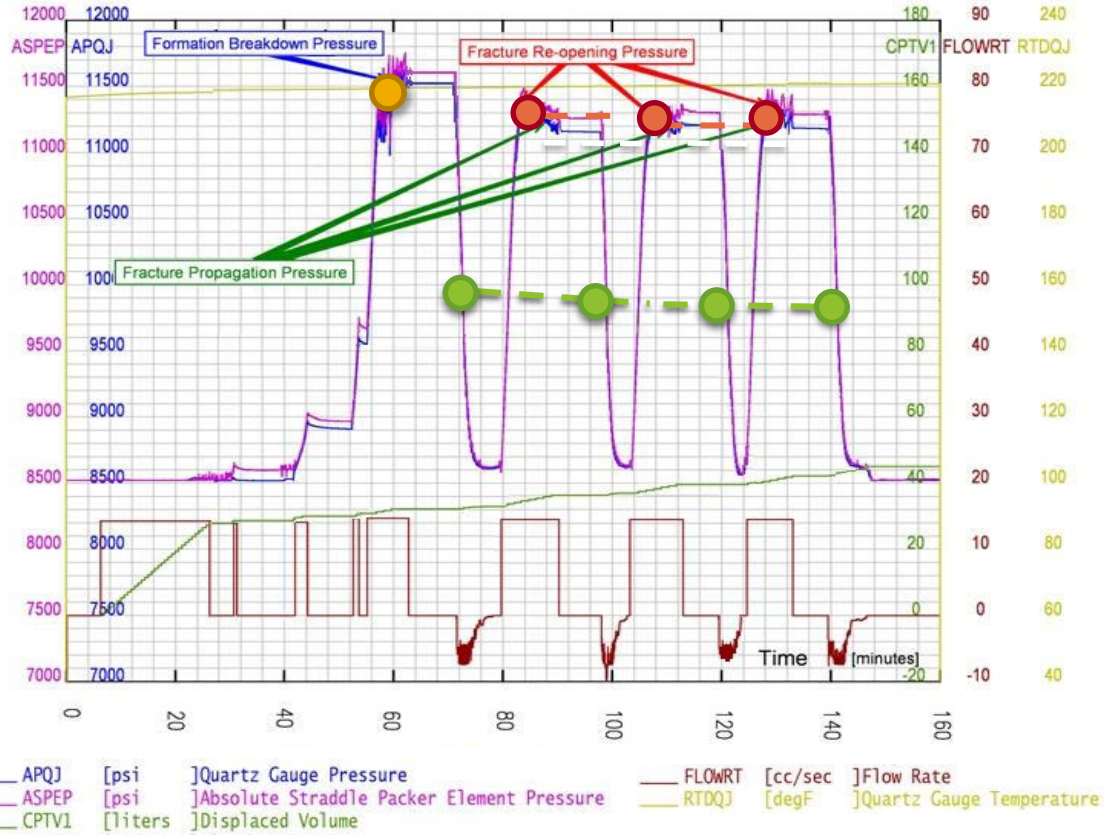
Franquet et al. (2018) SPE-193004-MS

Post Acquisition Interpretation (Shale)

SPE DISTINGUISHED LECTURER

Fracture Closure Analysis Using Controlled Flow-back





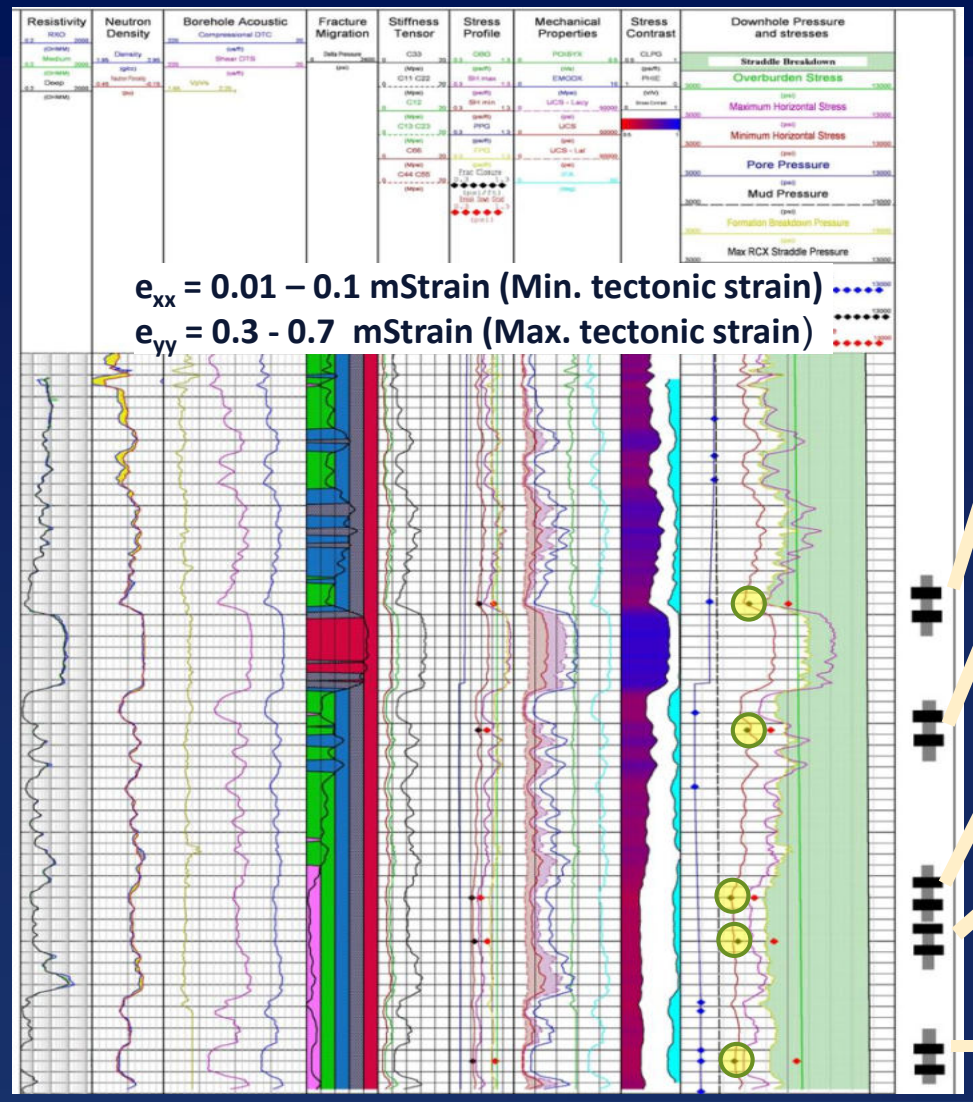
FORMATION BREAKDOWN PRESSURE FRACTURE REOPENING & PROPAGATION PRESSURE FRACTURE CLOSURE PRESSURE

MICROFRAC TEST

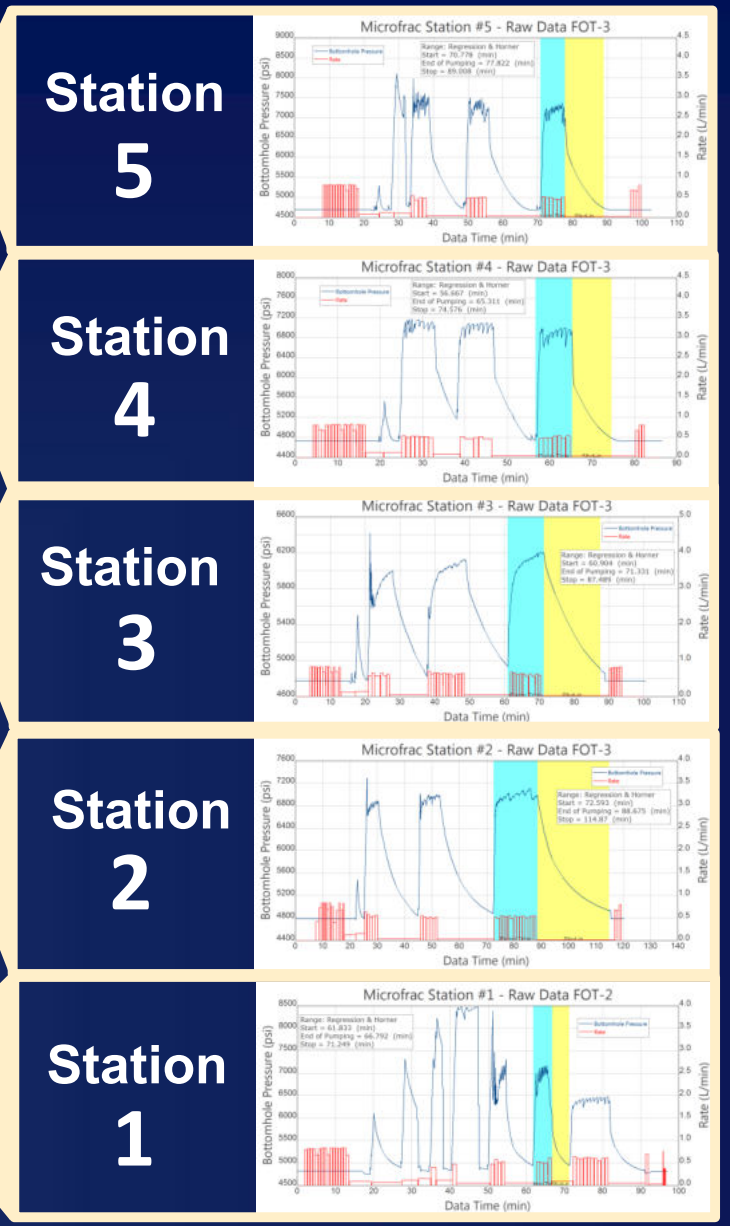
- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- **Post Acquisition Interpretation**
- Hstress Tectonic Calibration

