Fractured reservoir characterization using borehole images

Ágnes Bőgér & Ákos Hajdu
MOL Plc, E&P IFA GGDM

ISZA

Balatonföldvár, 28. 03. 2014.

MOLGROUP

OUTLINE

- INTRODUCTION
- REGIONAL GEOLOGICAL SETTING
- BOREHOLE IMAGES AND INTERPRETATION METHOD
  - NATURAL FRACTURES ON BOREHOLE IMAGE
  - FRACTURE APERTURE CHARACTERIZATION
- FRACTURED RESERVOIR CHARACTERIZATION
- IN-SITU STRESS ANALYSIS
- CONCLUSION

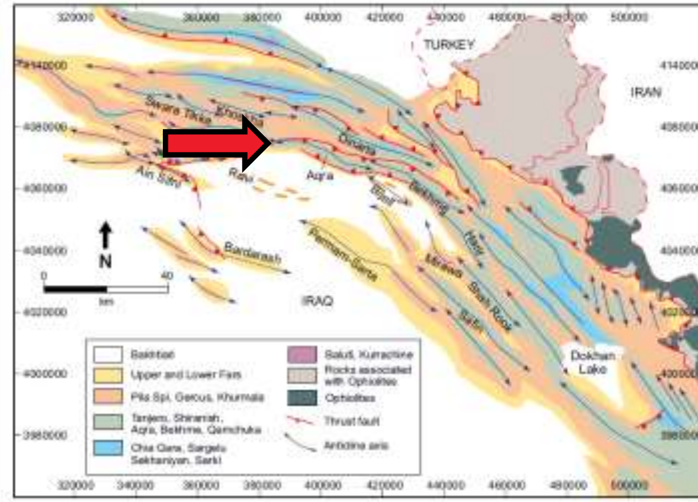
INTRODUCTION

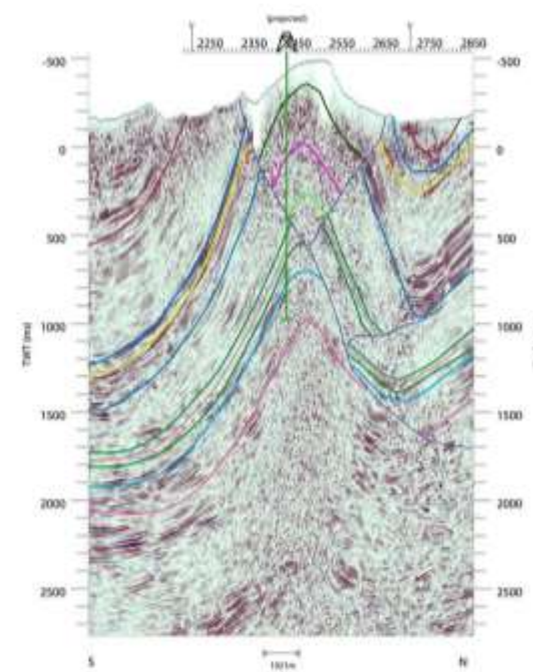
- ~5800 m image log interpreted in Cretaceous, Jurassic and Triassic carbonate formations
- Three borehole image log used (one acoustic – CBIL; and two electrical – XRMI & CMI: between 982 – 4102 m

- **Objectives:**
  - Process XRMI, CMI & CBIL
  - Manually pick and categorise features from XRMI, CMI & CBIL images with reference to petrophysical log curves
  - Analyse fracture and fault orientation and distribution
  - Calculate fracture aperture/porosity
  - Correlate with core/lab data; mud loss data and PWL interpretation,
  - In-situ stress analysis (Present-day in-situ stress feature identification)

REGIONAL GEOLOGICAL SETTING

- Cretaceous, Jurassic and Triassic limestones, dolomites
- Source rocks
  - Late Triassic Kurra Chine formation
  - Middle and Late Jurassic dark shales, marls (Sargelu, Sekhaniyan formation)
- Reservoirs
  - Kurra Chine dolomite, varied lithology: thick limestone beds, dolomitic limestone, dolomite, claystone, claymarl and anhydrite
  - Jurassic formations of Sargelu and Butmah
  - Fractures are very important for permeability
- Seals
  - The evaporitic Barsarin Formation works as an effective seal
  - anhydrite interbeds of Sarki/Butmah Formation may work as intra-formational seal
  - Baluti formation contains massive anhydrite layers, alternating with thin limestone and shale layers
  - Kurra Chine formation’s thick anhydrite beds also act as an effective seal

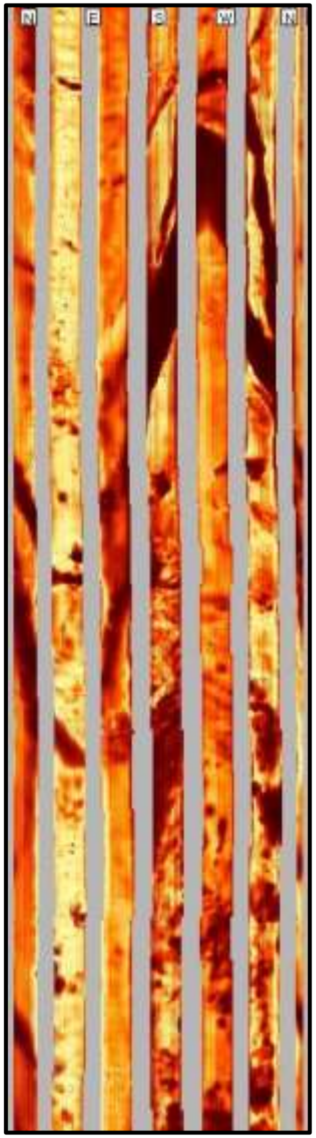


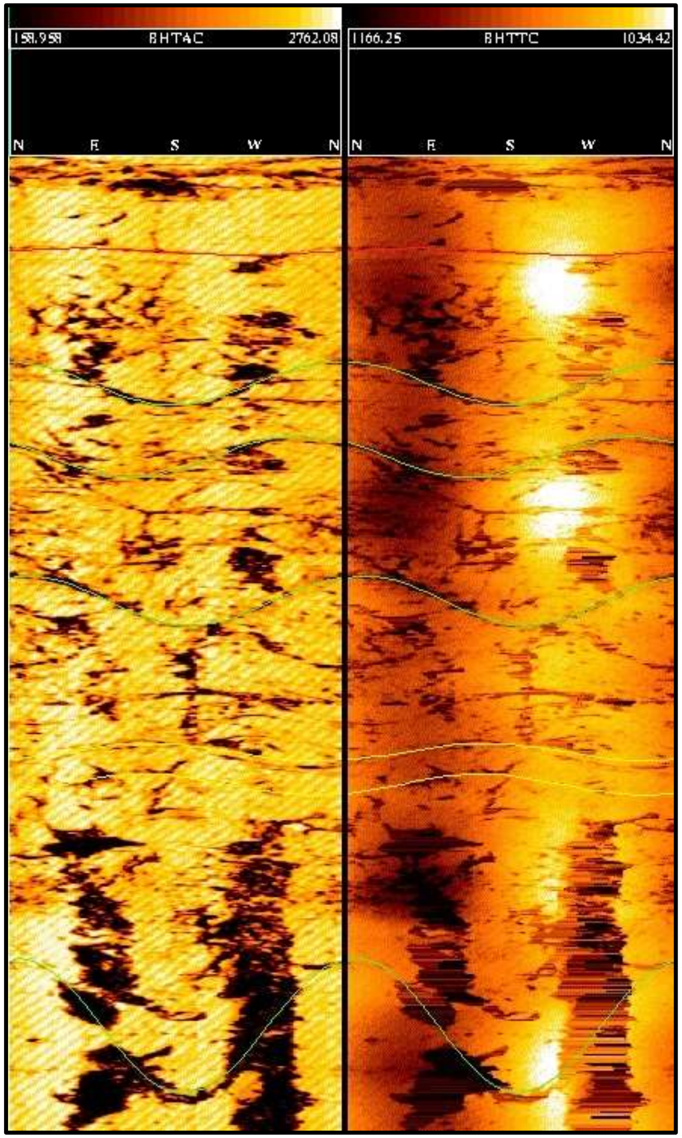


BOREHOLE IMAGING

- RESISTIVITY METHOD
- ACOUSTIC METHOD

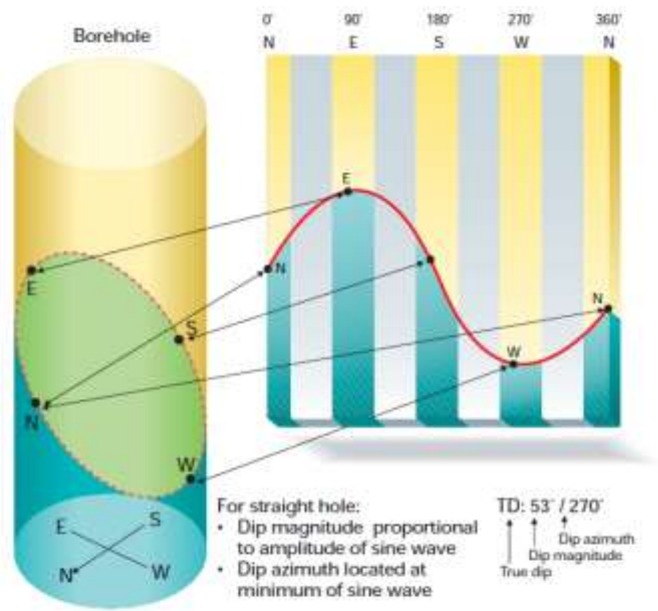
  - Structural analysis
  - Fracture analysis
  - Depositional environment analysis
  - Rock texture analysis
  - Porosity description
  - Comparison to core

