# Fracture Characterization and Sweet Spot Mapping in Naturally Fractured Tight Carbonate Reservoir, Opening a New Play in Lower Indus Basin, Pakistan*

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## Abstract

Chiltan Limestone of Jurassic age is widely developed in the Lower Indus Basin of Pakistan. The formation was deposited in a shelf-lagoon setting with wackestone-packstone as the dominant microfacies. Calcite cementation and intense compaction drastically reduced the matrix porosity (avg. 1.5%) and permeability (<0.01 mD) making the formation a tight reservoir in the study area. Natural fractures play an important role in hydrocarbon production from such tight carbonate reservoir, hence, knowledge of the exact positions of fractures is critical for precise placement of wells for better production.

In order to characterize and map the natural fractures, core and image logs along with 3D seismic data were used. Natural fractures were detected and studied on image logs at a fine scale, which revealed that these fractures exist in clusters, often called Fracture Corridors (FC). These FCs are mostly associated with minor faults, not visible on seismic data due to their subtle nature. However, by using seismic attributes such as variance, dip deviation and ant-tracking, these can be easily mapped. These attributes enhance the structural discontinuities by correlation of seismic amplitudes of adjacent traces, which helps in prediction of subsurface positions and lateral extents of these FCs.

Several attributes were extracted from the seismic datasets of pre-stack time and depth migrated volumes to map FCs, results were verified and calibrated with image log data. Regional and local in-situ stress directions and structure patterns in the study

area were important to interpret and understand the fracture patterns. This led to building a subsurface geological model, which revealed that the fractures are present all over the field area.

Based on the results of this study, horizontal drilling in the top part of the naturally fractured reservoir was proposed. Well path was designed to intersect a maximum number of critically stressed FCs, considered as zones of better permeability in the tight reservoirs. Drilling of the horizontal well validated the subsurface geological model of FCs and resulted in obtaining better hydrocarbon production from a Tight Gas reservoir. This is the first well in the area that was successfully tested to confirm the commercial flow of hydrocarbon from Tight Chiltan Limestone. This is a major step that has confirmed a new play of Jurassic Chiltan Limestone, thus creating a new opening for exploitation in the matured Lower Indus Basin of Pakistan.

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International Conference & Exhibition

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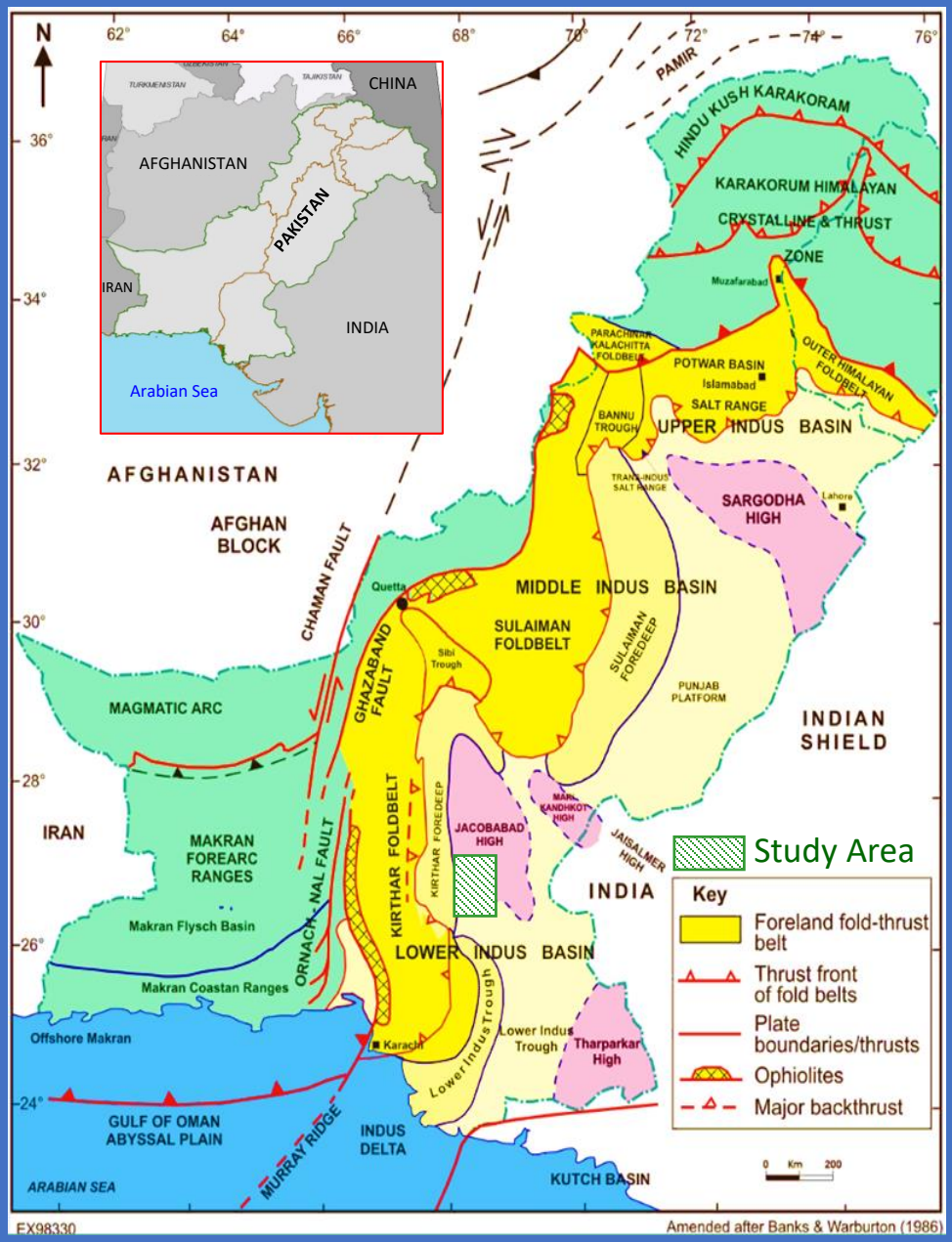
# Outline

- ❑ Introduction to Study Area
- ❑ Geological Setting & Stratigraphy
- ❑ Exploration History
- ❑ Sedimentological Characteristics of Chiltan Formation
- ❑ Characterization & Mapping of Natural Fractures
- ❑ Sweet Spot Identification & Well Placement
- ❑ Conclusions

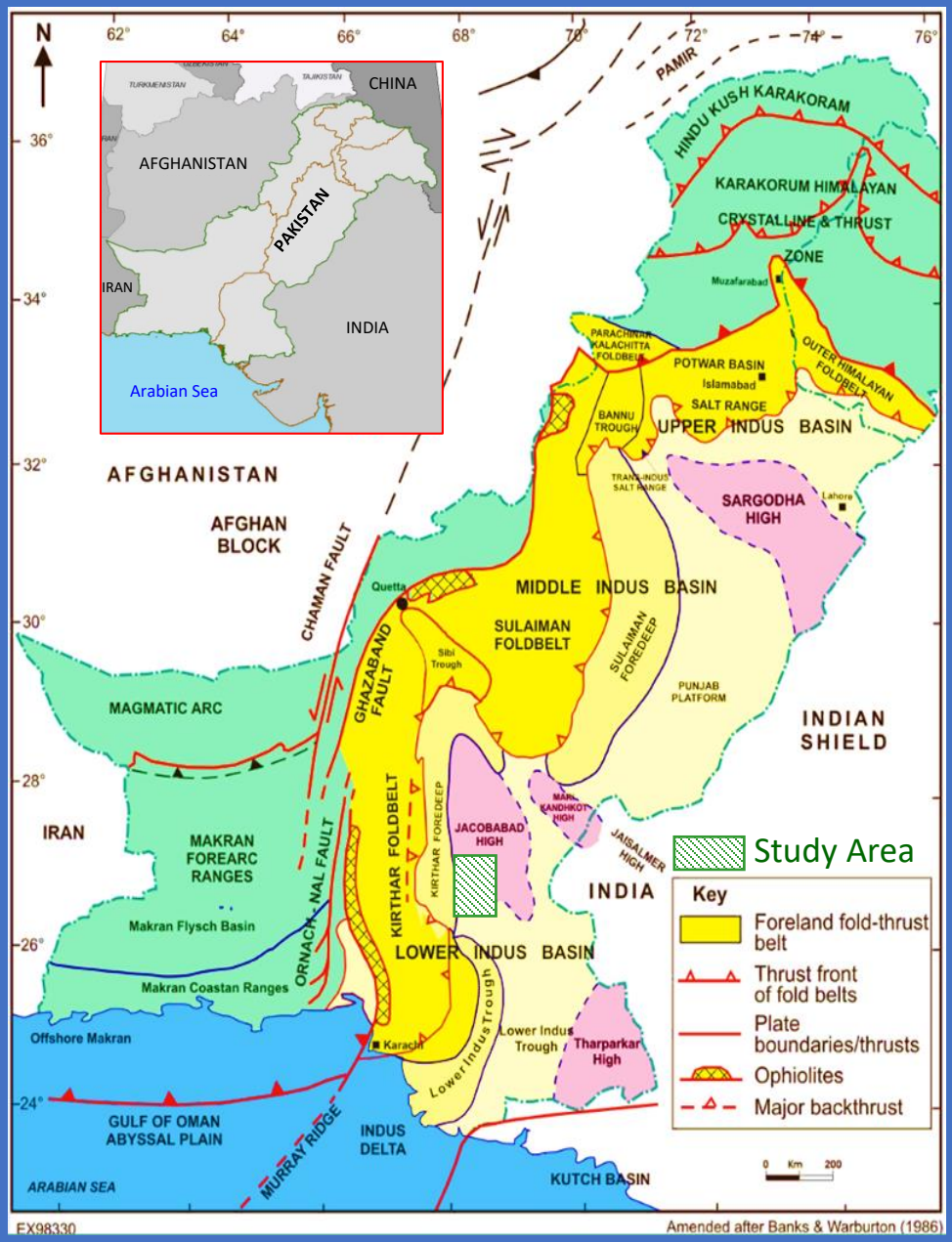
# Study Area

- Southern part of Pakistan
- North-Western part of Lower Indus Basin (LIB), Pakistan
- Well developed energy infrastructure



# Geological Setting

- LIB- western part of Indian shield
- Study area – fore bulge of Kirthar fold belt
- Area comprised mainly of normal faults
- Indications of Sinistral movement / inversion



