Water production driven by critically stressed fractures

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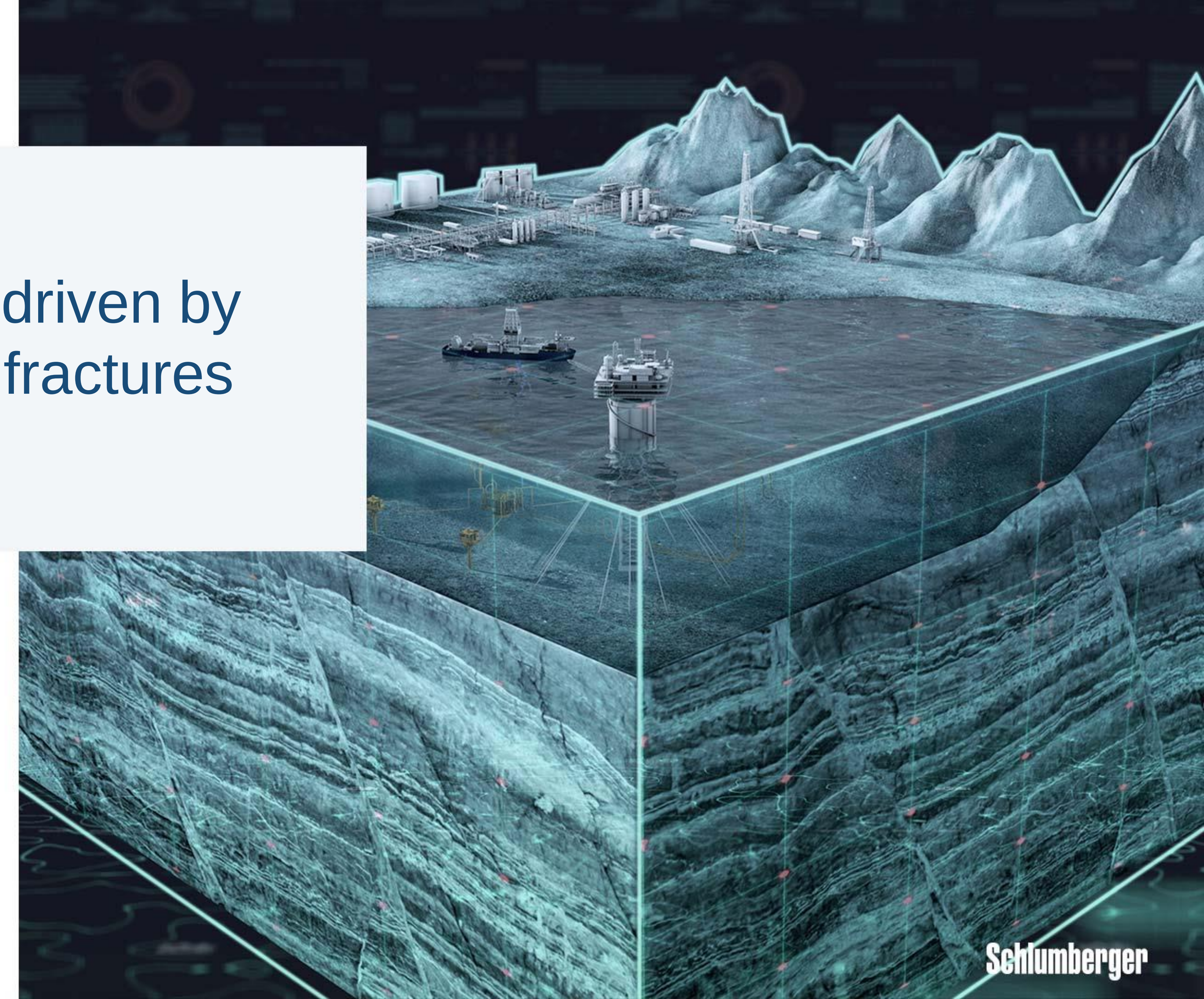
Amr Hegazy



- Introduction
  - Critically stressed fractures and its effect of well performance
  - Inputs to the geomechanical workflow: acoustic, borehole imaging, 3DFF
  - Geomechanical Techlog workflow for differentiating critically stressed fractures
  - Case study: Bakr-153
  - Mohr-Coulomb vs Barton-Bandis stress-aperture relations

Why fractures?

Good reasons: fractures are pathways for hydrocarbon migration

Bad reasons: can act as channels for water breakthrough and gas coning

Understanding of fracture mechanics and how it relates to permeability is essential for explaining well performance

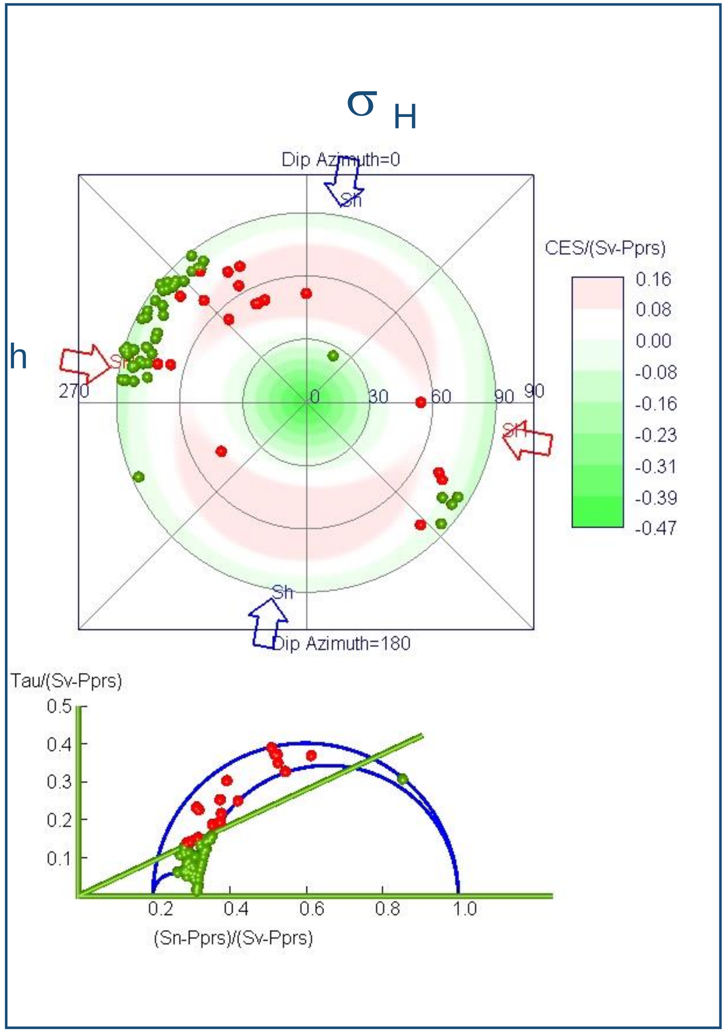
critically-stressed-fault hypothesis introduced by Barton, Zoback *et al.* (1995): a formation with faults at a variety of angles to the current stress field, the faults that are hydrologically conductive today are those that are critically stressed in the current stress field.