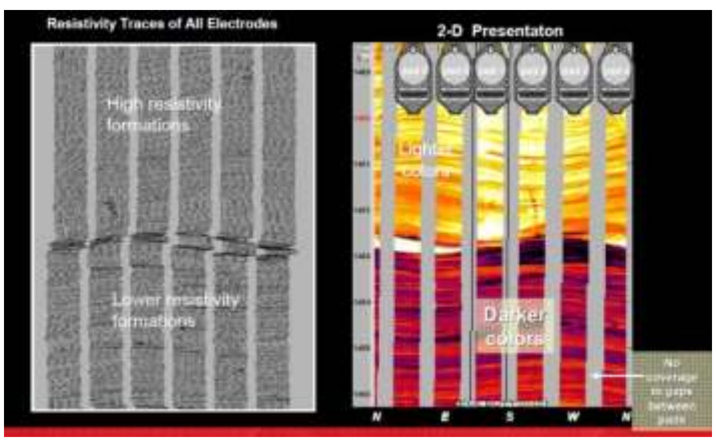


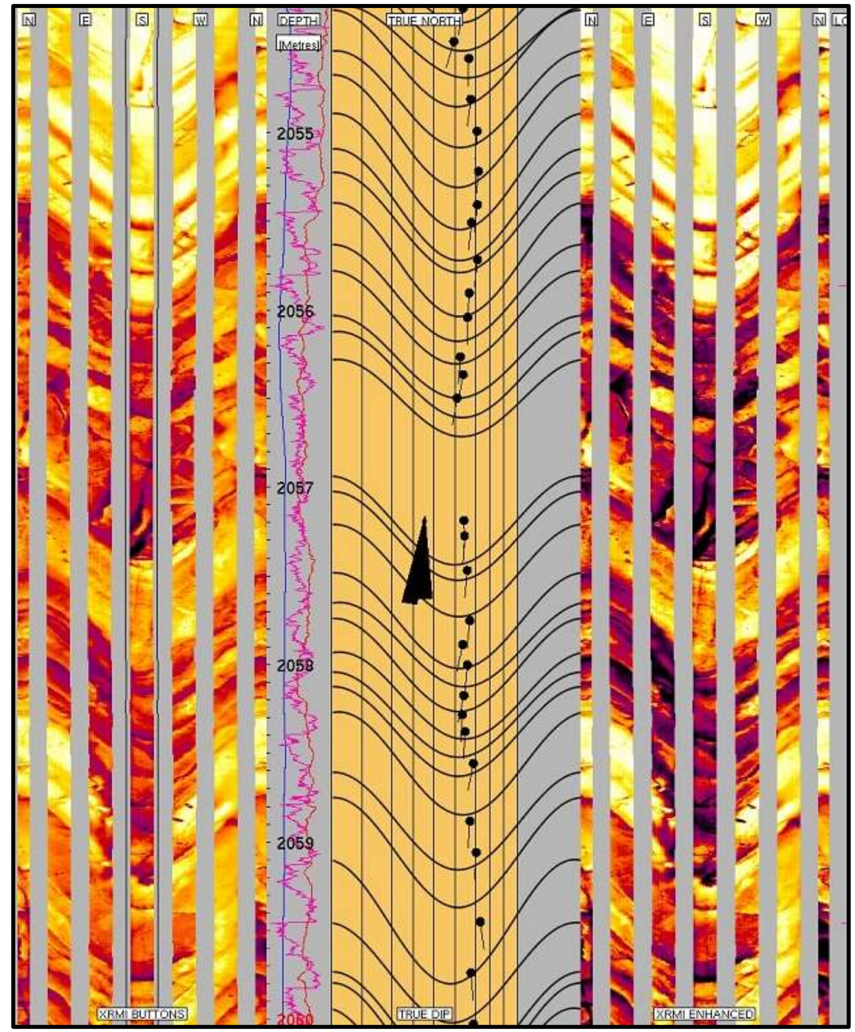


MOLGROUP

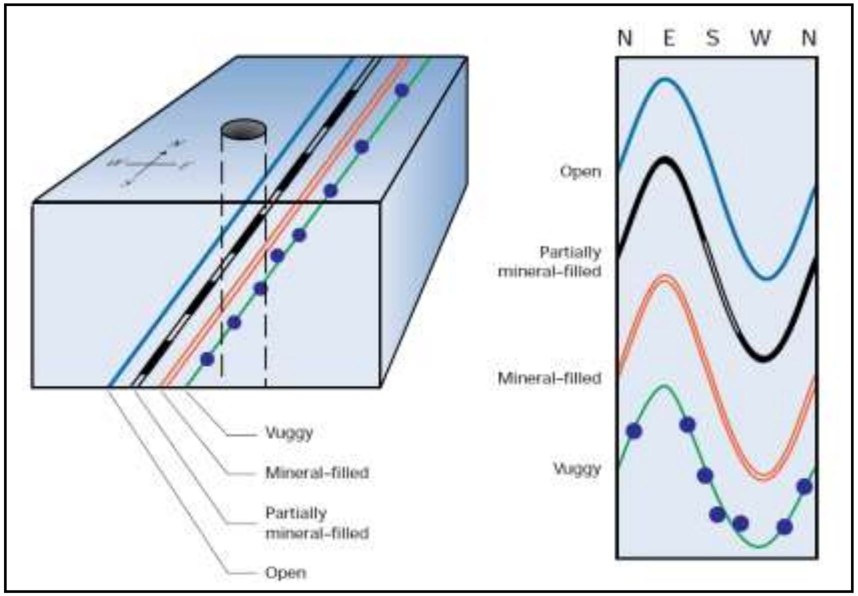
IMAGE INTERPRETATION PRINCIPLES



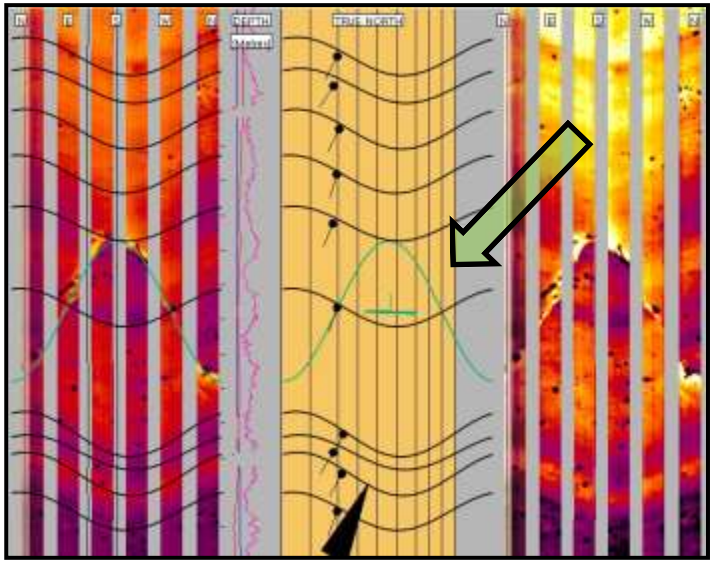


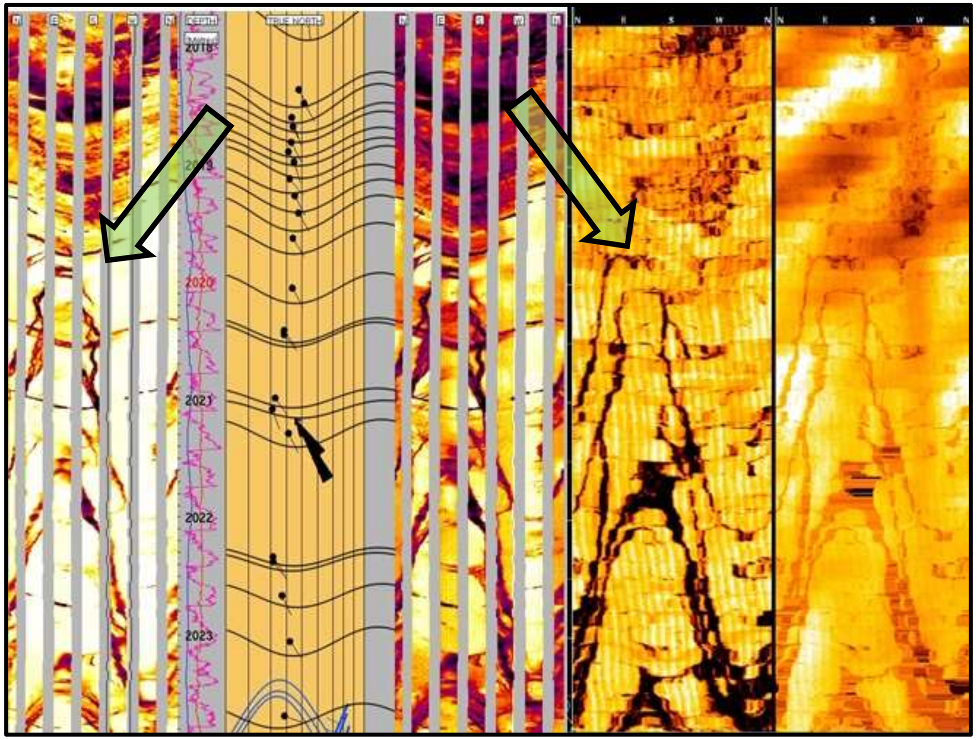


NATURAL FRACTURE TYPES



- Open & closed fractures
- Partially open / mineralized fractures
- Normal & reverse fault
- Mineralized, brecciated, fault zone



