Fracture Characterization of Najmah-Sargelu Tight Carbonates Reservoir using Geomechanical Attributes in Minagish Field, West Kuwait*

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[2]Paradigm (Emerson)

Abstract

The Minagish field is located in the Southern part of Kuwait with a complex structure that includes two culminations separated by gentle synclinal low. The Eastern flank is N-S trending while the Western flank is WNW-ESE trending structure. The area is divided into two compartments (northern and southern) by a major E-W trending transverse fault. Najmah Formation has been informally subdivided into three main members Upper, Middle, and Lower, while Sargelu is divided into two sub-units. These formations constitute tight organic rich carbonate rocks mainly limestones interbedded with thin shaly units. Majority of oil production is from Upper Sargelu reservoir & tight Upper Najmah limestone reservoir

It is commonly admitted that fracture can have a drastic impact on fluid flow within fractured reservoir. In the case of Minagish Najmah/Sargelu tight carbonates, the porosity and permeability of the reservoir in mainly provided by fractures. Among different challenges encountered in fractured reservoirs, the spatial repartition of the fracture network is a key parameter to assess. This paper demonstrates the added value of combining structural and geomechanical attributes in assessing the spatial repartition of tectonic fractures within the full Najmah/Sargelu reservoir volume by integrating 1) the stratigraphic column, 2) the fault throws and 3) the UVT transform. The UVT transform technology gives access to the total strain tensor in each cell of the geologic grid which results from all the deformations affecting the field and that is the key information in view of tectonic fracture characterization.

Ultimately, after building the structural model and fracture facies, the geologic grid is being simulated. From the strain-based model and the geomechanical parameters defined for each facies, a geomechanical attribute, the fracture probability has been computed. The fracture probability takes into account the intensity of the deformation to assess the zone where probability of occurrence of tectonic fractures is higher.

References Cited

Fonta, O., H. Al-Ajmi, N.K. Verma, S. Matar, V. Divry, and H. Al-Qallaf, 2005, The fracture characterization and modeling of a tight carbonate reservoir: the Najmah Sargelu of West Kuwait, SPE 93557.

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شركة نفط الكويت
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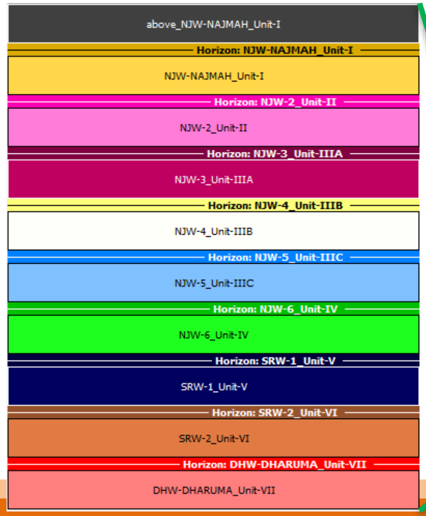
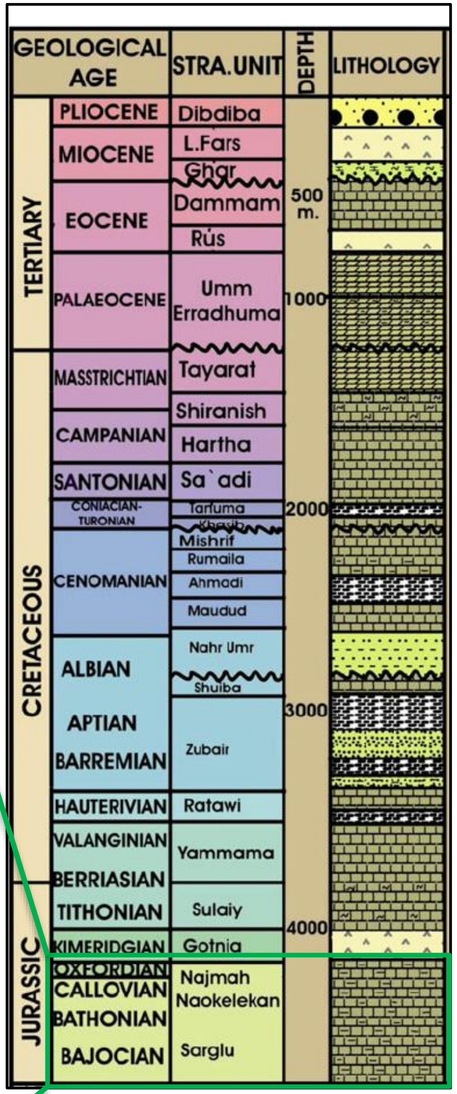
Minagish Field – Najmah-Sargelu Units

1. Jurassic carbonates reservoir (Oxfordian to Bajocian)
2. Tight Matrix Reservoir – Fluid Flow is dominated by Fractures. Z-type fractures (tectonic) have the main impact on flow [1]
3. Main stages of deformations at the scale of Kuwait are
   - Post Triassic rifting
   - Alpine 1 : Late Cretaceous transtension
   - **Alpine 2: Mid-Tertiary compression**

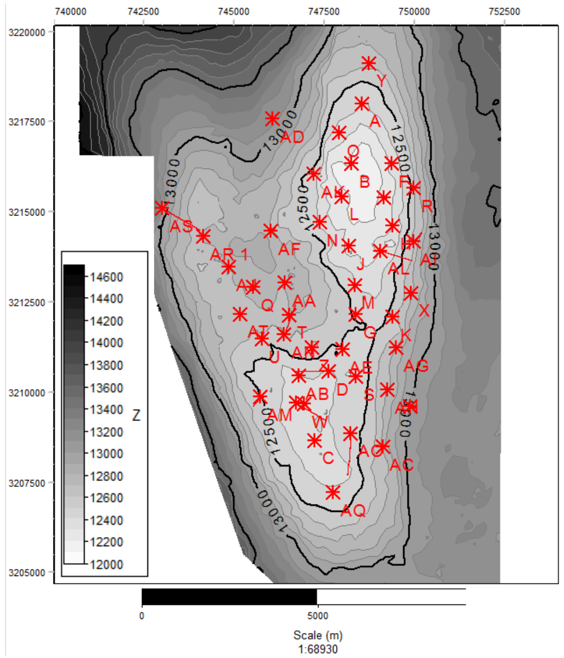
⇒ Formation of pre-Gotnia structures and tectonic fractures development [2]

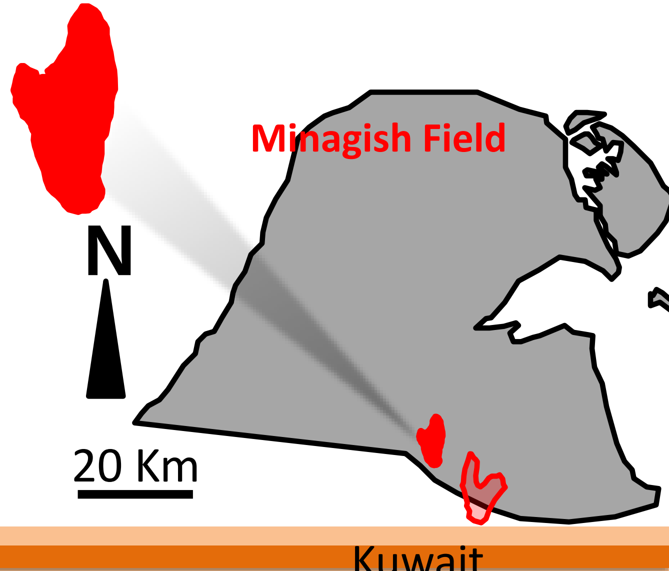
4. **Z-type Fractures are tectonically induced and related to the local deformation of the field**





Stratigraphic Column of Kuwait

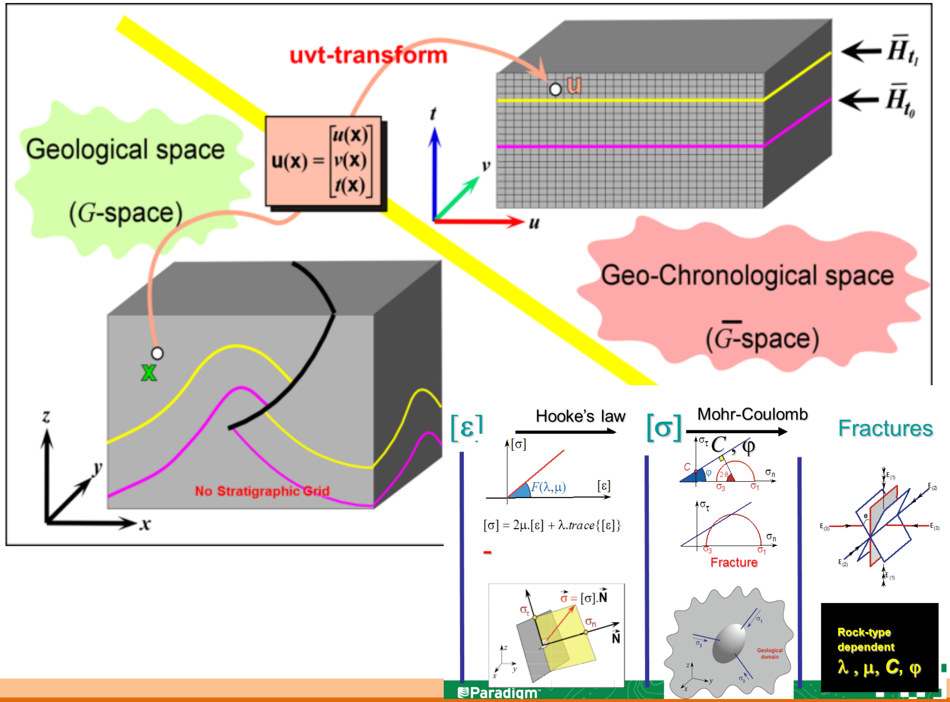




Objectives & Methodology

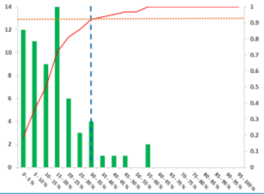
Objectives:

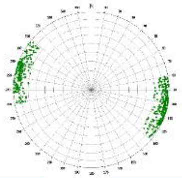
1. **Assess the spatial distribution of Natural Tectonic Fractures driving the fluid flow**
2. **Predictive model must be successfully calibrated to Well Data (Blind Tests)**

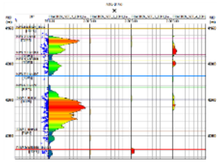


Well Data Analysis

- Identification of Tectonic Fractures Development Drivers based on Core Fracture Data
- BHI Tectonic Fractures Filtering
- Stereographic Analysis
- Fractures Statistics and P 32 logs computation
- Dual (Matrix & Fractures) Reservoir Behaviour Investigation