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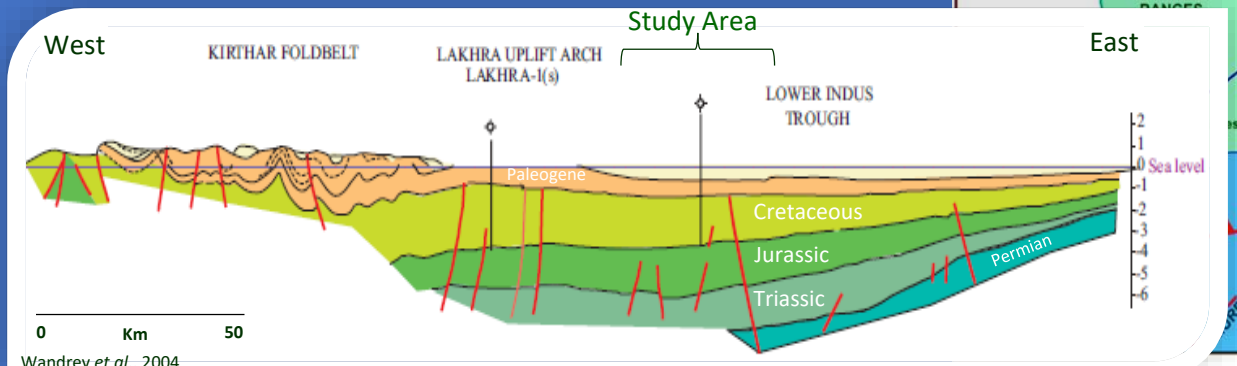
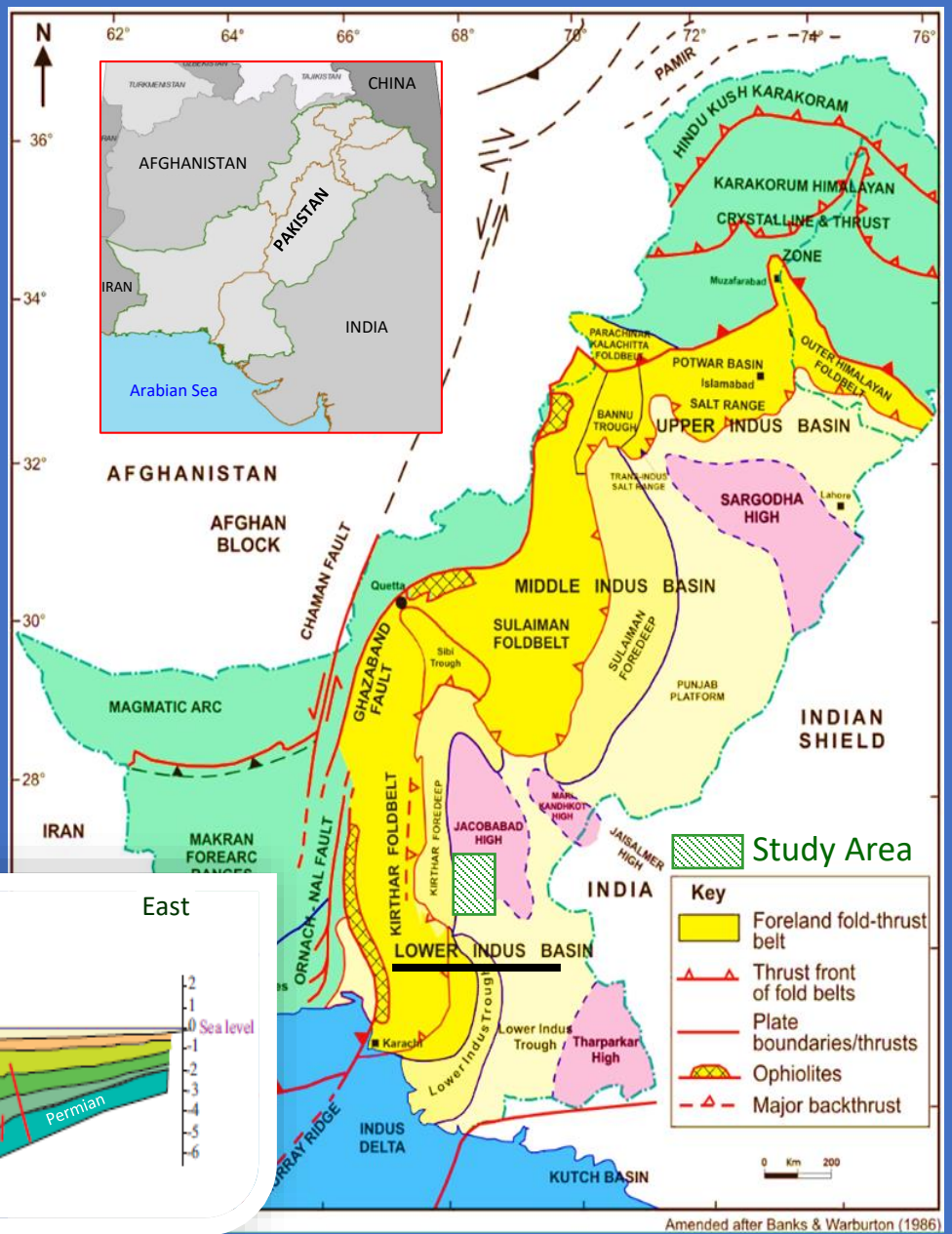
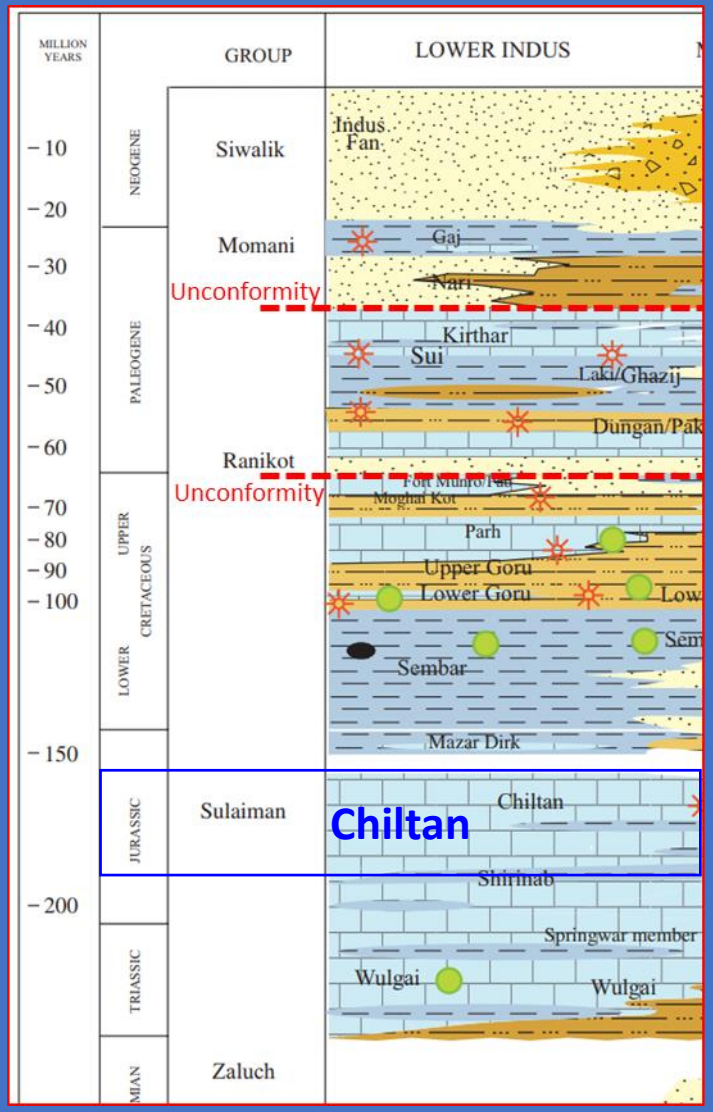
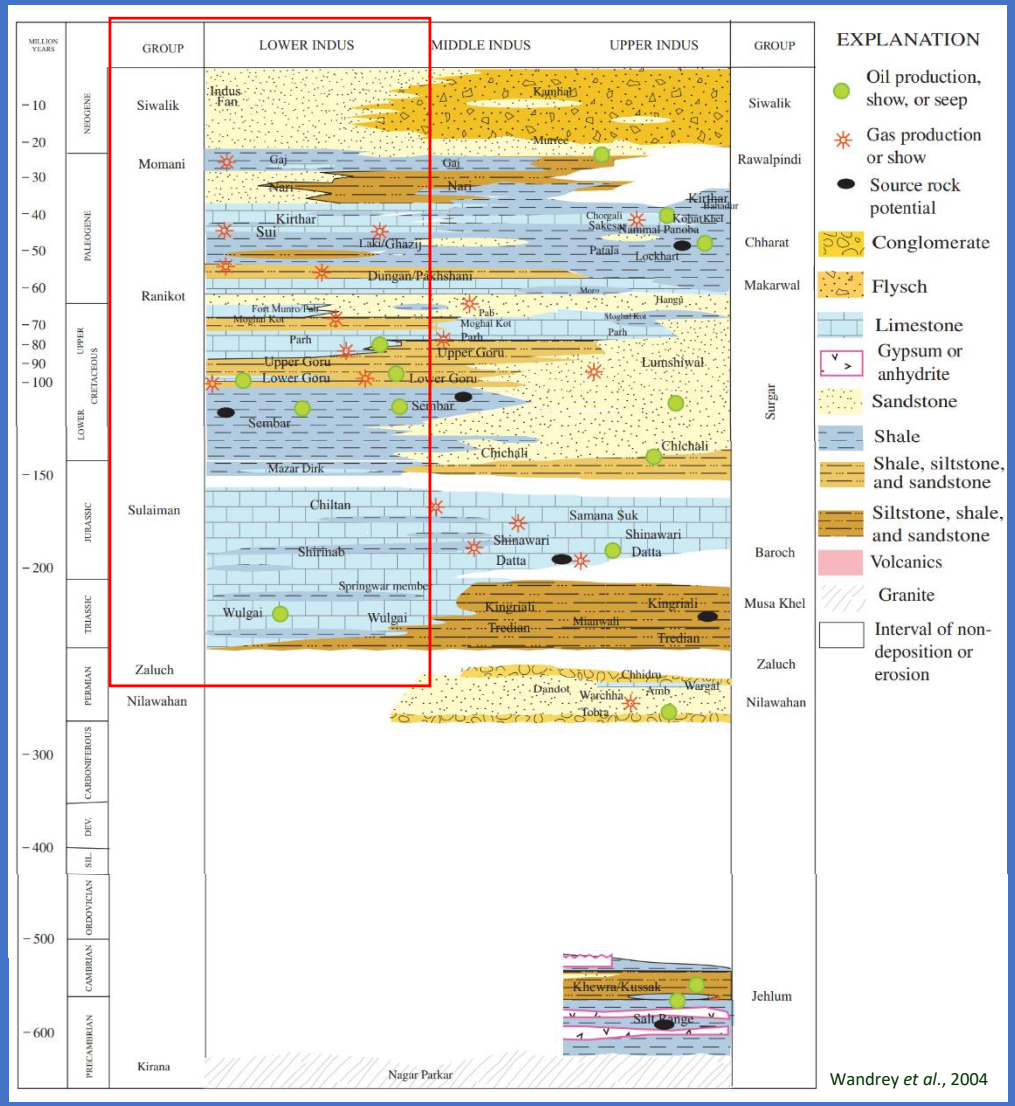


Wandrey *et al.*, 2004



# Generalized Stratigraphy



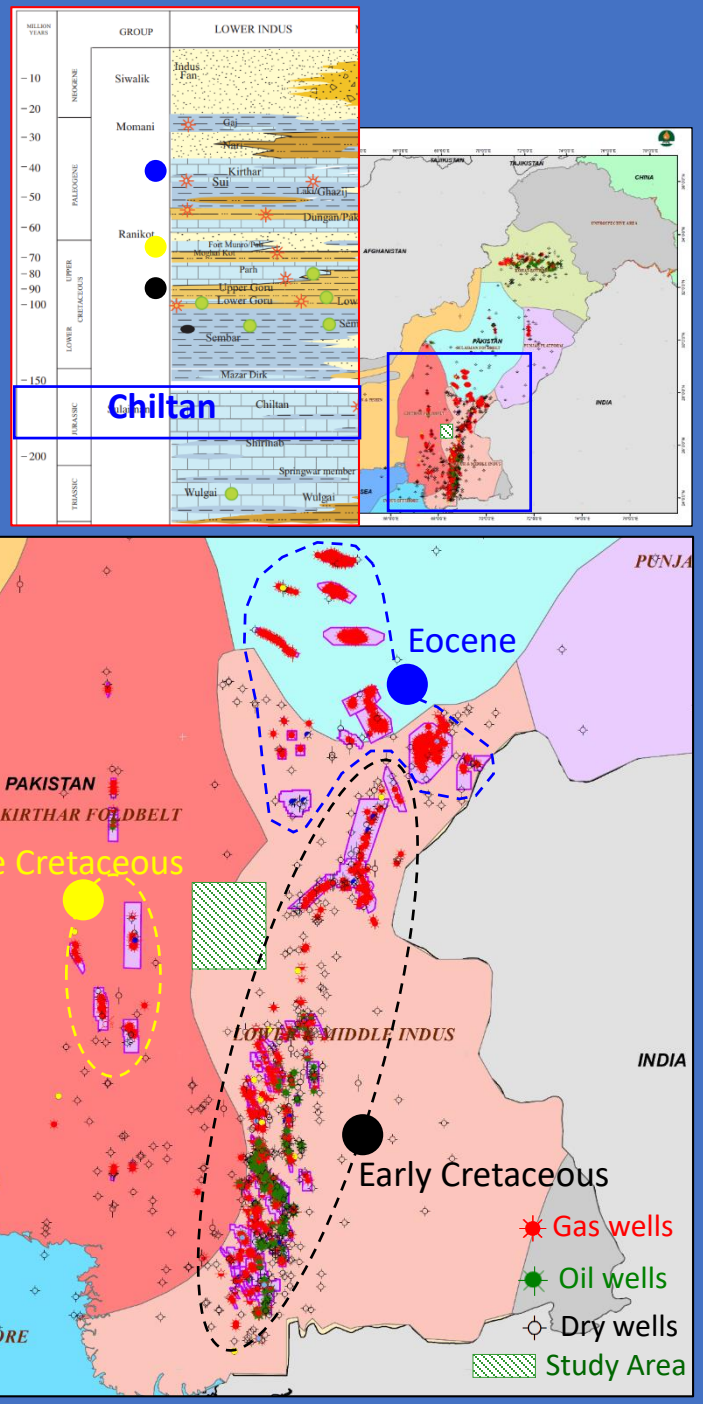




Wandrey *et al.*, 2004

# Exploration History

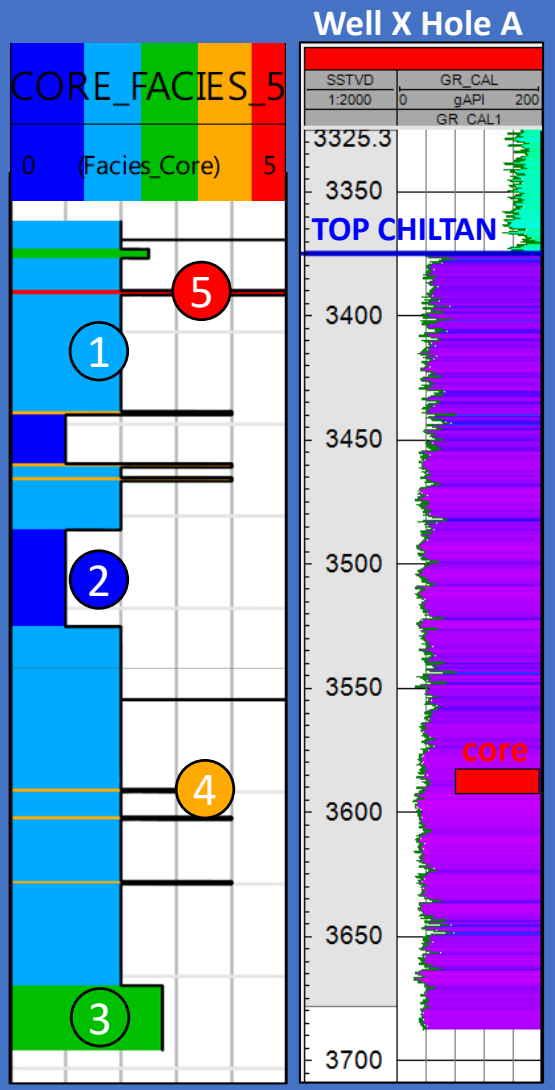
## Lower Indus Basin – LIB

- Area is under exploration since 1950 – quite matured basin
- ~655 exploratory wells
  - ~310 are discoveries
    - Early Cretaceous Clastic – LIB
    - Eocene Carbonates – LIB
    - Late Cretaceous – KFB
- ~50 wells penetrated Chiltan
  - Only 01 discovery



# Sedimentological Characteristics of Chiltan Fm

- Microfacies of Chiltan Formation
  1. Peloidal Wackestone to packstone (1)
  2. Peloidal Wackestone (2)
  3. Peloidal packstone-grainstone (3)
  4. Calcareous Dolostone (4)
  5. Peloidal Packstone (5)
- 1.5-3% Porosity
- < 0.01mD permeability
  (core plugs and well test)