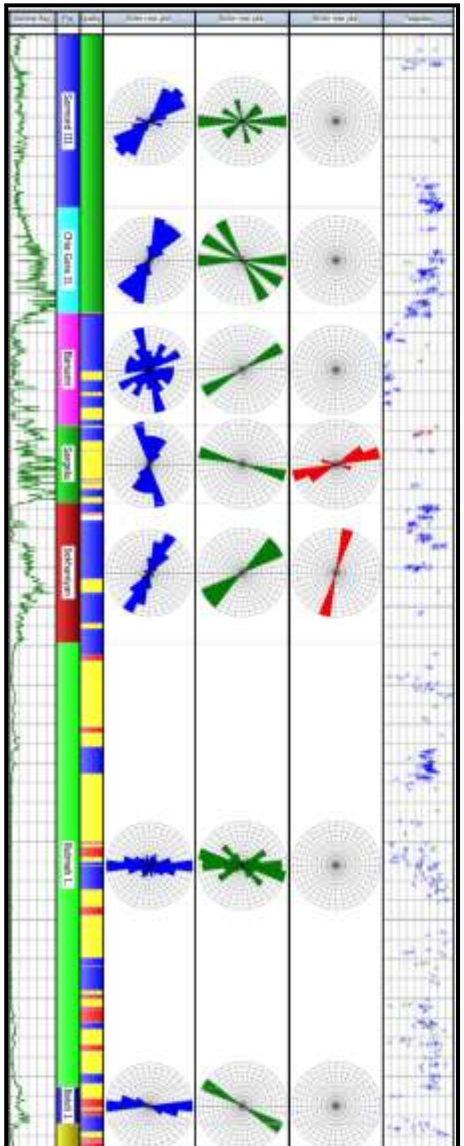


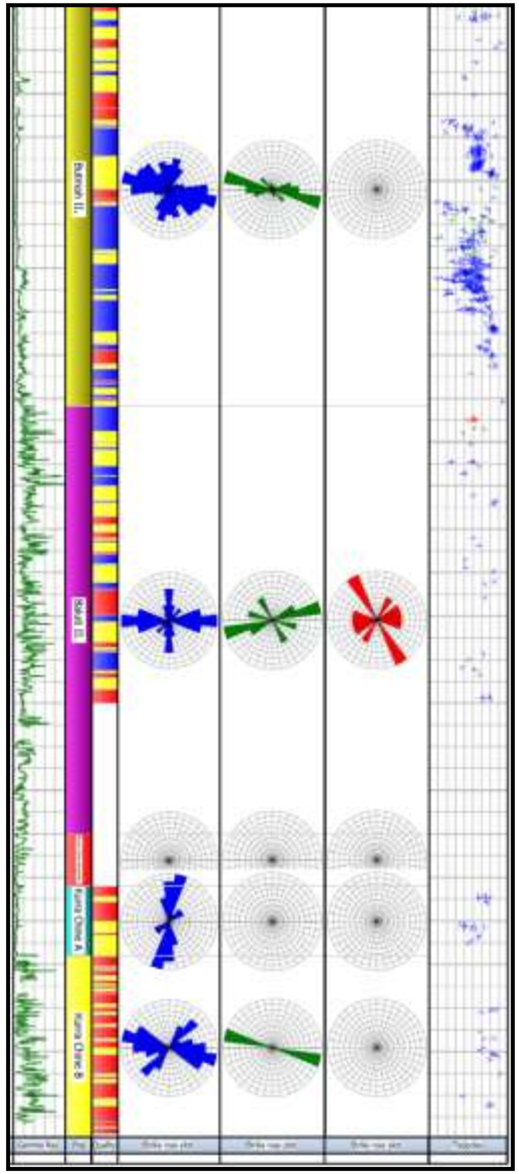
BOREHOLE IMAGE INTERPRETATION

- Borehole image data is generally good
- The interpretation more difficult
  - These carbonate rocks have some very fractured zones
  - Cavernous zones (in the lower part)
  - The image data were very noisy due to inefficient pad contact
  - Tool sticking

- We interpreted:
  - 15 Closed fractures,
  - 106 Fault planes,
  - 1087 Open fractures

BOREHOLE IMAGE INTERPRETATION





- The interpreted faults show a dispersed strike direction to:
- Main stinking direction:
  - E – W,
  - NW – SE
  - NNE - SSW.
- Their dip magnitude varies between ~25 to 55°

Category	Symbol
Bedding planes	
Conductive (or open) fractures	
Resistive (or closed) fractures	
Faults	

FRACTURE APERTURE FROM BORHOLE IMAGE

- **Fracture aperture**

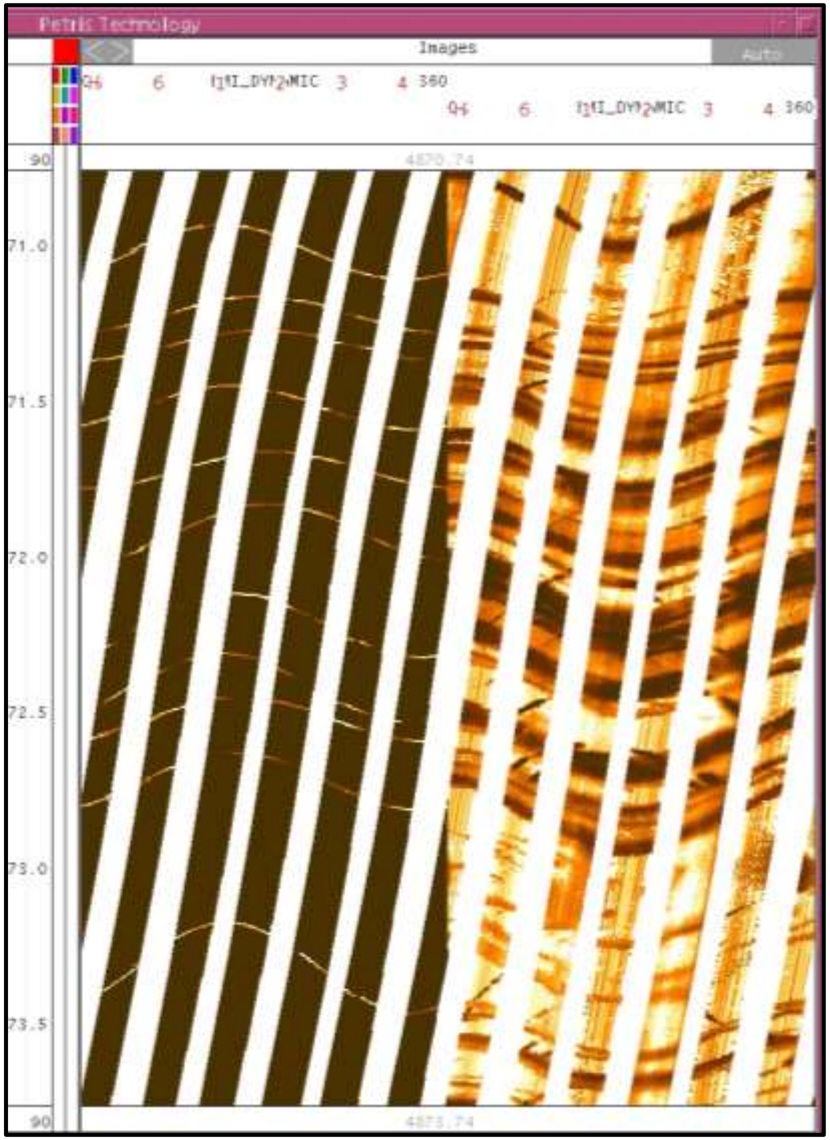
  W= A*Rm*Rxo

W= aperture, A= excess conductivity, Rm= mud resistivity, Rxo= flushed resistivity

Fracture interpretation -> scale & filter the image for open fractures -> calculate the aparture for open fractures

Calculated fracture aperture: **0.05-1.5 mm**

We used the average value: **0.5 mm**



FRACTURE POROSITY FROM BORHOLE IMAGE

Fracture Porosity:

PHIf = 0.001 * Wf * Df * KF1

KF1 = number of main fracture directions
= 1 for sub-horizontal or sub-vertical
= 2 for orthogonal sub-vertical
= 3 for chaotic or brecciated

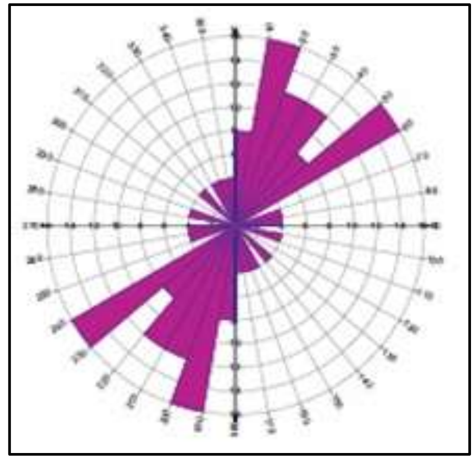
PHIfrac = fracture porosity (fractional), Df = fracture frequency (fractures per meter)
Wf = fracture aperture (millimeters)

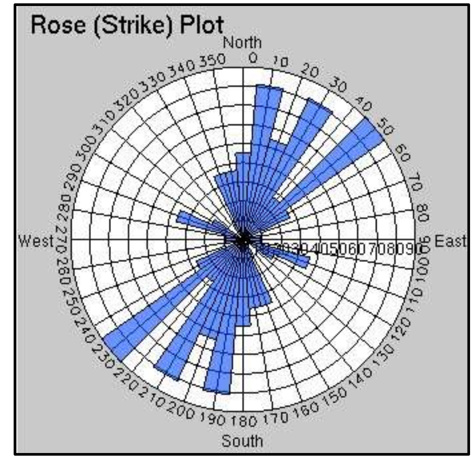
Window size: 1m

- We calculated from the weighted density curve, assume 0.5 mm fracture aperture
- We calculated the fracture porosity for each formation with different fracture directions
- Fracture porosity values are: **0.005-0.175%**