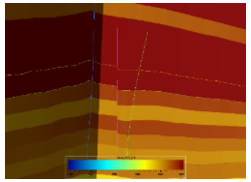


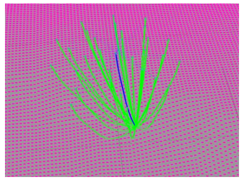




Geophysical Interpretation & Velocity Modelling

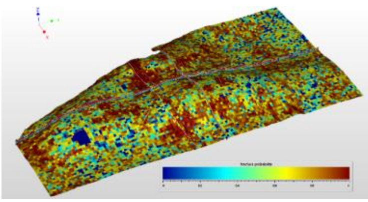
- Seismic Interpretation of main reflectors (Time Domain)
- Well to Seismic Tie
- Geologically Constrained Velocity Modelling
- Velocity Model update with Well-Tie-Tomography
- Time to Depth Conversion





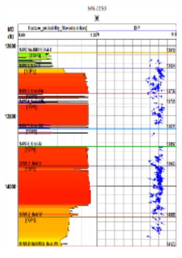
Geo-Modelling and Fractures Distribution Assessment

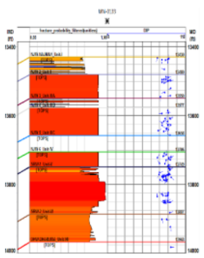
- High Resolution Volumetric Structural Modelling
- Geostatistical Fracture Rocktypes Interpolation
- Computation of Fracture Geomechanical Attributes

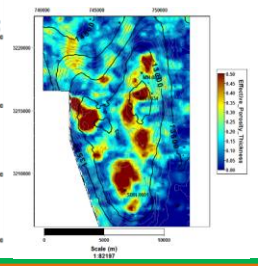


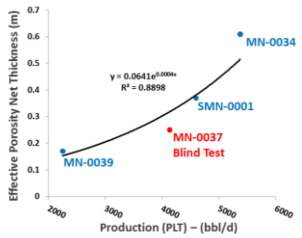
Model Validation

- Model against Well Data









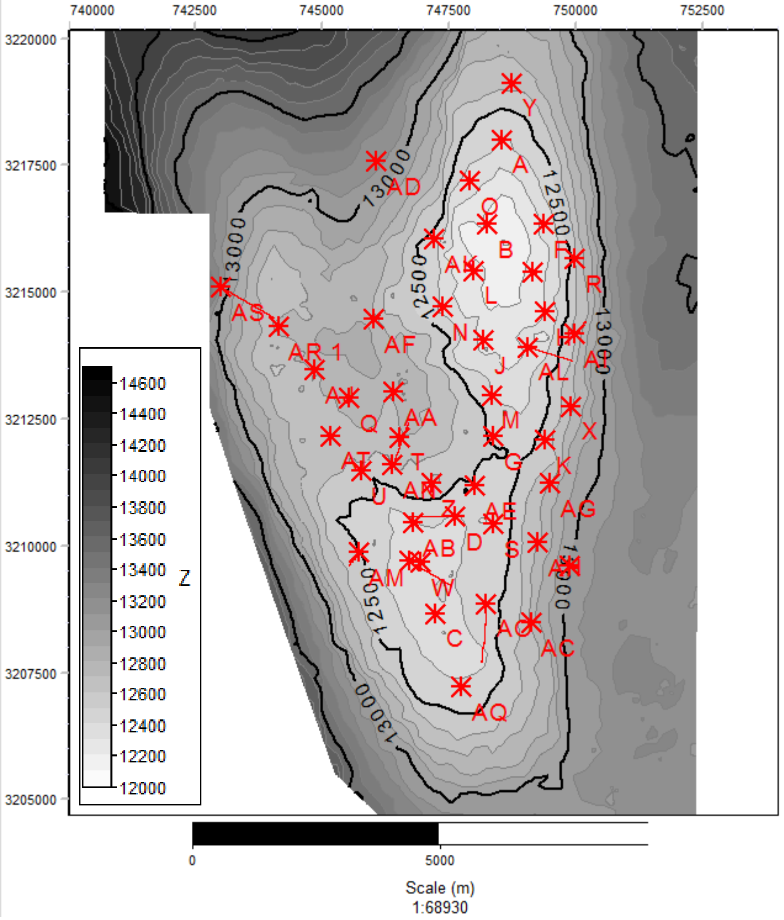
Data Presentation

Seismic Data & Interpretations		
Property	**Area**	
Seismic Amplitude	**276 km2**	√
Seismic RMS Velocities	**276 km2**	√

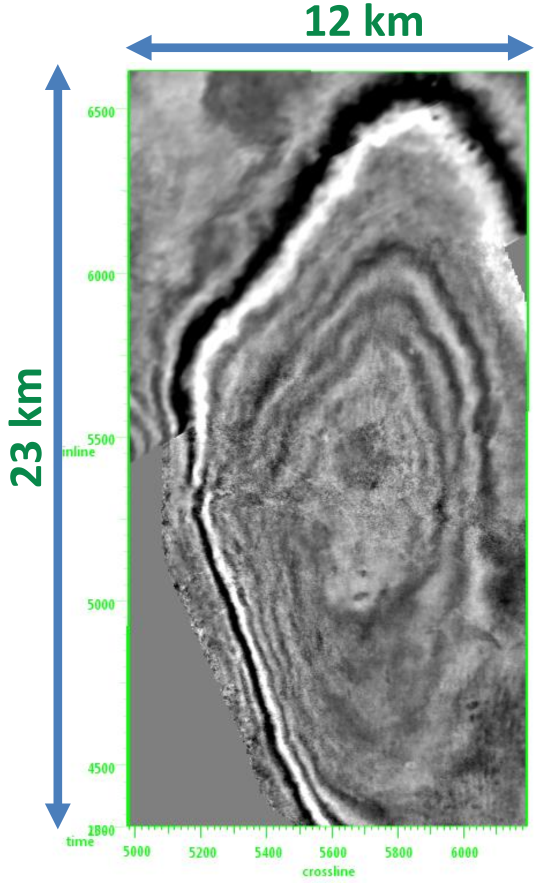
No post-stack seismic fracture attribute available or computed in this study !!

Well Data: Overview		
Wells	**Number**	
Shallow Wells	**25**	√
Jurassic Wells	**21**	√

Well Data: Jurassic Wells		
Processed Logs	**Number**	
VShale	**17**	√
Effective Porosity	**18**	√
Fracture BHI Interpretation	**8**	√
Fracture Cores Interpretations	**5**	√
PLT	**4**	√
VSP/ Checkshots	**3**	√



Wells and Structural Map (Top Najmah)



Seismic Amplitude Time Slice

Natural Fractures Interpretation at the Well Scale

Z Tectonic Fractures Interpretation on cores used as a reference

- Investigation of VShale impact on Tectonic Fractures development
- Vshale Cut-Off determination: Tectonic/ Non Tectonic

↓

- BHI Fractures Interpretation filtering based on Vshale:

  If VShale < 30% → Tectonic, If Vshale > 30 % non Tectonic
- Filtering based on Dip

  If Dip > 70˚ → Tectonic, If Dip < 70˚ non Tectonic

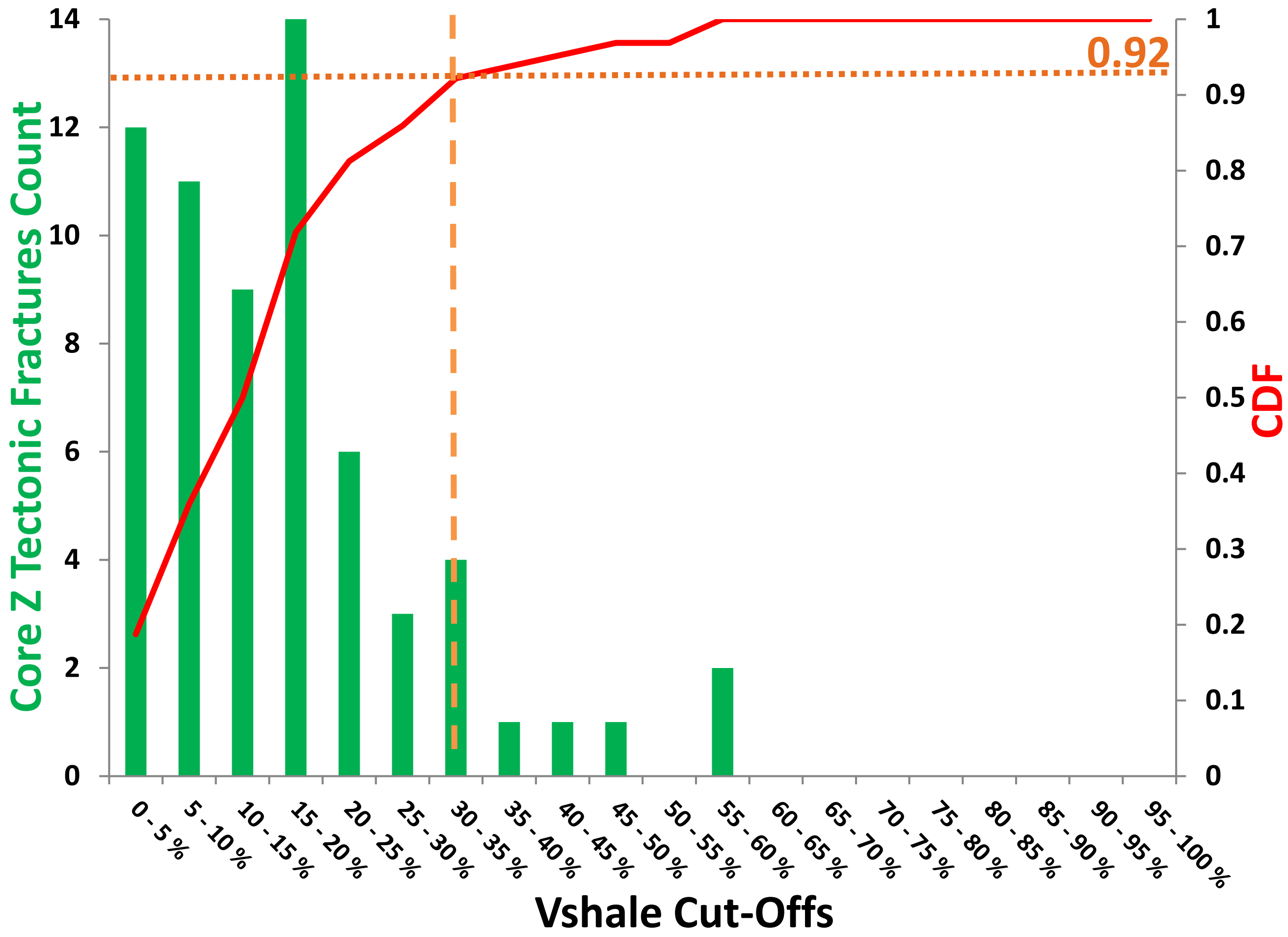
↓

- BHI Tectonic Fractures vs VShale Analysis
- Fracture Rocktypes Determination

Fracture Interpretation

- Natural Fractures are discriminated between XY (diagenetic) and Z (Tectonic) types
- Tectonic Fractures are clearly identified on cores ([1]). Most of Tectonic Fractures are sub-vertical
- Z Tectonic Fractures identified on cores are used as a reference
- Clear influence of Vshale on Z Tectonic Fractures development: 92 % of Z Fractures are in zones of Vshale is less than 30 – 35 %.