FINAL REPORT

Horizontal Tectonic Strain Calibration



Franquet *et al.* (2017) SPE-188643-MS



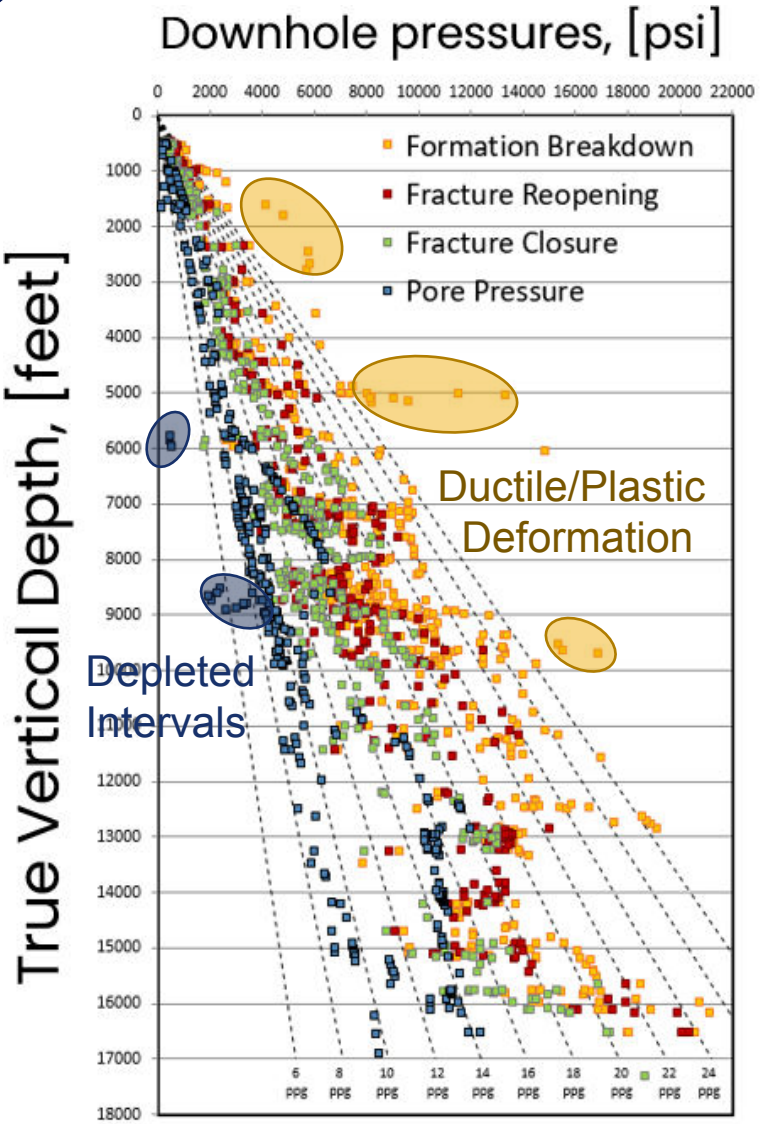
SPE DISTINGUISHED LECTURER

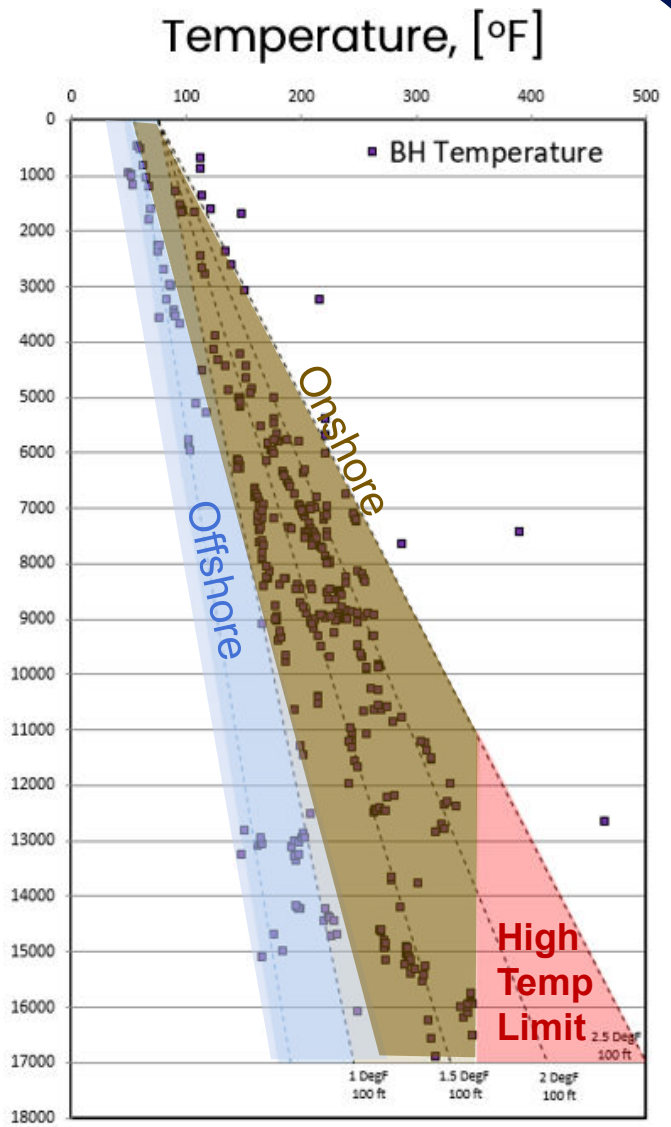
MICROFRAC TEST

- Prejob Assessment
- Interval Selection
- Real Time Monitoring
- Post Acquisition Interpretation
- Hstress Tectonic Calibration