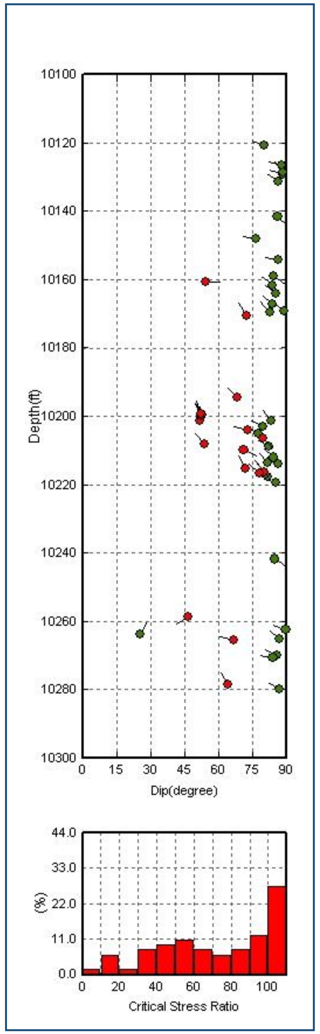
Stress Magnitudes & Fractures

Fracture / Fault stability using stress & pore pressure magnitudes

Calculation of “unstable” fractures under stress

Calibration of maximum horizontal stress is key from Mechanical Earth Model

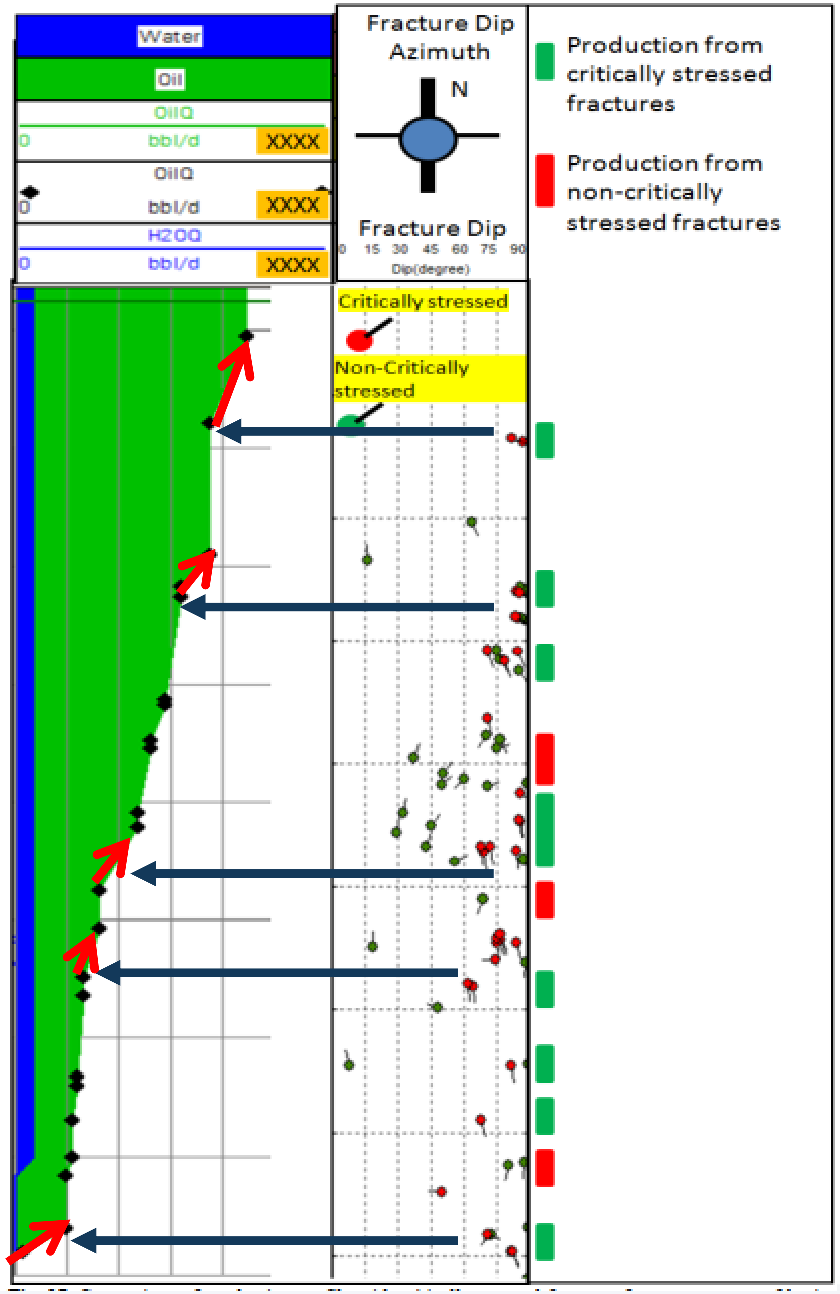




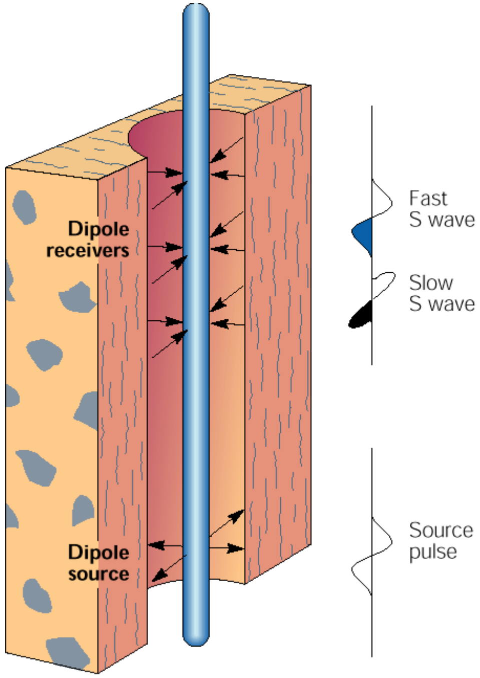
Validation of Barton/Zoback hypothesis through production logging

Comparison of production profile with critically stressed fractures for extreme case of horizontal stress anisotropy of critically stressed fractures are shown in red. All critically stressed fractures seem to produce and are responsible for major ramps in the production profile

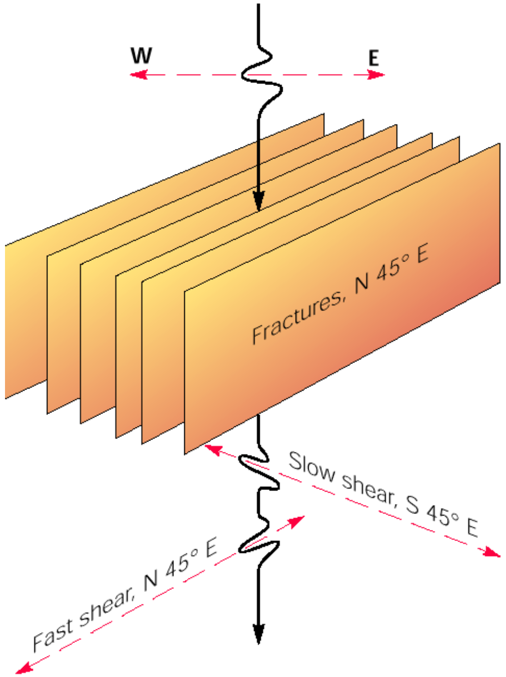
It is also worth noting that fracture density does not often correlate to production increase.



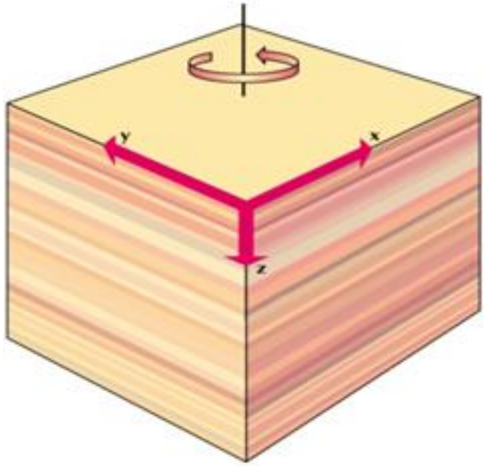
Multiple anisotropy mechanisms



Stress-induced



Fracture-related



Intrinsic

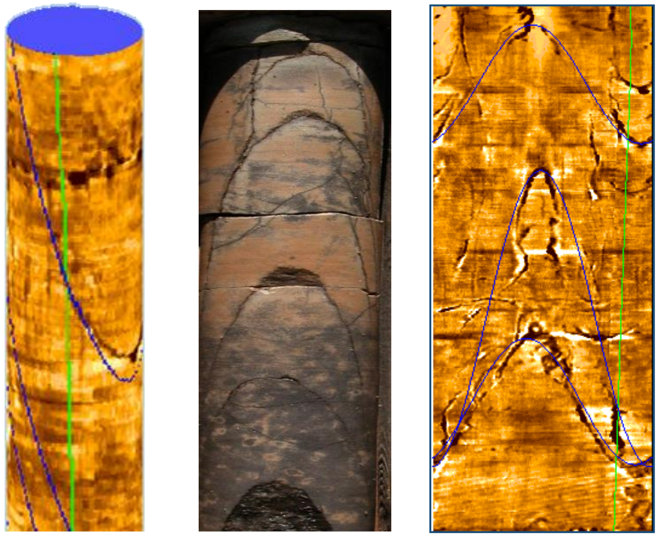
Fracture identification and discrimination

Borehole Image logs

- Bedding
- Structural
- Fractures

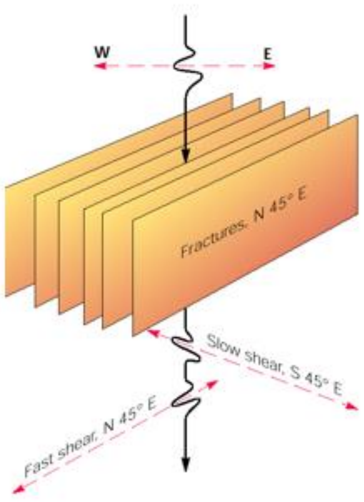
Natural

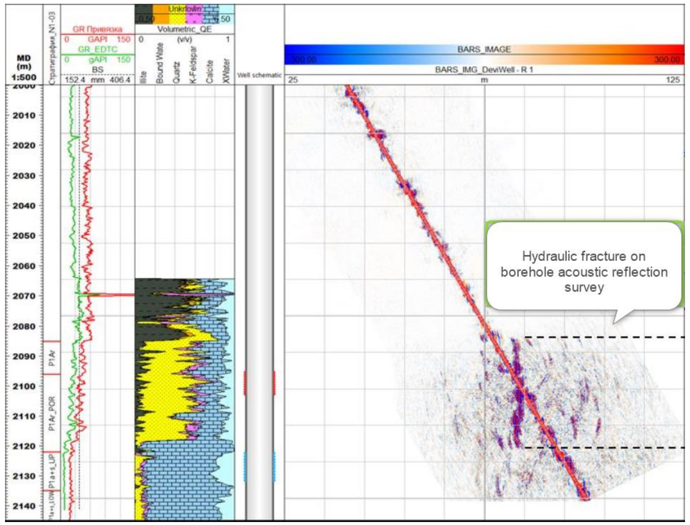
Stress-induced



Sonic logs

- Stoneley fracture analysis
- Cross dipole anisotropy
- Borehole refection analysis (BARS)/3D Far filed