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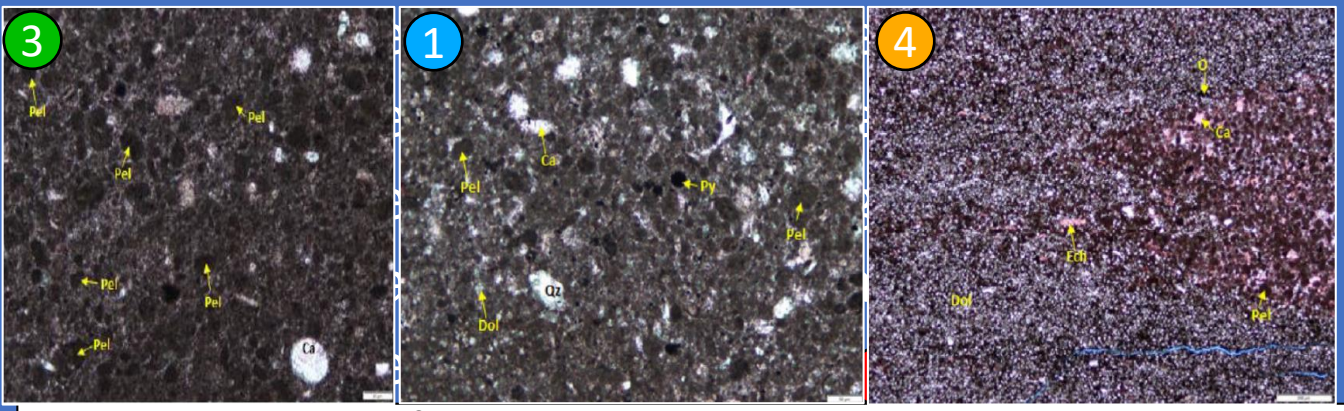
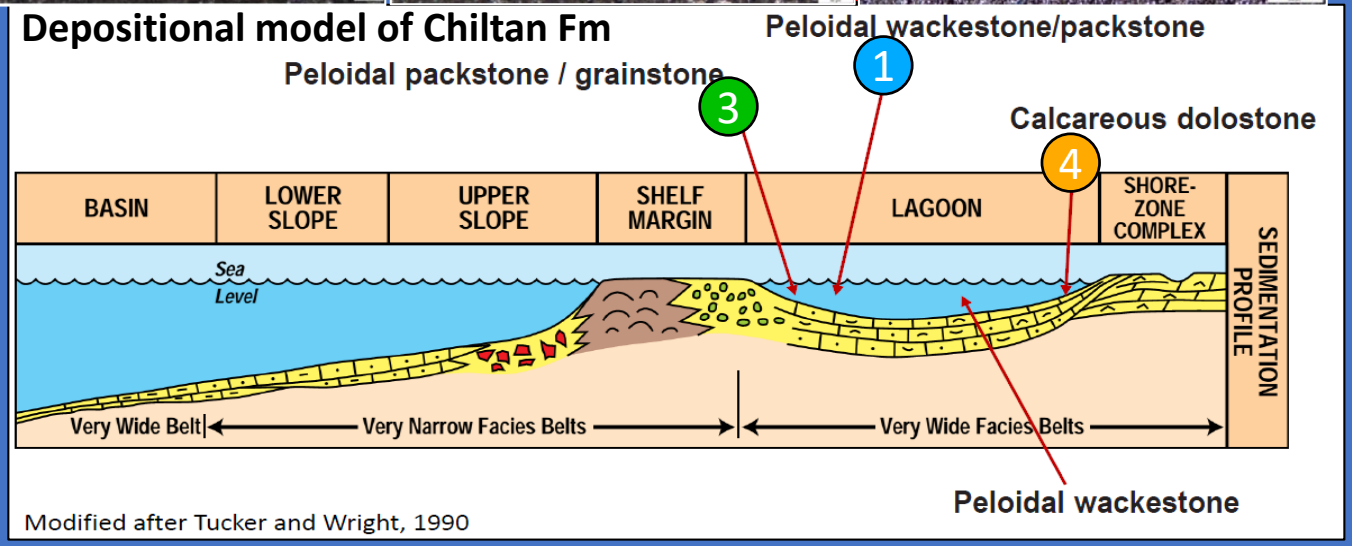
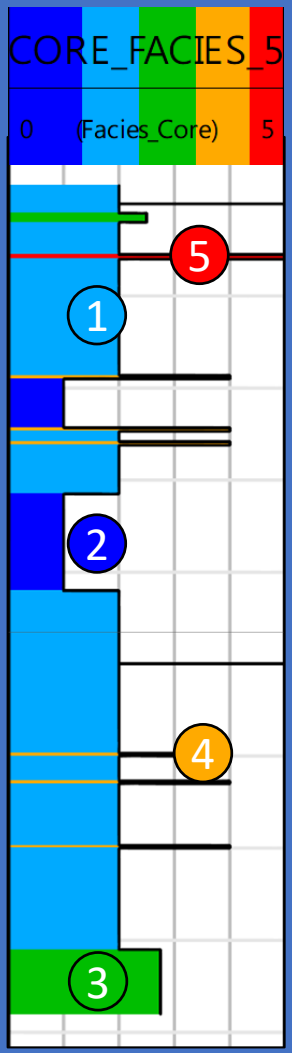
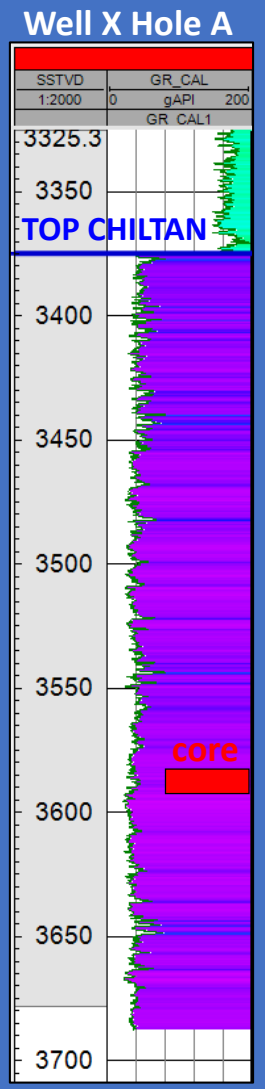


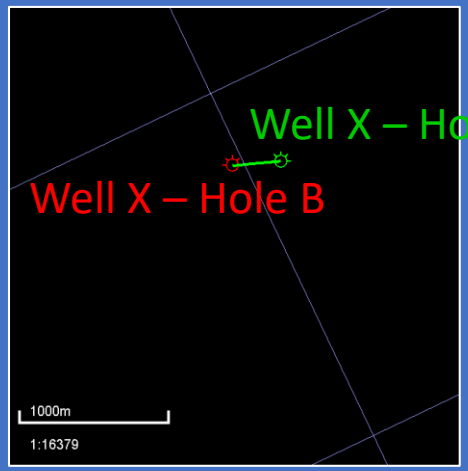



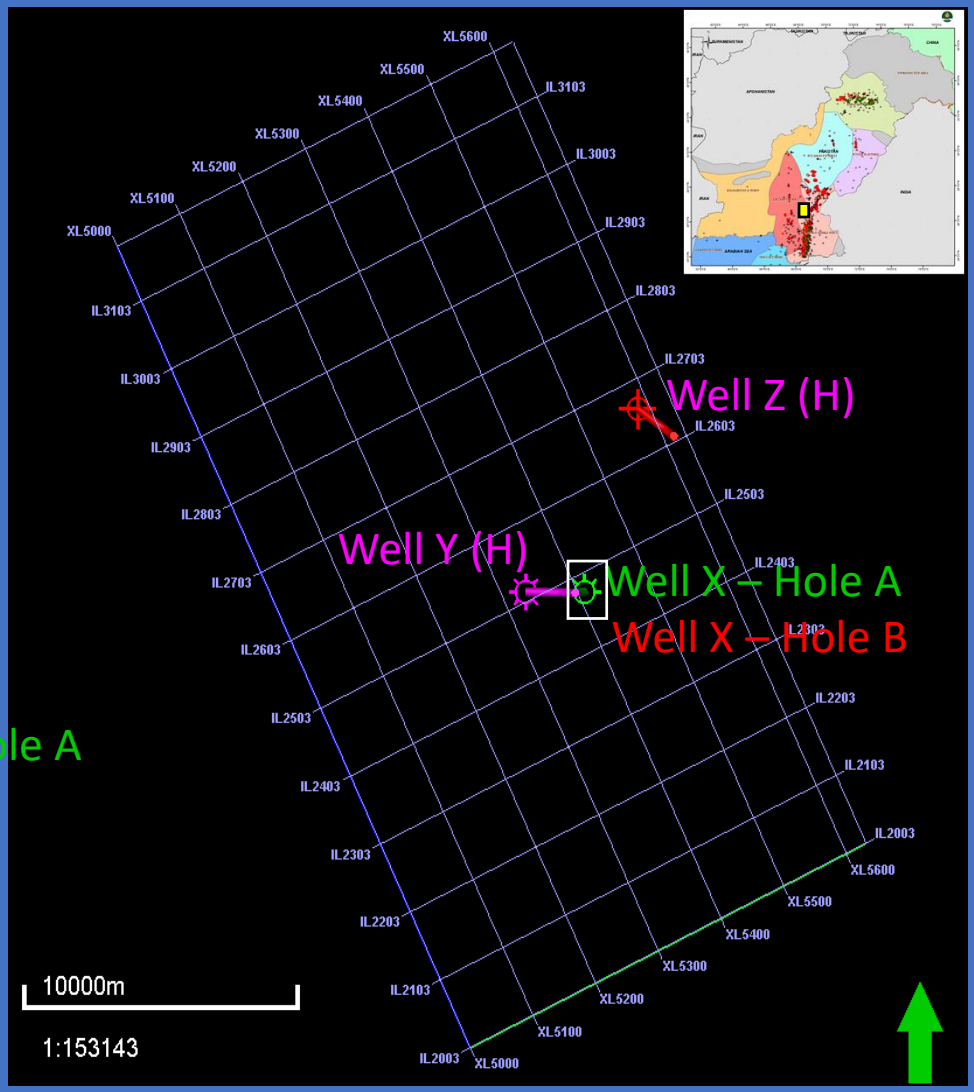



# Fracture Characterization & Mapping – *Data Set*

- Well Data-FMI
  - 2 wells prior to study (1 vertical & 1 slant)
  - 2 well after study (Both horizontal wells)
- 3D seismic data – PSTM & PSDM

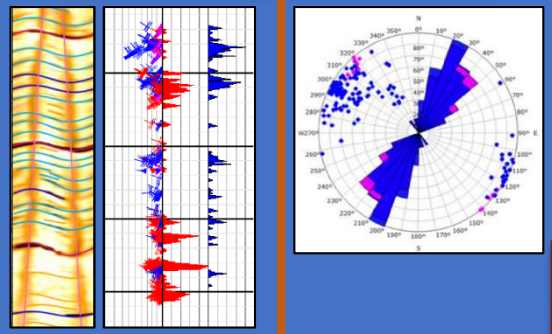


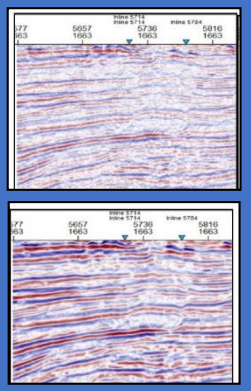
# Fracture Characterization & Mapping – *Workflow*

Well Data
(FMI logs, cores)

Interpretation
(Density & Direction)



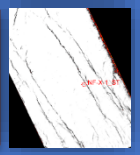
Seismic Data
PSTM, PSDM
(Unfiltered, Unscaled)



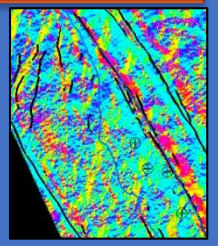
Data Conditioning
(Structural Smoothing)

Edge Attributes

Variance, Dip deviation

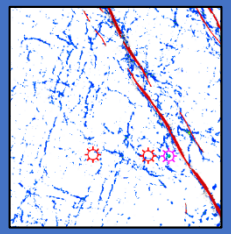


Other Attributes
(Curv, Dip Azim etc.)