FINAL REPORT

In-situ Stress from 557 Microfrac Testing



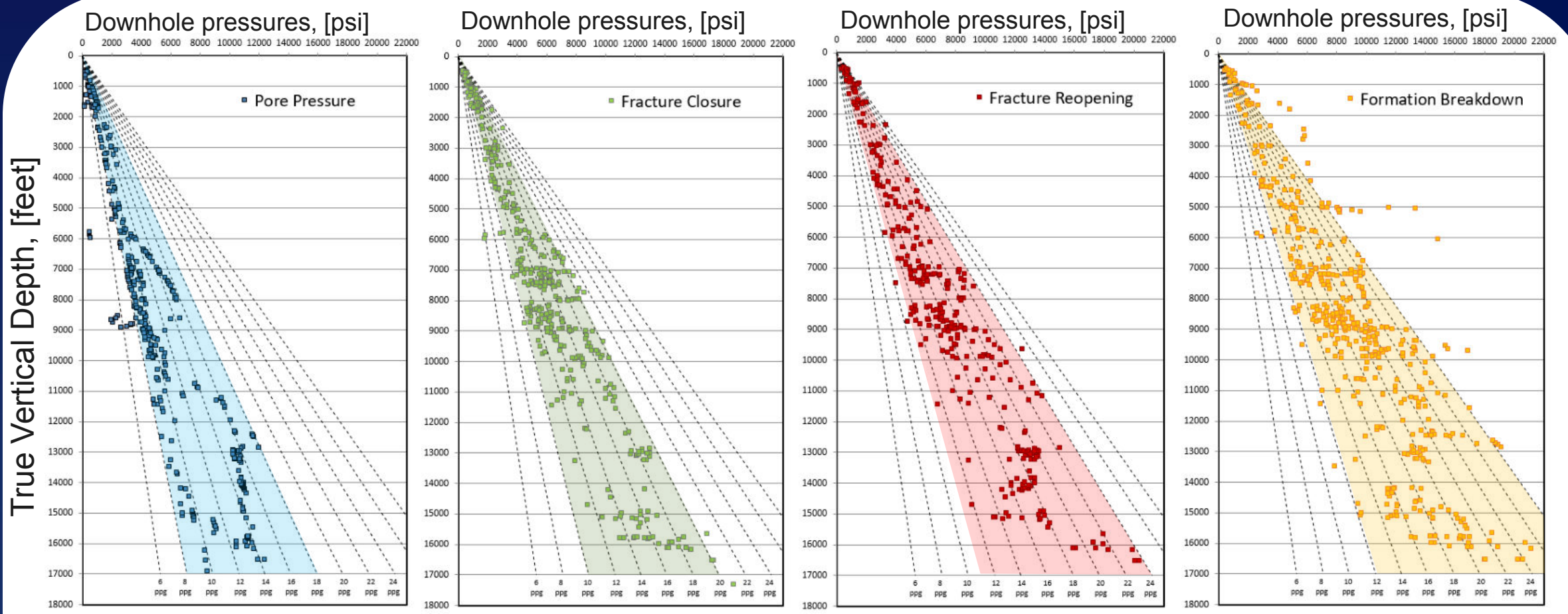


Franquet et al. (2020) IPTC-20257

Evans & Engelder (1986) SPE-015609
De Bree & Walters (1989) *Int. J. Rock Mech. & Min. Sc.* 26
Ahmed et al. (1991) SPE-019004
Thiercelin et al. (1993) SPE-025906
Ramos et al. (1994) ARMA 94-361
Desroches et al. (1998) SPE-058086
Klee et al. (1999) *Int. J. Rock Mech. & Min. Sc.* 36
Nelson et al. (2003) USGS
Haimson & Cornet (2003) *Int. J. Rock Mech. & Min. Sc.* 40
Fourmaintraux et al. (2005) SPE-094253
Olson et al. (2005) SPE-096773
Ramakrishnan et al. (2009) SPE-124147
Cig et al. (2009) IPTC-13390 / SPE-127233
Franquet et al. (2011) OMC
Achmitt et al. (2012) ARMA 12-168
Elarouci et al. (2012) SPE-150611
Bautmans et al. (2013) ARMA 13-545
Ihab et al. (2014) IPTC-17301
Malik et al. (2014) SPE-169009
Rohmer et al. (2015) SPE-174380
Malik et al. (2015) SPE-175002
Noora et al. (2015) SPE-177626
Parotidis et al. (2015) SPE-180075
Wahaj et al. (2015) SPE-181136
Franquet et al. (2016) SPE-181627
Gui et al. (2016) SPE-182178
Mishra et al. (2016) OTC-27091
Franquet et al. (2017) SPE-188643
Wang & Li Zhi (2017) EAGE WE P04
Karpov et al. (2017) SPE-187935
Hamza et al. (2018) SPE-190126
Franquet et al. (2018) SPE-192959
Franquet et al. (2018) SPE-193004
Doucette et al. (2018) SPE-193032
Povstyanova et al. (2018) SPE-193272
Franquet et al. (2019) ARMA 19-1635
Raziperchikolaee et al. (2019) ARMA 19-1637
Prasad et al. (2020) IPTC-20077
Franquet et al. (2020) IPTC-20257
Zhang et al. (2020) OTC-30297
Ibrahim et al. (2020) SPE-202600