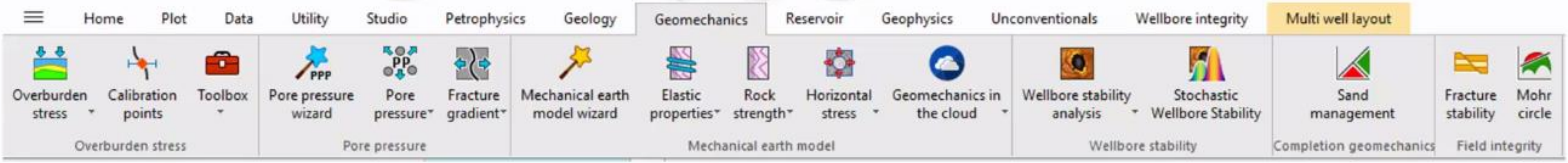


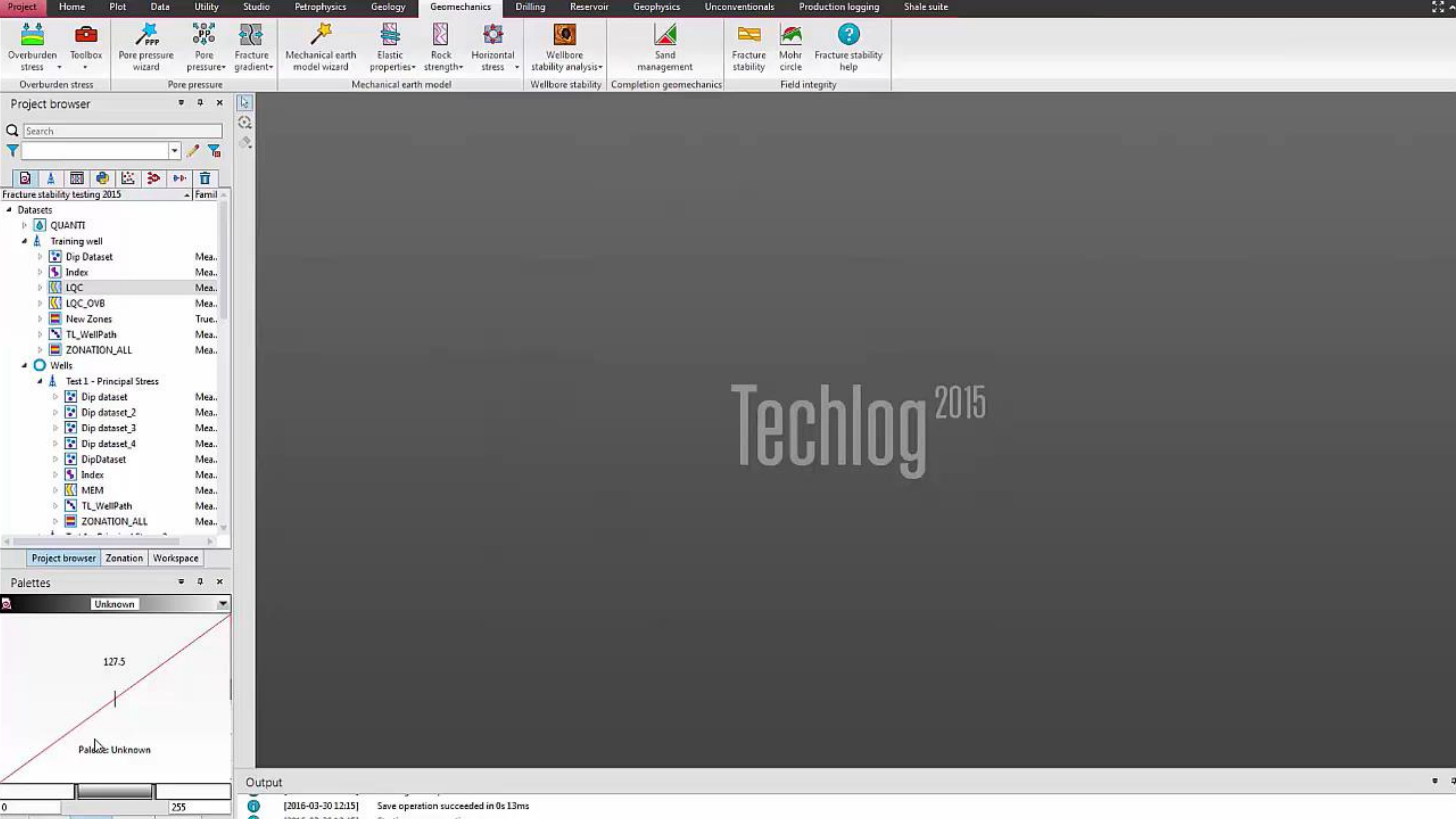


Inputs for evaluating critically stressed fractures

Fracture Stability

Optimal mud weights
Casing depths
Stable drilling direction
Stimulation stage design
Sand production




Project
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Utility
Studio
Petrophysics
Geology
Geomechanics
Drilling
Reservoir
Geophysics
Unconventionals
Production logging
Shale suite
Overburden stress
Toolbox
Pore pressure wizard
Pore pressure
Fracture gradient
Mechanical earth model wizard
Elastic properties
Rock strength
Horizontal stress
Wellbore stability analysis
Sand management
Fracture stability
Mohr circle
Fracture stability help
Overburden stress
Pore pressure
Mechanical earth model
Wellbore stability
Completion geomechanics
Field integrity
Project browser
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Datasets
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LQC_OVB
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ZONATION_ALL
Wells
Test 1 - Principal Stress
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Dip dataset_2
Dip dataset_3
Dip dataset_4
DipDataset
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TL_WellPath
ZONATION_ALL
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Workspace
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Unknown
127.5
Palette: Unknown
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Techlog 2015
Output
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Problem Definition

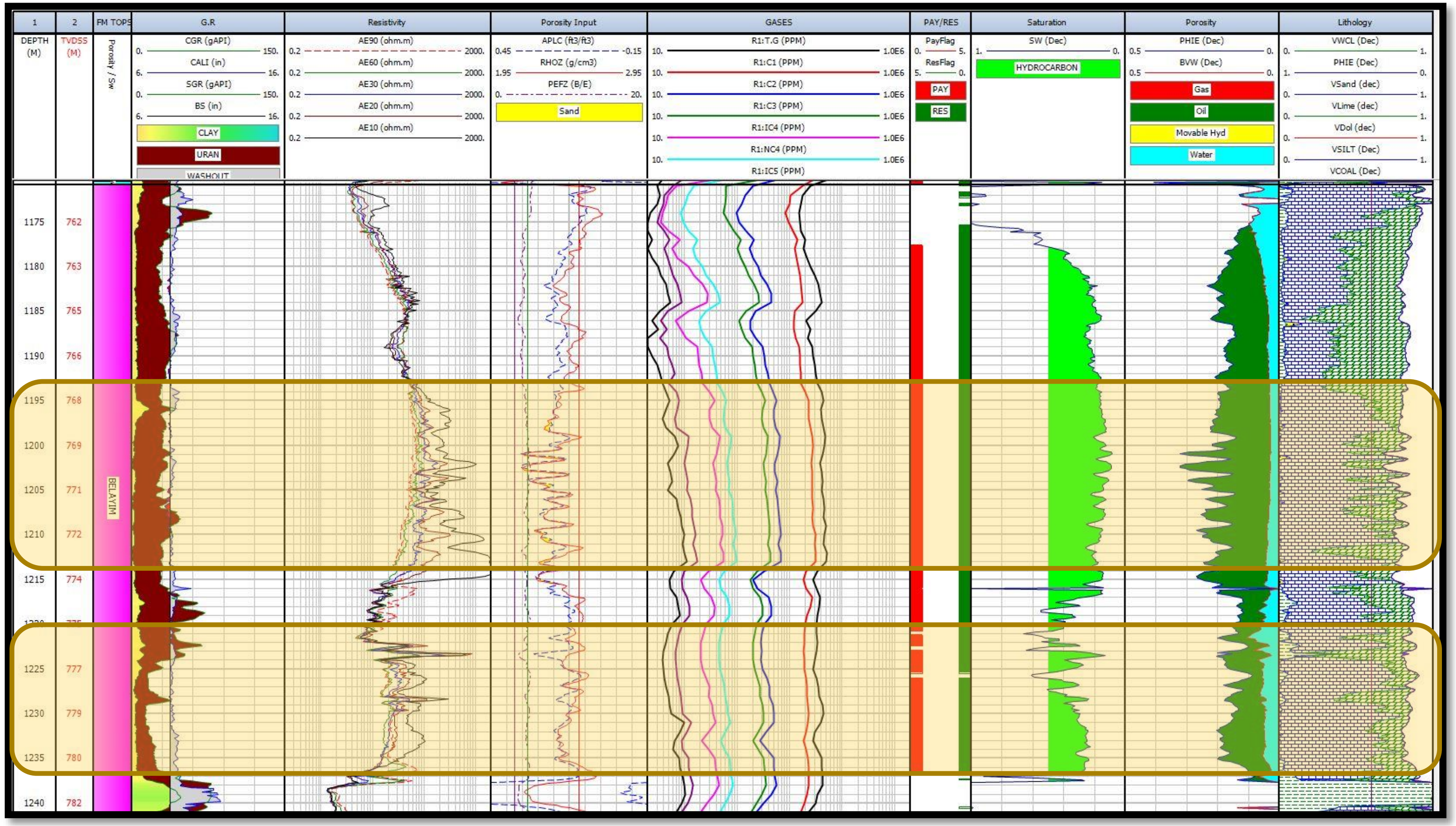
- ✓ **Water breakthrough in carbonate reservoir is a great challenge faced by engineers to maximize EUR.**
- ✓ **Usually fractures contribute to water breakthrough at early time of production hindering oil production especially if the oil is heavy.**

Problem Initiatives

- ✓ Two key wells initiate the problem of rapid water breakthrough in carbonate reservoir.

- ✓ The first well is Bakr-151, Deviated well.
- ✓ The second well is Bakr-52, Vertical.

Bakr-151

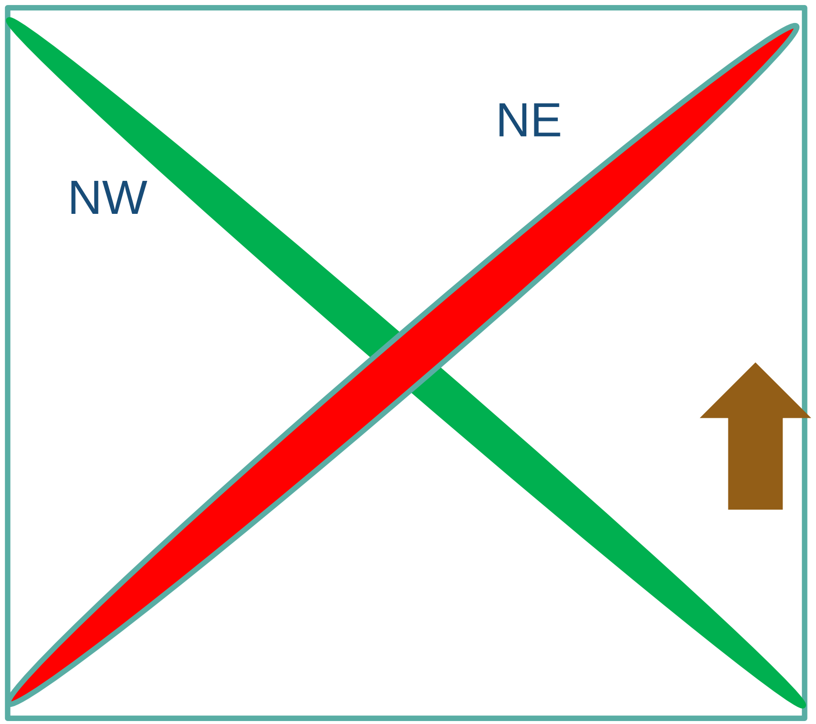


- Lifted, produced 500-700 BFPD, 1-3 % W.C
- Stimulated , produced 100-500 BFPD, >30 % W.C