Guide

Ant-Tracking

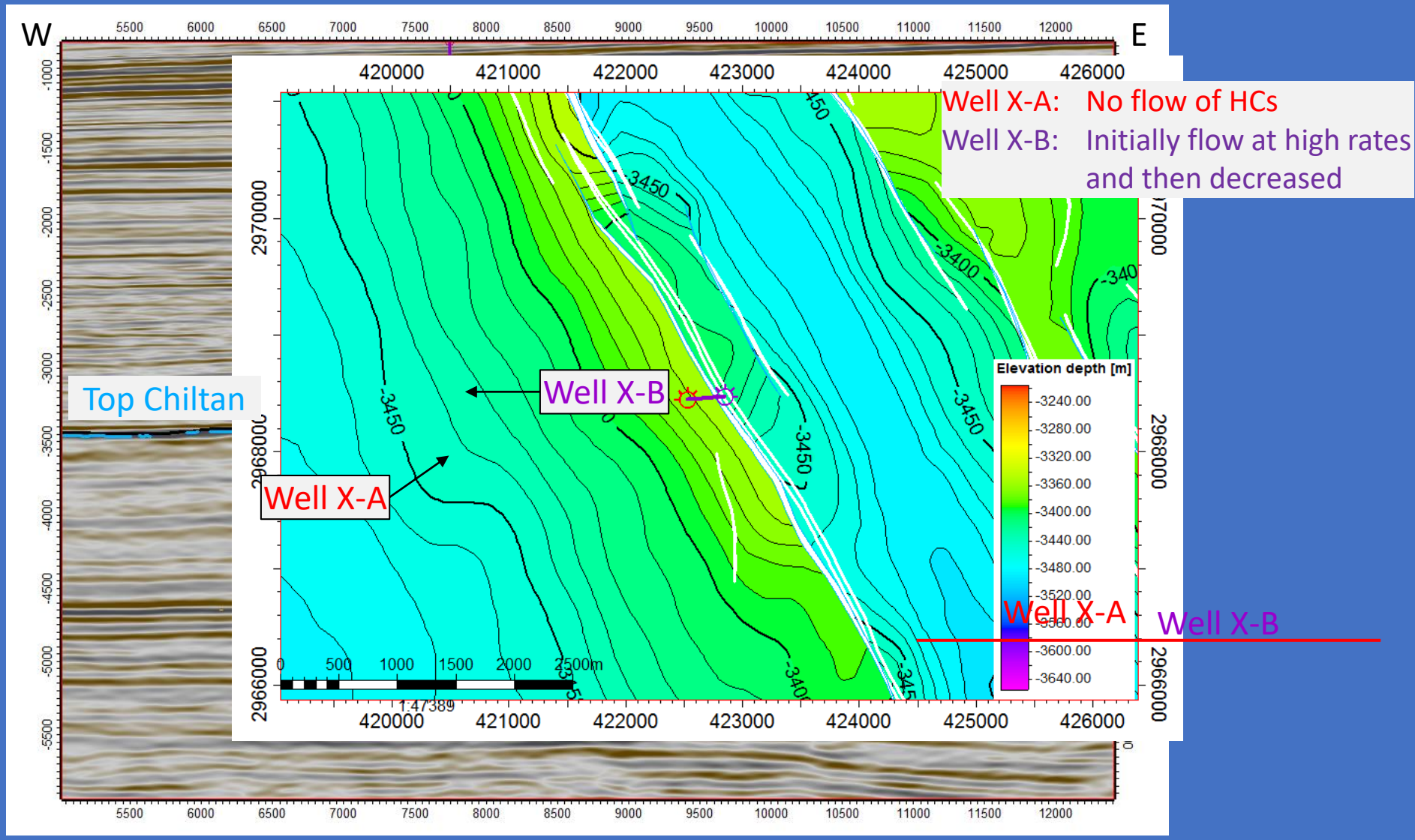


Calibrate

Compare

Fracture Volumes

# Fracture Characterization – Well Data



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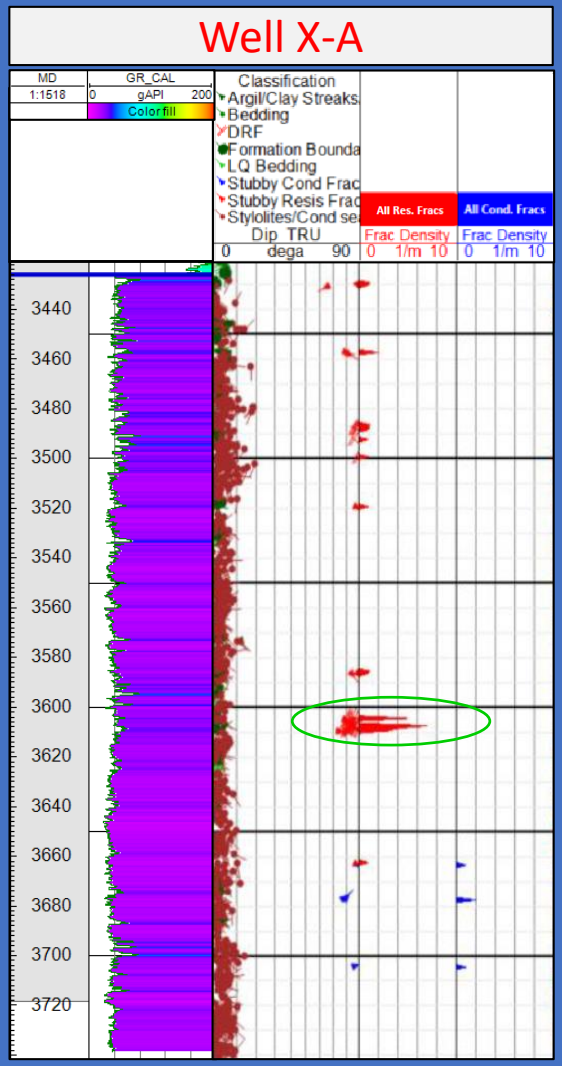
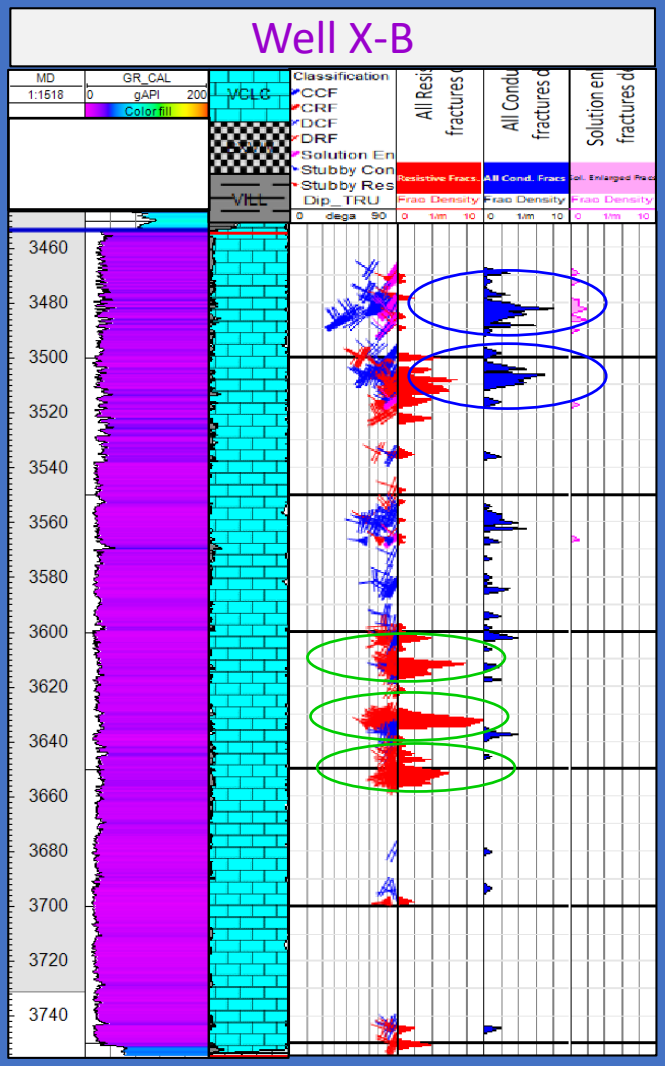
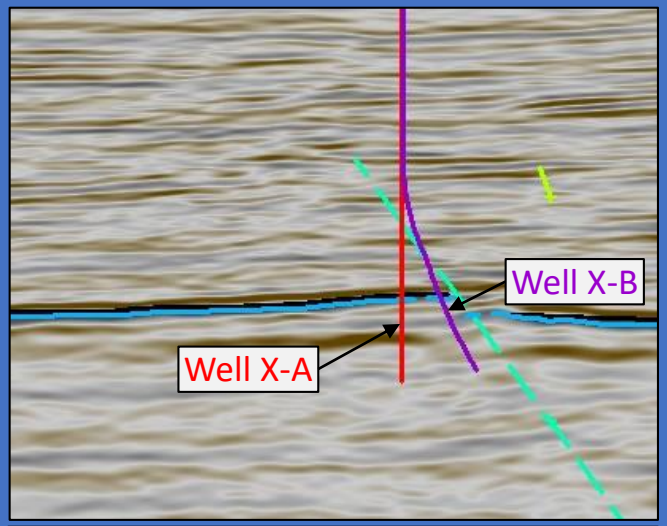
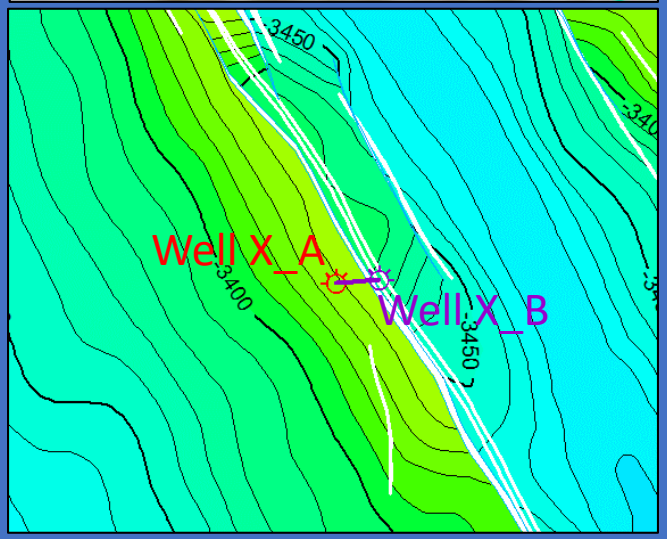
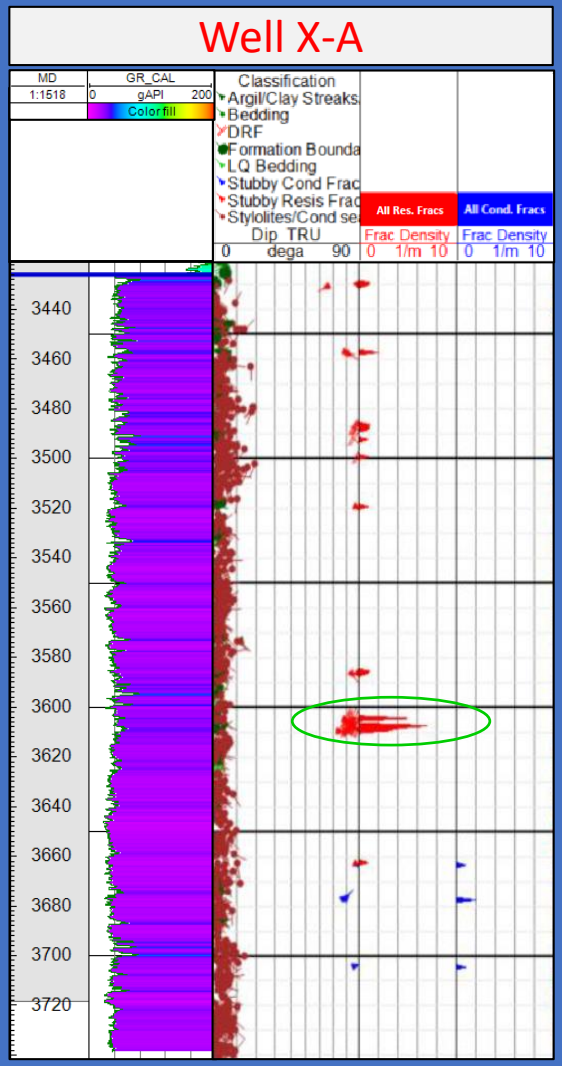