Z-Type – Tectonic Fractures (Core Data)



Number of samples: 60

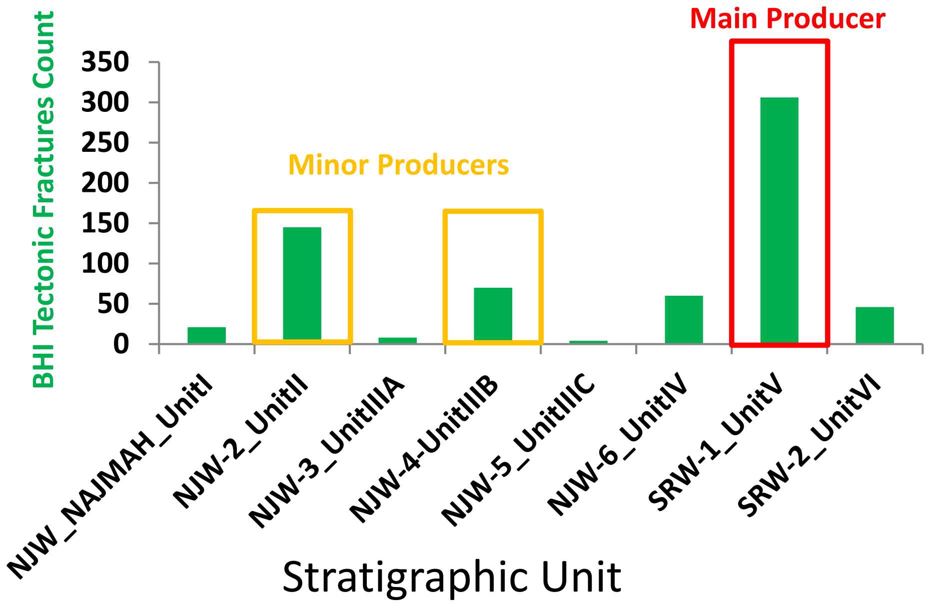
Fracture Rocktyping

BHI Fractures Filtering

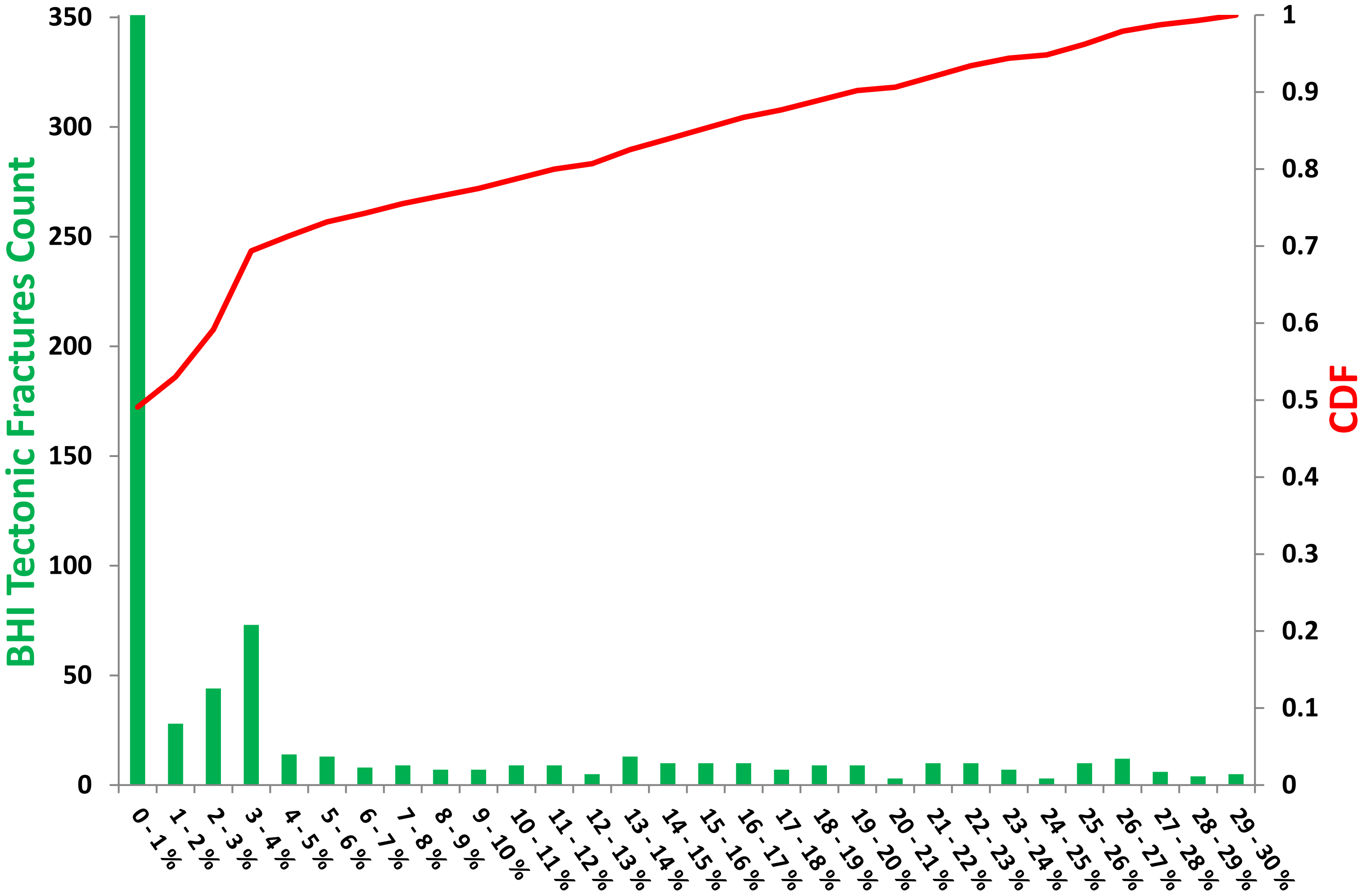
- BHI Fractures Interpretation filtering based on Vshale & Dip:

If VShale < 35% → Tectonic, If Vshale > 35 % non Tectonic
If Dip > 70˚ → Tectonic, If Dip < 70˚ non Tectonic

BHI Tectonic Fracture Statistics



Fractures Interpreted on BHI



Number of samples: 660

Fracture Rocktyping

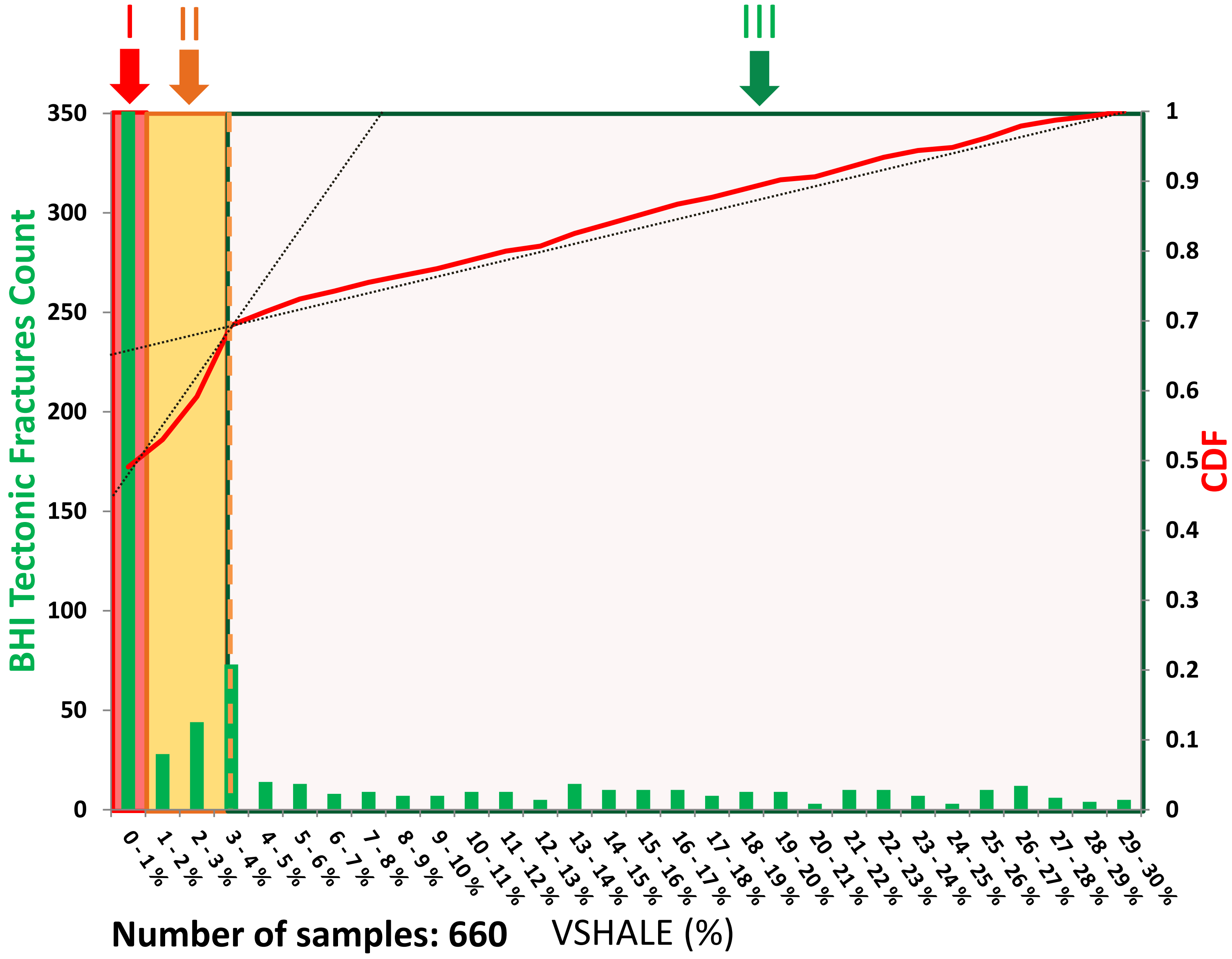
I: 0<VSH<1%

II: 1<VSH<3.5%

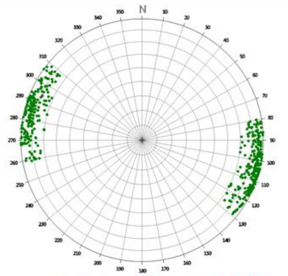
III: 3.5<VSH<30%

IV: (Not Fractured) VSH>30%

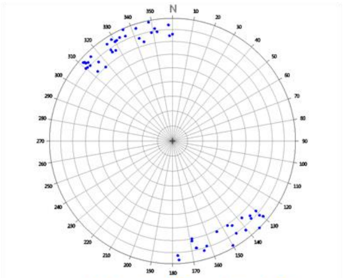
BHI Tectonic Fractures



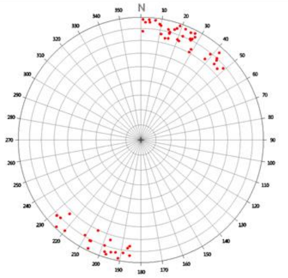
Fracture Stereographic Analysis & Fracture Density Computation (BHI)