CORE DATA

- **Core data intervals**
  - 1th interval: 1077-1089 m
  - 2nd interval: 1880-1886 m
  - 3th interval: 2207-2219 m
  - 4th interval: 3932-3932.4 m

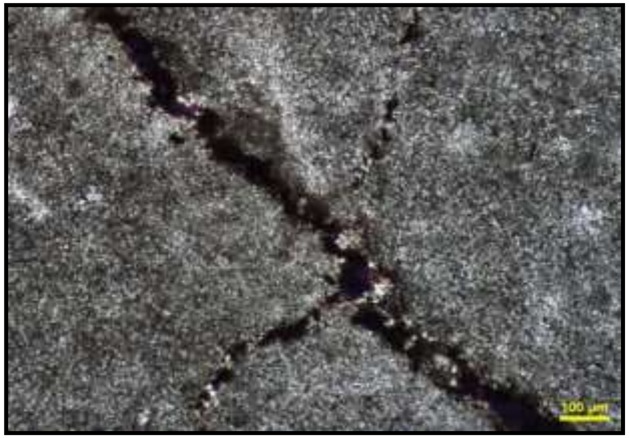




- Partially open and open fractures
- Predominantly: Tension fractures
- Main strike direction: NNE-SSW, NE-SW
- The dip magnitude ranges from 50-80°
- Fracture density: 7/m

APERTURE (mm)							
Formation	**Core No.**	**Depth (m)**	**Lithology**	**Min.**	**Max.**	**Main Strike**	**Dip Magnitude**
Sargelu	2	1880-1886	Marl, dolomit	0.3	1	N40°	60°-70°
Butmah	4	3932.2-3932.7	Dolomit breccia	0.01	0.6	N10°-N60°	50°-80°

CORE DATA



Results of the labor measurements

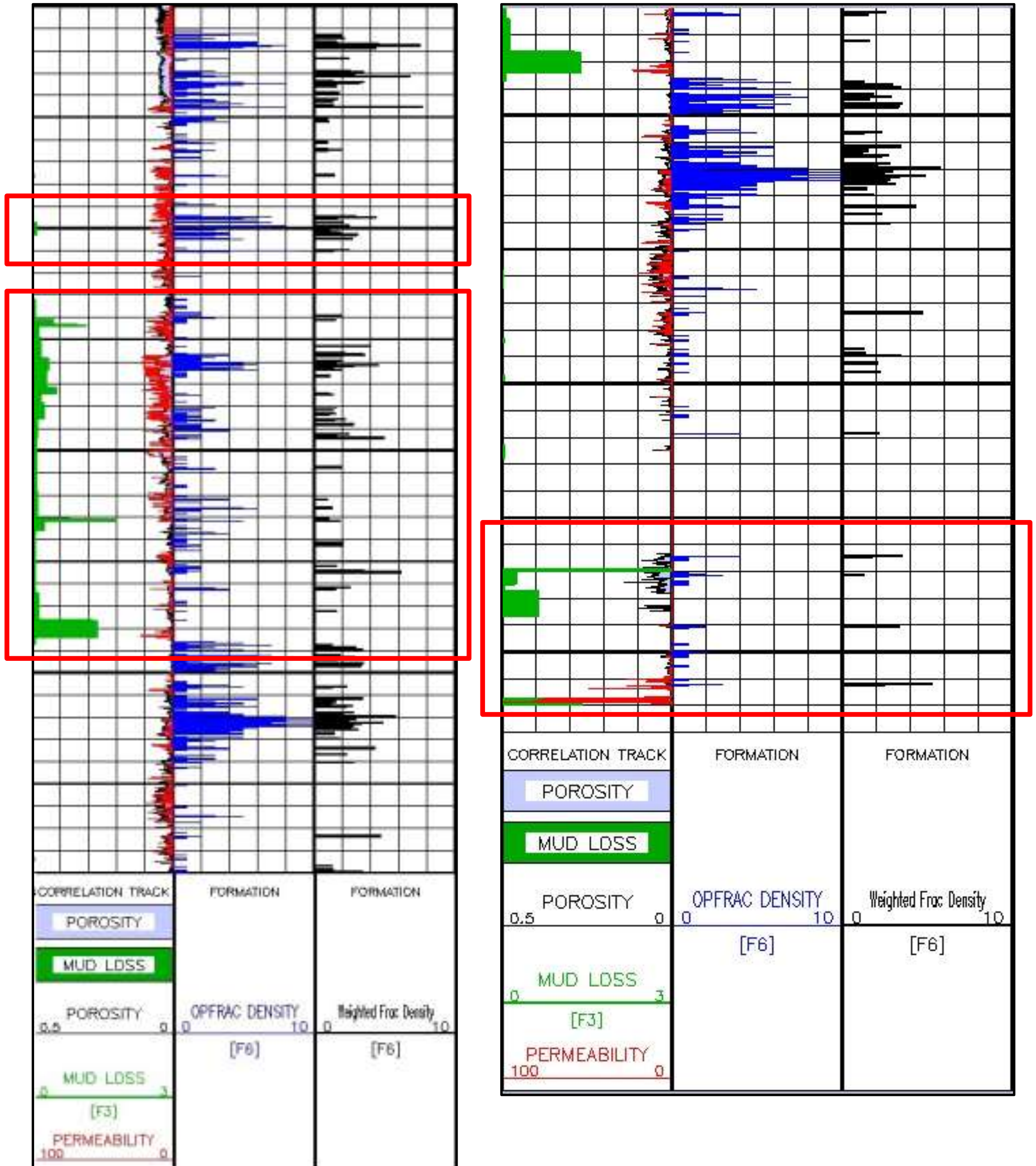
- Porosity: 38 samples
- Permeability: 11 samples

POROSITY (-)									
Formation	**Core No.**	**Depth (m)**	**Lithology**	**Min.**	**Max.**	**Average**	**Median**	**Standard deviation**	**Number of samples**
Garagu	1	1077-1089	Limestone	0.028	0.0353	**0.0117**	0.0078	0.0094	23
Sargelu	2	1880-1886	Marl, dolomit	0.0017	0.0152	**0.0075**	0.0055	0.0043	11
Butmah	4	3932.2-3932.7	Dolomit breccia	0.0351	0.0665	**0.0485**	0.0463	0.0136	4

PERMEABILITY ($10^{-3} \mu m^2$)								
Formation	**Core No.**	**Depth (m)**	**Lithology**	**Min.**	**Max.**	**Average**	**Median**	**Number of samples**
Sargelu	2	1880-1886	Marl, dolomit	<0.01	28.60	**<6.26**	0.30	11