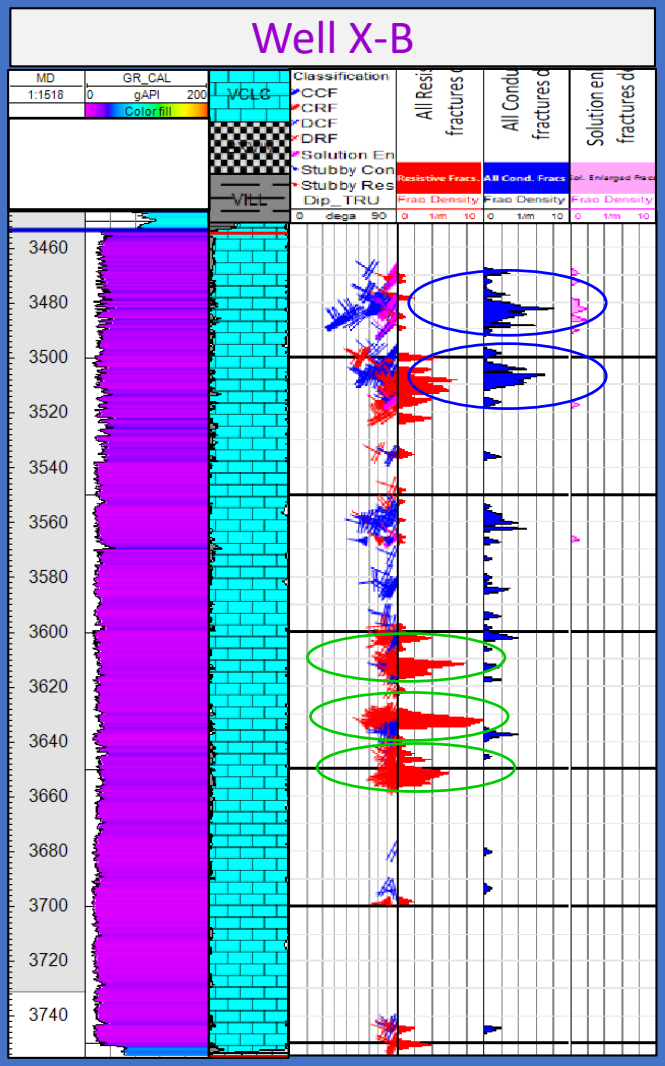



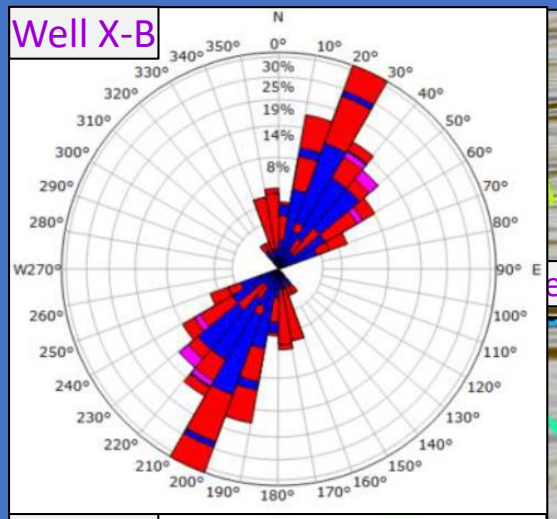



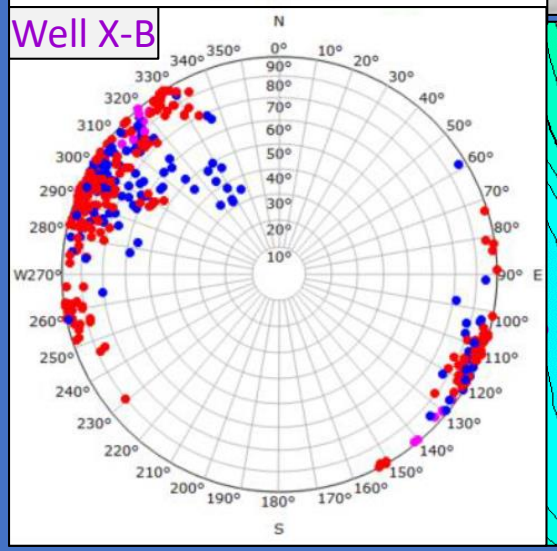



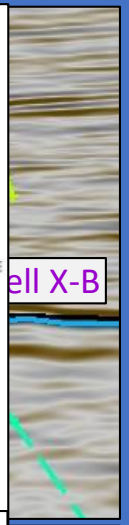
# Fracture Characterization – Well Data

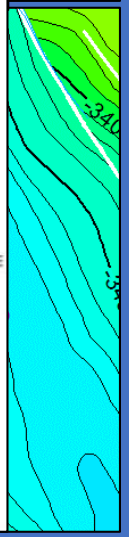


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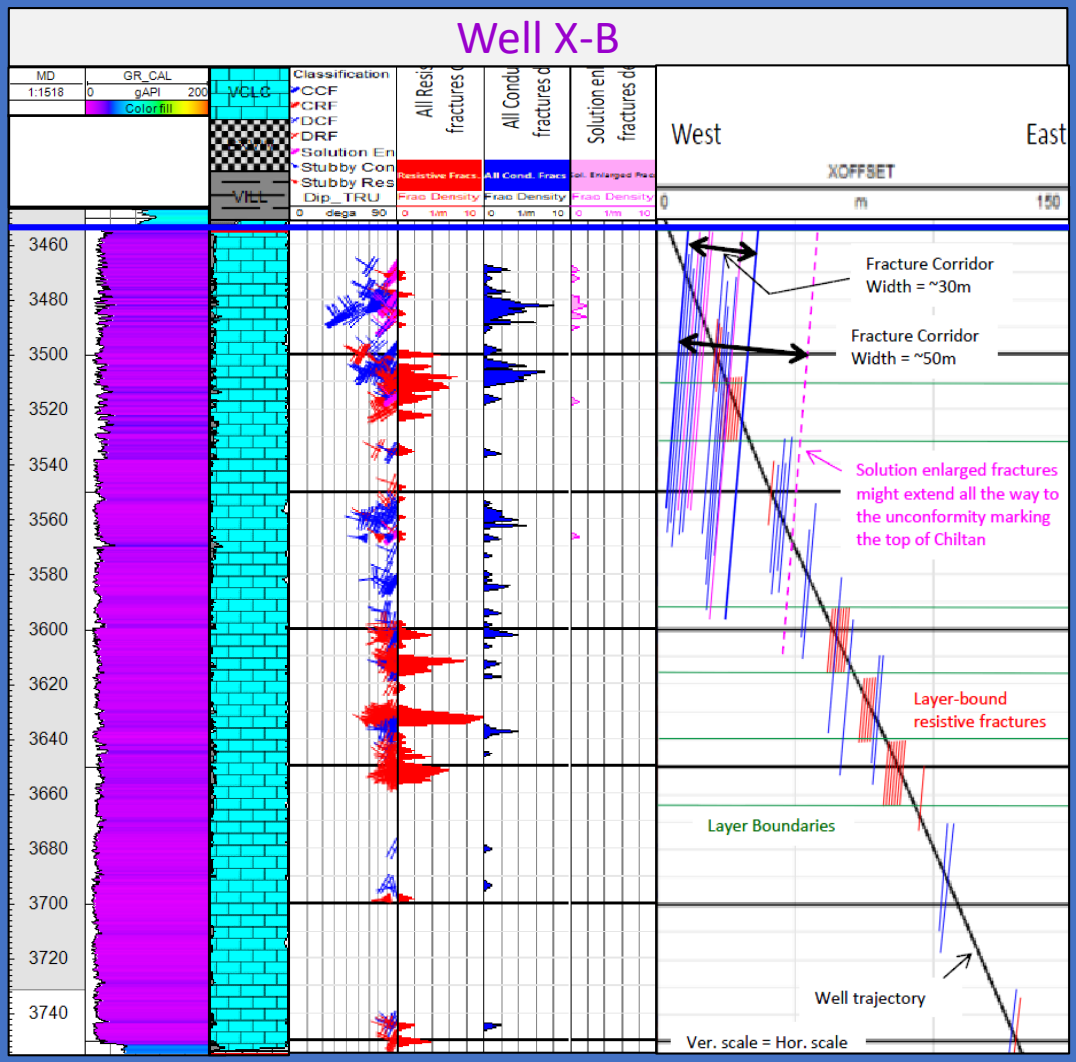
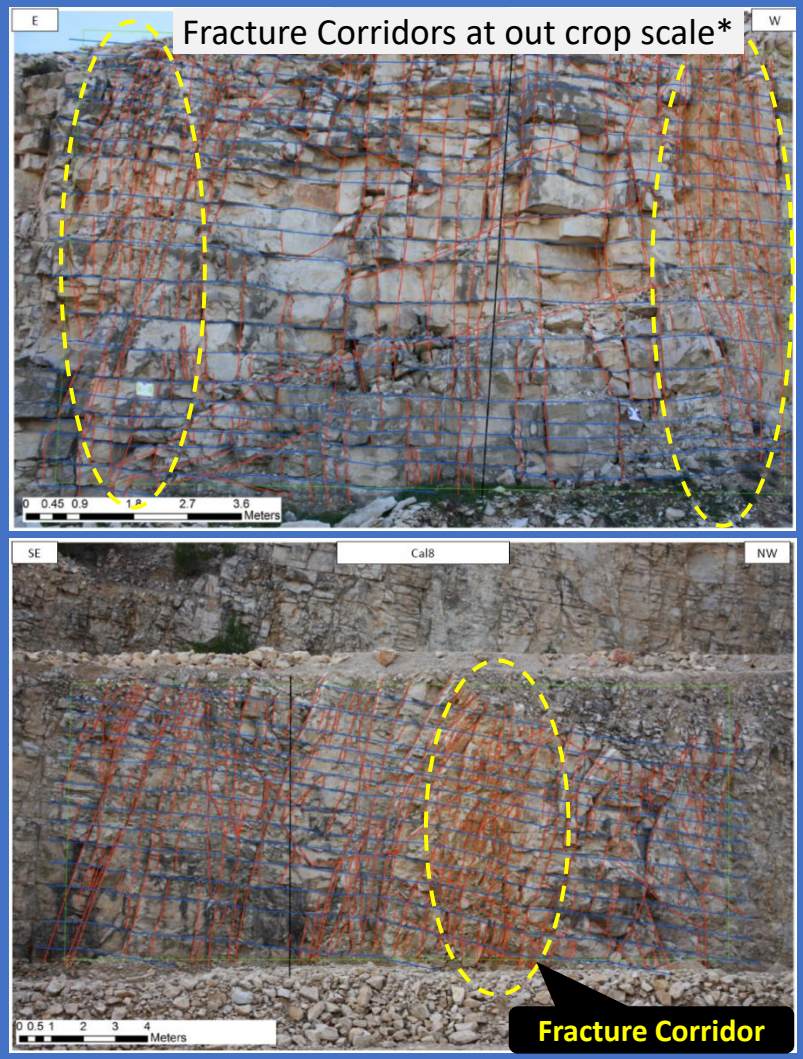
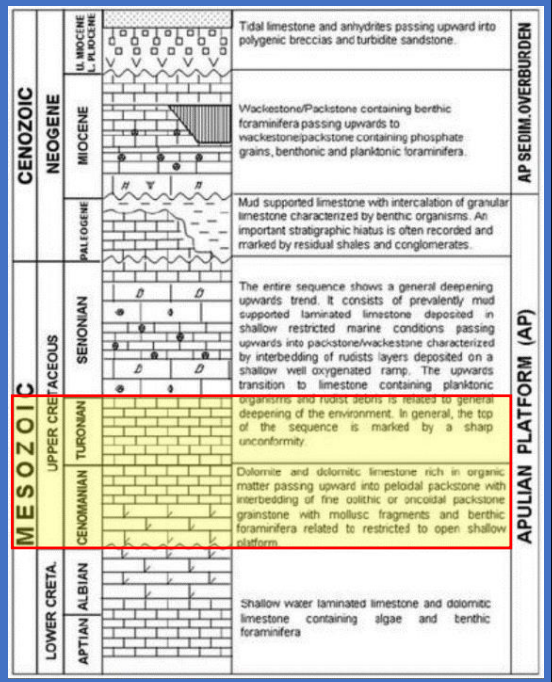


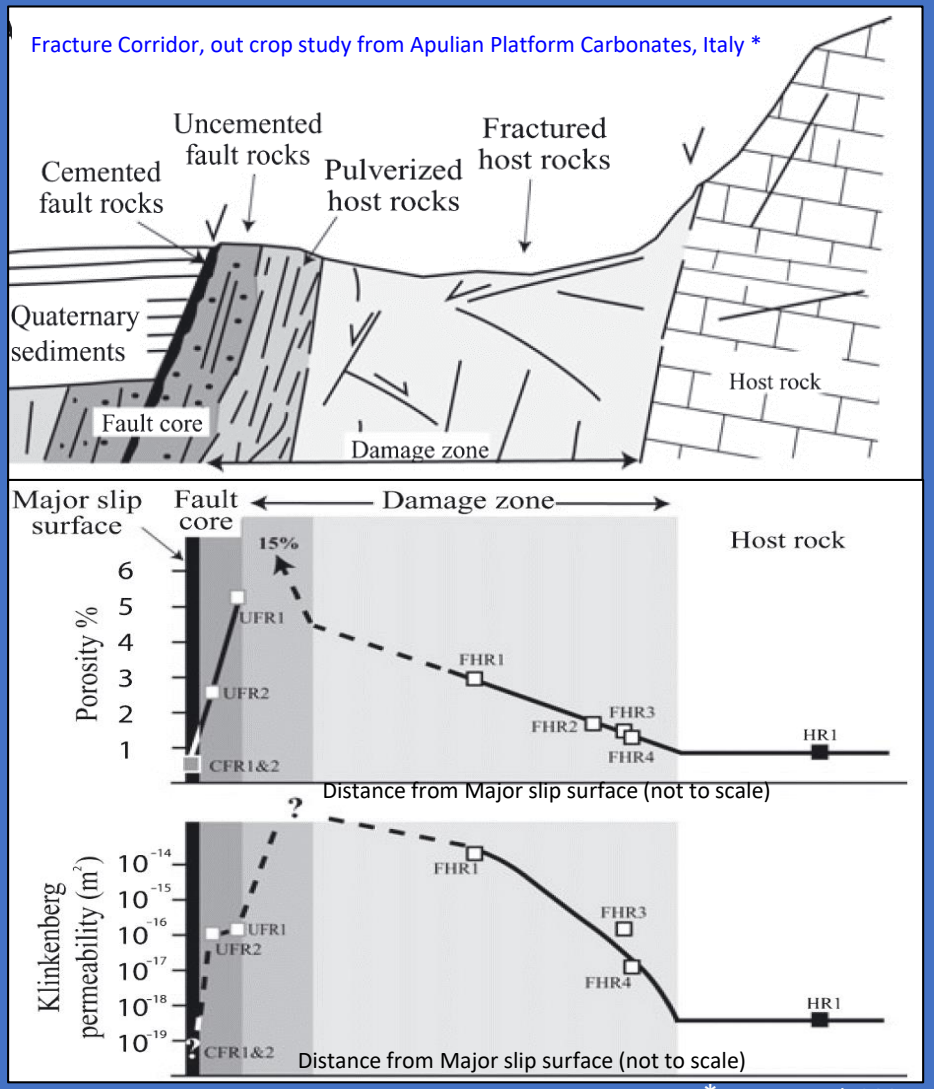




*Adapted from oral presentation at AAPG Hedberg Conference, Fundamental controls on fluid flow in Carbonates, July 2012, France

# Internal Structure of Fractures Corridors

- Fracture Corridors (FCs)
  - Associated with slip surface
  - Rock properties changes laterally across the FCs