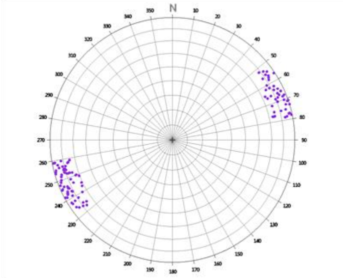
Mean Dip-Az: 284
Mean Dip: 90
Fisher: 34



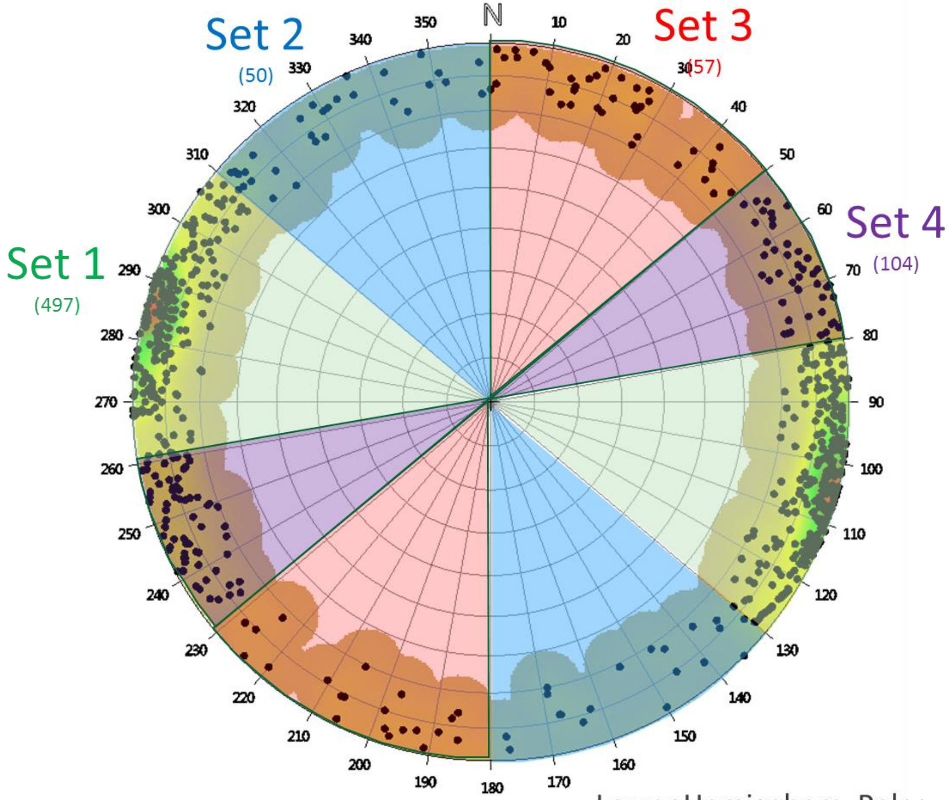
Mean Dip-Az: 151
Mean Dip: 89
Fisher: 18



Mean Dip-Az: 203
Mean Dip: 87
Fisher: 23

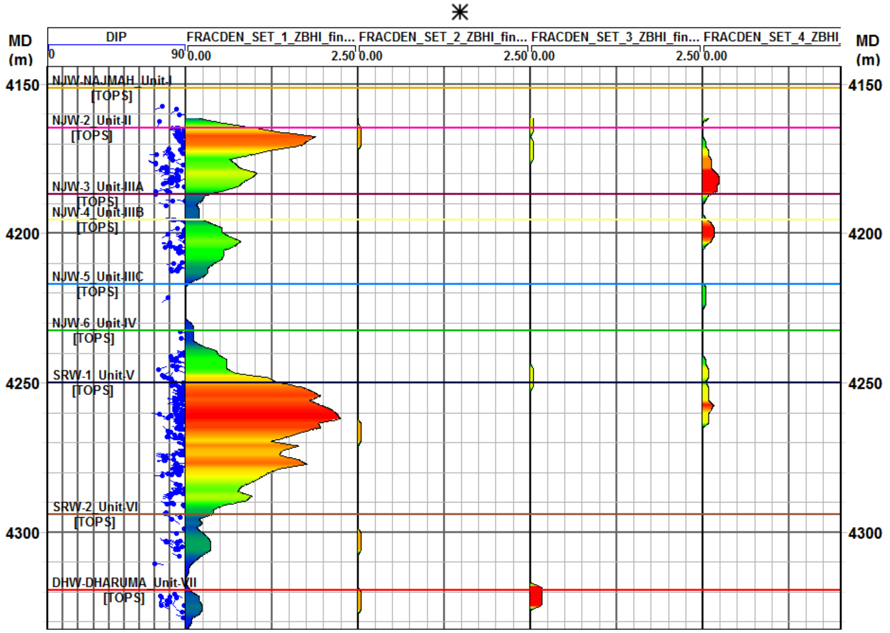


Mean Dip-Az: 68
Mean Dip: 87
Fisher: 44



Lower Hemisphere, Poles

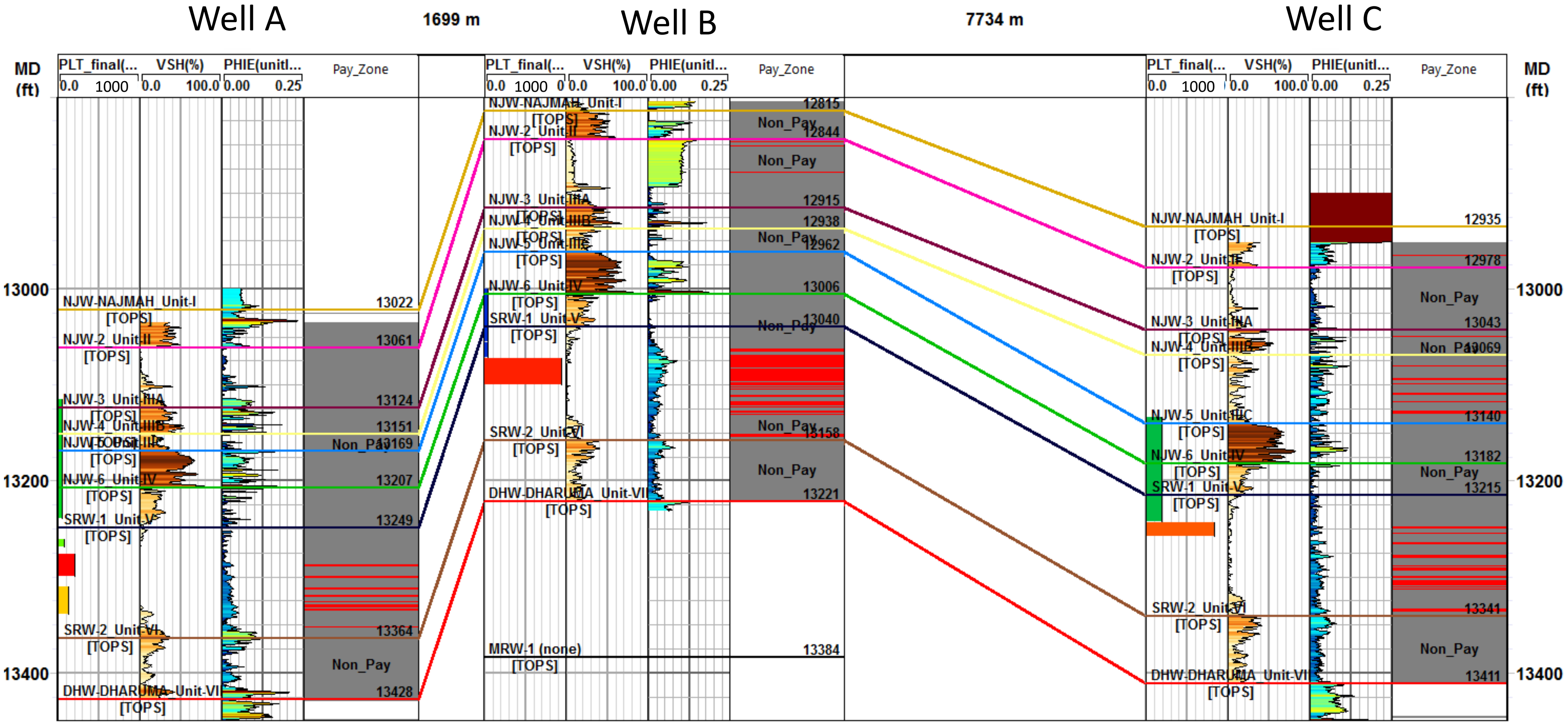
Well D



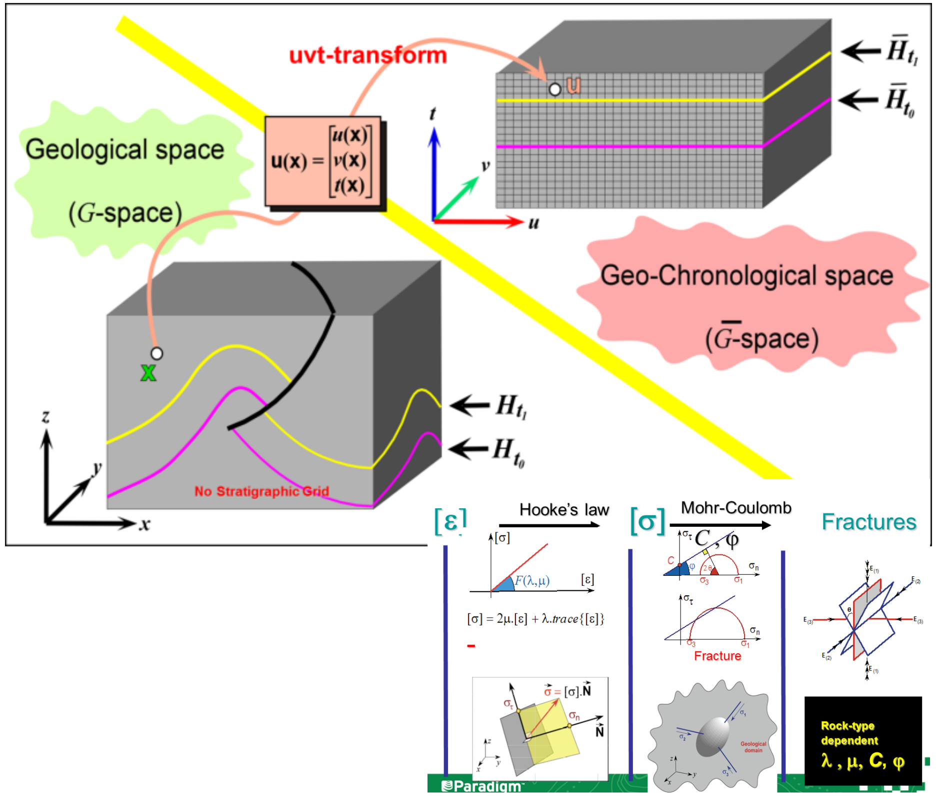
Fracture Density (P 32 – 1/m) :
Window Length: 25 ft
Window Step: 5 ft