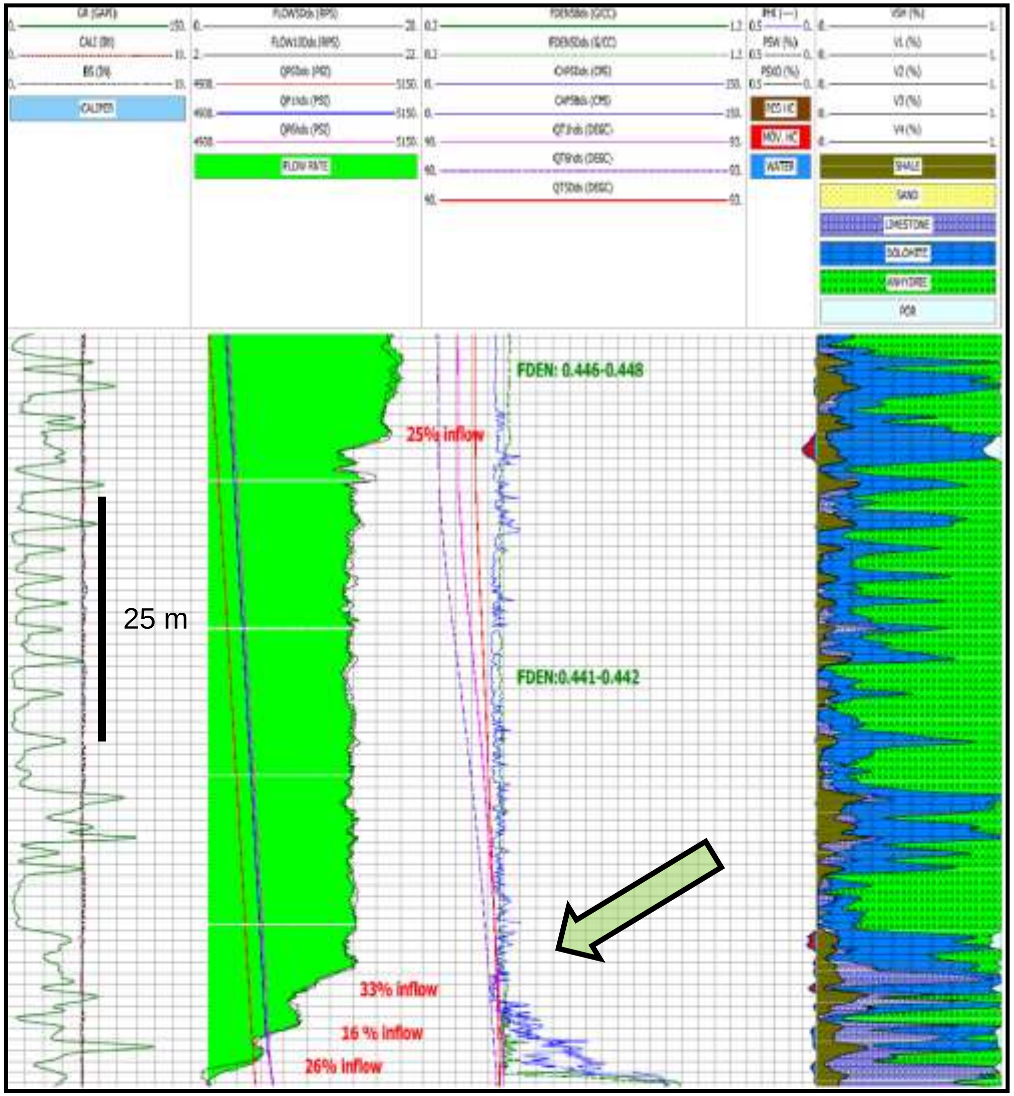
MUD LOSS

- Mud loss with fracture intervals



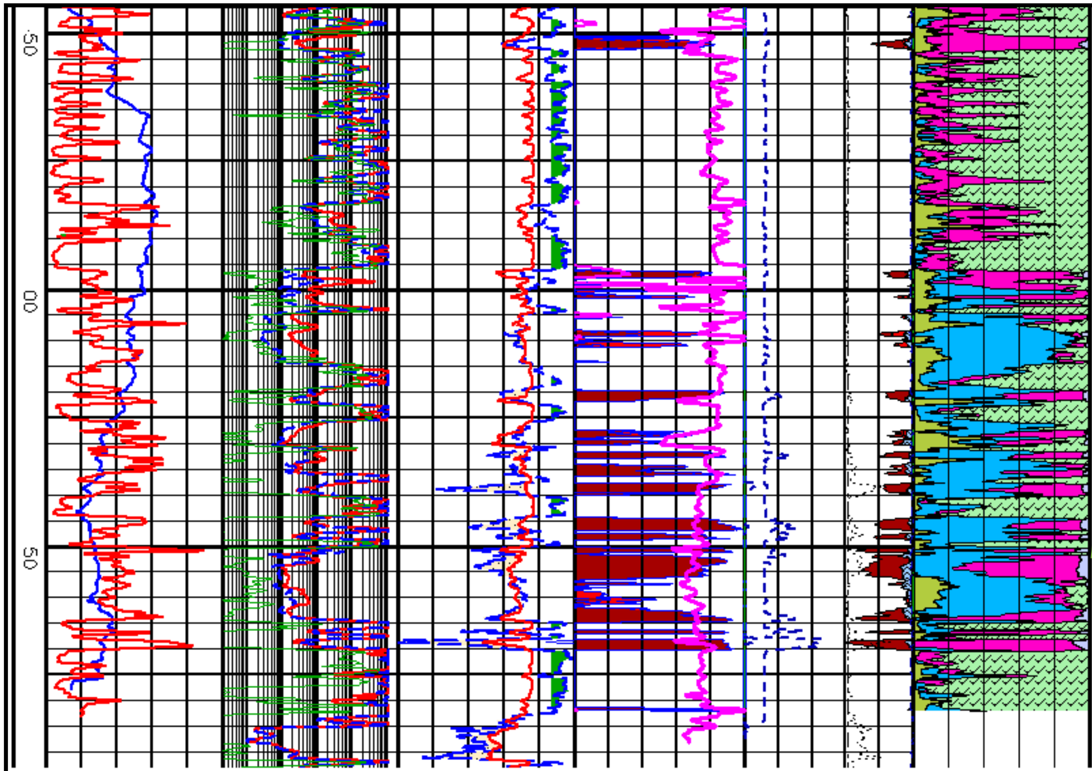
MOLGROUP

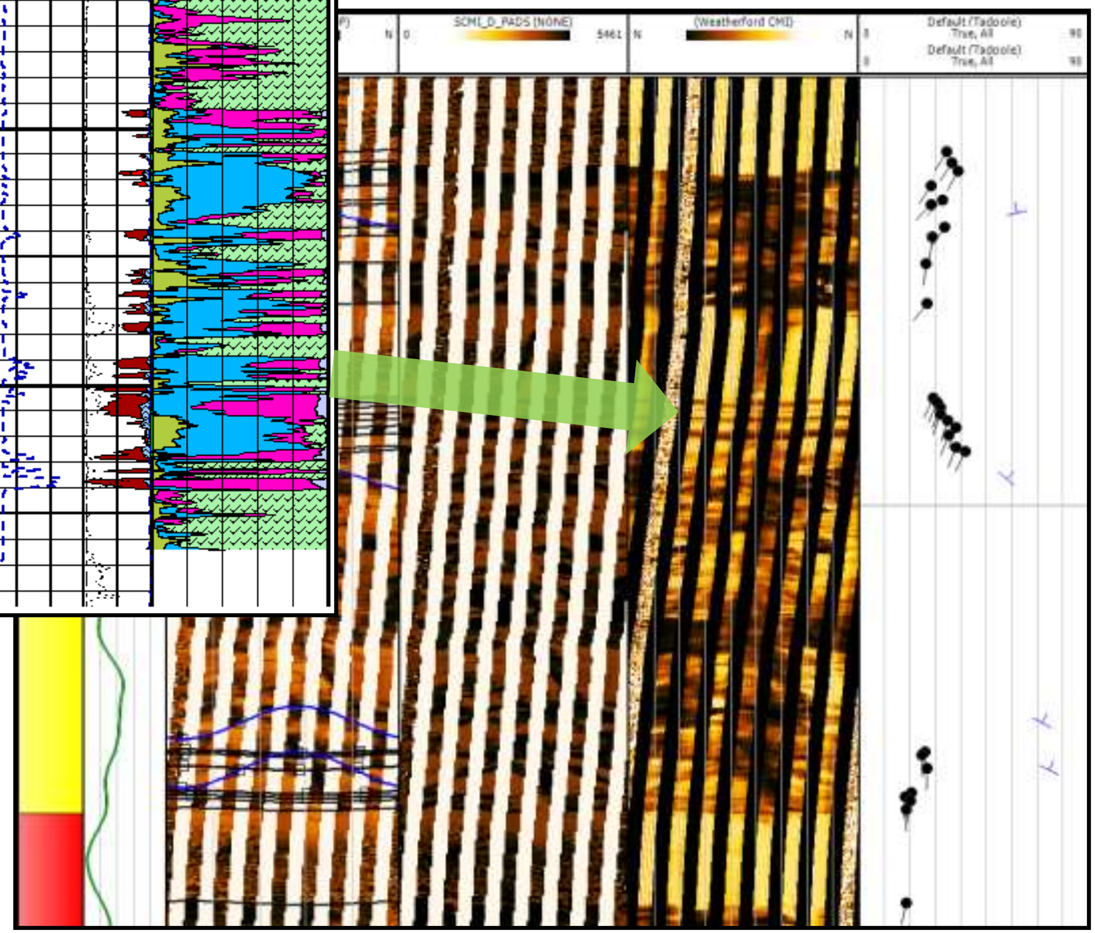
PRODUCTION WELL LOG (PWL)



- Production well log (PWL) interpretation shows that there is connection between
- Production zones HC production was identified from the fractured zones between
- HC comes from fractures

PWL INTERPRETATION

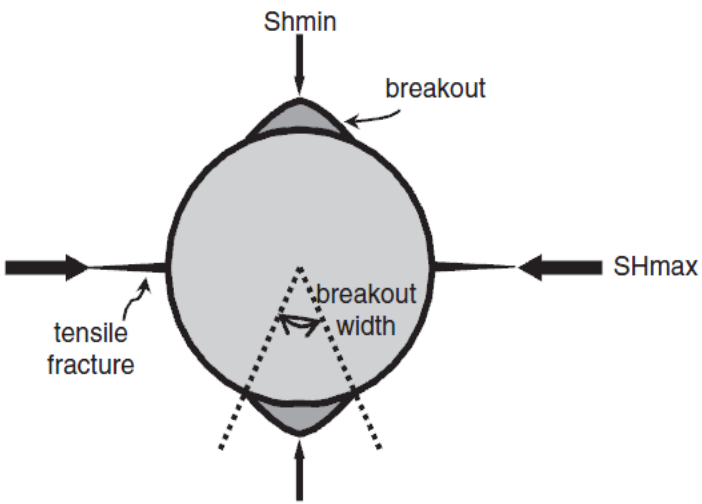


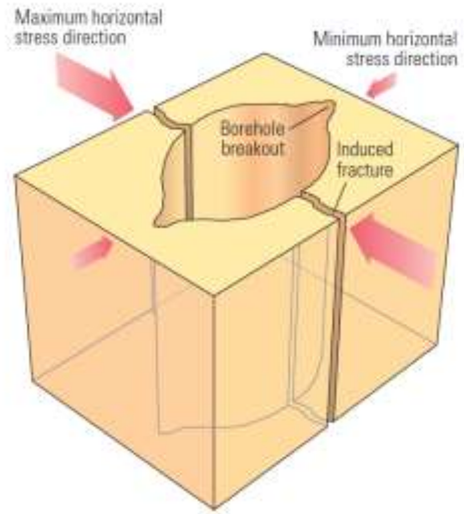


- 33% of the total production comes from this interval
- Bad quality image in this interval
- Only a few interpreted fracture
- Very low primary porosity