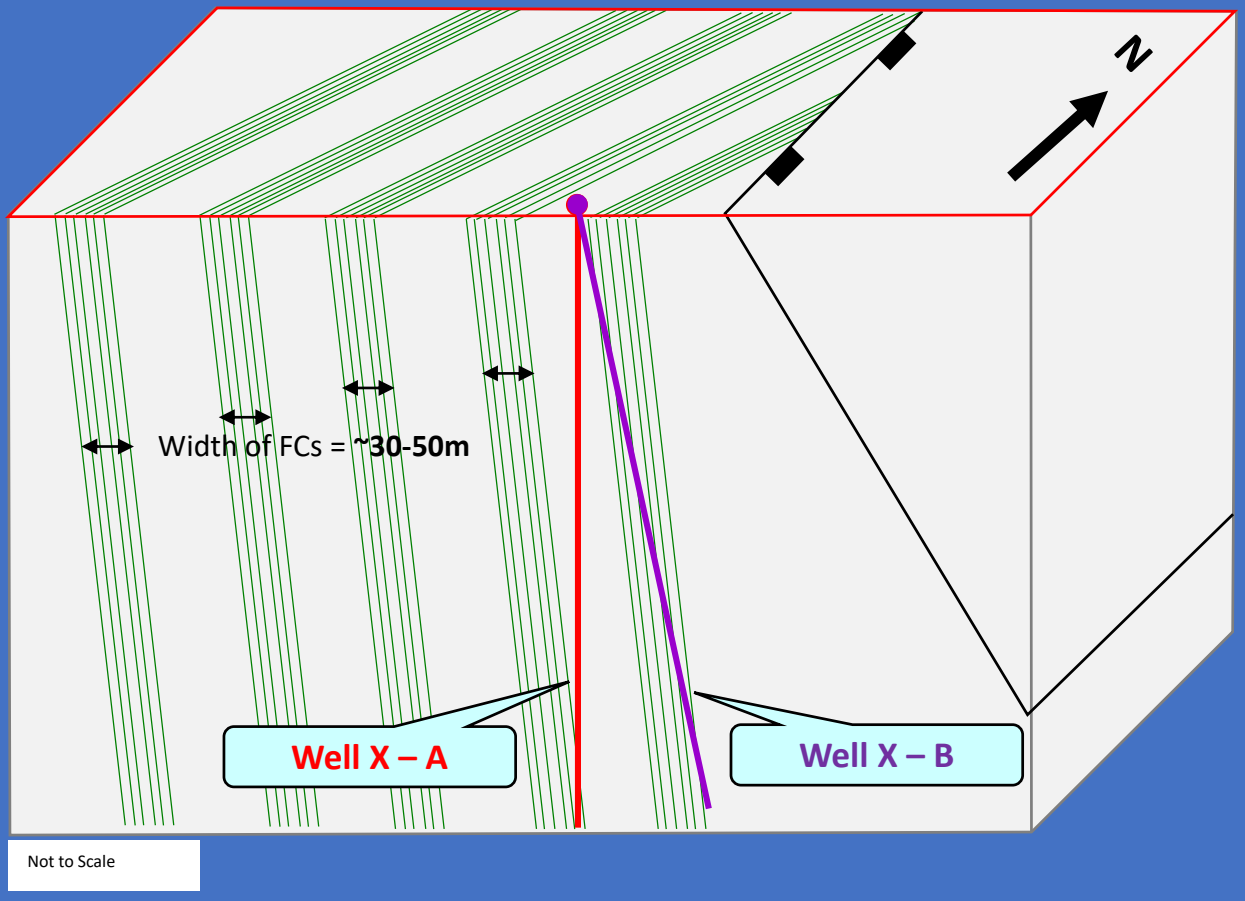


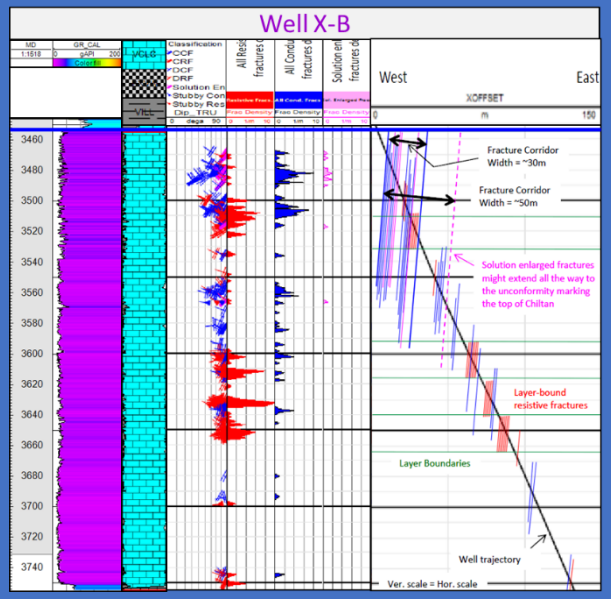



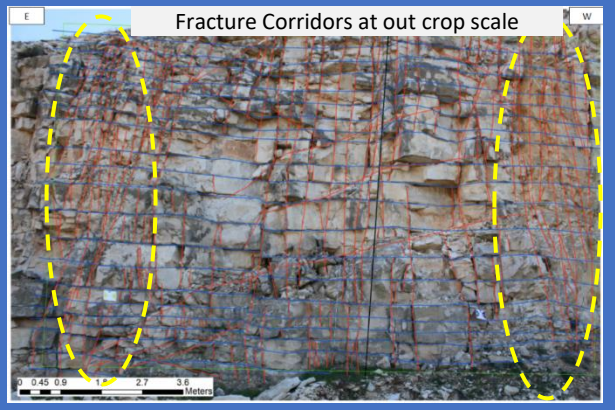

*Agosta et al. 2007

# Schematic Model of Fracture Corridors

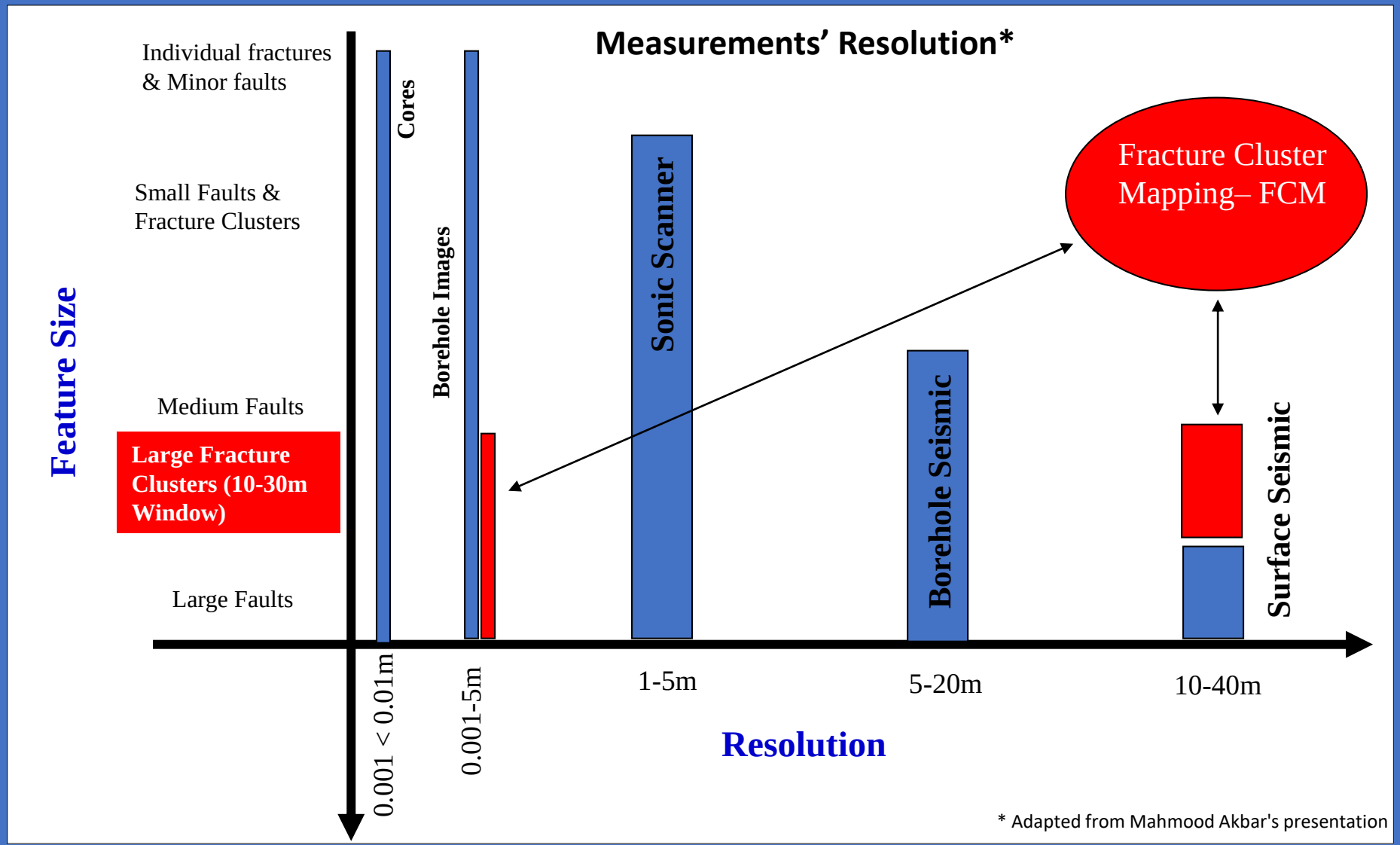
## Based on well data and outcrop analogues



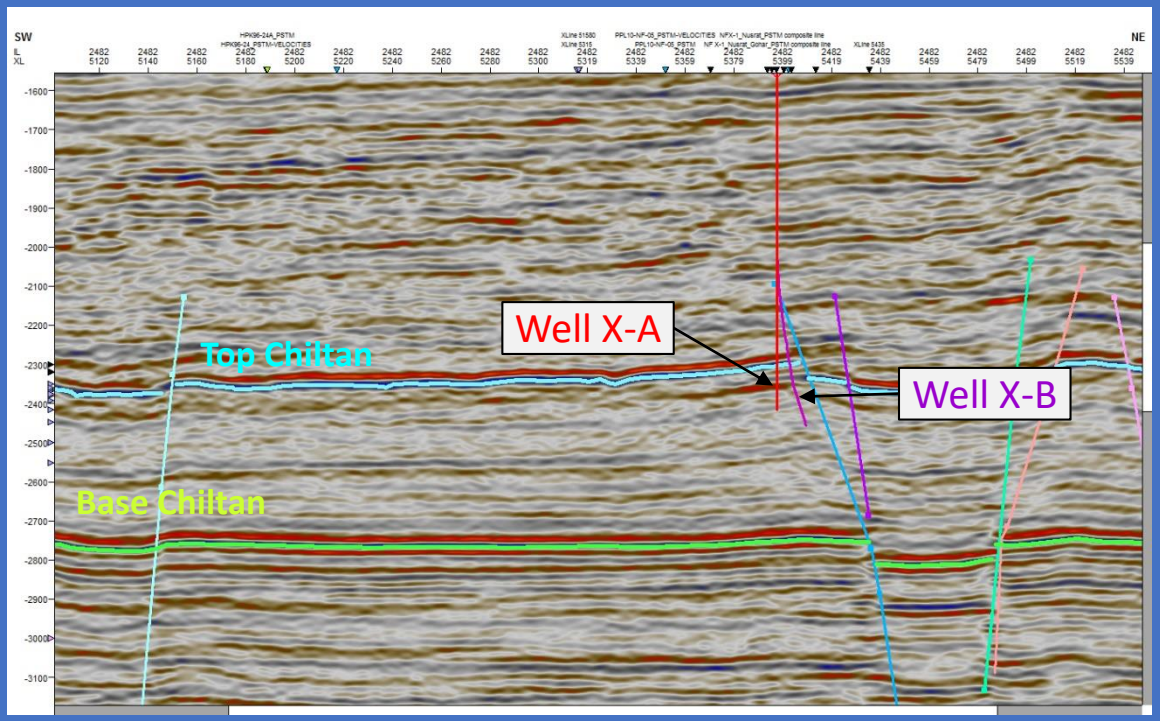



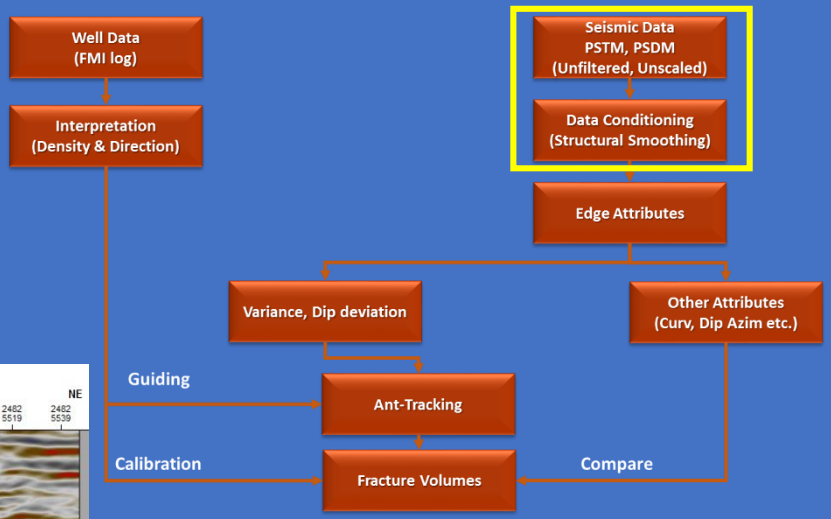
# Fracture Corridors (FCs) Mapping – Seismic

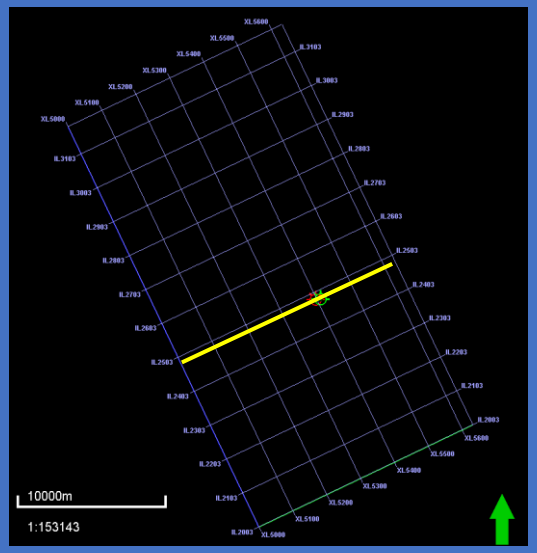


# Fracture Corridors (FCs) Mapping – Seismic

- 3D seismic data
  - PSTM & PSDM
- Well X-A & Well X-B

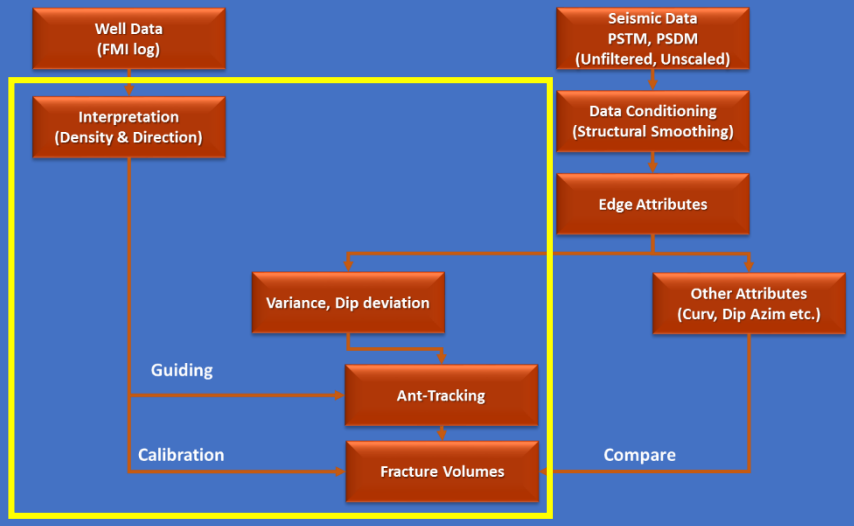


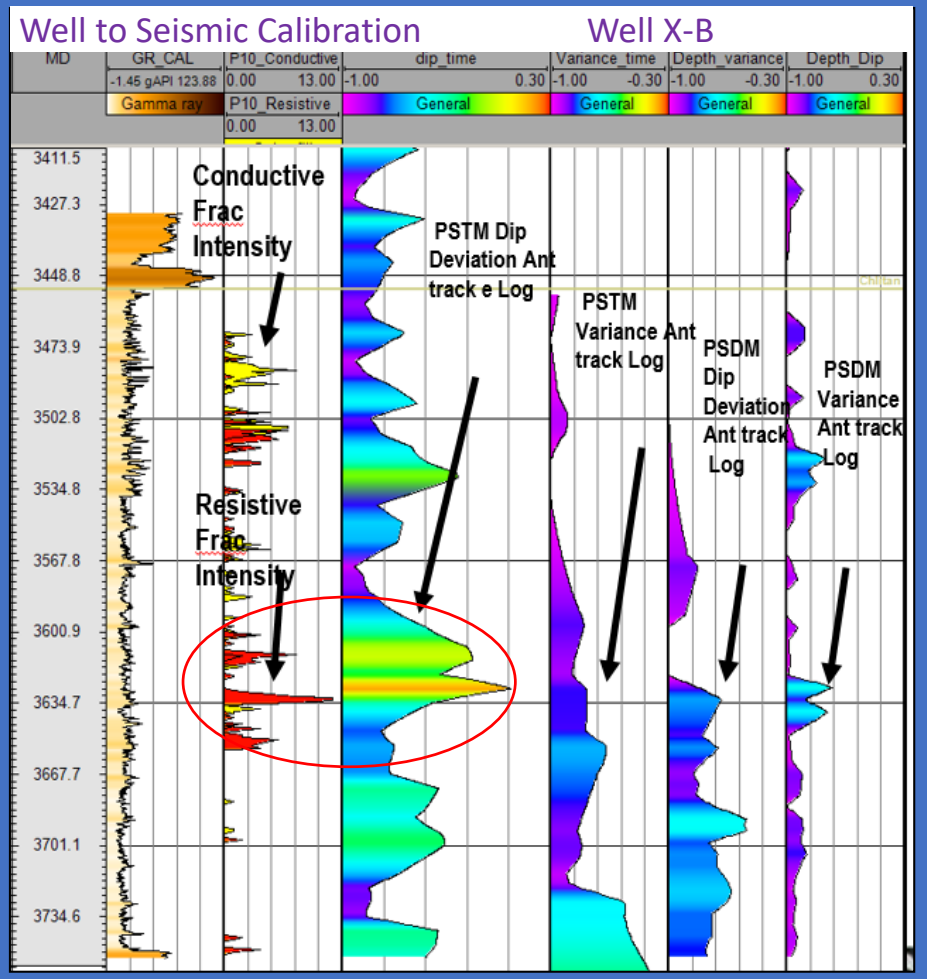



# Fracture Corridors (FCs) Mapping – Seismic

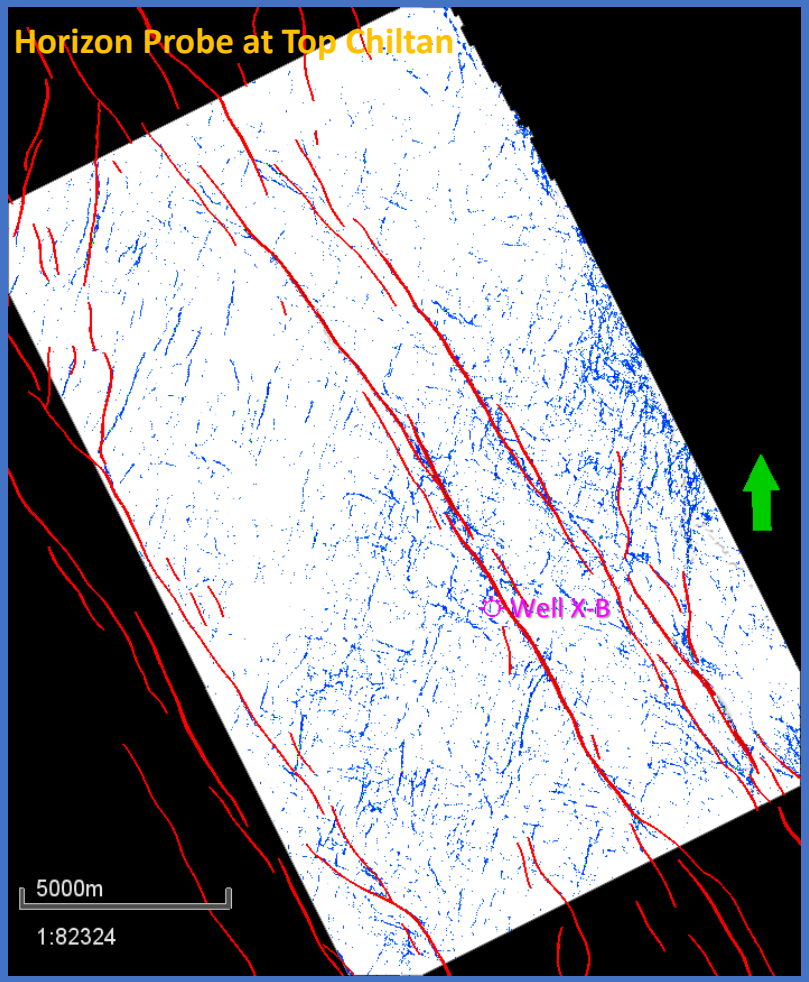
- Variance & Dip Deviation volumes generated on both PASTM & PSDM data sets.
- Calibrated with well data