Dual Contribution Conceptual Model Investigation

- Most of the fluids production is coming from SRW-1_Unit-5
- High productive zones are found to be located in low VSH (< 3.5%) and slightly higher matrix porosity (PHIE > 3%)
- Reasonable to consider a dual contribution to flow: matrix porosity and fracture permeability



Velocity Modelling Workflow



- Structural Model is used to compute the intensity of deformation in the reservoir
- Deformation Tensor is coupled to Geomechanics to assess the probability of fracturing

QC Input Seismic and Well Data

↓

Well to seismic Calibration

↓

Seismic velocities: Transform Seismic RMS to Interval Velocities using CVI | **Well velocities: Well log editions (filtering, smoothing,…)**

↓

Create Structural Framework respecting the structure and the stratigraphy

↓

Create a calibrated velocity volume geologically constrained using geostatistics

↓

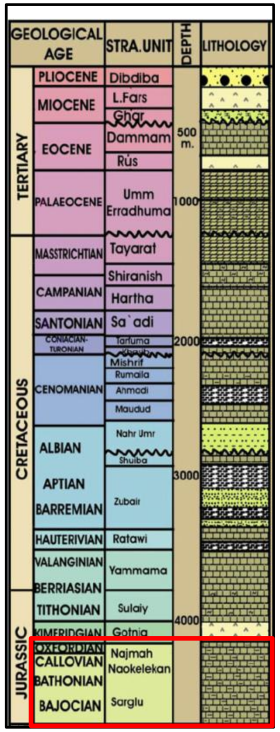
Scale data to depth

↓

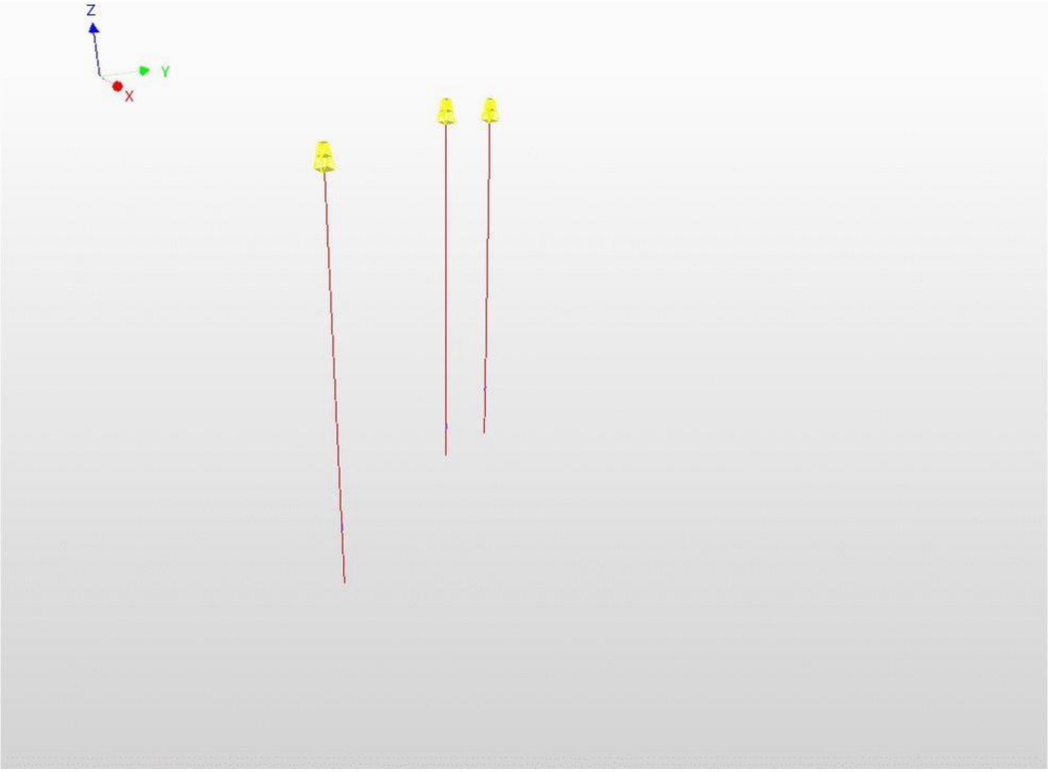
Calibration using Well Tie Tomography

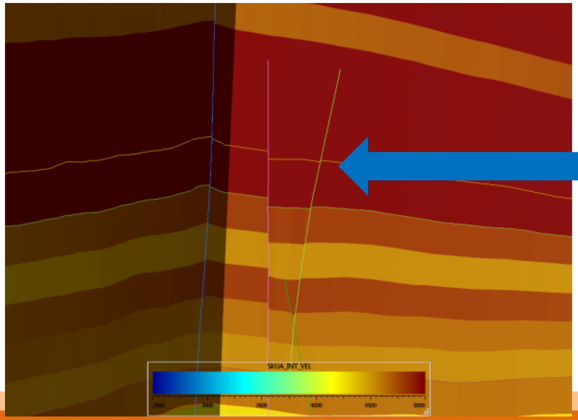
Geologically Constrained Velocity Model (Time Domain)

- Seismic Interpretation QC & Well-to-Seismic Tie
- Volumetric Structural Modelling
- Geological Grid Building
- Transfer of Seismic Interval Velocity to SKUA Grid
- Computation & Interpolation of Correction Factor between Wells and Seismic Interval Velocities
- Final Interval Velocity Computation



Surface to Najmah - Sargelu

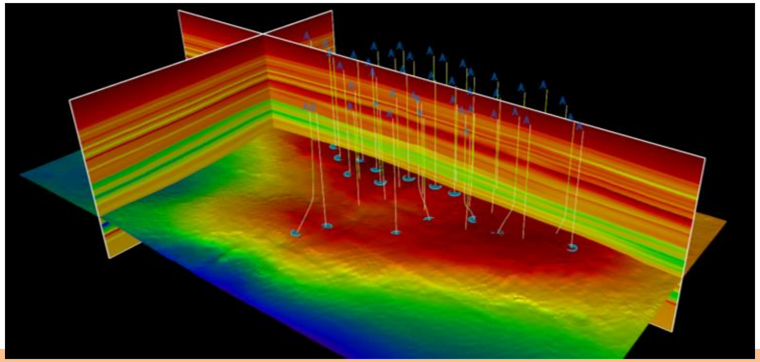




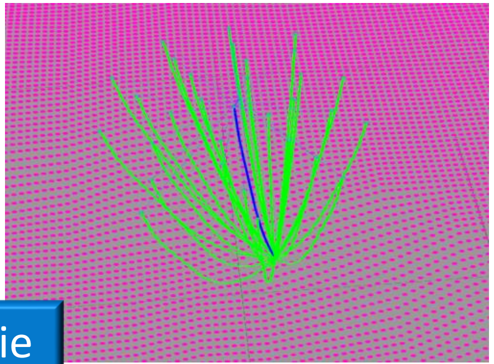
Faults Integrated in the Velocity Model

Well Tie Tomography

Initial Interval Velocity
↓
Scale Horizons to Depth with Initial Velocity
↓
Calibrate Grids to Wells
↓
Generate Mis-tie Maps → Mis-tie
↓
Run Well Tie Tomography → (back to Calibrate Grids to Wells)
↓
Scale Data to Depth with Updated Interval Velocity



Welltie Tomography is a full tomographic inversion procedure that updates the medium to rescale depth maps according to misties while keeping loyal to travel-times along the traced rays.



Ray fans are shot from structure maps and are traced up to the surface in order to update the velocity model.

Let us distinguish between:

- **Normal incident ray**
- **All other shot rays**

Normal incident ray:

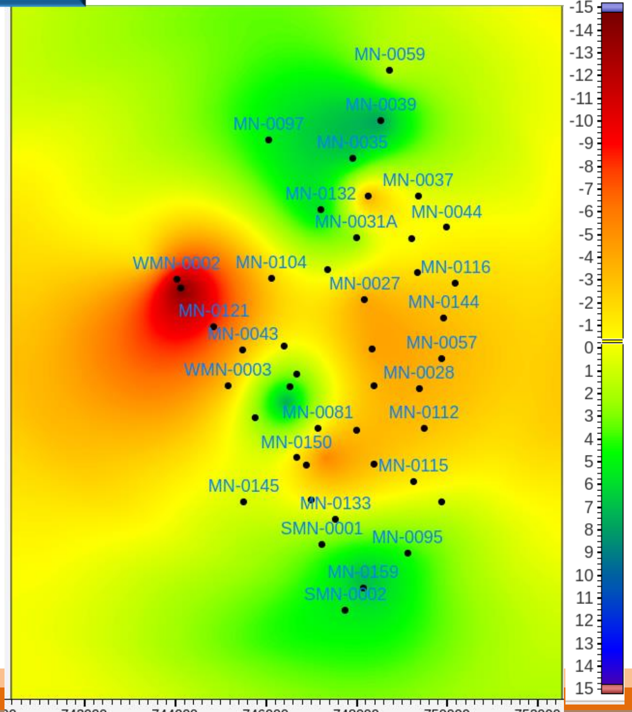
$$0 = A_v\overrightarrow{\Delta v} + p_z\Delta z$$

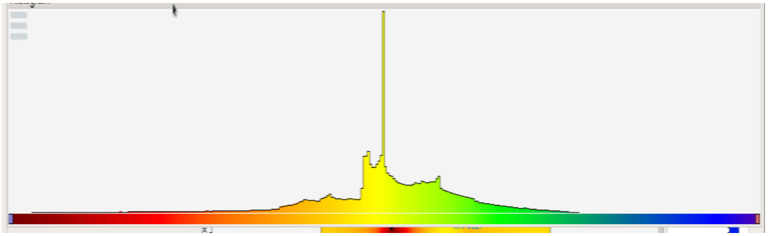
Mistie

Rest of shot rays:

$$0 = A_v\overrightarrow{\Delta v} + A_\delta\overrightarrow{\Delta\delta} + p_z\Delta z$$

From normal incident ray equation





All misties are under 8 feet's except only 2 wells which have misties of ~-12 feet's