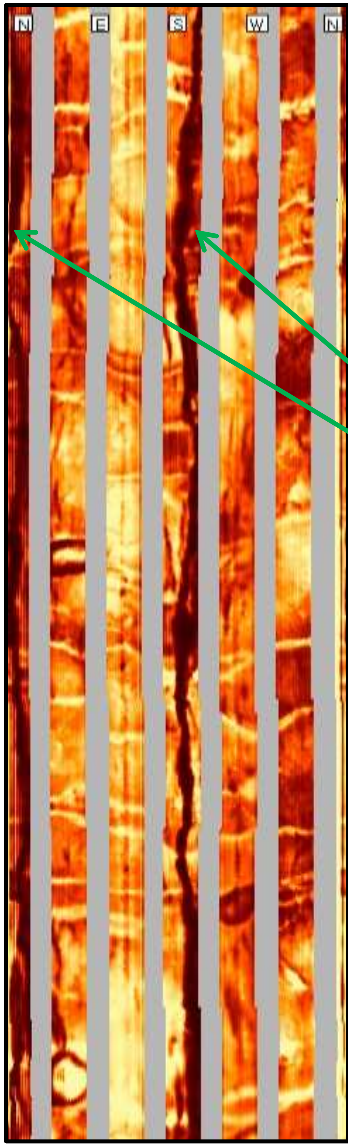
IN-SITU STRESS ANALYSIS

- Borehole breakout occur in the direction of the minimum horizontal stress (Sh)
- The hole elongates in the direction of the minimum stress (Sh)
- Hydrostatic pressure induces shallow fractures
- Drilling induced fractures occur in the direction of the maximum horizontal stress (SH); propagation vertical along the borehole wall



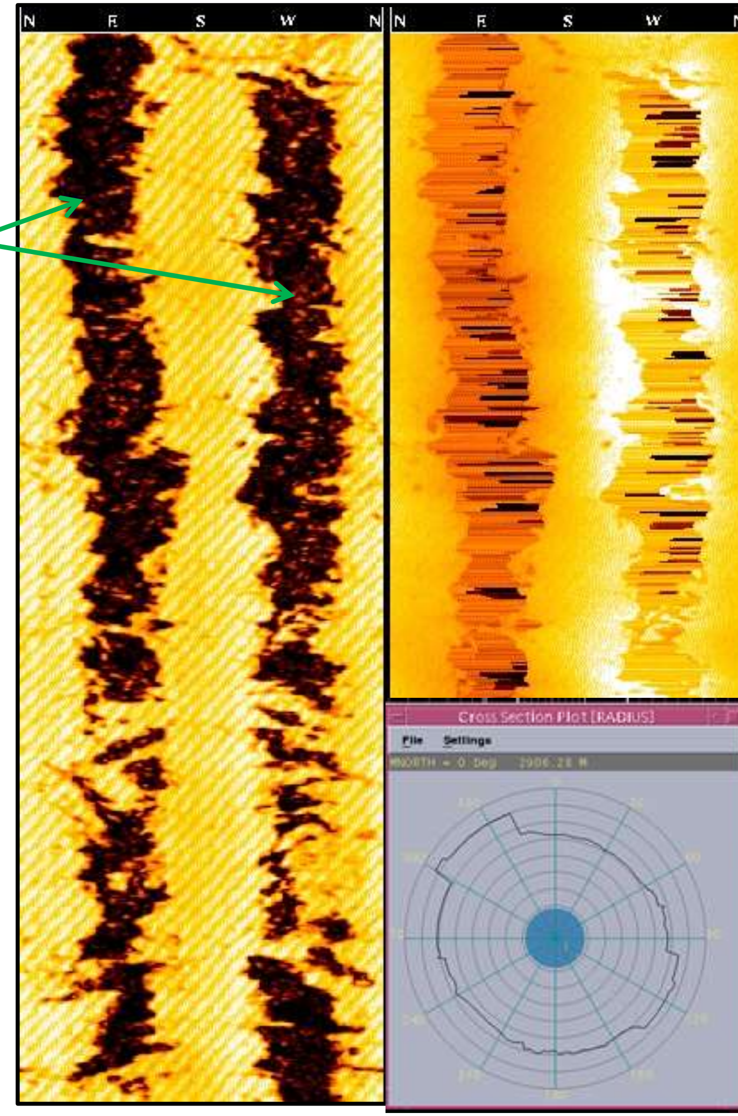


STRESS RELATED BOREHOLE DEFORMATIONS

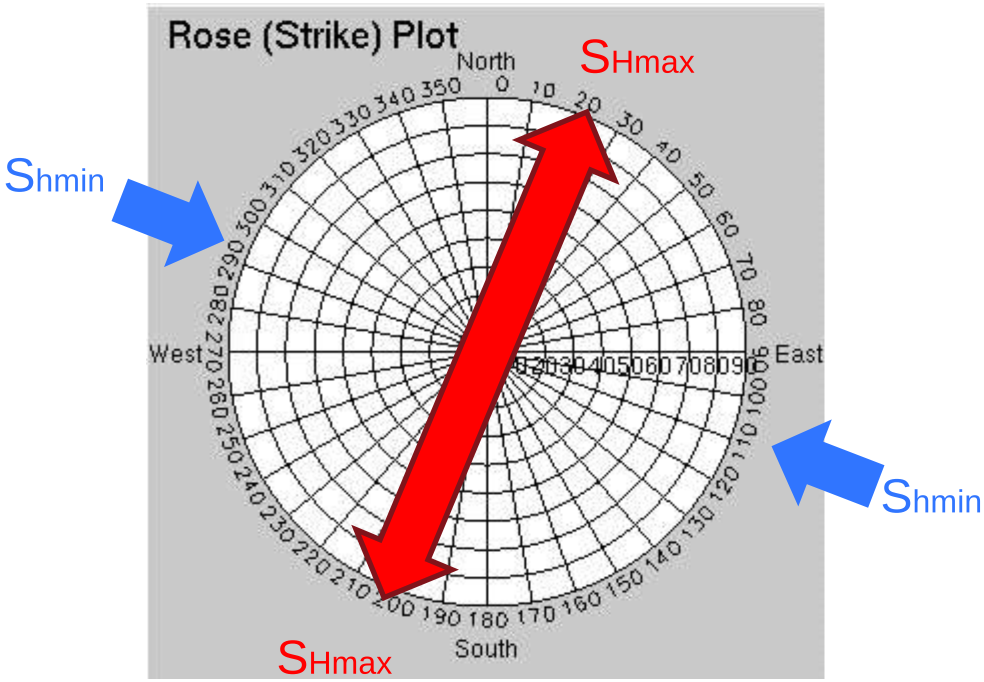


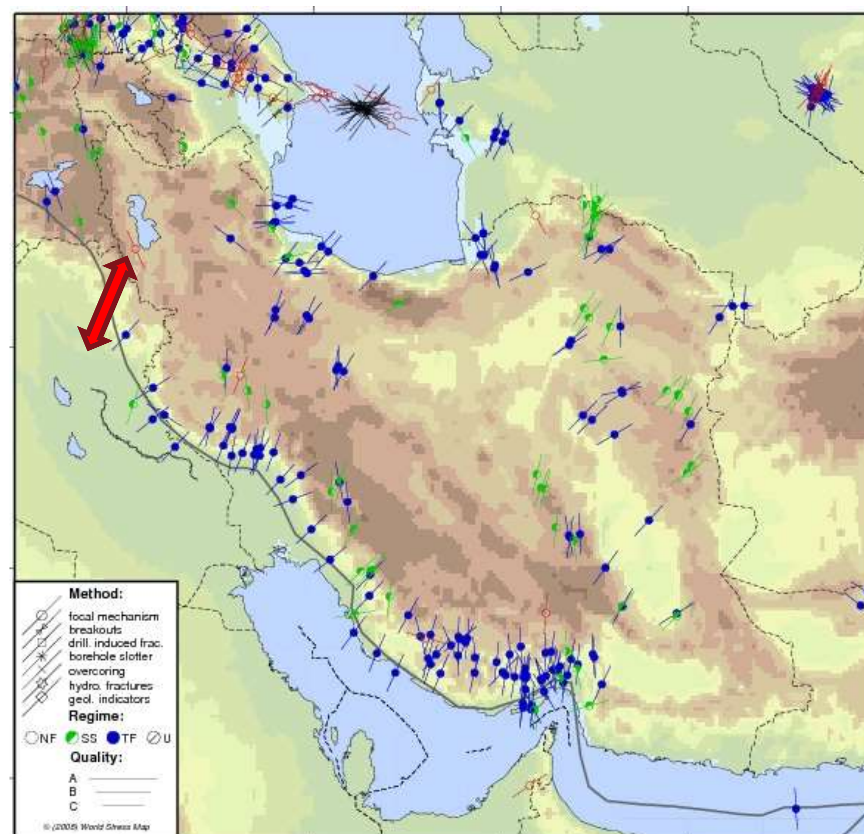
Drilling induced tensile fracture

Borehole Breakout



IN-SITU STRESS DIRECTION





CONCLUSION

- We interpeted different types of borehole images

- We calculated the fracture aperture and fracture porosity

- The results of the core data analysis are consistent with values of the calculated from the borehole images

- The mud losses predominantly occured in the fractured zones.

- The HC production was identified from the fractured zones, addition to very low primary porosity.

- In the study area the porosity and permeability of the HC reservoir rocks (carbonates) are due to open fractures. Borehole images are very important, because it is possible to detect fractures on them, and additionally, the secondary porosity can be calculated from the logs.

- We determined the in-situ maximum horizontal stress direction (NE-SW). This direction is consistent with the regional stress directions.

Thank You for Your Attention!