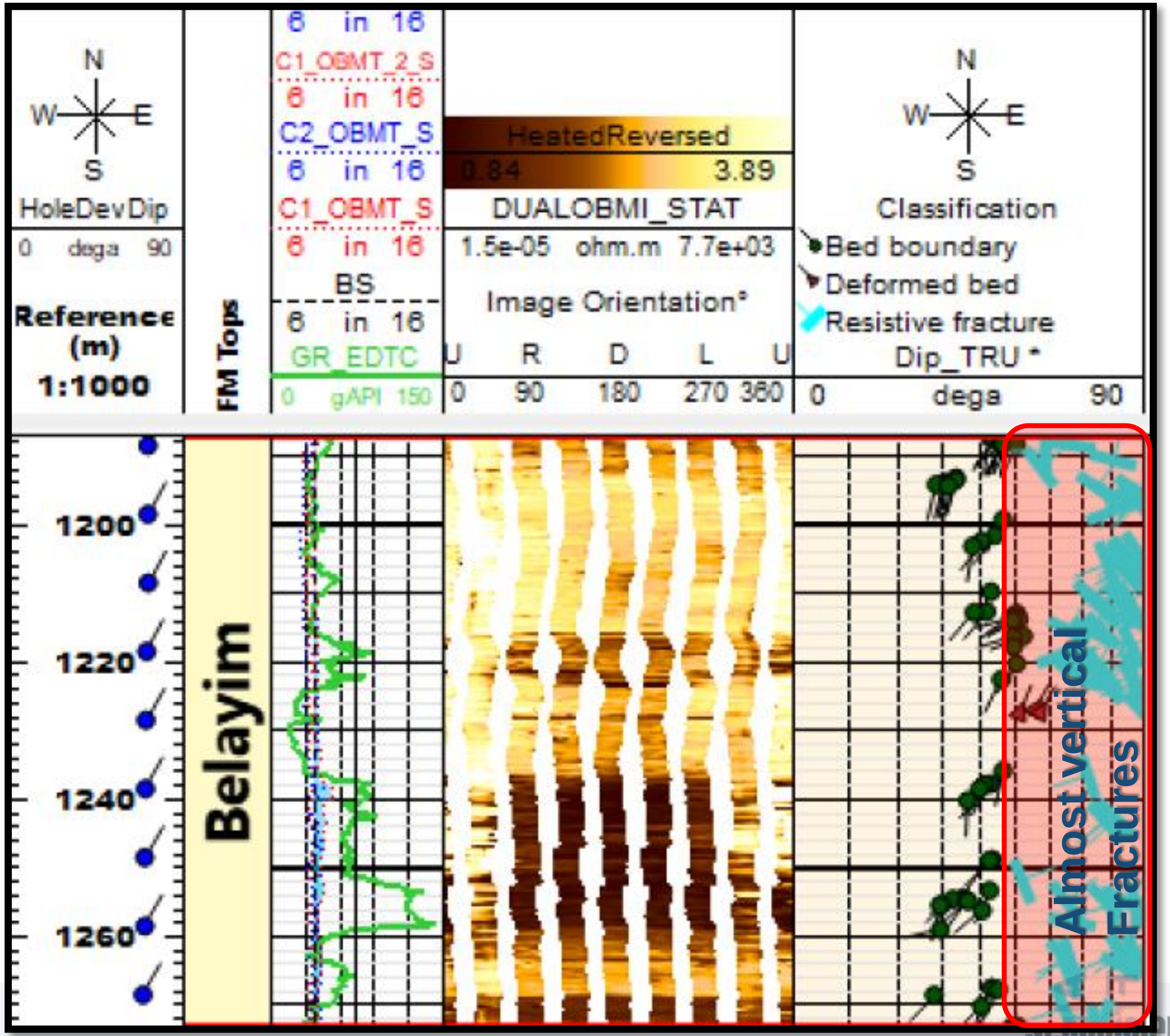
- Stimulated , produced 600-800 BFPD, 1 % W.C