Franquet et al. (2020) IPTC-20257

Fracture Initiation Uncertainty



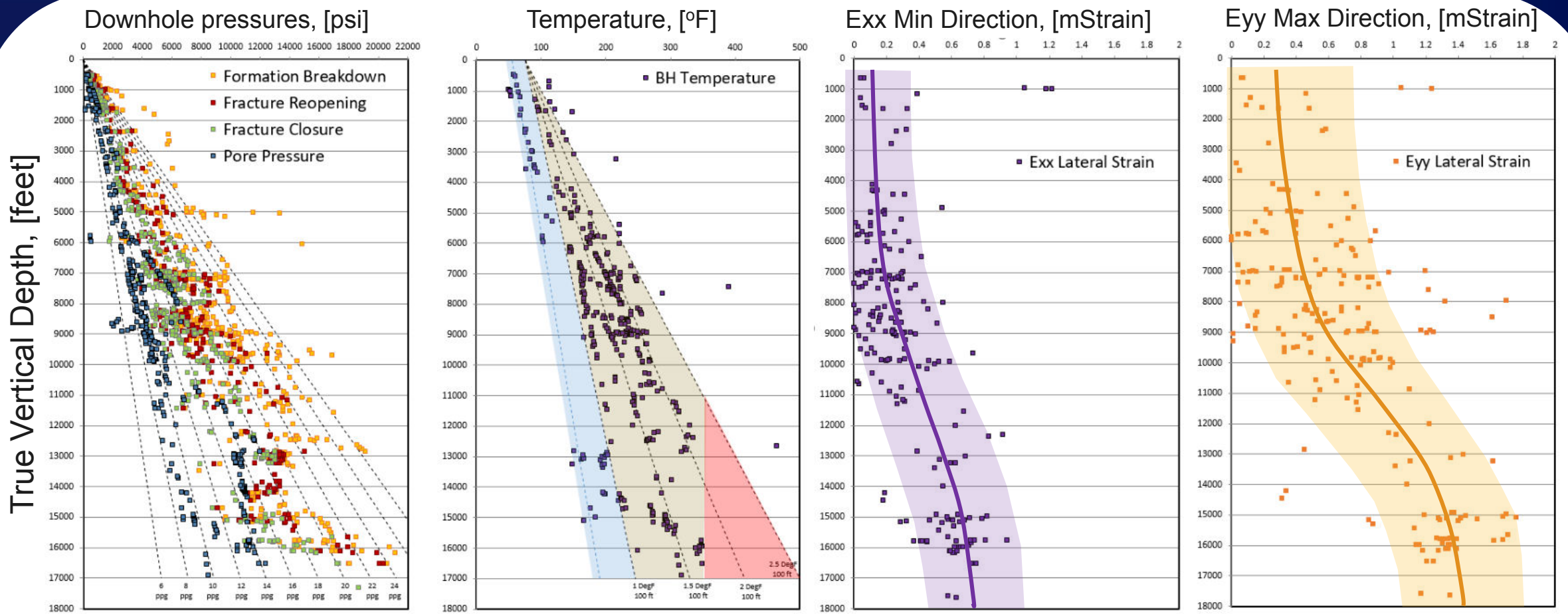
Pore [8–18 ppg] uncertainty

Closure [10–20 ppg] uncertainty

Reopening [11–24 ppg] uncertainty

Breakdown [12–28 ppg] uncertainty

Tectonic Strain Analysis

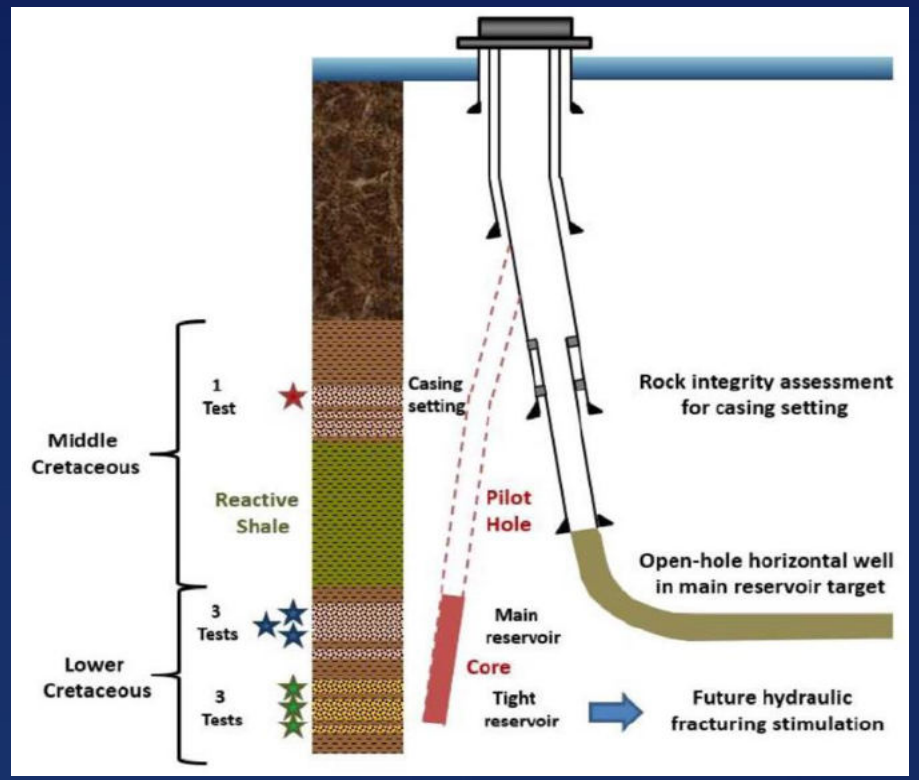


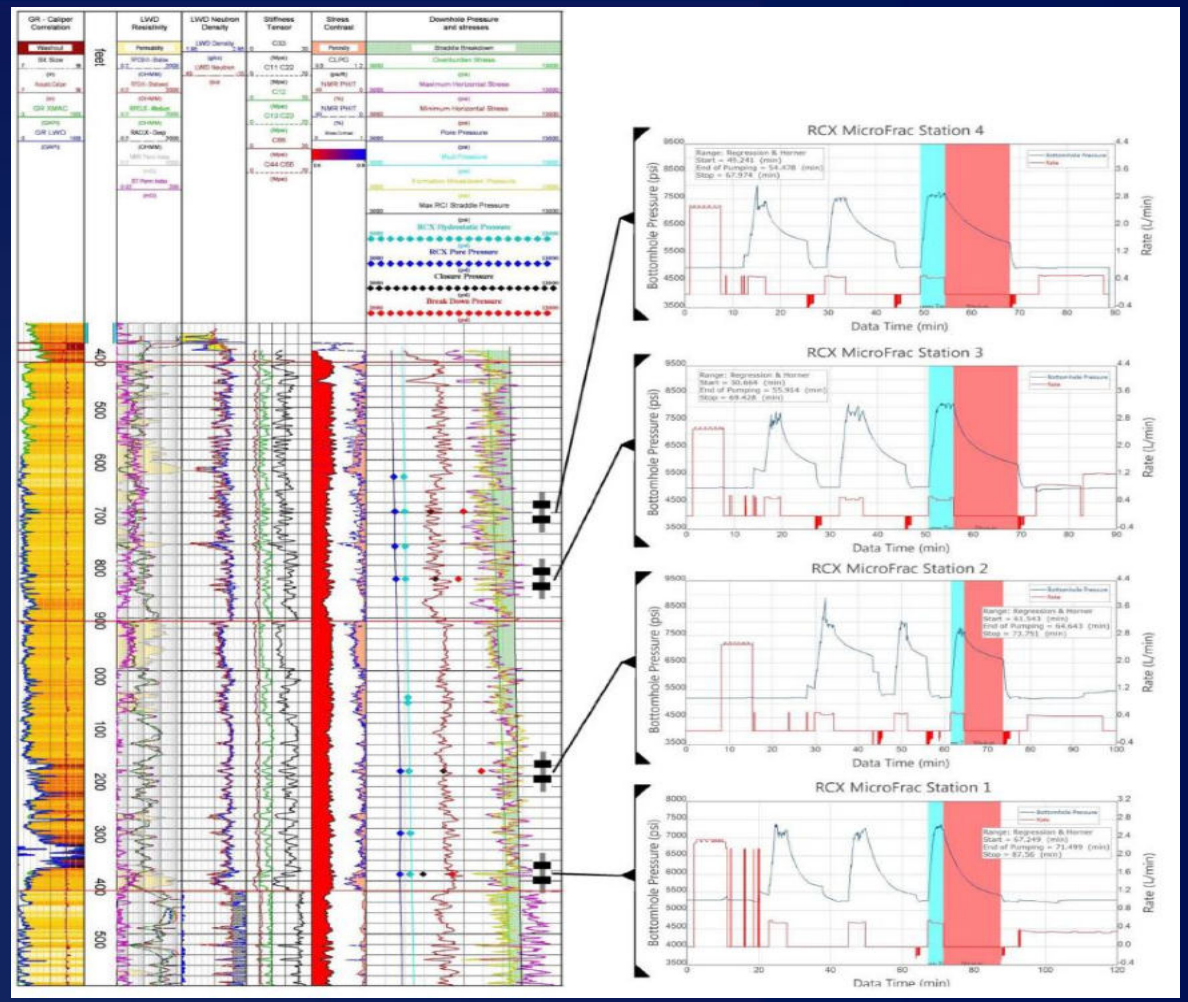
Franquet et al. (2020) IPTC-20257

Minimum Strain
[0.31 mStrain]

Maximum Strain
[0.74 mStrain]