High Resolution Geomodel Building in Depth Domain

Fault Framework Building

↓

Stratigraphic Horizons Modelling

↓

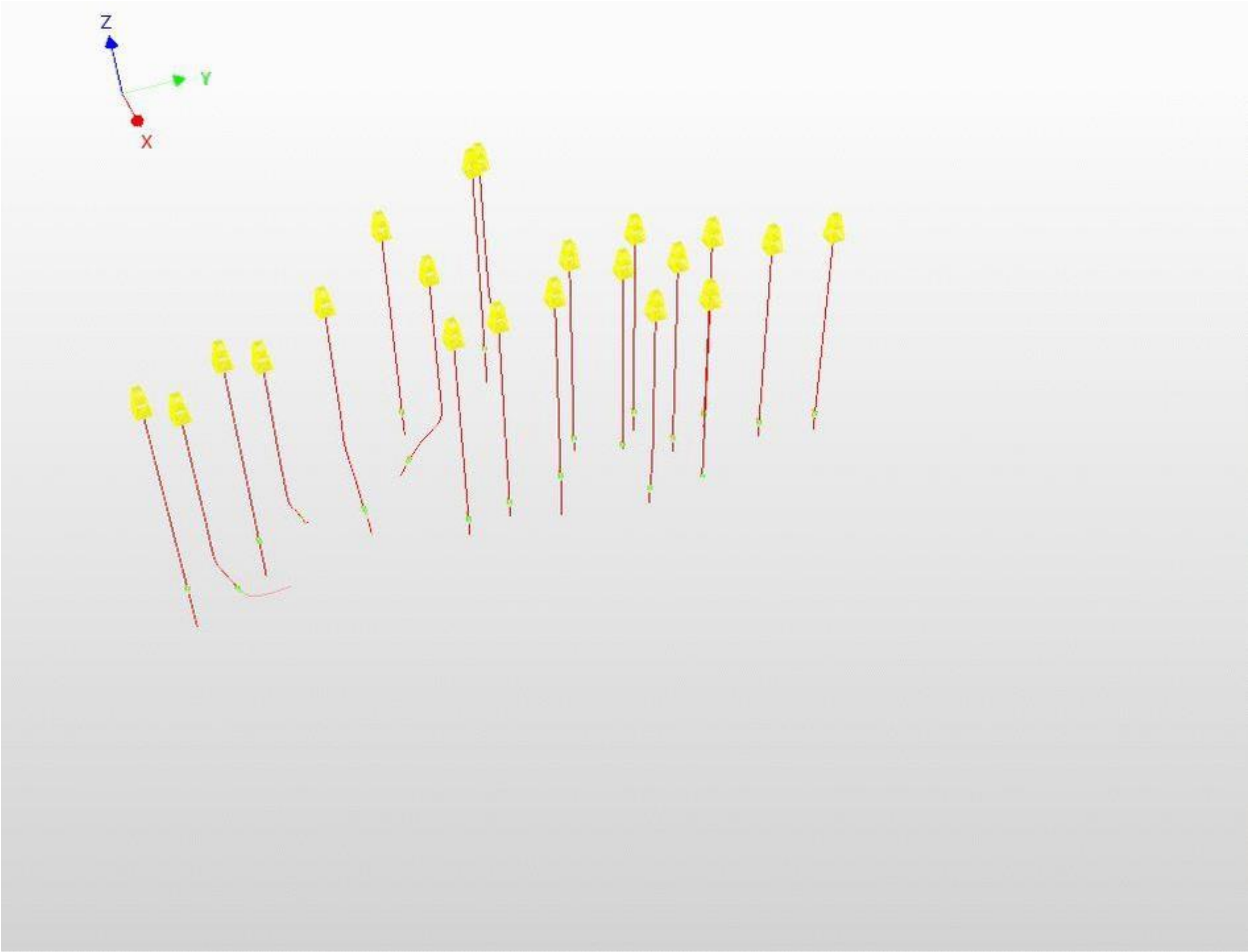
SKUA Geological Grid Building

High Resolution SKUA model: 50m * 50 m

Perfect mismatch between well tops and horizons:

Well marker error summary (unit: m)

	NAJMAH_	JW-2_Unit	W-3_Unit-I	W-4_Unit-I	W-5_Unit-I	IW-6_Unit-	RW-1_Unit	W-2_Unit-	HARUMA_
Minimum	0	0	0	0	0	0	0	0	0
Average	0	0	0	0	0	0	0	0	0
Maximum	0	0	0	0	0	0	0	0	0



Property Modelling in Depth Domain

Matrix Porosity Interpolation

25 Realizations

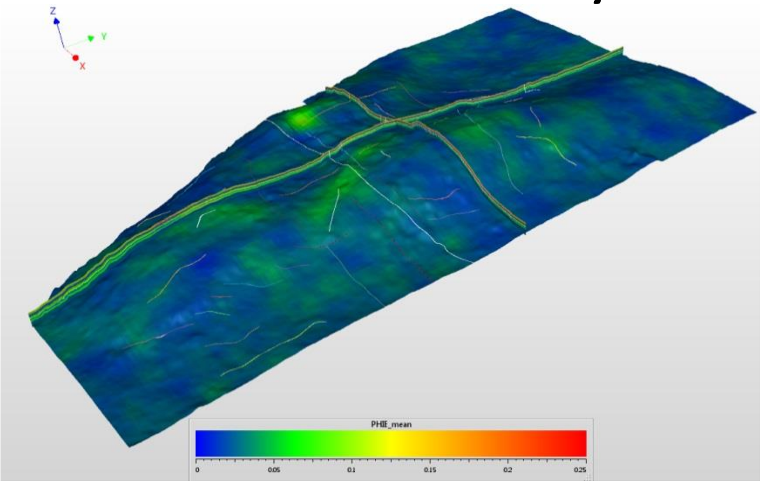
- SGS per stratigraphic horizon
- Blocking method: nearest to cell center
- Histograms per stratigraphic horizons
- Gaussian Variograms

VSHALE Interpolation – Fracture Rocktypes Computation

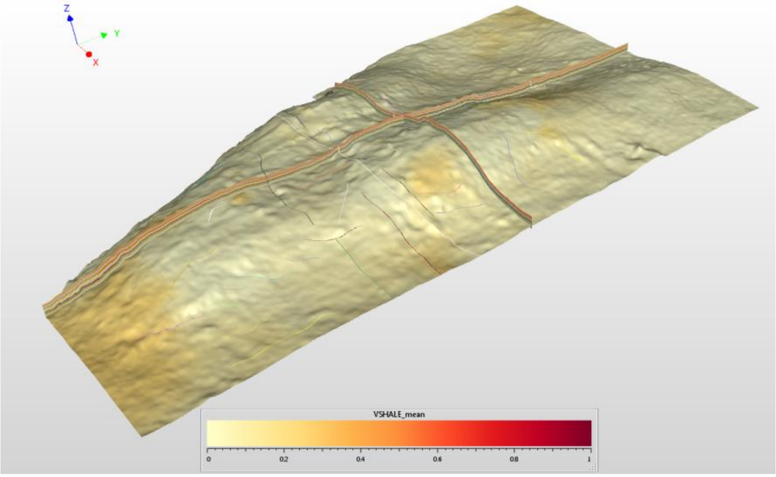
25 Realizations

- SGS per stratigraphic horizon
- Blocking method: nearest to cell center
- Gaussian Variograms
- Spatial VTC used as secondary trend
- Fracture Rocktypes: cut-offs on VSHALE