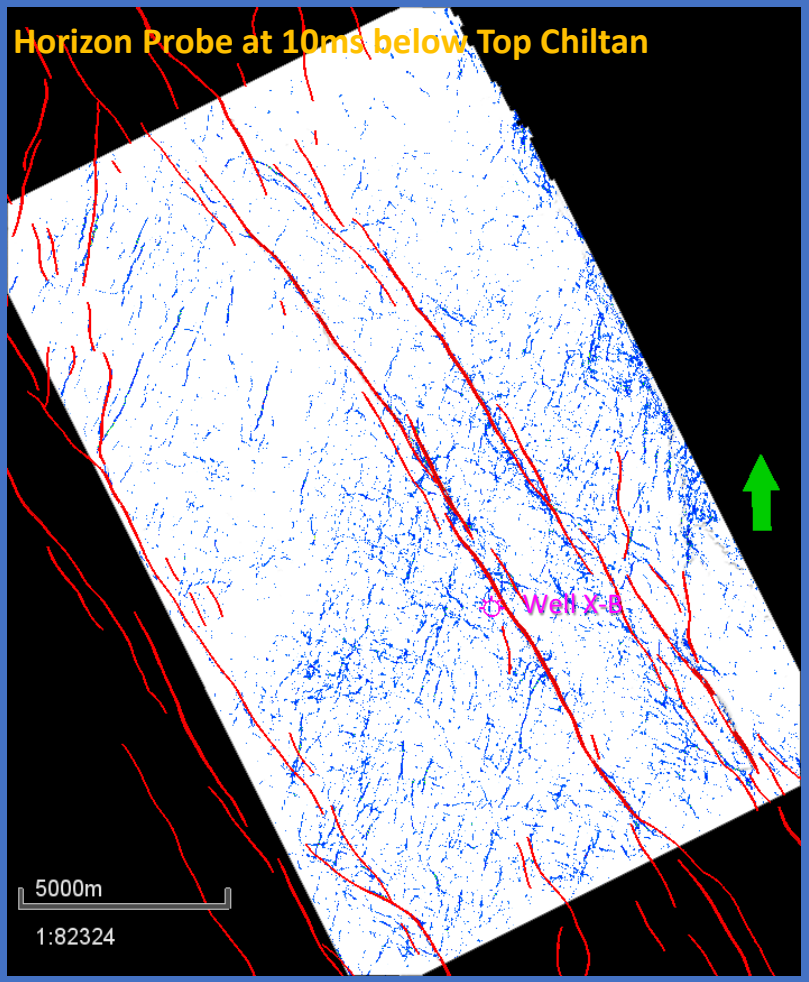


# Fracture Corridors (FCs) Mapping – Seismic

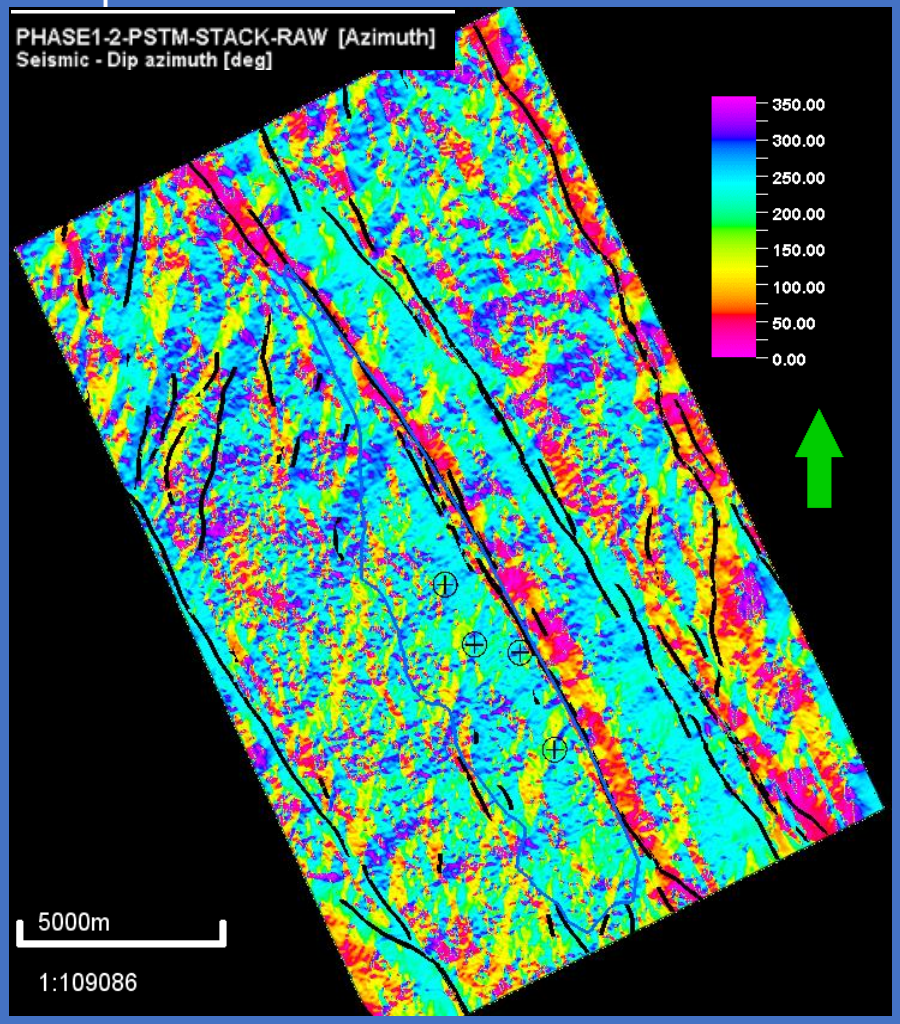
Ant Tracking Result – PSTM data set

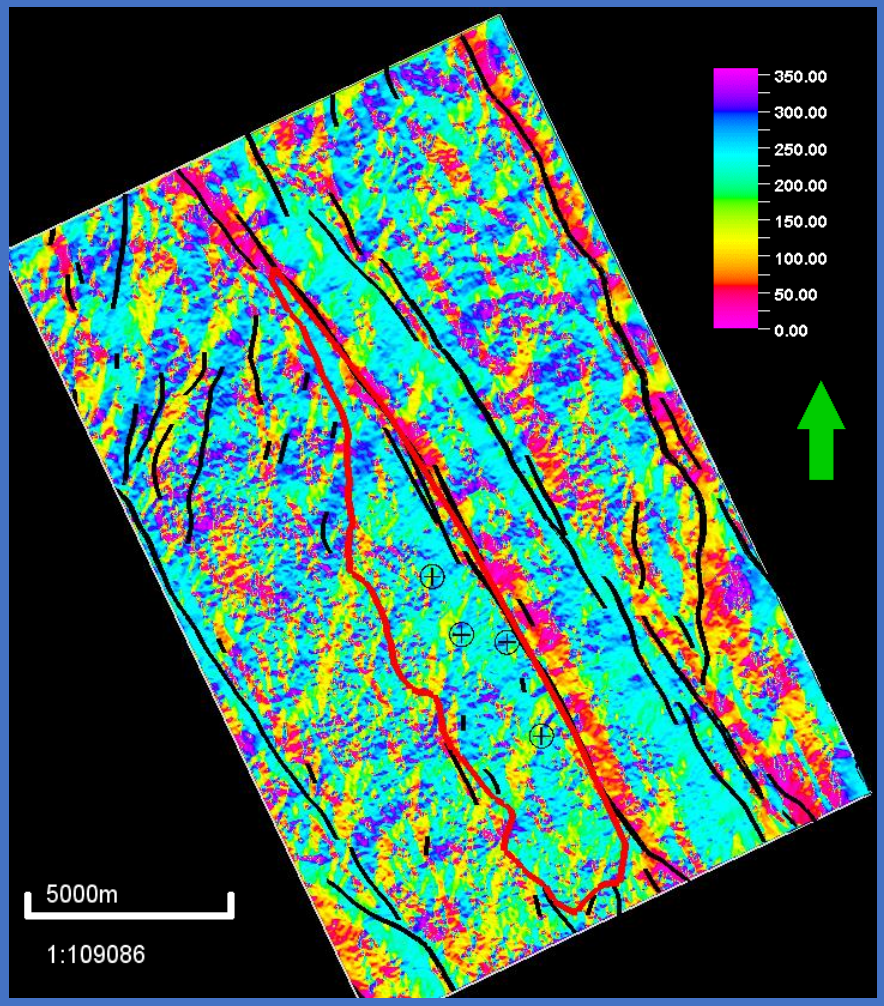


# Fracture Corridors (FCs) Mapping – Seismic

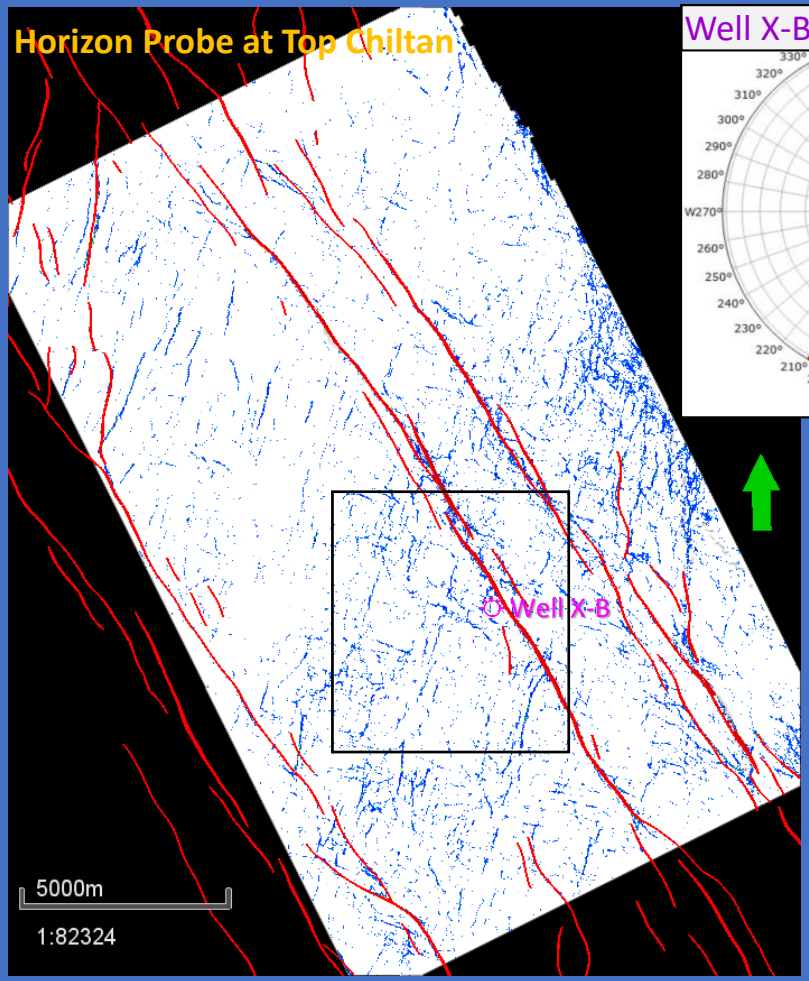
Dip azimuth Result – PSTM data set

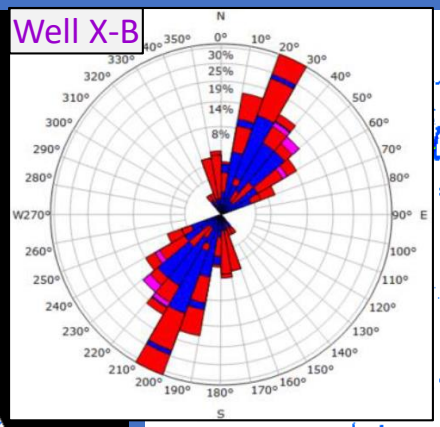


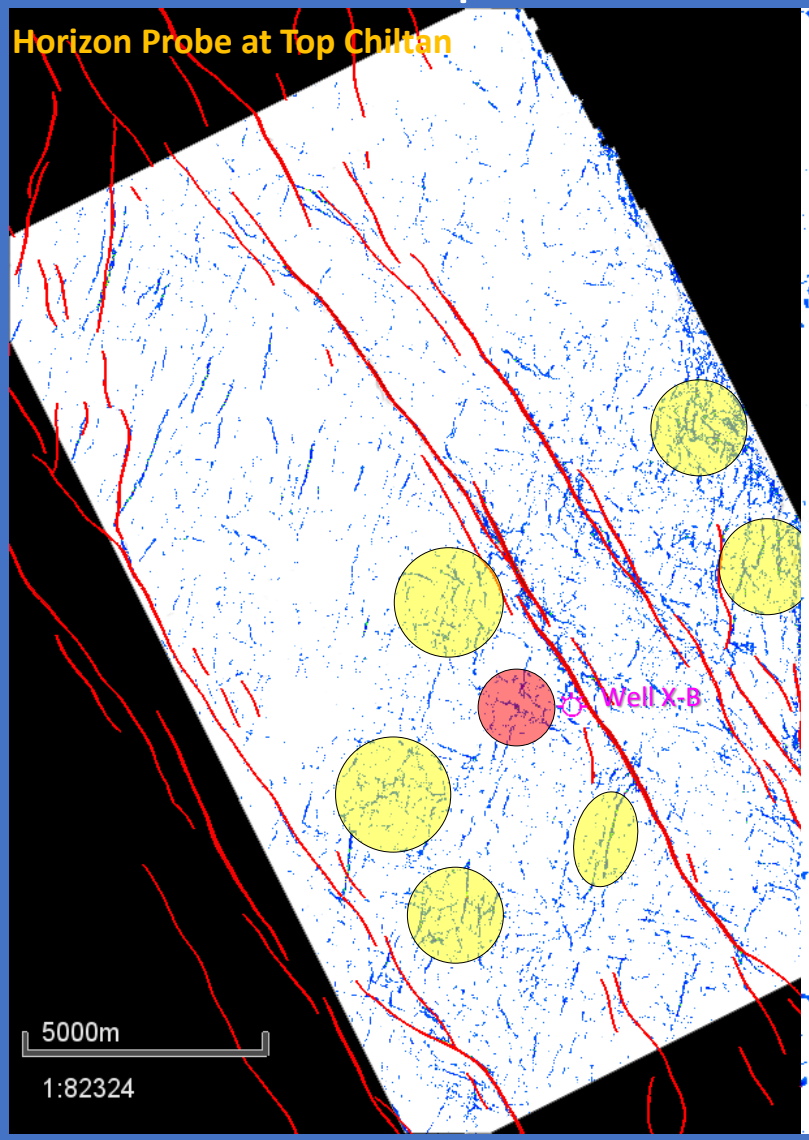
# Fracture Corridors (FCs) Mapping – Seismic