Case Study: Casing Design / Hor. Drilling



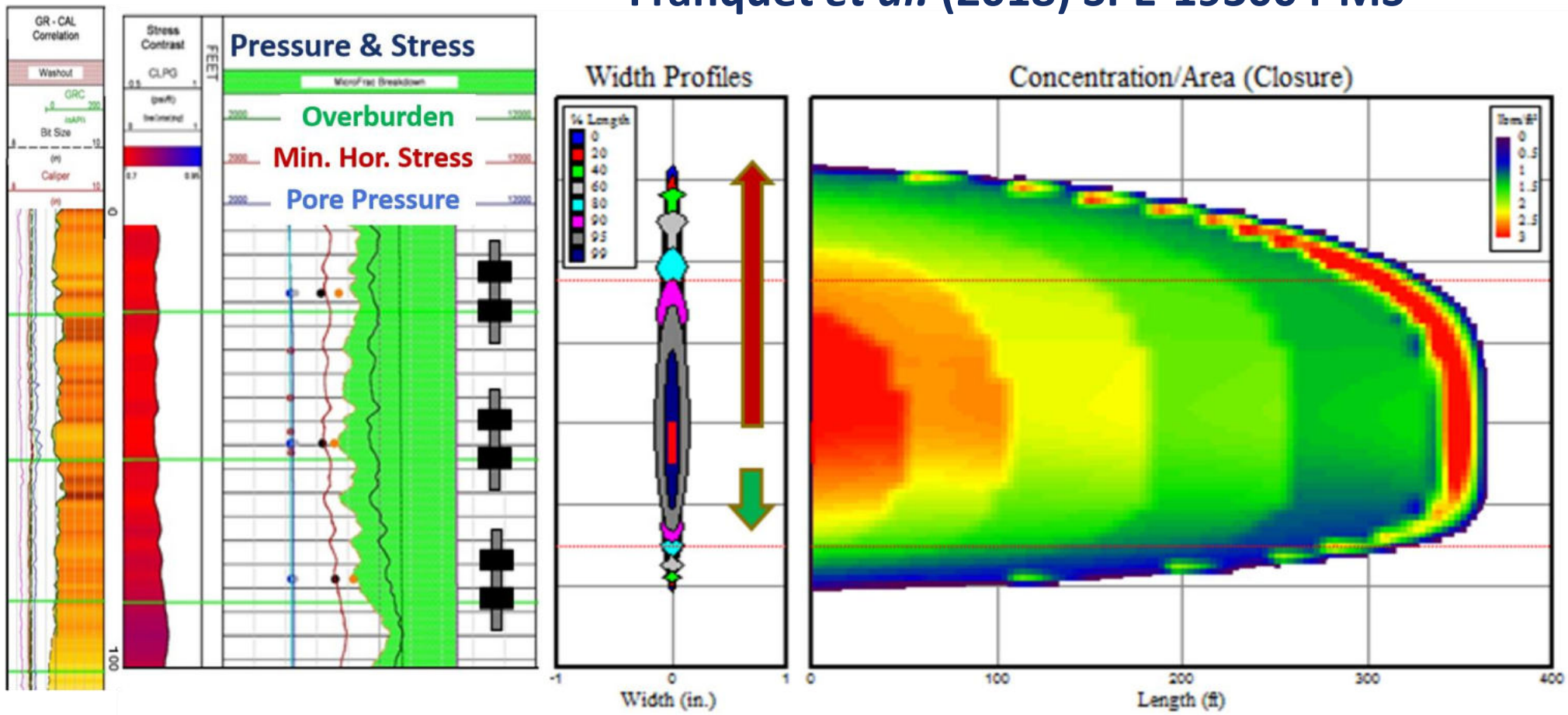


Franquet *et al.* (2018) SPE-192959-MS
Franquet *et al.* (2018) SPE-193004-MS

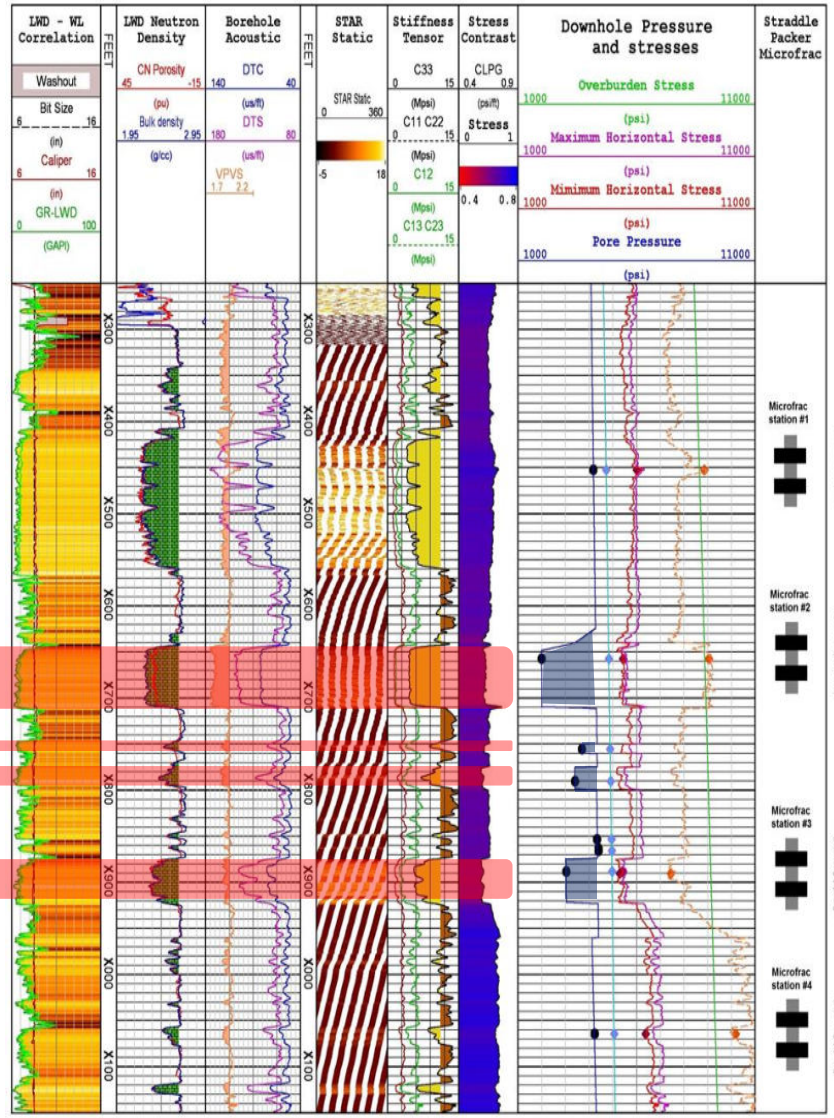
Case Study: Reservoir Stimulation

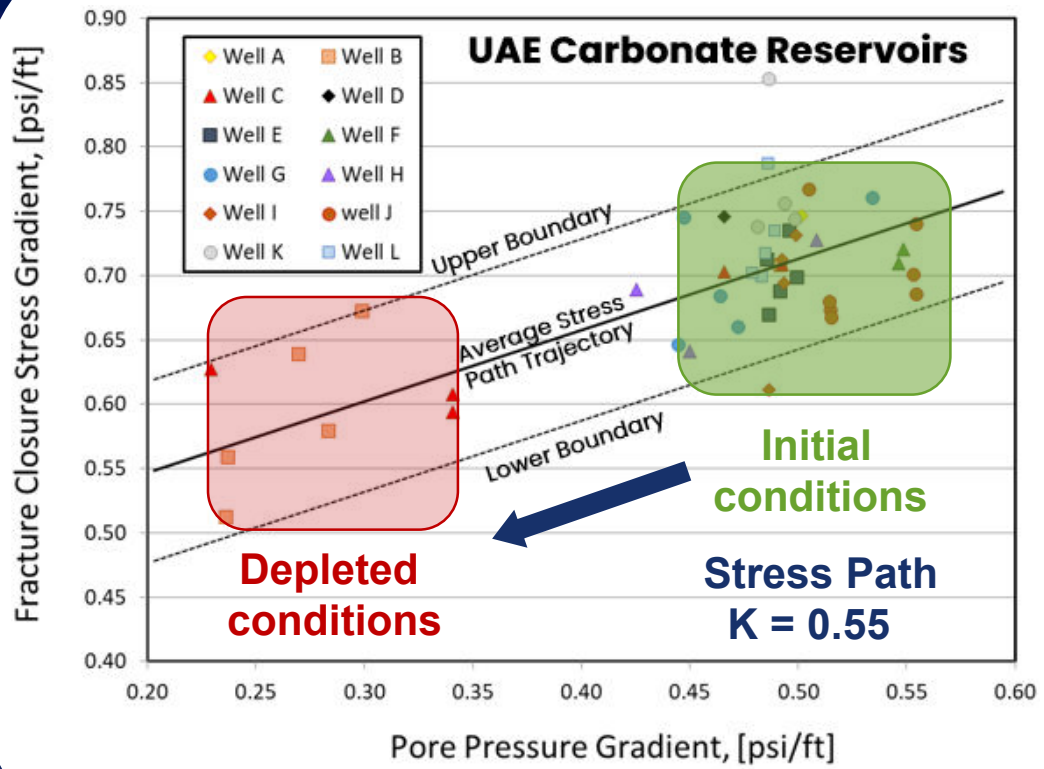
SPE DISTINGUISHED LECTURER