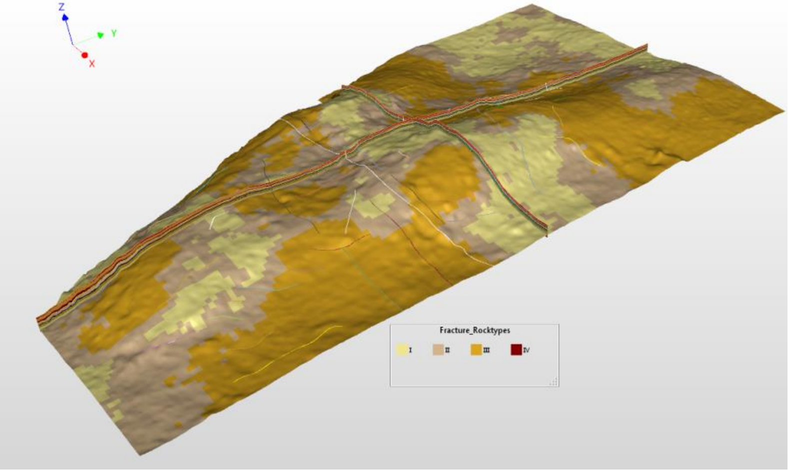
Matrix Porosity



VHSALE



Fracture Rocktypes

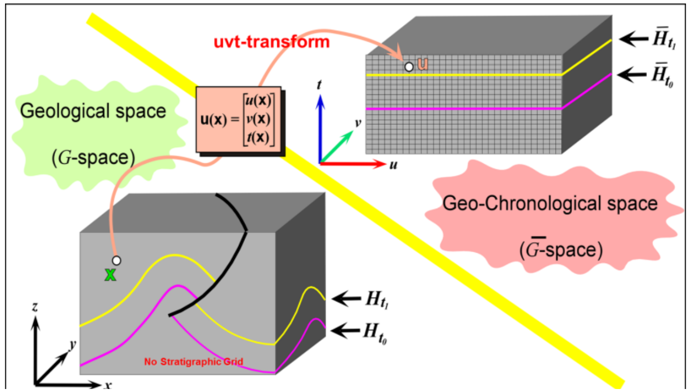


Matrix Permeability Computation

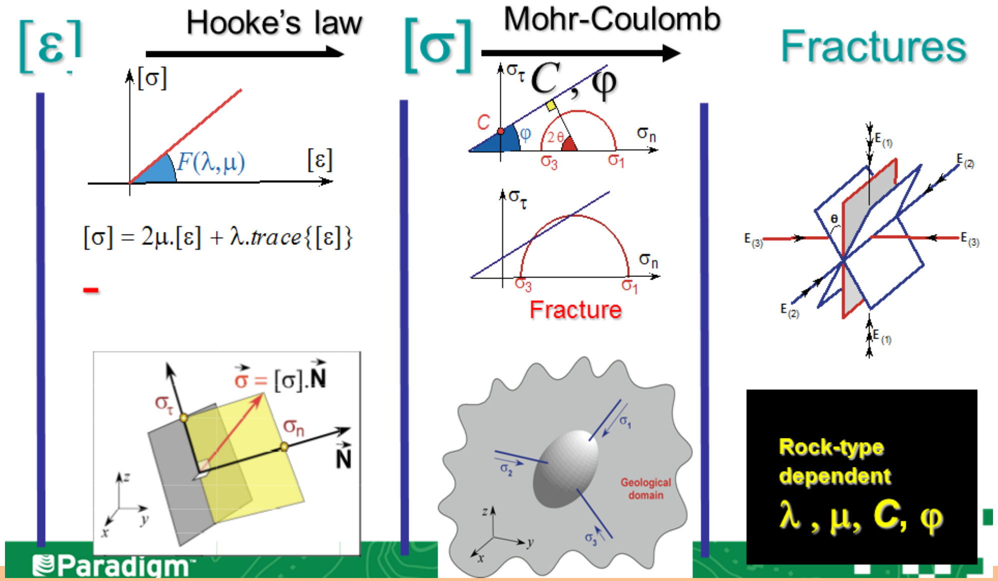
- Script on matrix porosity

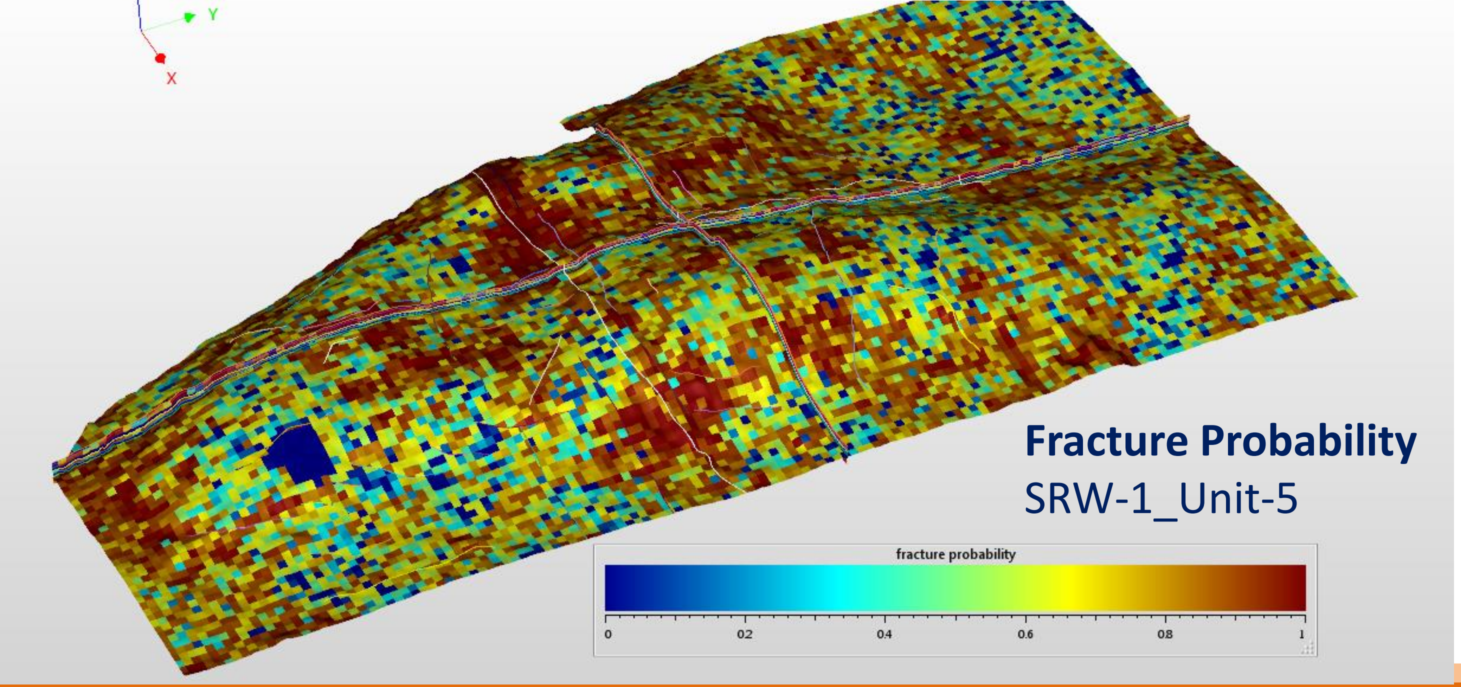
Tectonic Fractures Characterization

- **Deformation (Strain Tensor) derived from volumetric structural model**
- **Geomechanical coefficients allocated to each Fracture Rocktypes class**



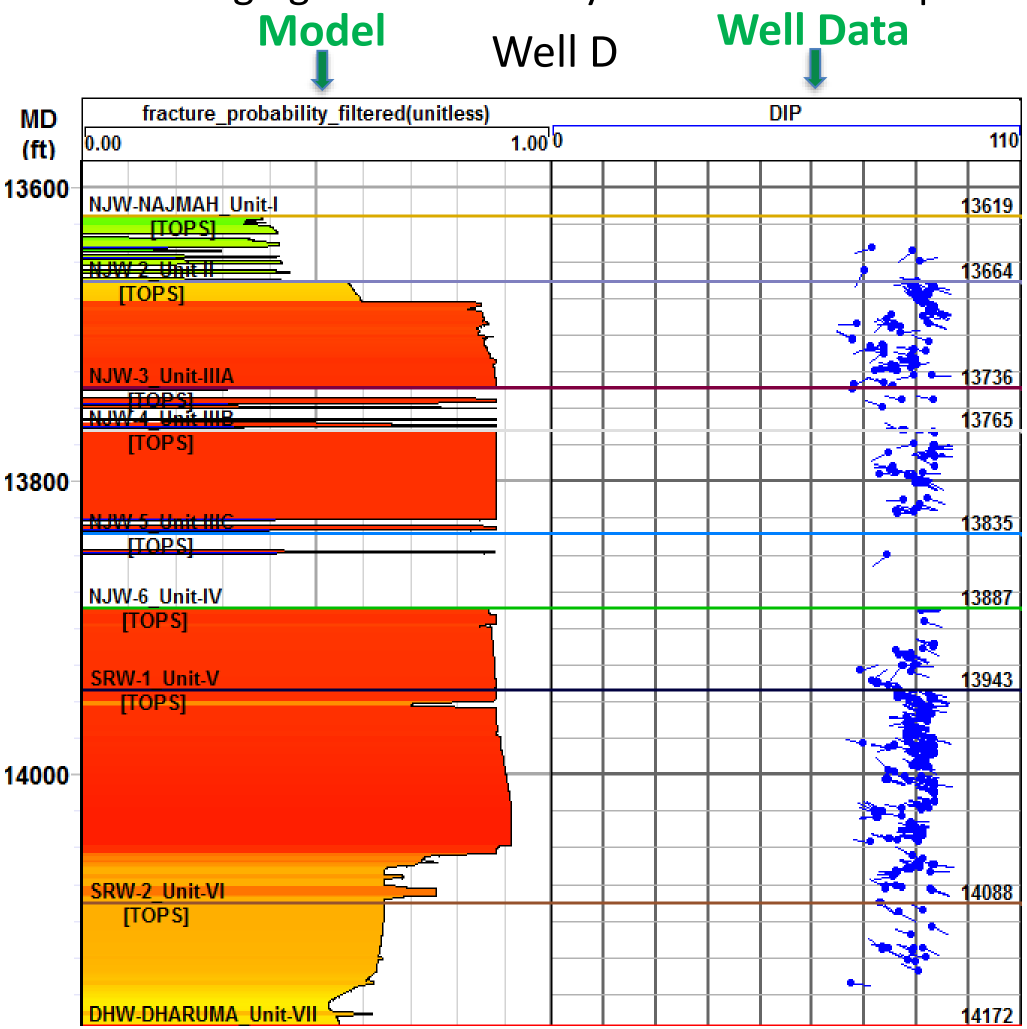
Class No	Class Name	Class Description	Pattern	Color	Mohr-Coulomb cohesion range (C) (GPa)	Mohr-Coulomb friction angle (phi) (deg)	Poisson ratio range	Young modulus range (GPa)
1	I		none		0.05 0.1	22 34	0.1 0.3	5 70
2	II		none		0.1 0.2	22 34	0.1 0.3	5 70
3	III		none		0.25 0.35	22 34	0.1 0.3	5 70
4	IV		none		100 150	22 34	0.1 0.3	5 70

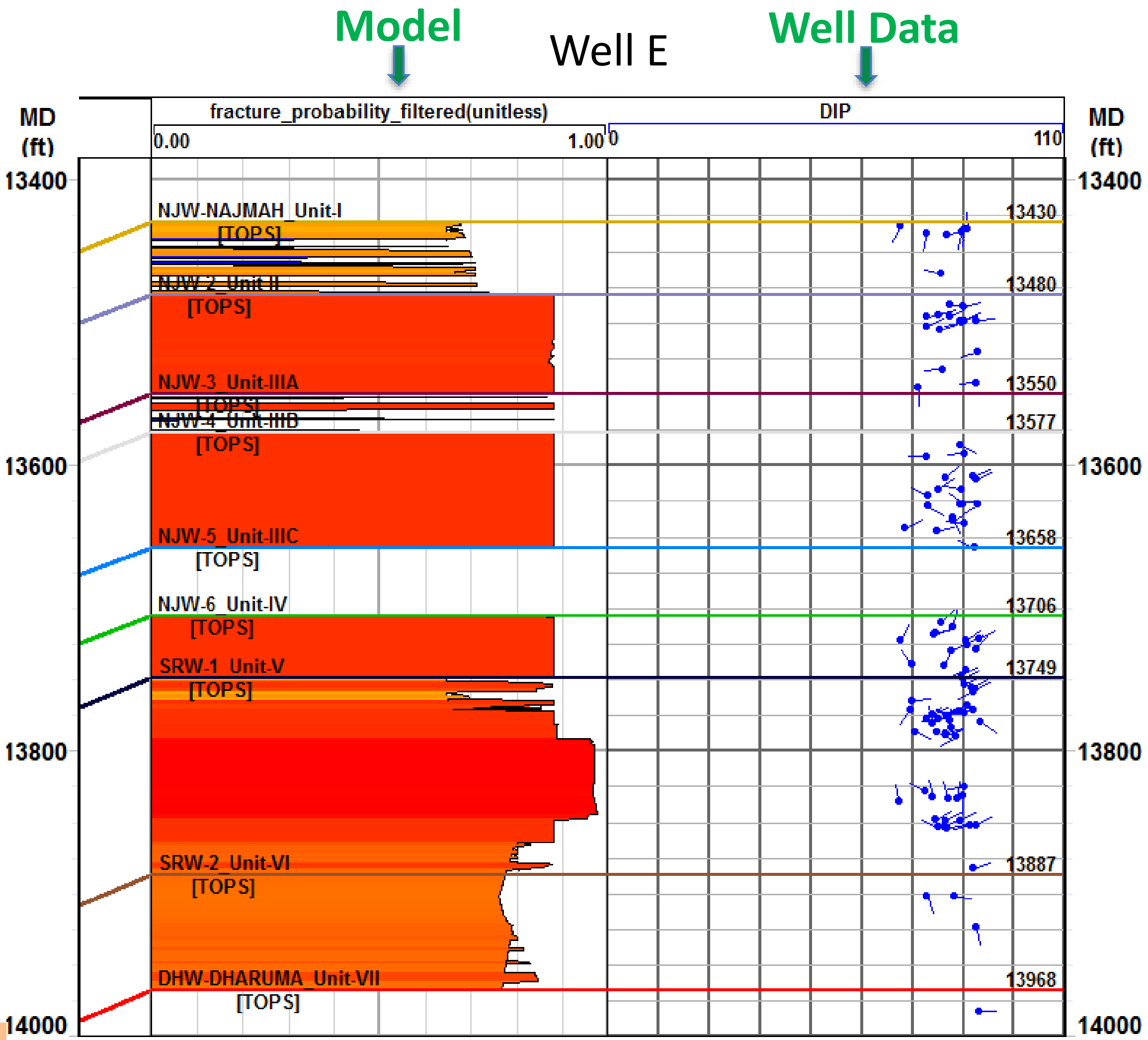




Tectonic Fractures Characterization

- Filtered BHI Fracture Data are used for Fracture Probability model validation
- Acknowledging the uncertainty around BHI Interpretation, overall tectonic fractures trend is preserved in the model