Bakr-151

Fracture Network

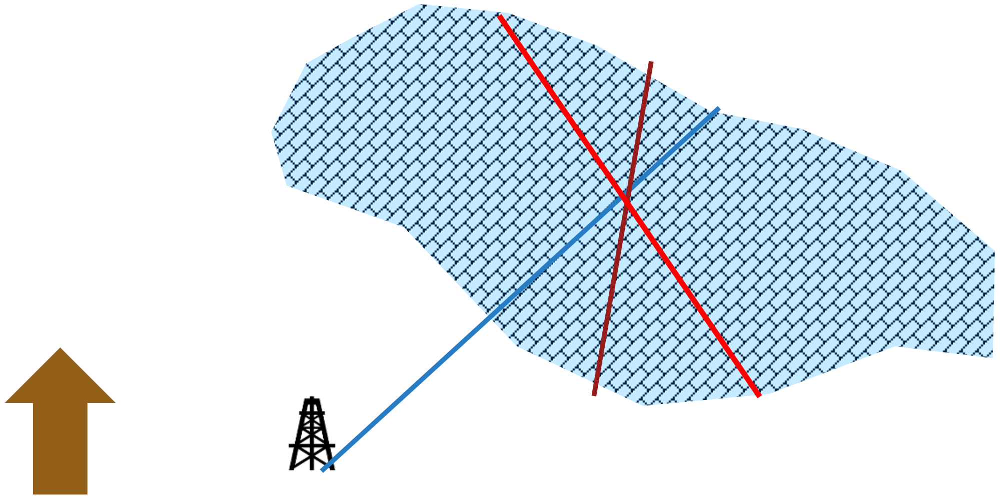


Plan View

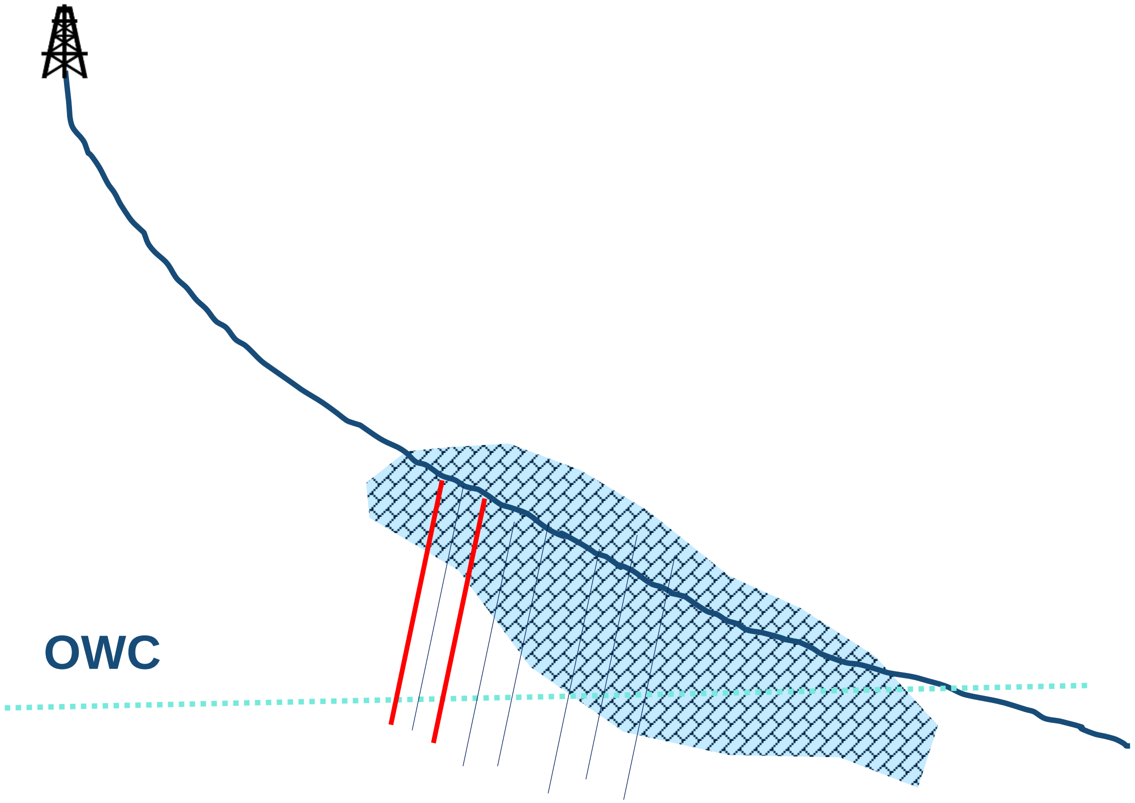


Bakr-151

Schematic illustration

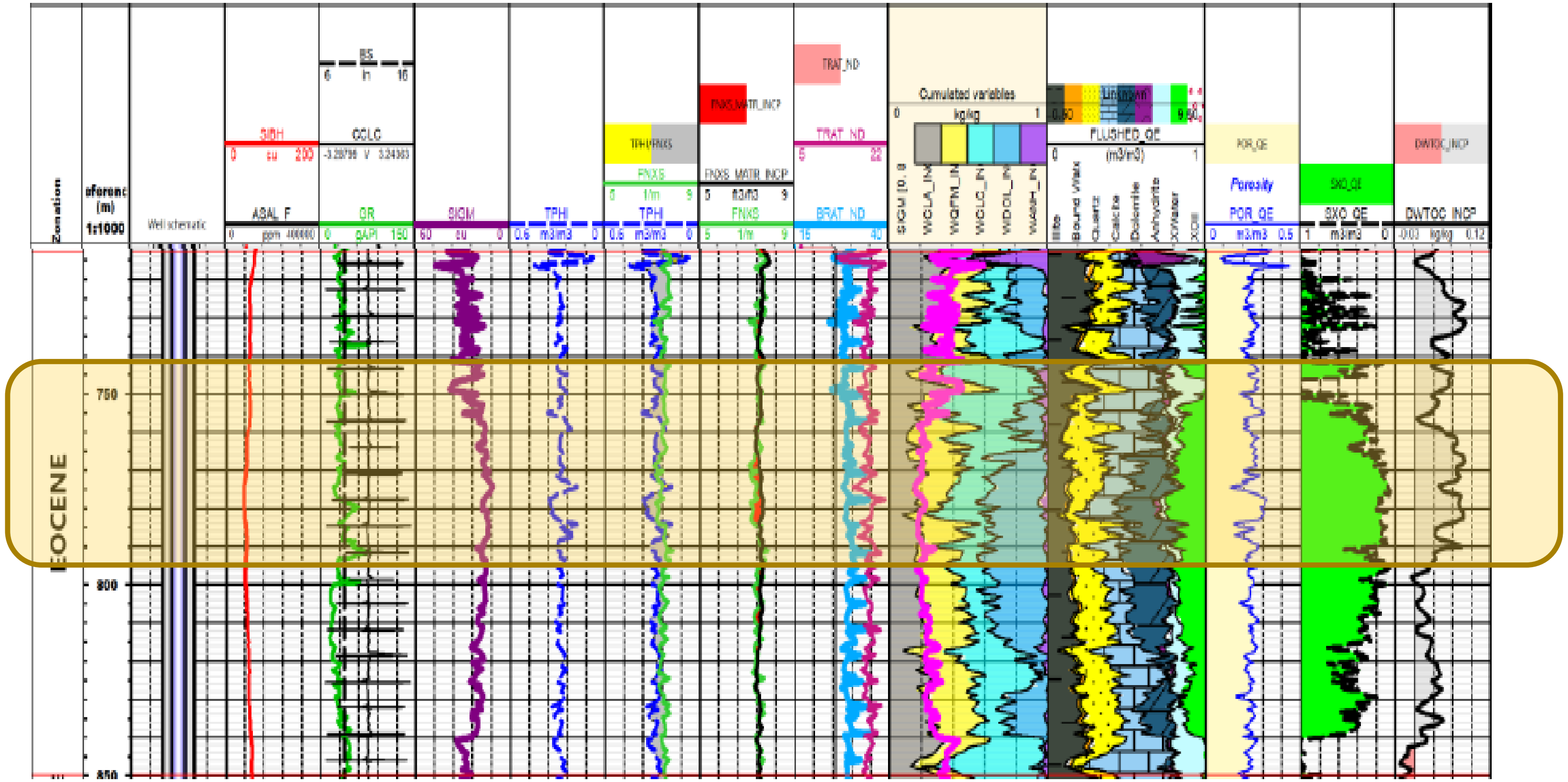


Map View

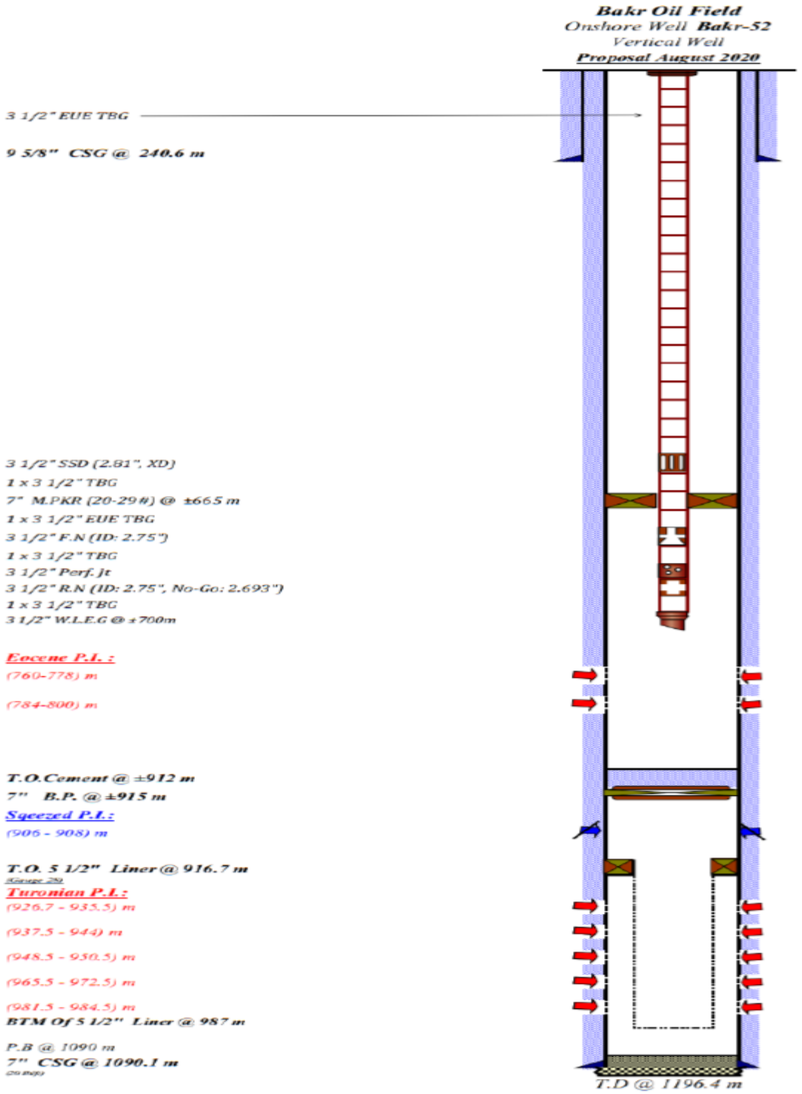


Section View

Bakr-52

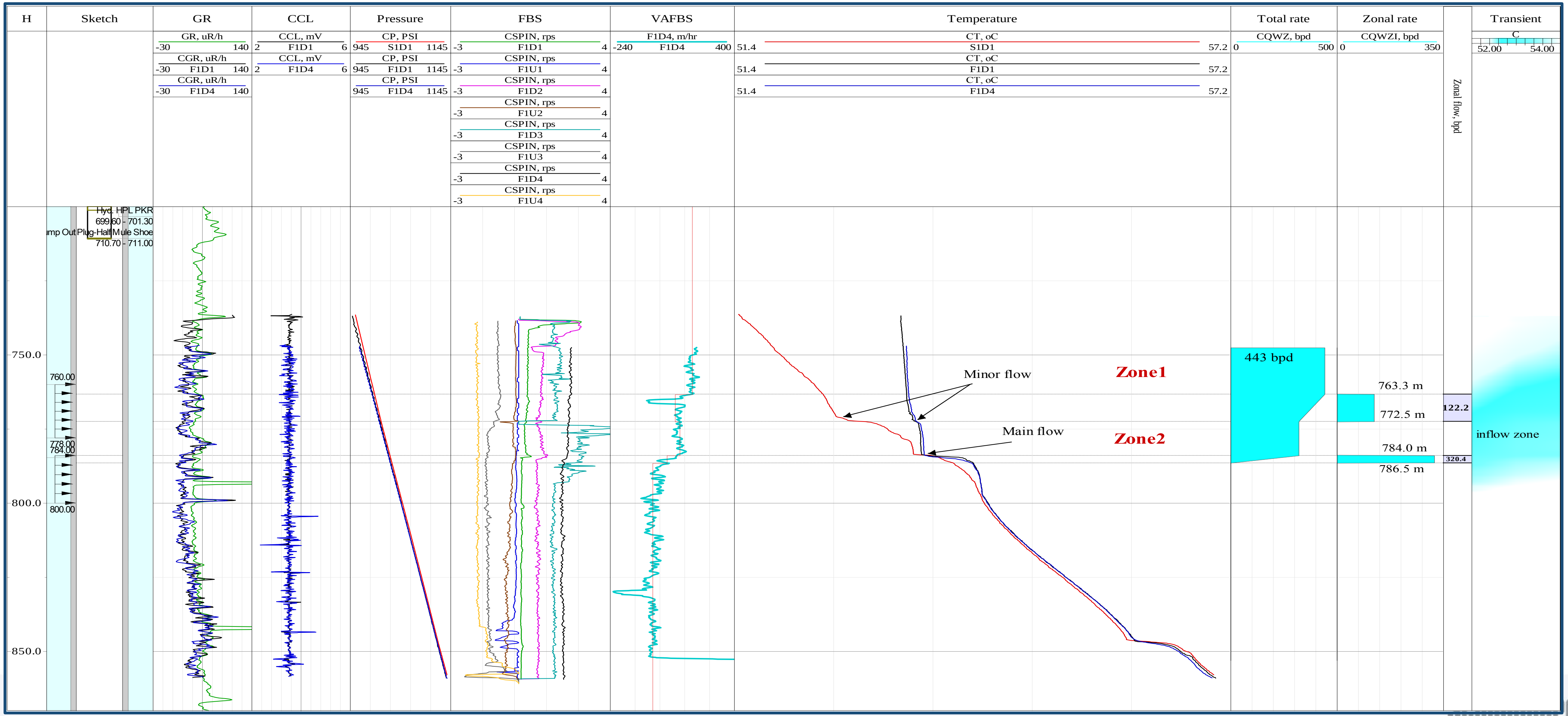


Zonation
Reference (m)
1:1000
Well schematic
EOCENE
750
800
850
SIGH
ASAL_F
CCLC
GR
SIGM
TPH
TPH/FNXS
FNXS
FNXS_MATR_INCP
TRAT_ND
BRAT_ND
Cumulated variables
FLUSHED_QE
POR_QE
Porosity
SXO_QE
DWTOC_INCP



Bakr Oil Field
Onshore Well Bakr-52
Vertical Well
Proposal August 2020
3 1/2" EUE TBG
9 5/8" CSG @ 240.6 m
3 1/2" SSD (2.81", XD)
1 x 3 1/2" TBG
7" M.PKR (20-29#) @ ±665 m
1 x 3 1/2" EUE TBG
3 1/2" F.N (ID: 2.75")
1 x 3 1/2" TBG
3 1/2" Perf. Jt
3 1/2" R.N (ID: 2.75", No-Go: 2.693")
1 x 3 1/2" TBG
3 1/2" W.L.E.G @ ±700m
Eocene P.I. :
(760-778) m
(784-800) m
T.O.Cement @ ±912 m
7" B.P. @ ±915 m
Sqeezed P.I.:
(906 - 908) m
T.O. 5 1/2" Liner @ 916.7 m
Turonian P.I.:
(926.7 - 935.5) m
(937.5 - 944) m
(948.5 - 950.5) m
(965.5 - 972.5) m
(981.5 - 984.5) m
BTM Of 5 1/2" Liner @ 987 m
P.B @ 1090 m
7" CSG @ 1090.1 m
T.D @ 1196.4 m