Franquet *et al.* (2018) SPE-193004-MS



Case Study: Depleted Reservoirs



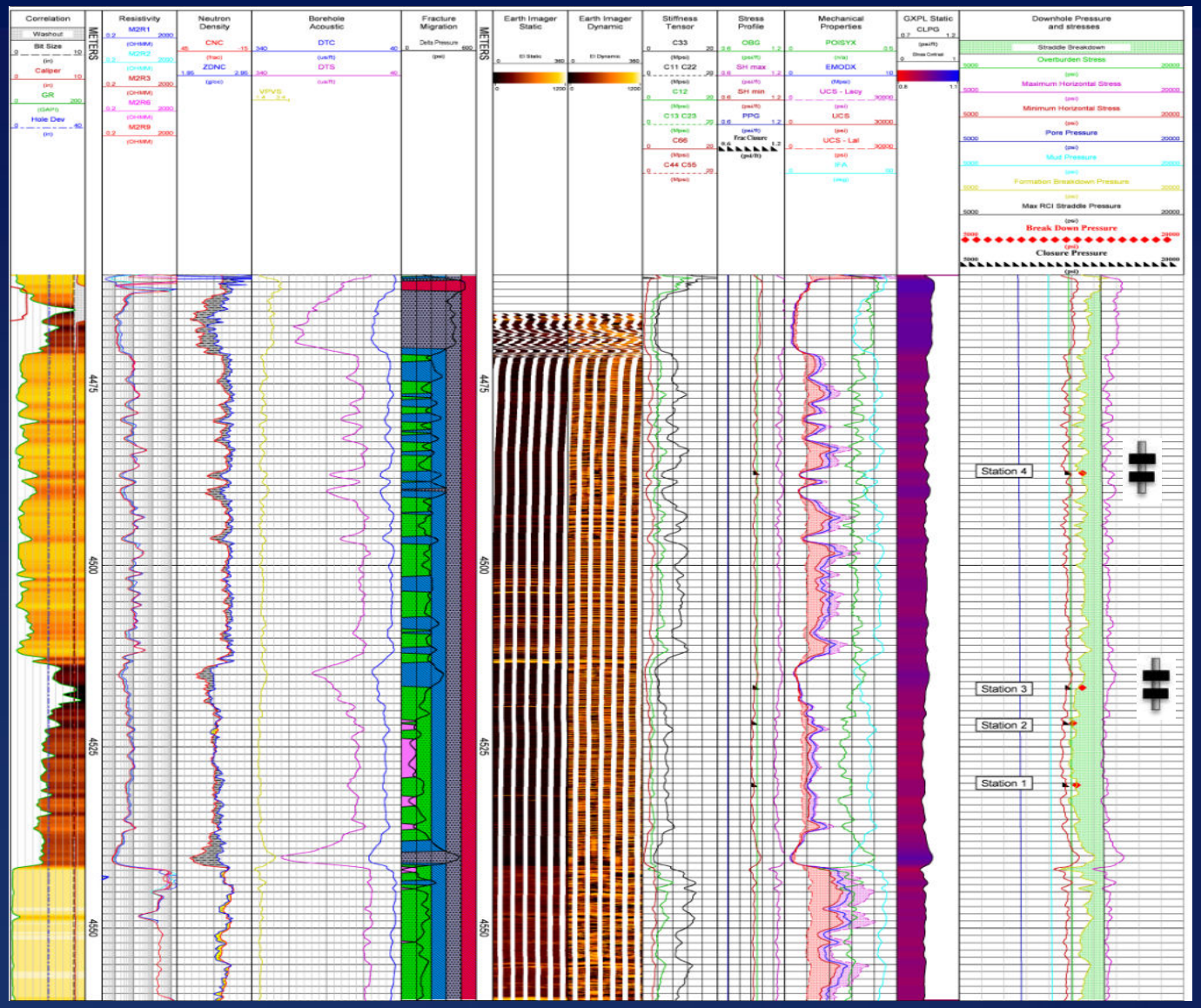


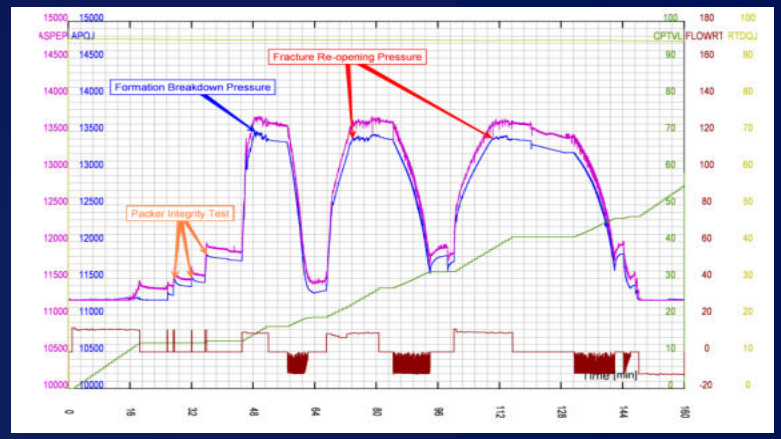
Franquet *et al.* (2016) SPE-181627 ATCE

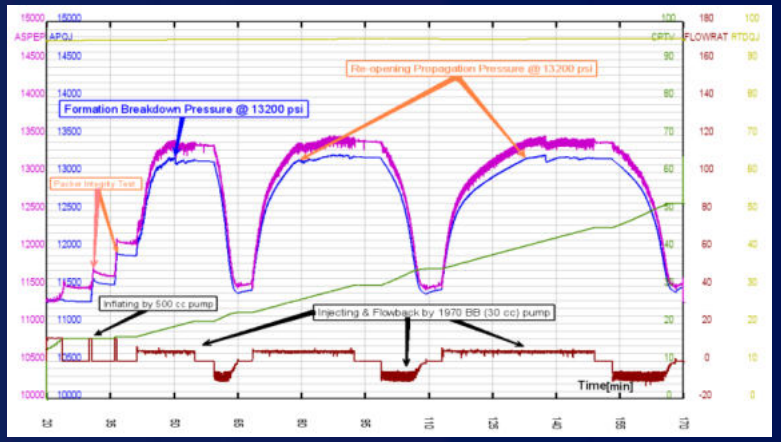
Franquet *et al.* (2017) SPE-188643 ADIPEC