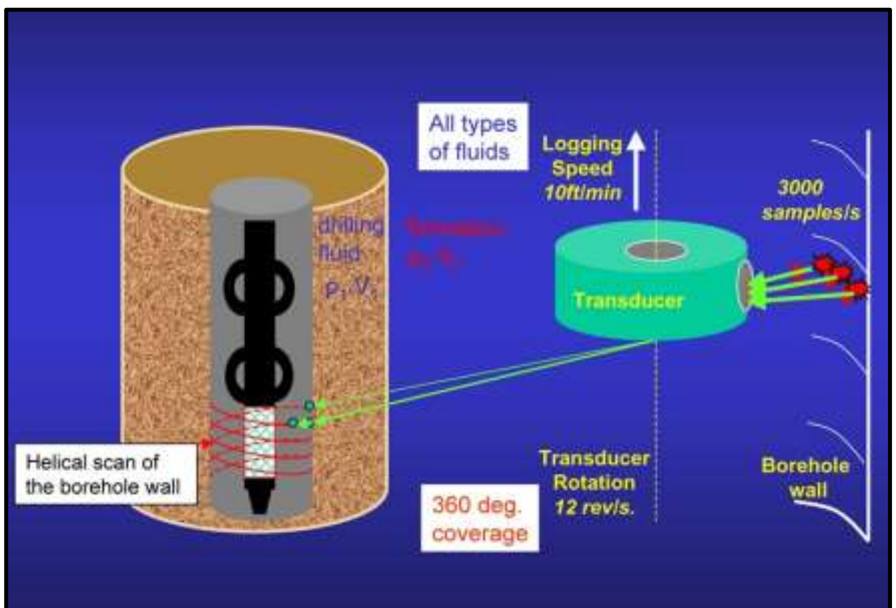
MOLGROUP

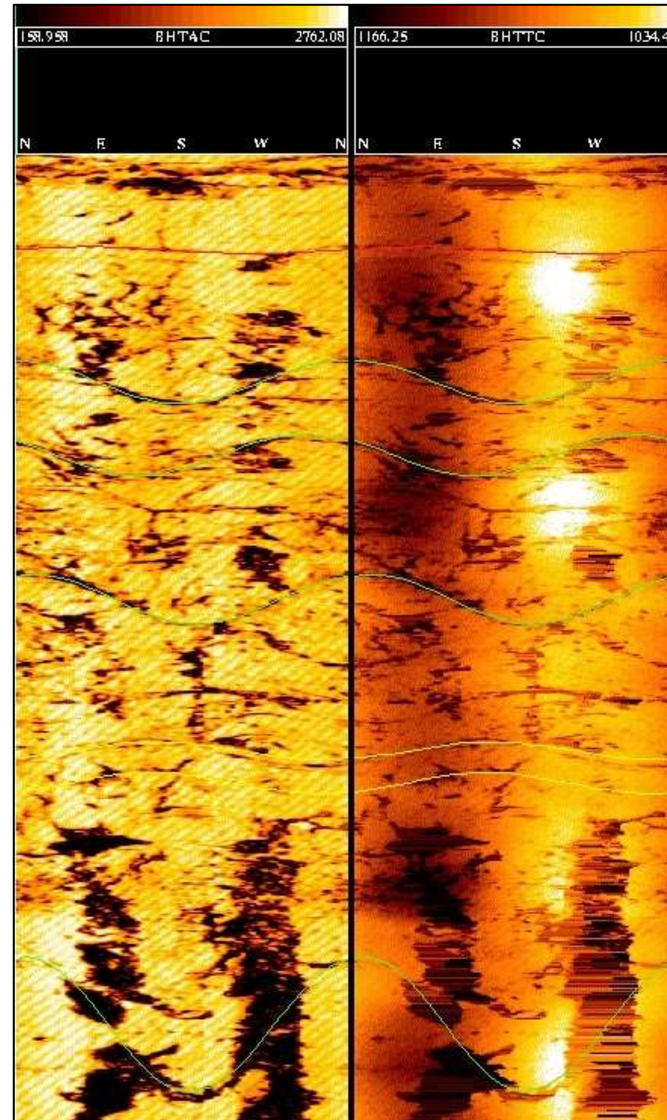
REFERENCES - FIGURES

- Hansen, B., and J. Buczak, 2010, Making interpretable images from image logs, in M. Po¨ppelreiter, C. Garcı´a-Carballido, and M. Kraaijveld, eds., Dipmeter and borehole image log technology: AAPG Memoir 92, p. 51 – 66.
- GeoArabia, 2012, v. 17, no. 2, p. 81-116 Csontos et al modified from
- Gulf PetroLink, Bahrain Structural evolution of the northwestern Zagros, Kurdistan Region, Iraq: Implications on oil migration
- Sissakian, V.K. 1997. Geological map of Arbeel and Mahabad Quadrangles. 1: 250.000 State establishment of Geological Survey and Mining, Iraq. Baghdad.
- Luthi, S. M. Souhaité, P. 1990 Fracture apertures from electrical borehole scans Geophysics, vol 55. no.7
- http://www.world-stress-map.org
- http://www.halliburton.com
- http://www-odp.tamu.edu
- http:// www.naturalfractures.com
- http://www.slb.com
- http:///www.spec2000.net

ACOUSTIC IMAGING METHODS

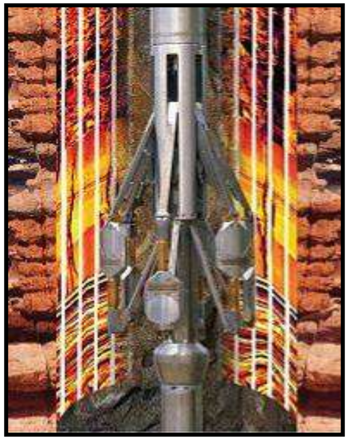
- Acoustic tools are applicable to image the „deformations” of the borehole wall in 360°
- Rotating ultrasonic transducer
- The tool records the amplitude of the returned echo as well as the total travel time of the pulse
- Images of borehole wall reflectance and borehole radius.
- Can be run in oil and water based mud

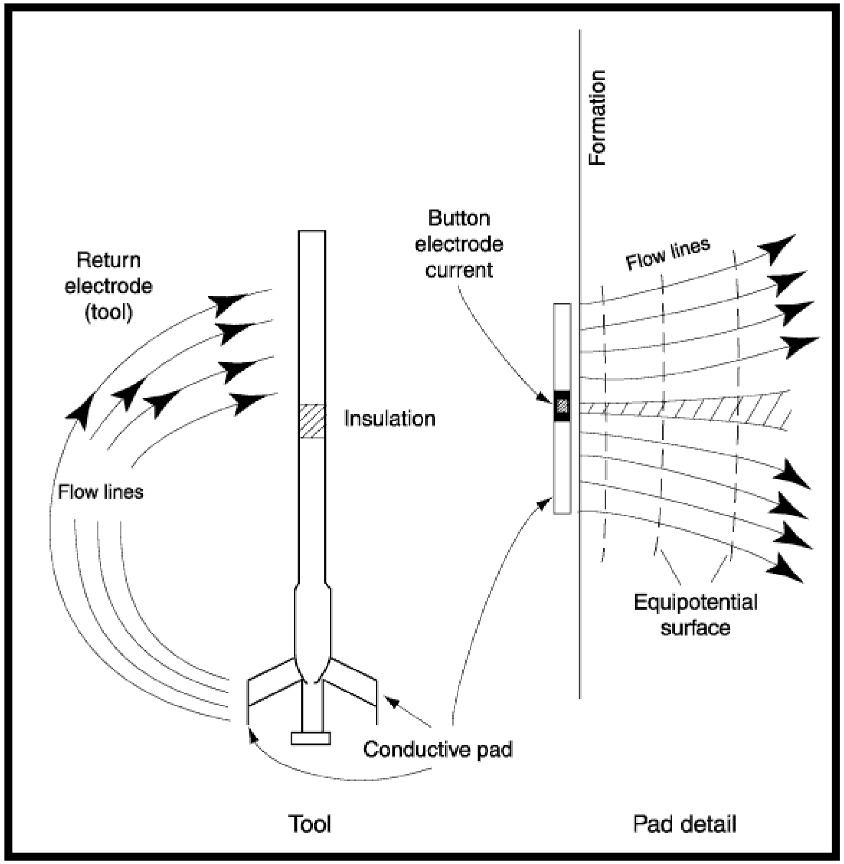




ELECTRICAL IMAGING METHODS

- Borehole imagers are based on the micro laterolog principle, they are focused resistivity devices
- The tools measuring and mapping formation micro-resistivity with each of the pad mounted buttons
- Each button’s current is recorded as a curve, sampled at 0.1 inch or 120 samples/foot
- Can be run in water based mud



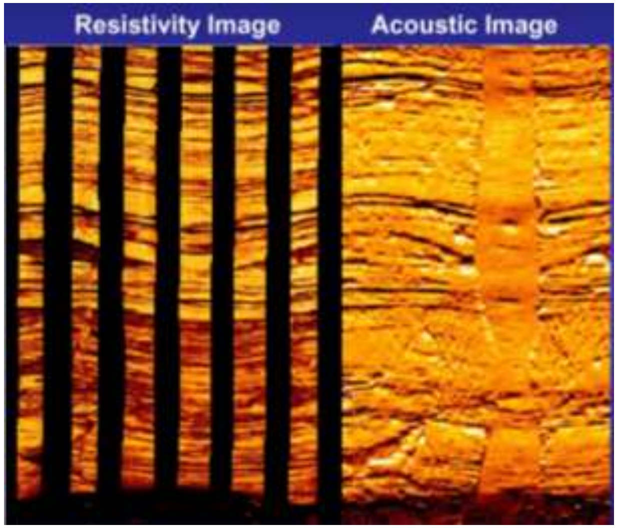


TOOL TYPES

ACOUSTIC

- **Advantages**
  - Can be run in Oil or Water based Mud
  - Provides 360 degree image coverage

- **Disadvantages**
  - Must maintain good centralization
  - Reliant on high impedance contrast
  - Lower image resolution