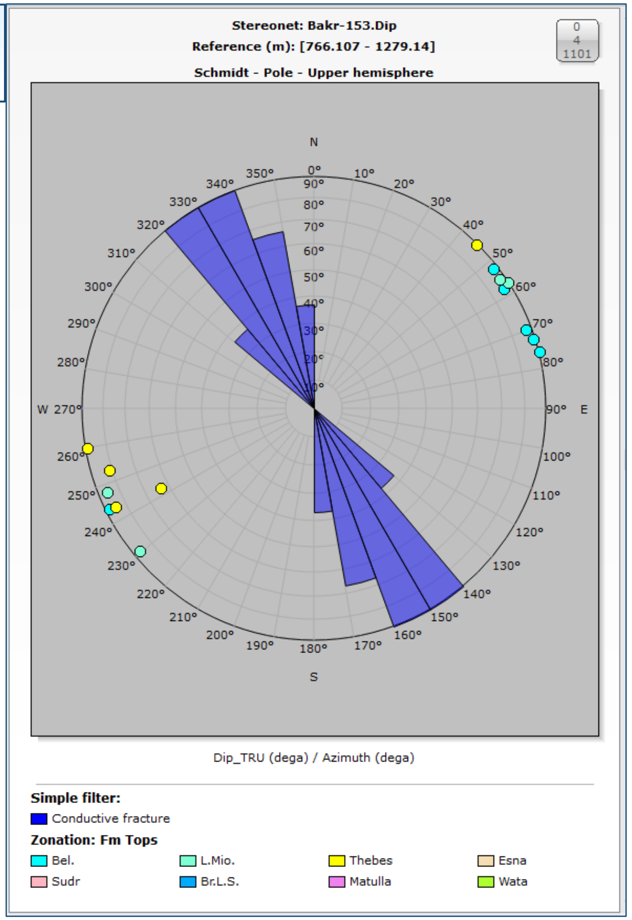
Bakr-52



H
Sketch
GR
CCL
Pressure
FBS
VAFBS
Temperature
Total rate
Zonal rate
Transient
GR, uR/h
-30 140
CGR, uR/h
-30 F1D1 140
CGR, uR/h
-30 F1D4 140
CCL, mV
2 F1D1 6
CCL, mV
2 F1D4 6
CP, PSI
945 S1D1 1145
CP, PSI
945 F1D1 1145
CP, PSI
945 F1D4 1145
CSPIN, rps
-3 F1D1 4
CSPIN, rps
-3 F1U1 4
CSPIN, rps
-3 F1D2 4
CSPIN, rps
-3 F1U2 4
CSPIN, rps
-3 F1D3 4
CSPIN, rps
-3 F1U3 4
CSPIN, rps
-3 F1D4 4
CSPIN, rps
-3 F1U4 4
F1D4, m/hr
-240 F1D4 400
CT, oC
51.4 S1D1 57.2
CT, oC
51.4 F1D1 57.2
CT, oC
51.4 F1D4 57.2
CQWZ, bpd
0 500
CQWZI, bpd
0 350
Zonal flow, bpd
52.00 54.00
Hyd. HPL PKR
699.60 - 701.30
Plug-Half Mule Shoe
710.70 - 711.00
760.00
778.00
784.00
800.00
750.0
800.0
850.0
Minor flow
Main flow
Zone1
Zone2
443 bpd
763.3 m
772.5 m
784.0 m
786.5 m
122.2
320.4
inflow zone

Bakr-153 (Well of study) Fractures statistics

1



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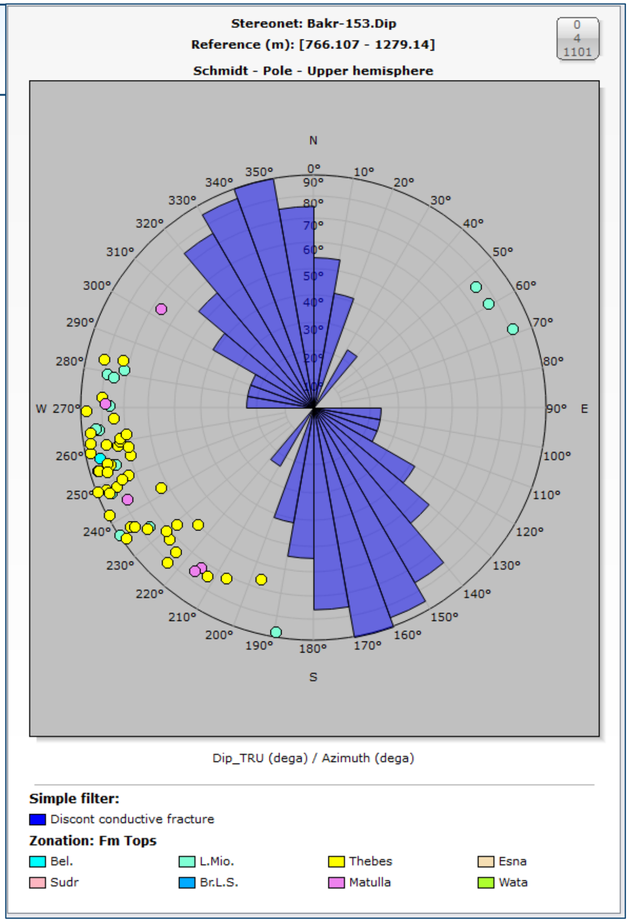

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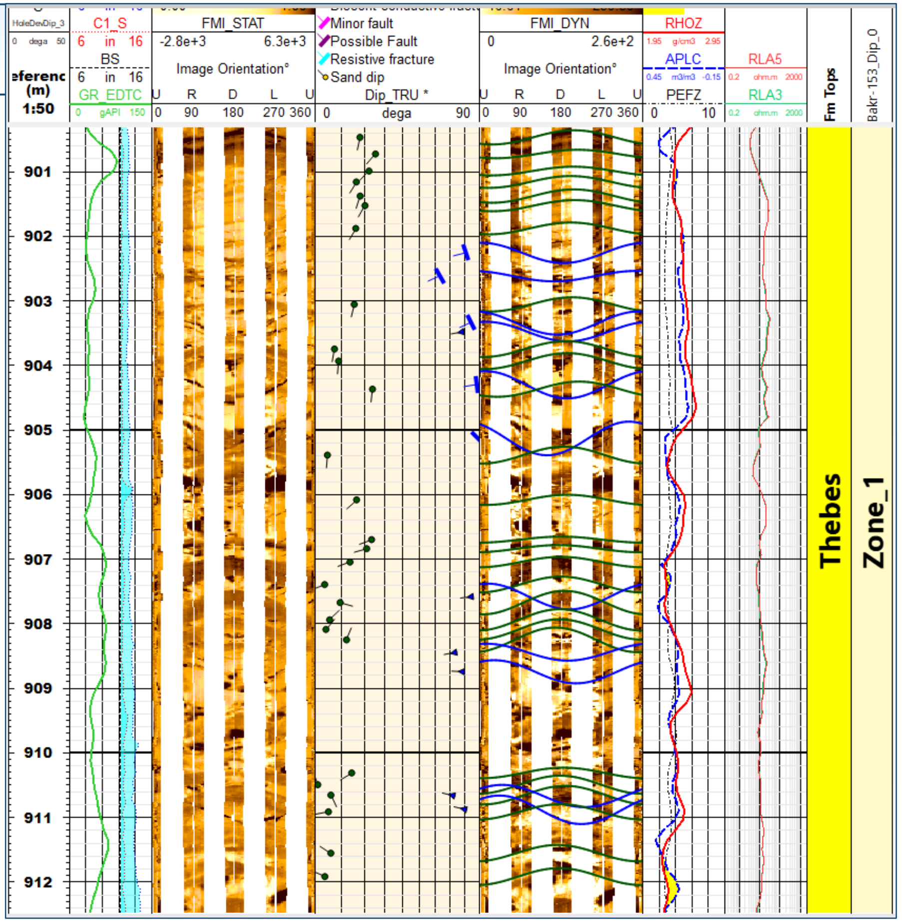
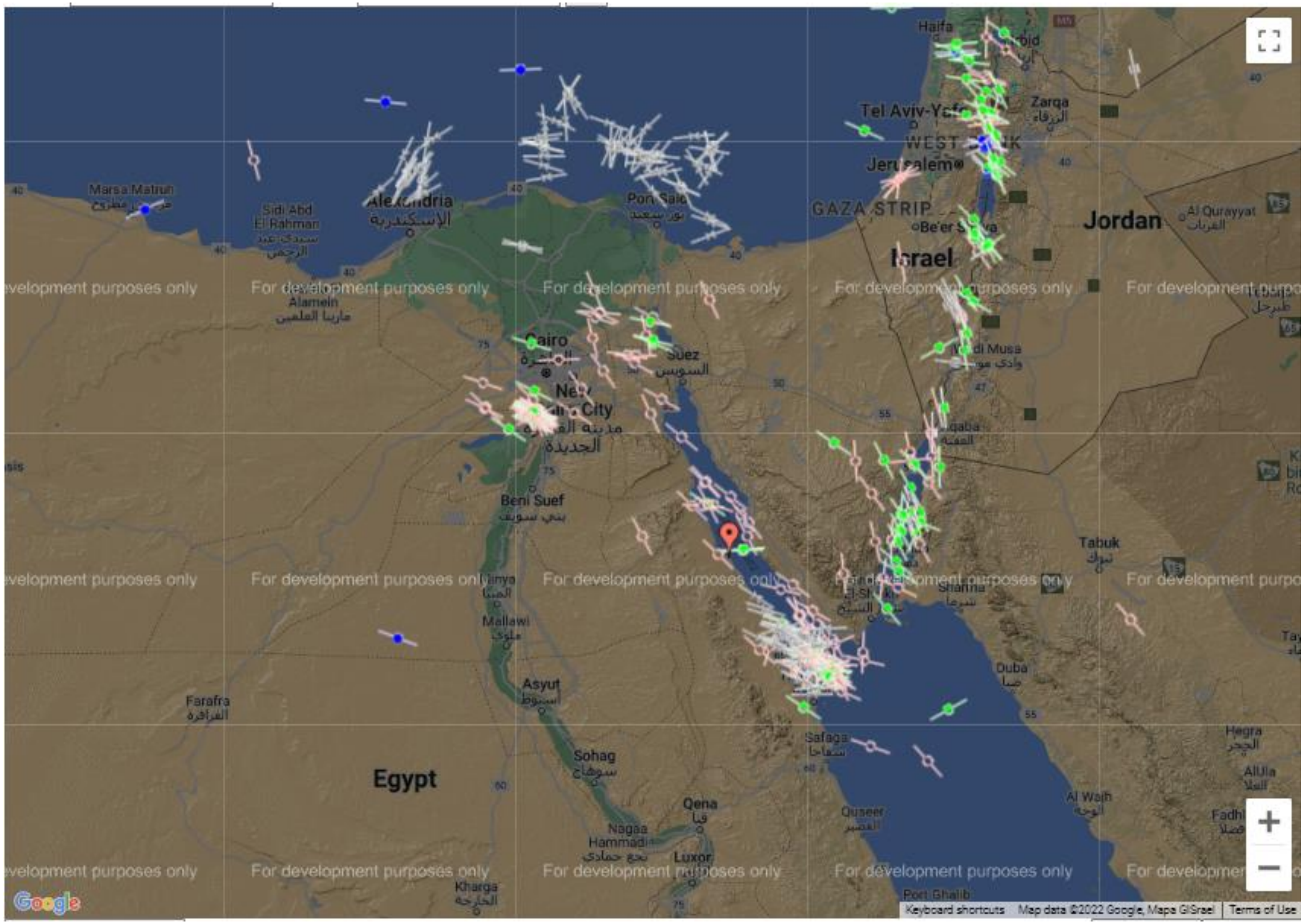
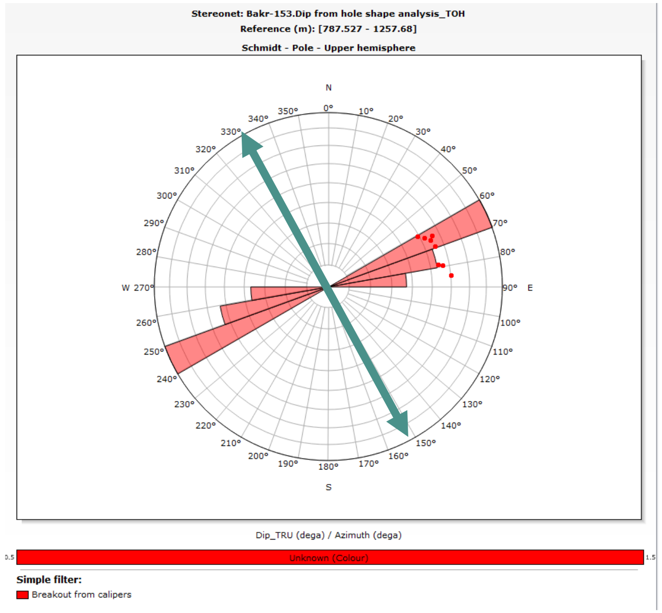