Franquet *et al.* (2020) SPE-202600 ADIPEC

Case Study: Cap Rock Integrity Caspian Sea



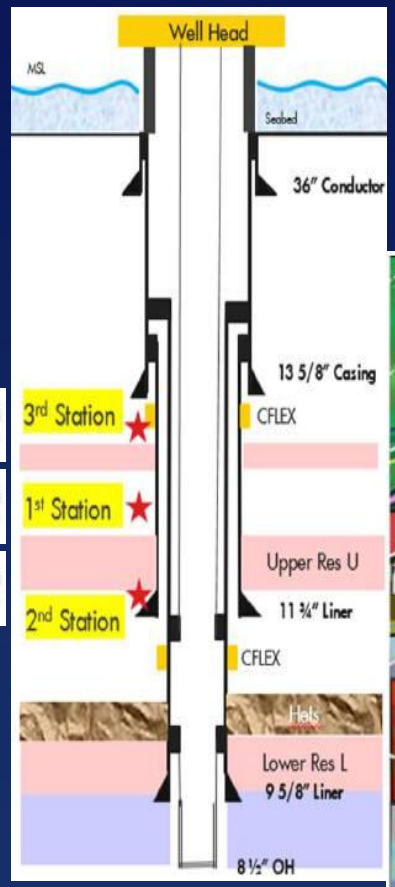




Prasad *et al.* (2020) IPTC-20077-MS

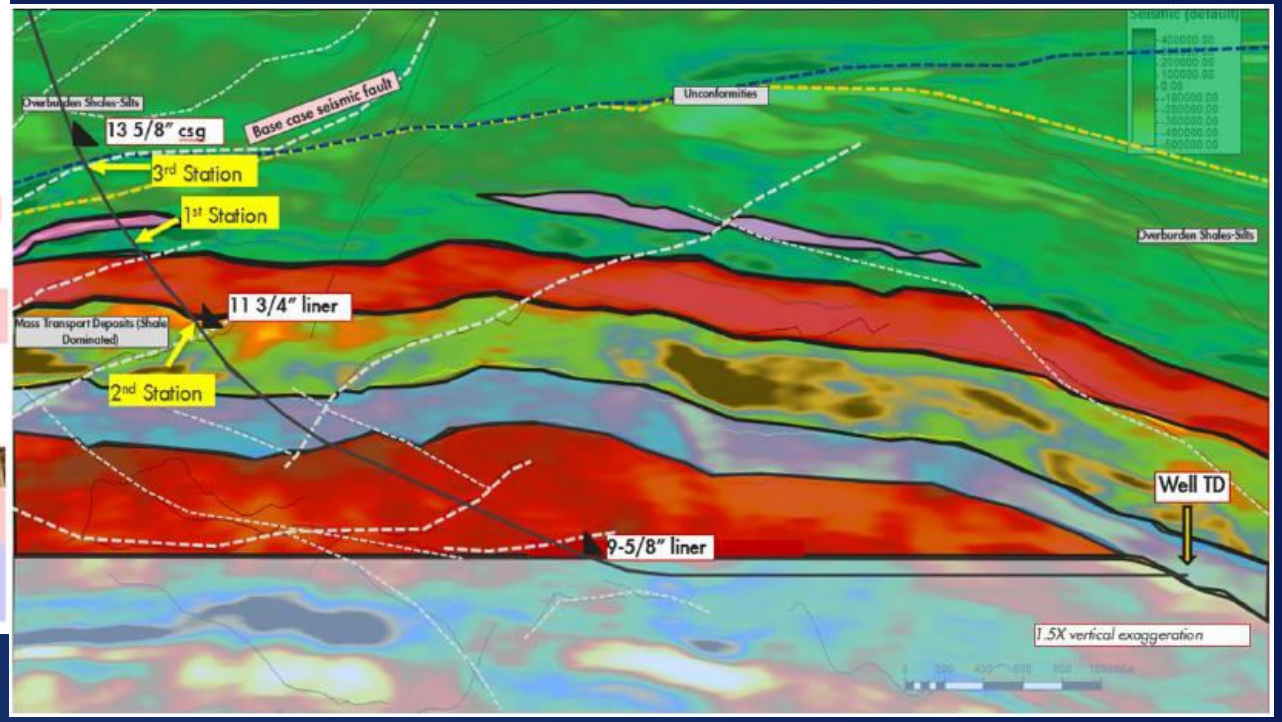
Franquet *et al.* (2011) OMC

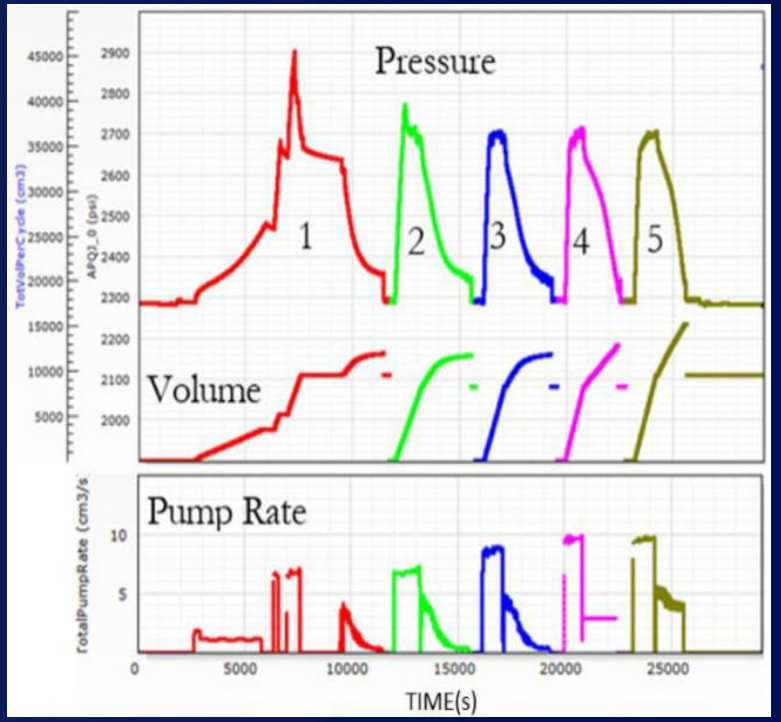
Case Study: Offshore Water Flooding



Heavily faulted deep-water rocks
Large fluid losses while drilling

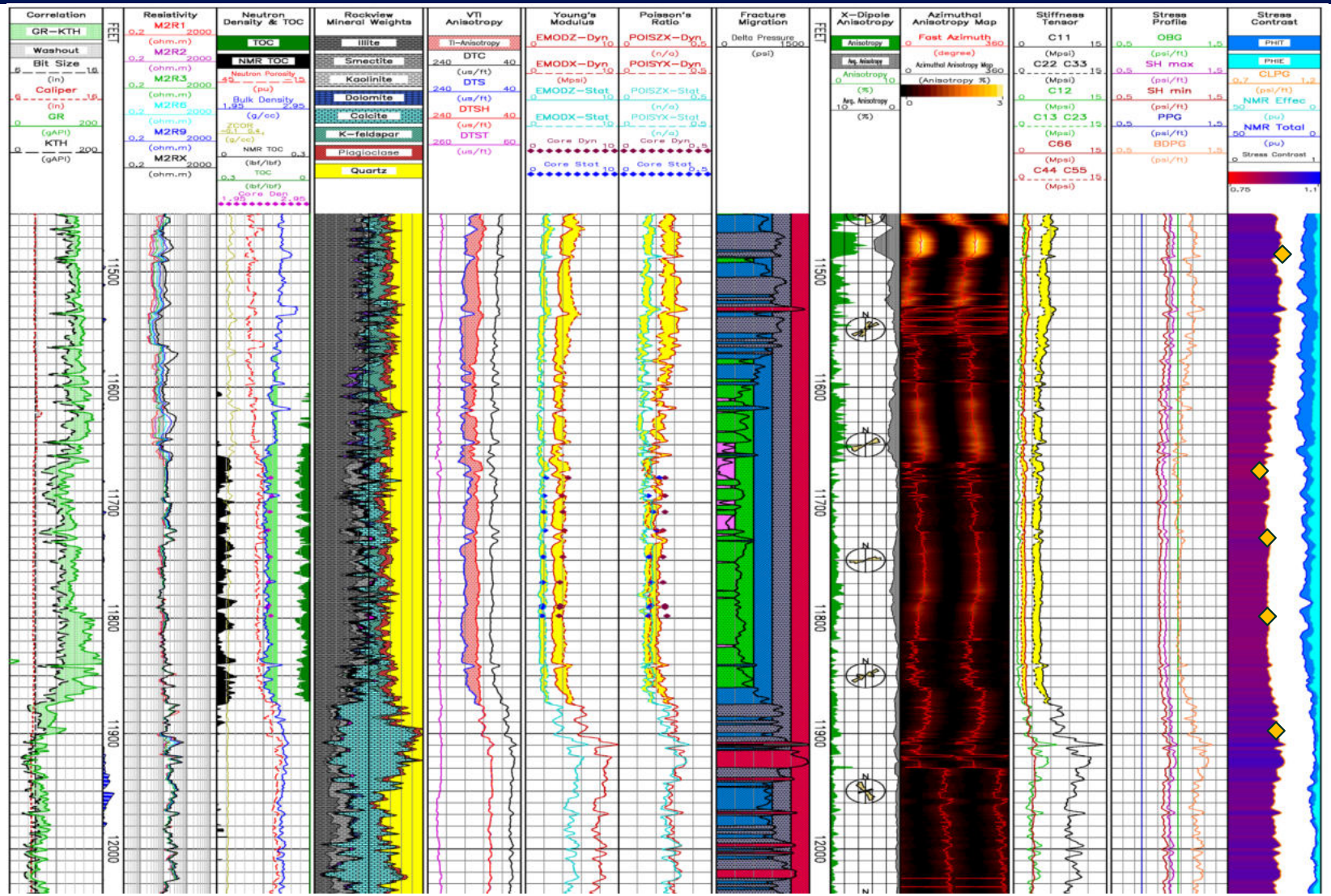
Caprock integrity and flowback tests
Proper wellbore stability analysis
Maximum water injection pressure

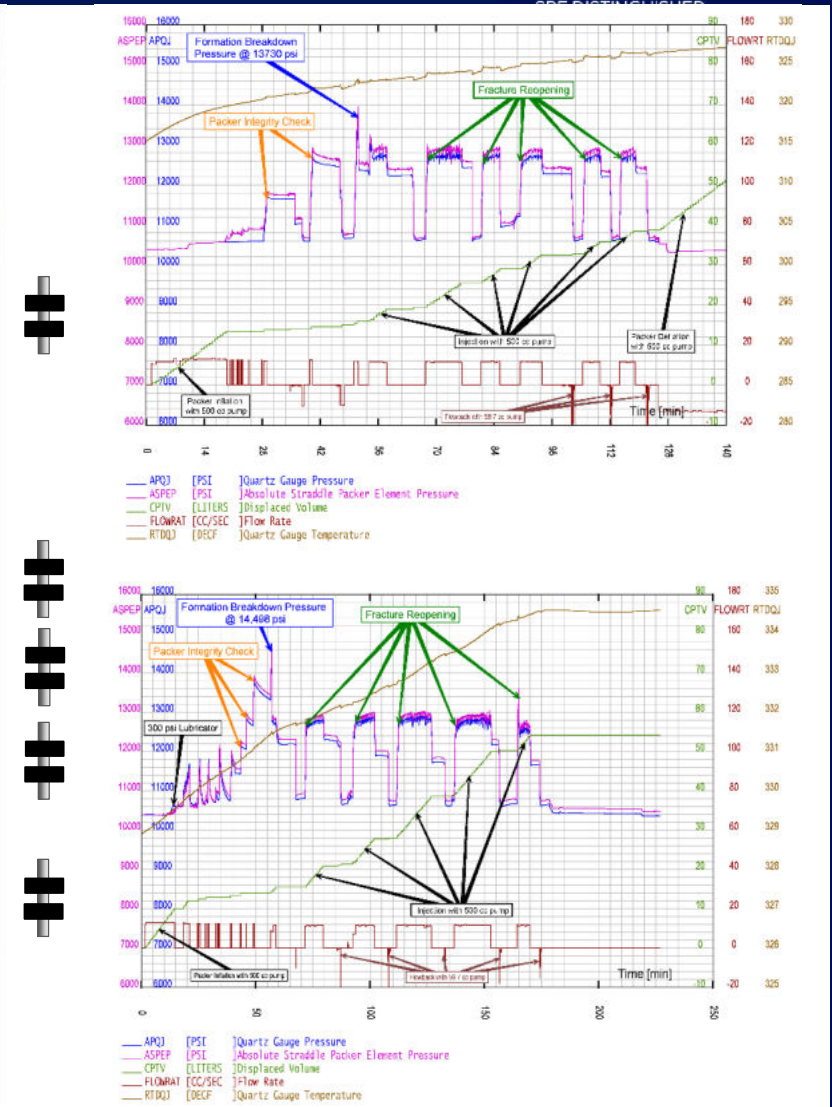




Zhang *et al.* (2020) OTC-30297

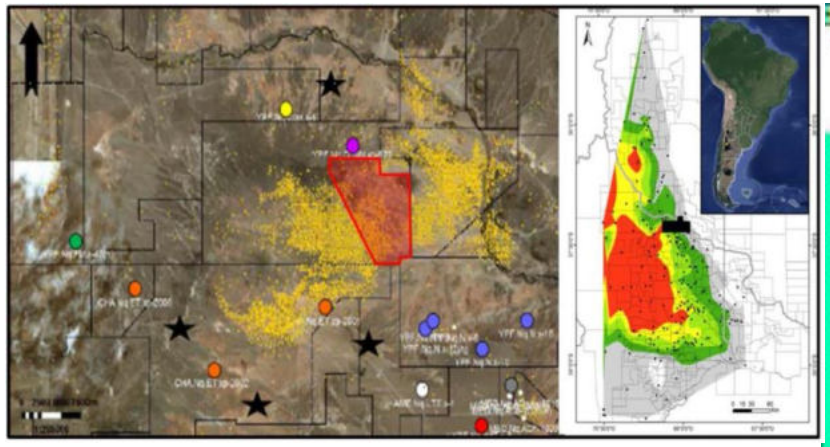
Case Study: HF in Unconventional Reservoirs