Dual Contribution Model Validation

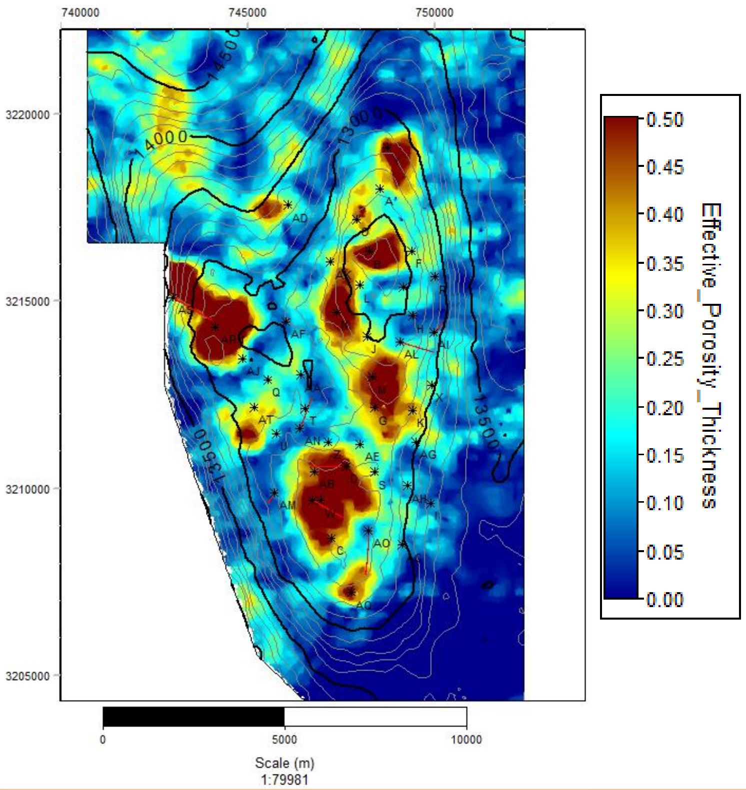
Computation of Pay Zone

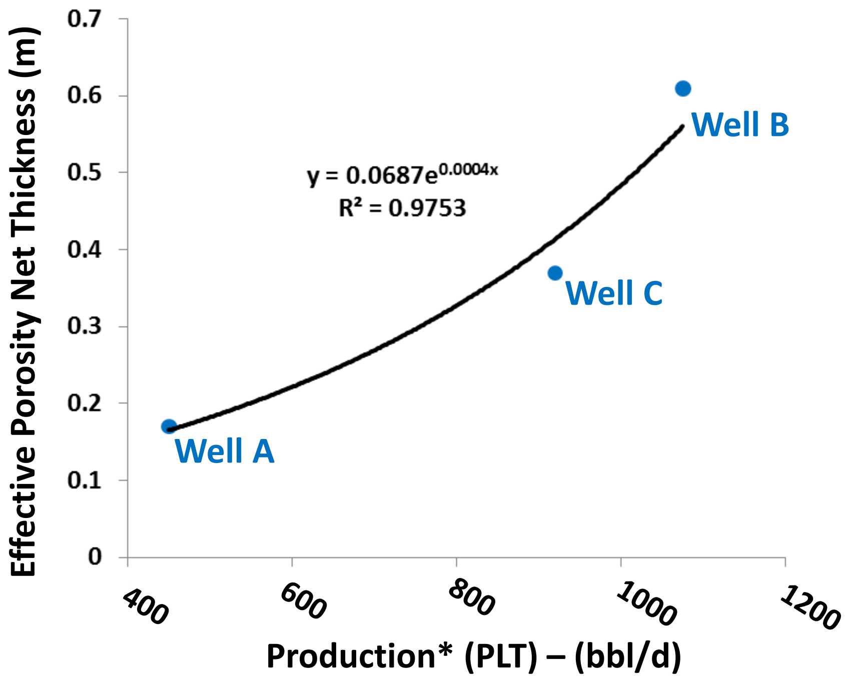
If PHIE > 3% & VSHALE < 3.5 %, PAY_ZONE = 1 | else PAY_ZONE = 0

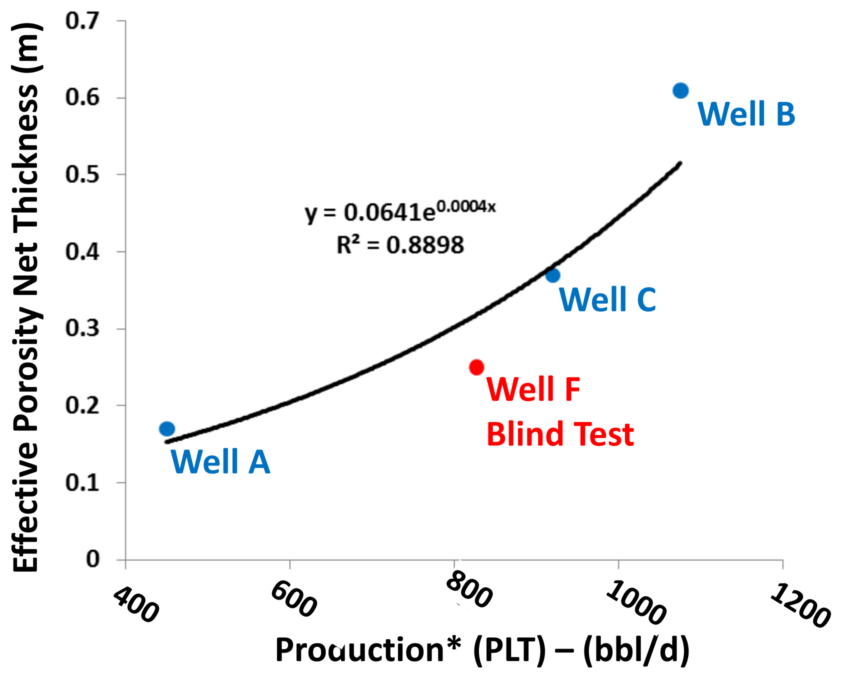
Filtering based on SKUA Fracture Probability

If Fracture Probability = 0, PAY_ZONE = 0

Computation of Effective Porosity (matrix) thickness filtered by Fracture Probability







*Normalized Data

Dual Porosity/ Dual Permeability Model Creation

Interpolation of Fracture Densities – P 32 (Per Fracture Set)

Fracture Probability used as secondary trend

Definition of Fracture Parameters

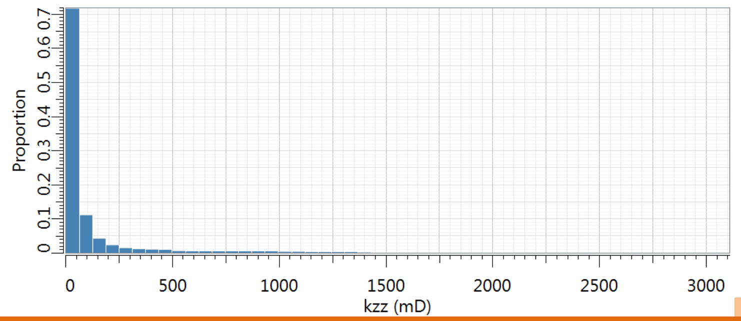
Fractures Orientation: Dip-AZ, Dip
Fractures Dispersion: K-Fisher
Fracture Length & Aspect Ratio
Fracture Aperture

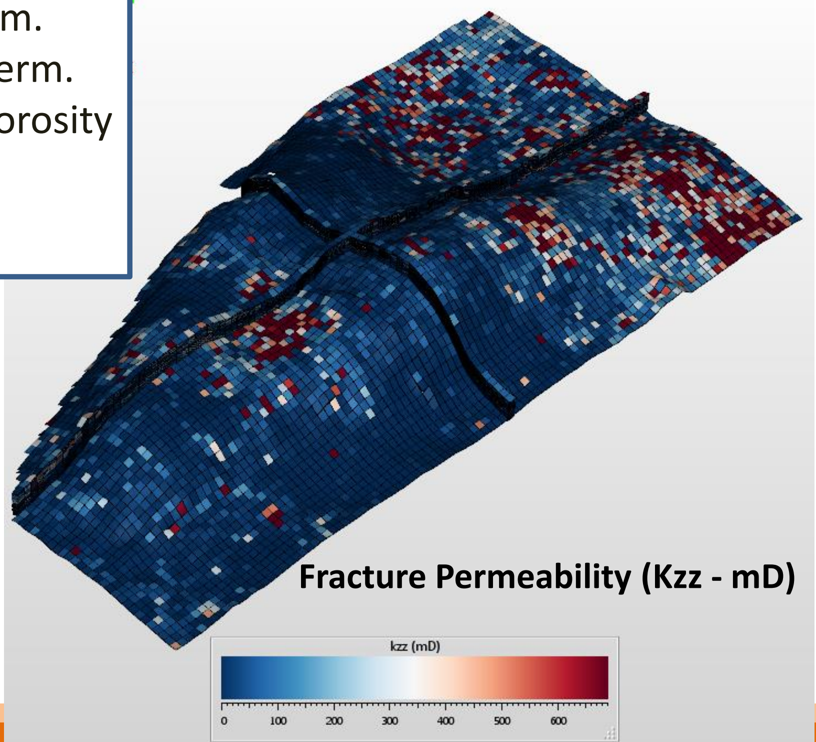
Computation of Fracture Properties: Porosity & Permeability

Matrix Porosity & Permeability (already created)

DFN

- Matrix Porosity
- Matrix Perm.
- Fracture Perm.
- Fracture Porosity





Fracture Permeability (Kzz - mD)

Conclusions

- Natural Tectonic Fracture Distribution within Minagish Jurassic carbonates reservoir has been assessed coupling a mathematical paleo-geochronological transformation and geomechanics.
- In order to ensure the validity of the volumetric structural model, reference for deformation intensity computation, seismic interpretations QC and advanced velocity modelling has been performed
- Dual behavior of the reservoir (matrix and fractures) has been demonstrated
- Final predictive model has been successfully calibrated against well data

Thank You

References

[1]. Fonta, O., Al-Ajmi, H., Verma, N. K., Matar, S., Divry, V., and Al-Qallaf, H. 2005. The fracture characterization and modeling of a tight carbonate reservoir: the Najmah Sargelu of West Kuwait, **SPE** 93557..

[2]. Richard, P., Bazalguette, L., Kidambi, V. K., Laiq, K., Odreman, A., Al Qadeeri, B., Narhari, R., Pattnaik, C., Al Ateeqi, K. 2014. Structural Evolution Model for the North Kuwait Carbonate Fields and its Implication for Fracture Characterisation and Modelling. Presented at the International Petroleum Technology Conference, Doha, 20 – 22 January.