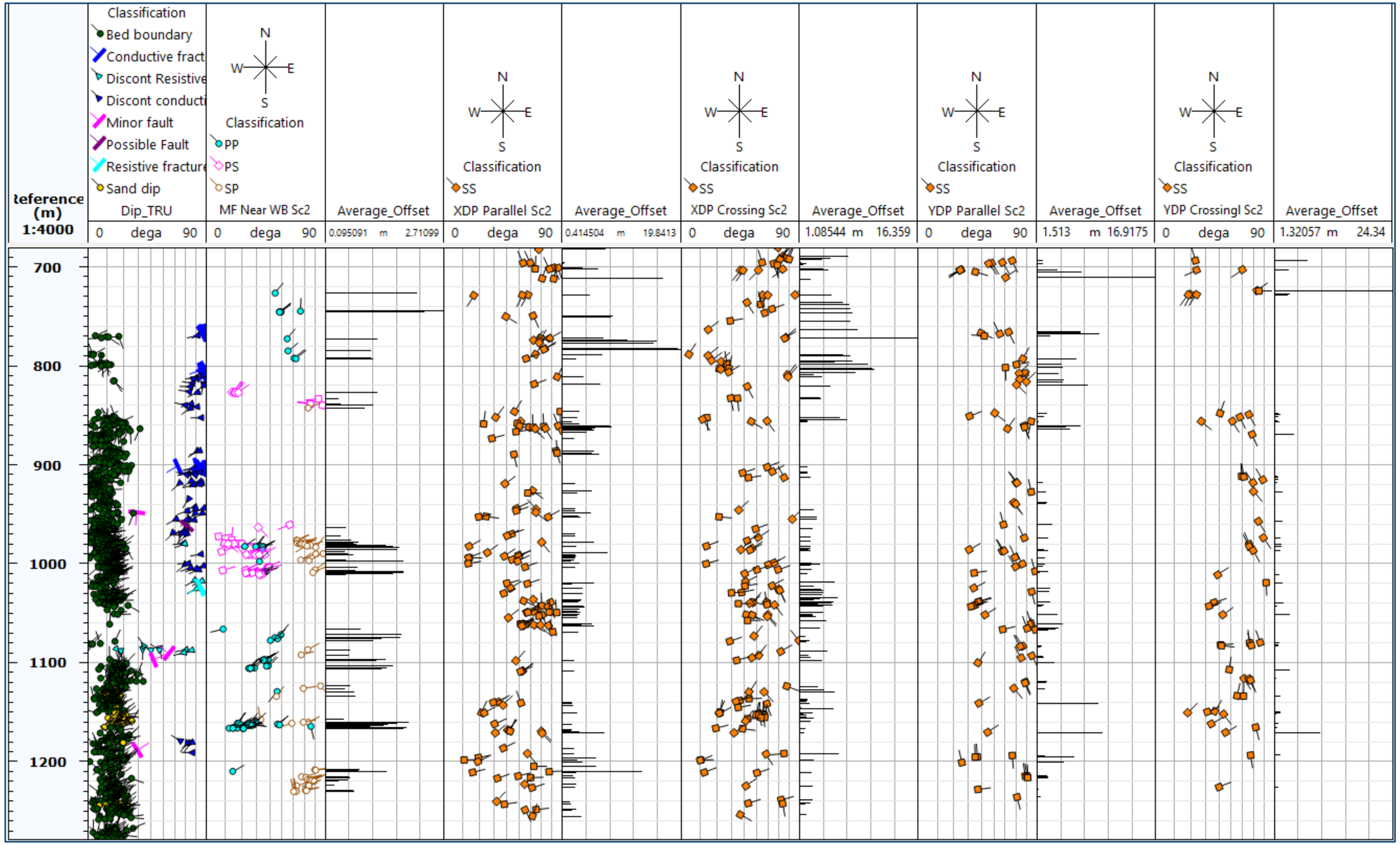
1. Continuous conductive fractures strike through the whole interval colored by Fm. tops. **2.** Discontinuous conductive fractures strike through the whole interval colored by Fm. tops. **3.** High resolution example of conductive fractures cutting through Thebes Formation. Note overall dominant NNW-SSE strike.

Most of the fractures from borehole image interpretation are oriented along the present day maximum horizontal stress direction