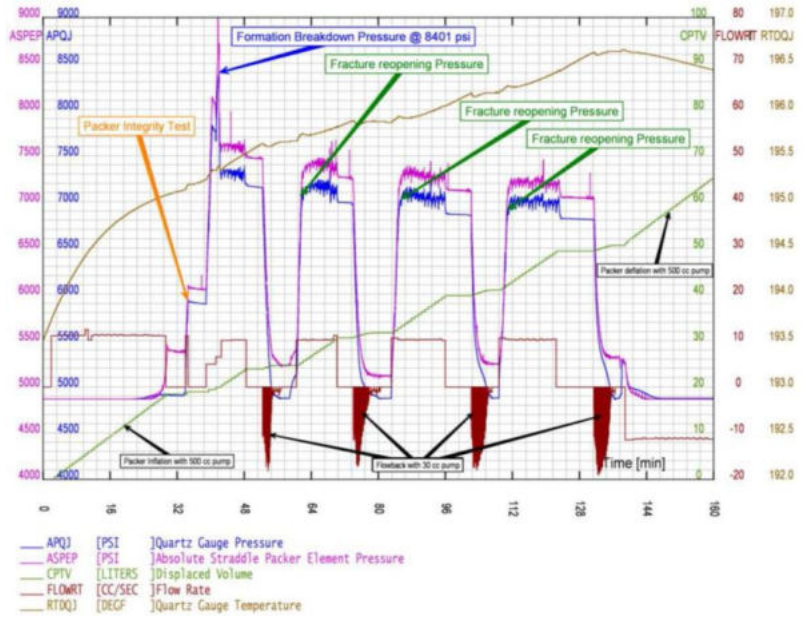


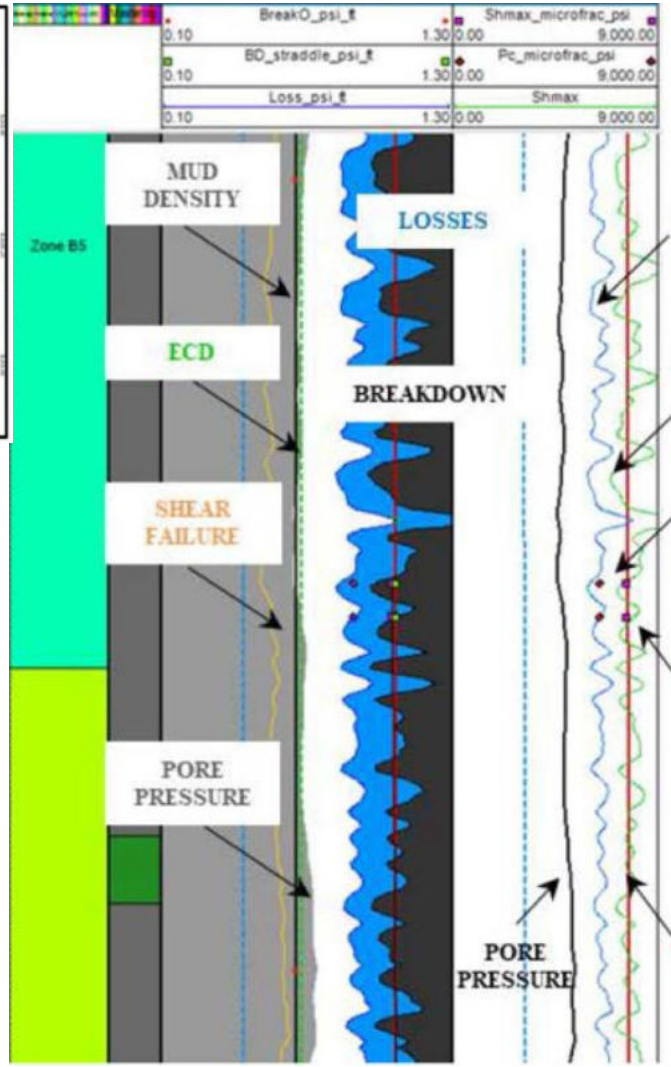


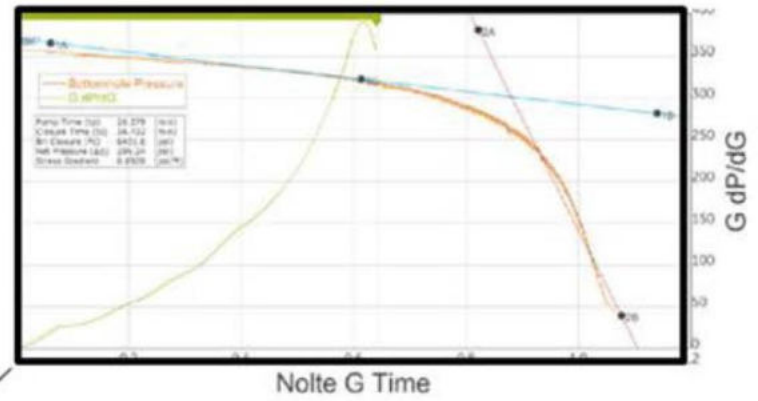
Franquet *et al.* (2019) ARMA 19-1635

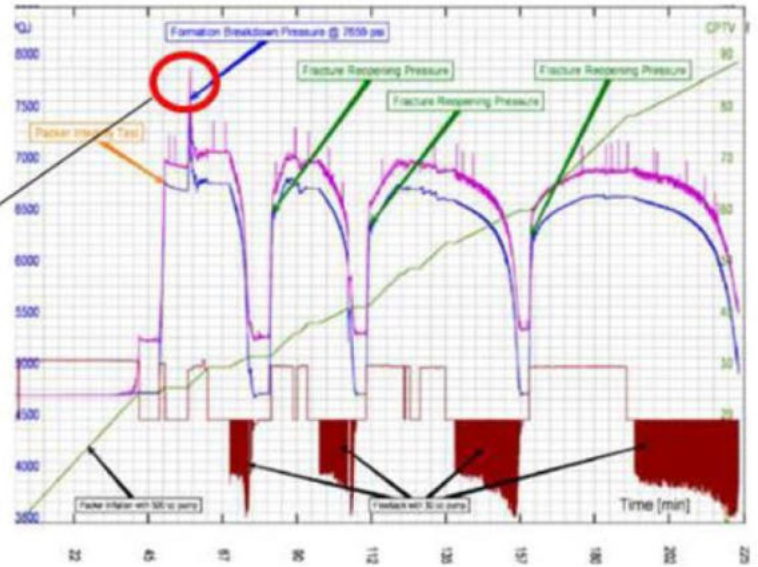
Case Study: HF in Vaca Muerta - Argentina











Ferlaza *et al.* (2020) SPE-1999159-MS

Take Away Summary

SPE DISTINGUISHED LECTURER

- Subsurface stresses cannot be measured directly by any logging technology at in-situ conditions
- Only small volume & low rate Straddle Packer Microfrac Testing can accurately calibrate tectonic stress profiles by performing multiple stress measurements at different lithologies
- Calibrated stress profiles provide accurate prediction of:
  - Hydraulic fracturing propagation and containment
  - Reservoir stress-path compaction and solid production
  - Wellbore stability during drilling campaigns
  - Cap-rock integrity during injection

SPE DISTINGUISHED LECTURER

Your Feedback is Important

Enter your section in the DL Evaluation Contest by completing the evaluation form for this presentation

Visit SPE.org/dl

#SPEDL

SPE International

Society of Petroleum Engineers
Distinguished Lecturer Program
www.spe.org/dl