ELECTRICAL

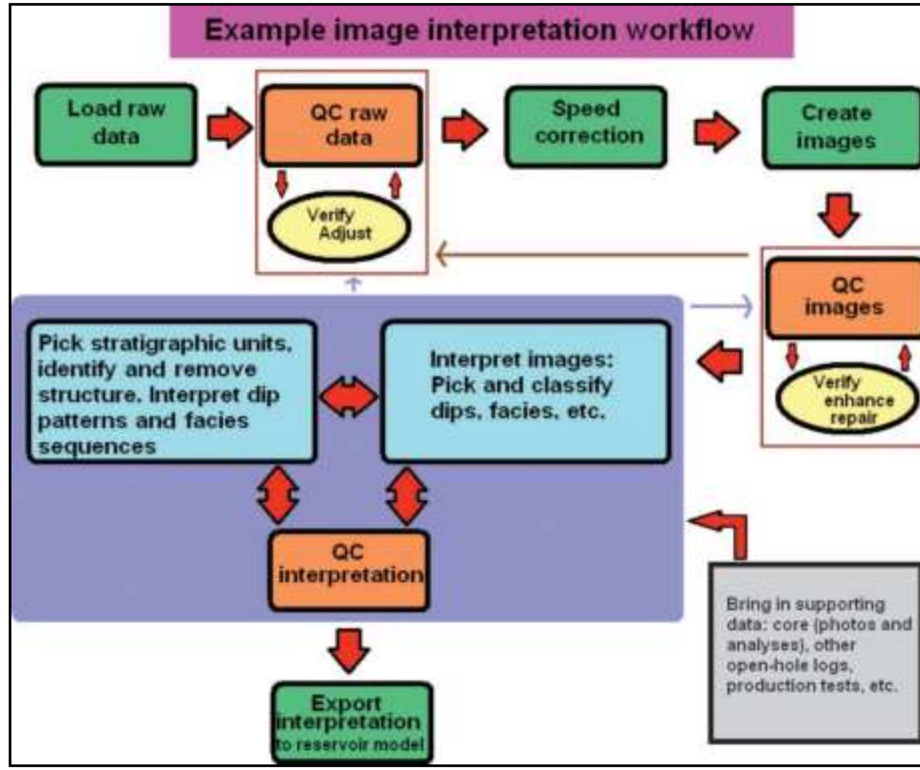
- Highly superior image resolution

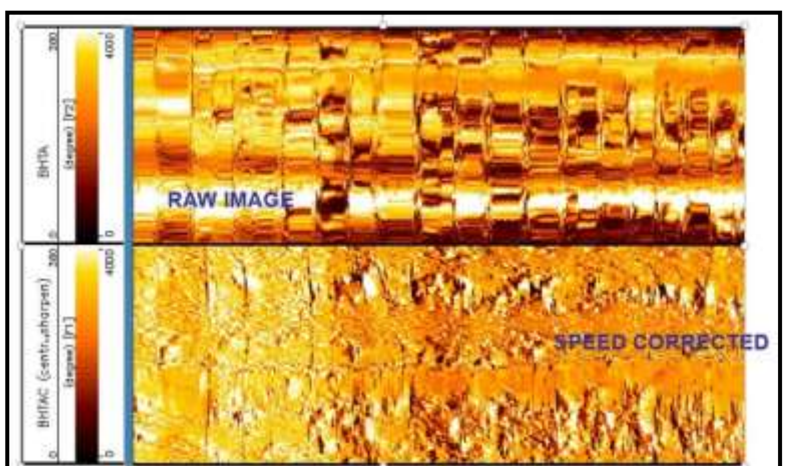
- Reliant on good borehole wall to maintain effective pad contact
- Does not provide 100% image coverage
- Requires separate tool technology to run in OBM

- Structural analysis
- Fracture analysis
- Depositional environment analysis
- Rock texture analysis
- Porosity description
- Comparison to core

IMAGE PROCESSING

- Depth shift to OH curves
- Accelerometer & speed correction
- Static and dynamic image normalization, travel-time and amplitude image generation
- The formation dip parameters and other objects (fractures, faults) were determined by interactive correlation method
- Making dip tadpole, rose-azimuth and strike plots were plotted
- Fracture aperture calculation





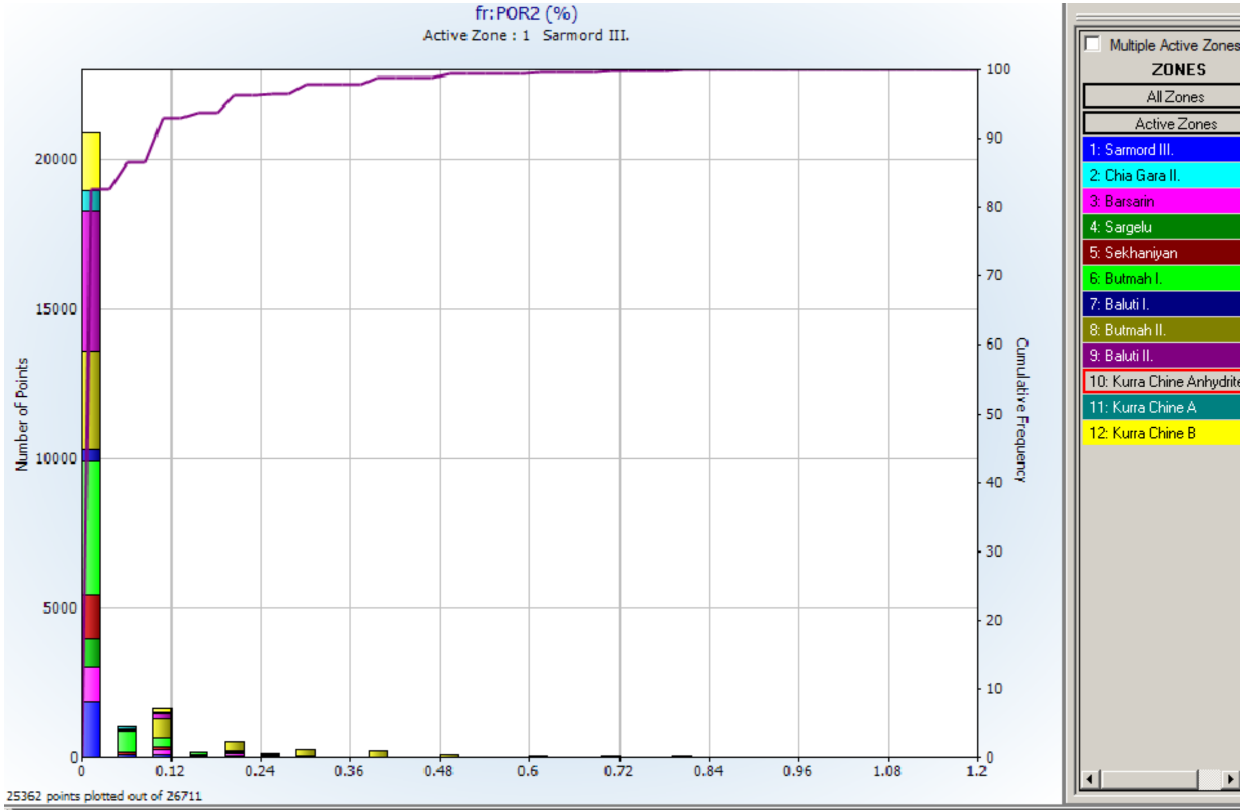
MOLGROUP

FRACTURE APERTURE CALCULATION

Limitations of the method

1. The very nature of the infilling material, natural clay or drilling mud **cannot** be inferred from image examination. This requests core analysis or hydraulic tests.
2. The uncertainty on the aperture calculation is high as it depends on how deep the mud has penetrated into the fracture. The thinner is the fracture the less precise is the aperture computation. For fracture around 1.0 mm, the uncertainty is approximately 50%.
3. The hydraulic aperture corresponds to the “size” of the fracture section relatively to a potential flow. But there is **no** way to know, from image analysis, whether or not a fluid is flowing through the fracture. In the oil industry, such an aperture is used to compare fracturation (aperture and density) between different wells. It is used to compute the maximum theoretical production for determining the average effectiveness of the fractures relatively to production tests.
4. The way a fracture is connected to others fracture **cannot** be inferred from image analysis. Testing fracture with dual packers is the best approach to answering this question.

FRACTURE POR CALCULATION



Curve	Well	Zone	Top	Bottom	Min	Max	Std Dev	Mean	Mode	P10	P50	P90
fr:POR2	Bakrman-1	Sarmord III.	1370 M	1590 M	0	0.4	0.054839	0.017934	0.012	0	0	0.05
fr:POR2	Bakrman-1	Chia Gara II.	1590 M	1725 M	0.1	0.25	0.10606	0.175		0.1	0.1	0.25
fr:POR2	Bakrman-1	Barsarin	1725 M	1869 M	0	0.8	0.094513	0.039486	0.012	0	0	0.1
fr:POR2	Bakrman-1	Sargelu	1869 M	1967 M	0	0.2	0.024877	0.0051478	0.012	0	0	0
fr:POR2	Bakrman-1	Sekhaniyan	1967 M	2146 M	0	0.45	0.072448	0.028252	0.012	0	0	0.1
fr:POR2	Bakrman-1	Butmah I.	2146 M	2714 M	0	0.3	0.042619	0.017998	0.012	0	0	0.05
fr:POR2	Bakrman-1	Baluti I.	2714 M	2760 M	0	0.1	0.020614	0.0065075	0.012	0	0	0.05
fr:POR2	Bakrman-1	Butmah II.	2760 M	3259 M	0	1.1	0.16874	0.090763	0.012	0	0	0.3
fr:POR2	Bakrman-1	Baluti II.	3259 M	3750 M	0	0.5	0.032138	0.0054978	0.012	0	0	0
fr:POR2	Bakrman-1	Kurra Chine A	3810 M	3890 M	0	0.2	0.030282	0.011922	0.012	0	0	0.05
fr:POR2	Bakrman-1	Kurra Chine B	3890 M	4100 M	0	0.3	0.032409	0.0085673	0.012	0	0	0
All Zones					0	1.1	0.092047	0.03017	0.012	0	0	0.1