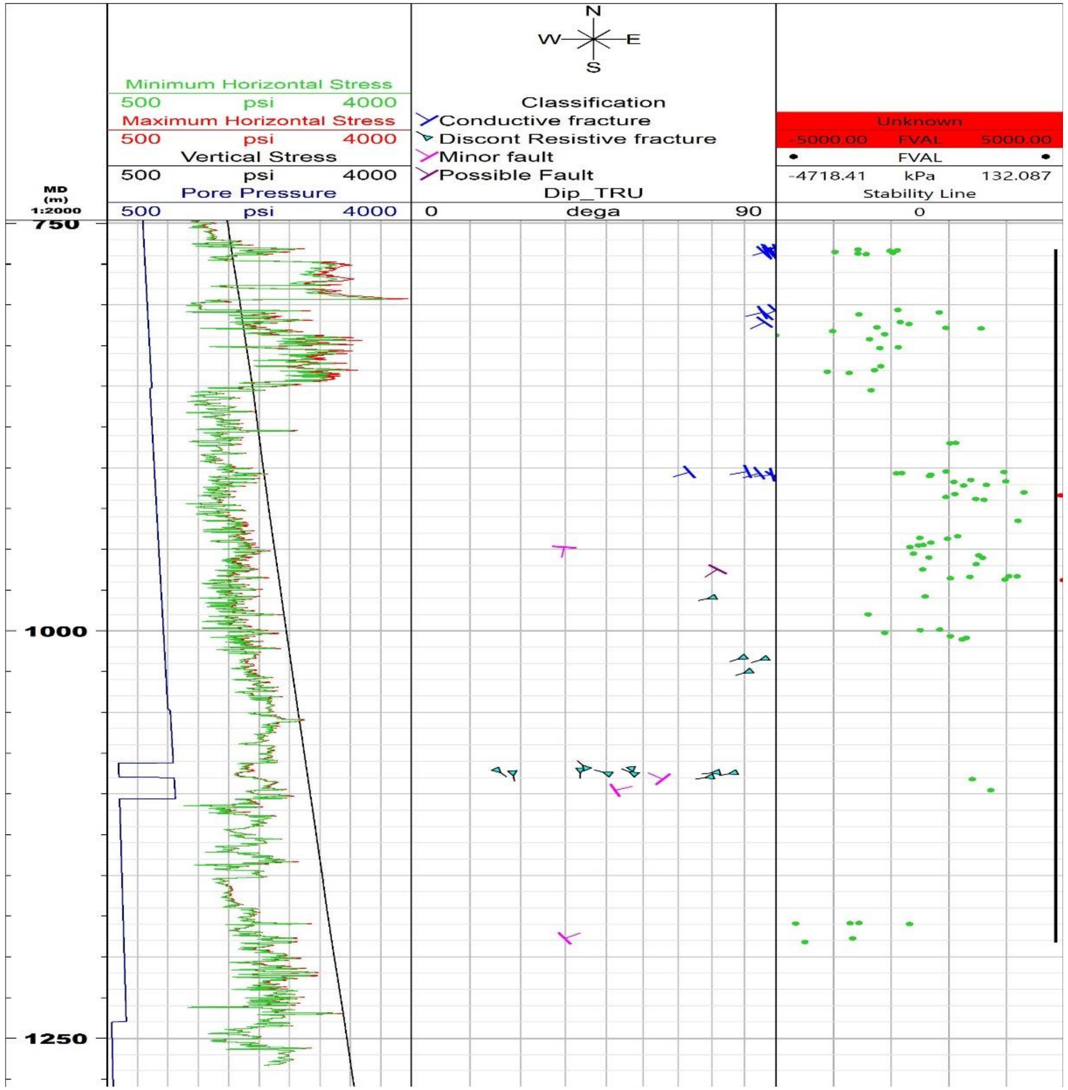


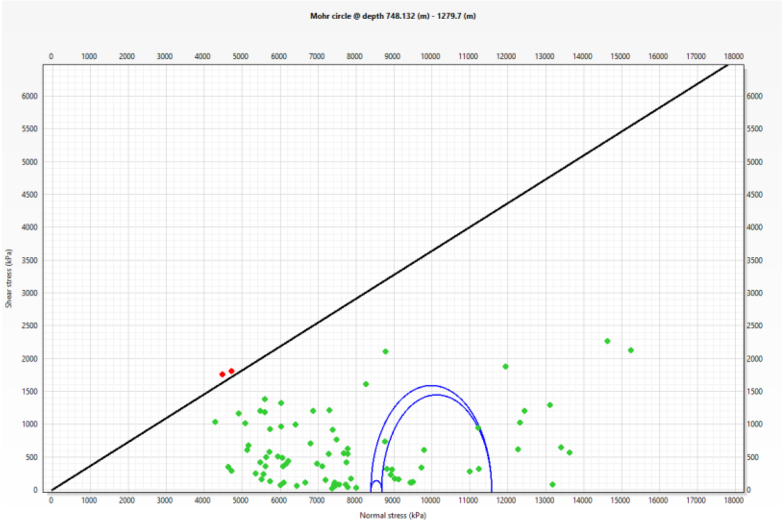


Fracture interpretation: borehole images and 3DFF

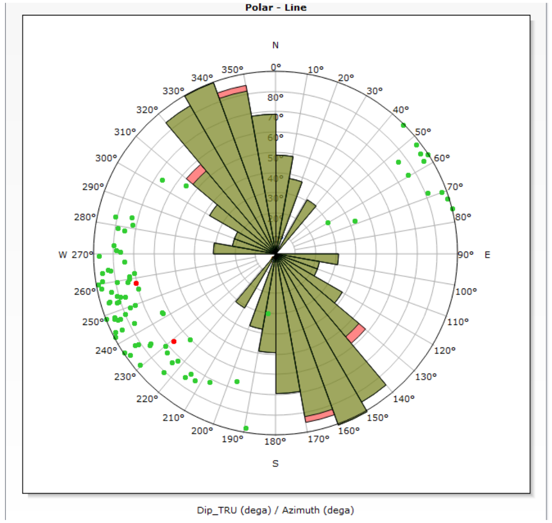


Fracture Stability Analysis

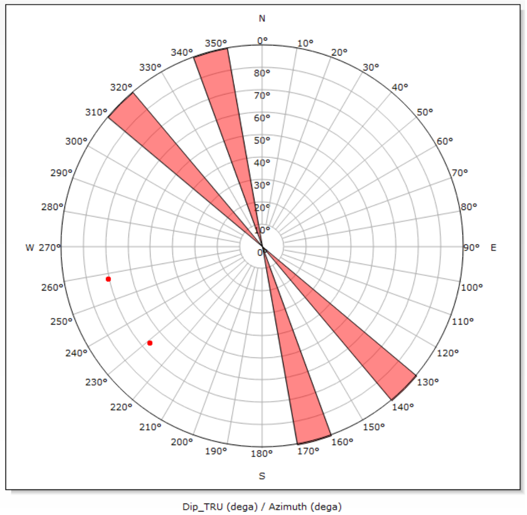




All Conductive Fractures/Faults



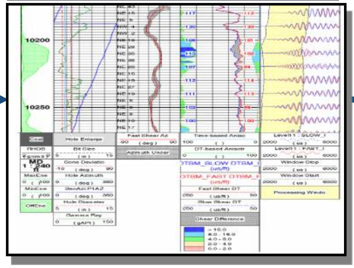
Critically Stressed Fractures/Faults

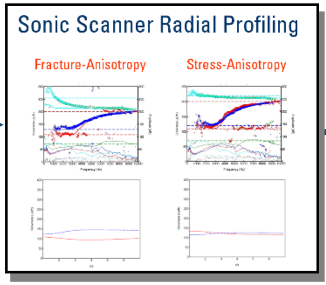


Fracture-Anisotropy-Modeling Workflow Process in 3D

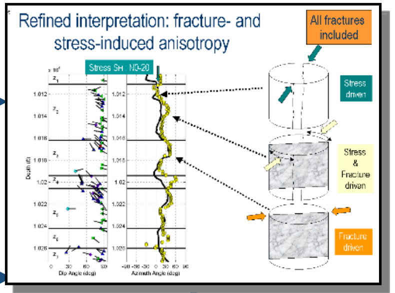
Sonic Scanner Processing

Anisotropy Processing



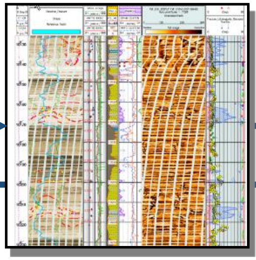


Forward Model of Image Fracture Data and Compare to Sonic Anisotropy

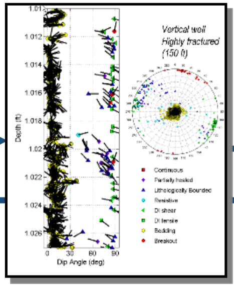


Borehole Image Processing

Dip and Image

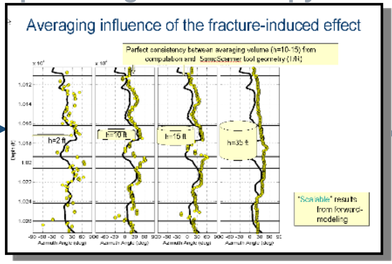


Natural Fracture Data Export

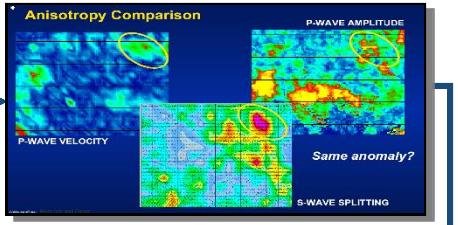


Multiwell Integration

Up-Scaling of Anisotropy Results



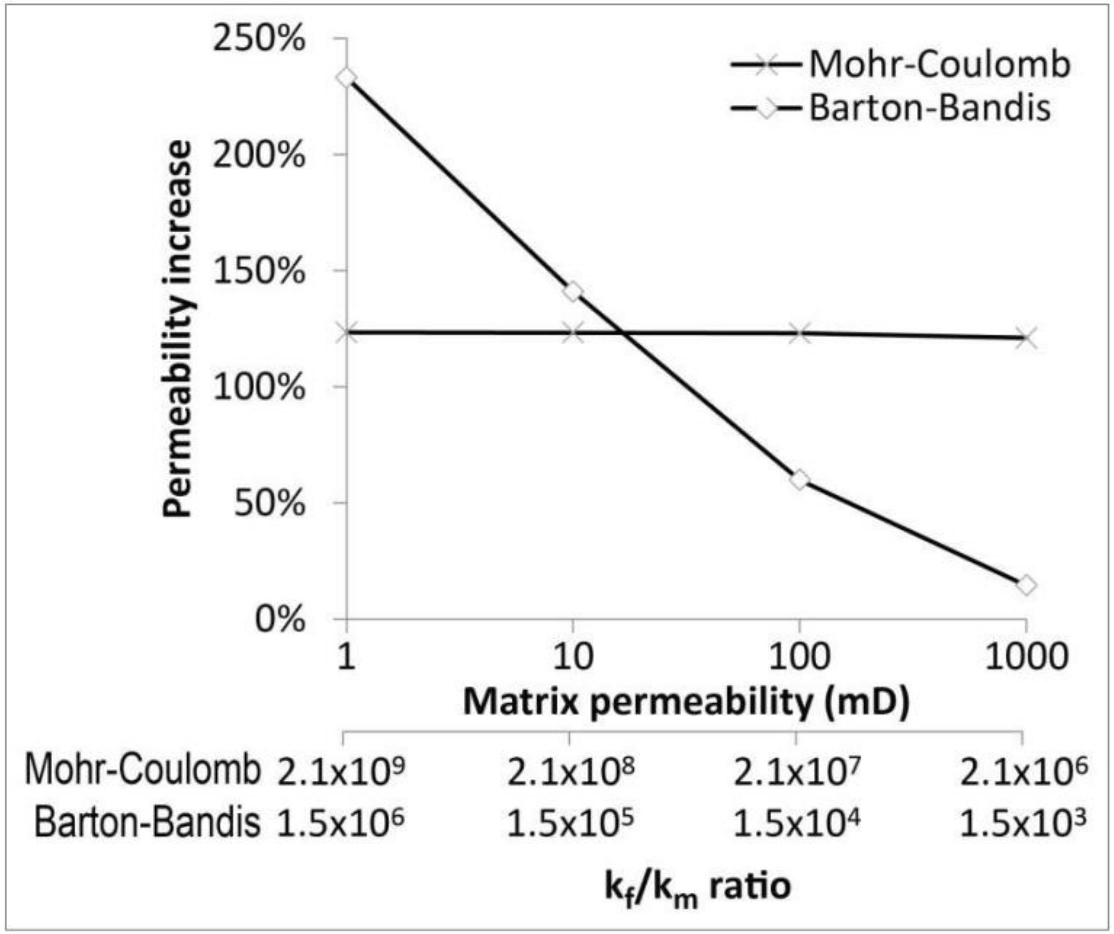
Borehole to Seismic Calibration of Anisotropy



Tiered Deliverables:

1. Data Visualization
   - Fracture Attributes
   - Azimuth Symmetry and Slowness
   - Anisotropy Analysis and Property Flag
2. Data Integration & Interpolation of the Seismic Scale Anisotropy
3. Input to 3D-MEM

Image and Sonic Data Merge> Forward Model Anisotropy > 3D Visualization


250%
200%
150%
100%
50%
0%
Permeability increase
Mohr-Coulomb
Barton-Bandis
1
10
100
1000
Matrix permeability (mD)
Mohr-Coulomb $2.1x10^9$ $2.1x10^8$ $2.1x10^7$ $2.1x10^6$
Barton-Bandis $1.5x10^6$ $1.5x10^5$ $1.5x10^4$ $1.5x10^3$
k_f/k_m ratio

Conclusions

- Brown Fields Challenges requires proper understanding of the fracture network for better reservoir development.
- This study can be performed whenever there is an integration between the NOC and the service provider.
- 3D geomechanical modelling will be required in the level of field in the future.