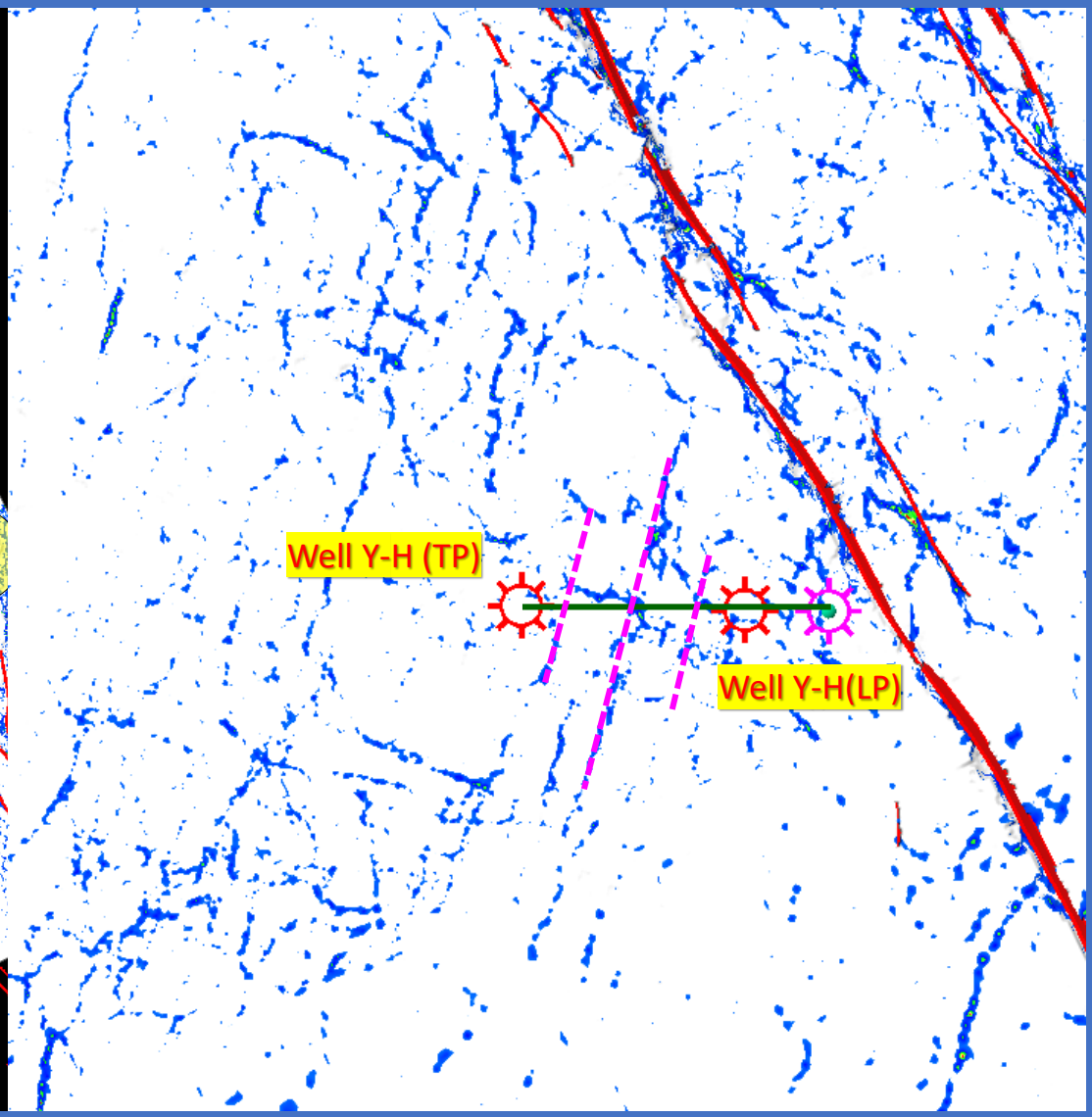
Ant Tracking Result – Calibration with FMI data



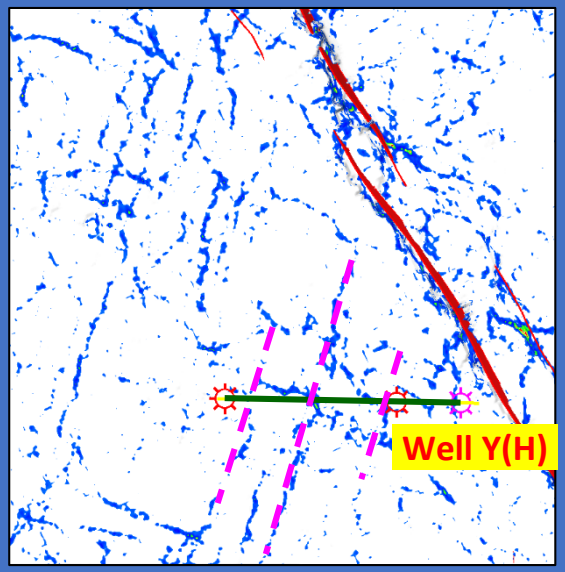



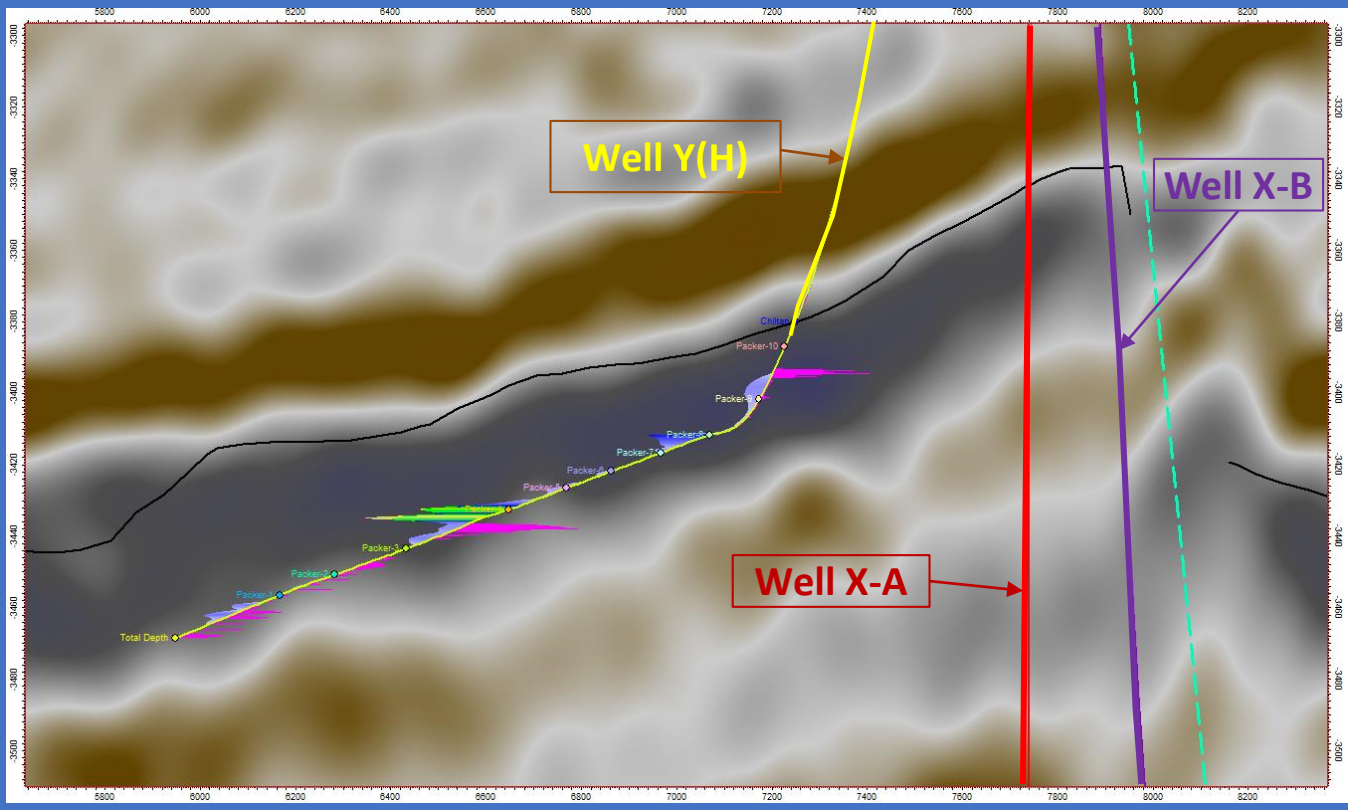
# Sweet Spot Identification & Well Placement



# Post Drill Results of Well Y (H)



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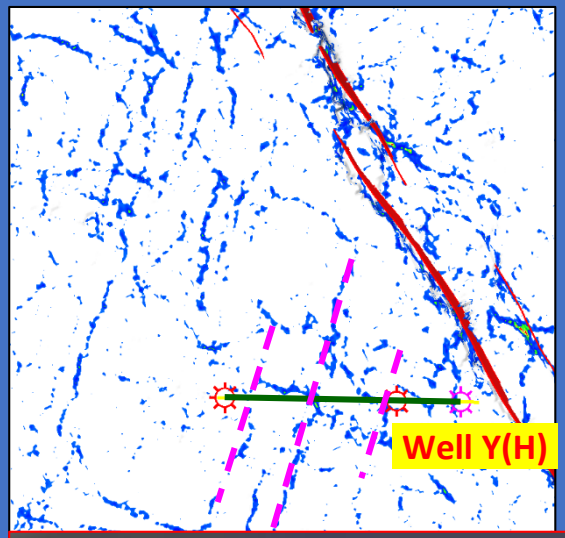


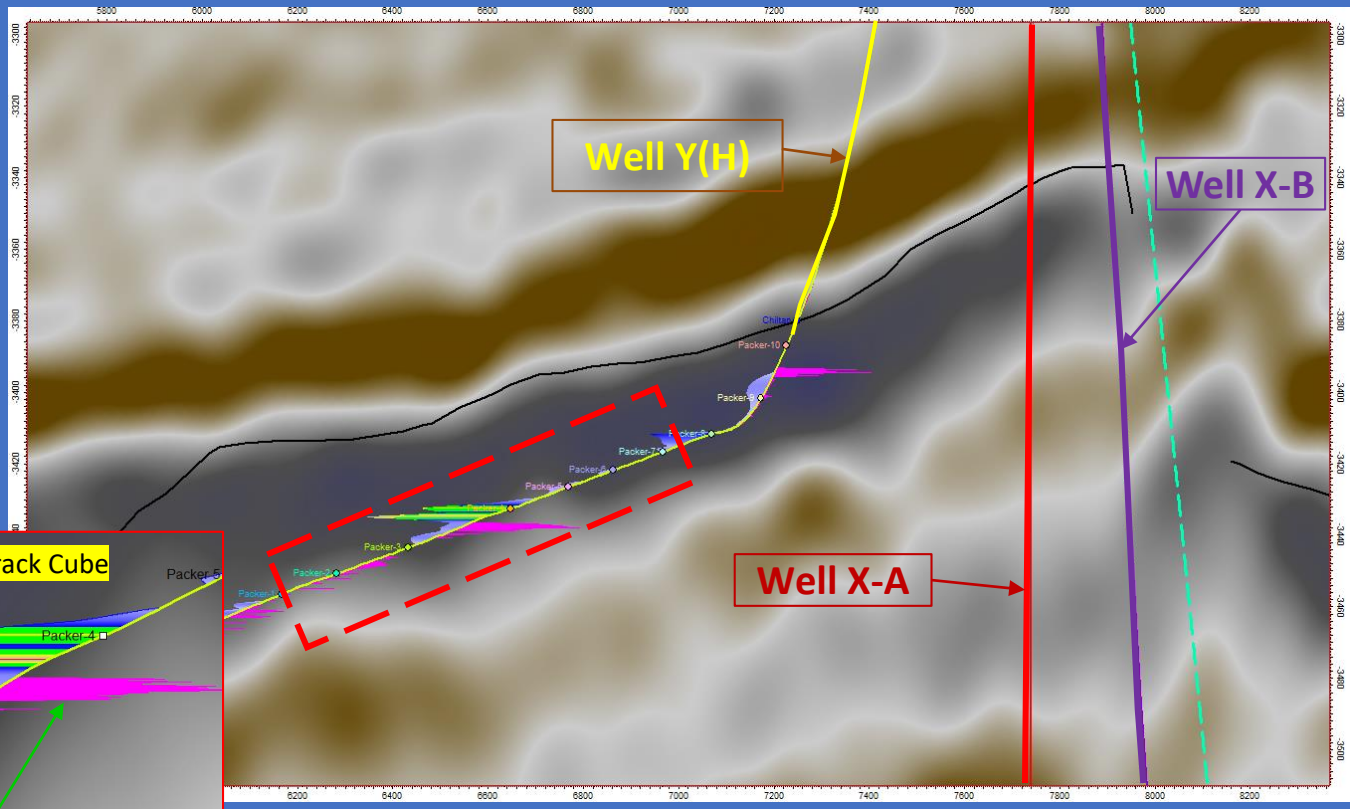


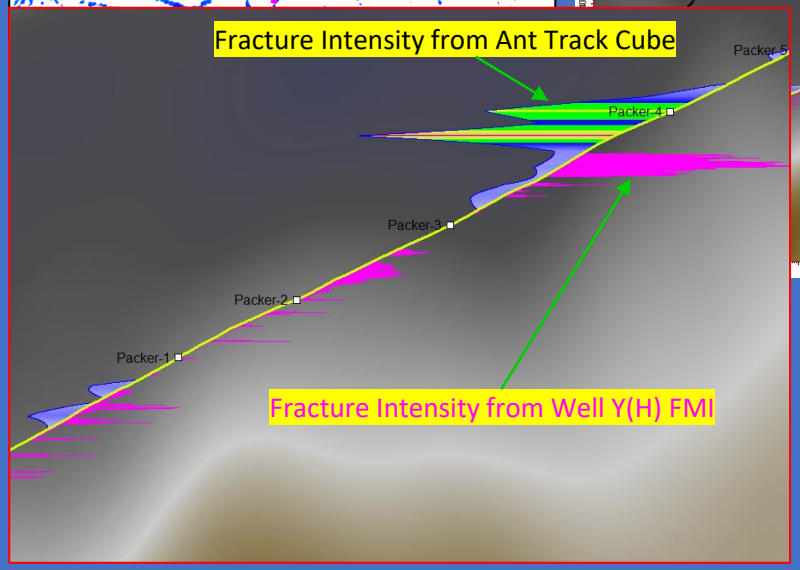

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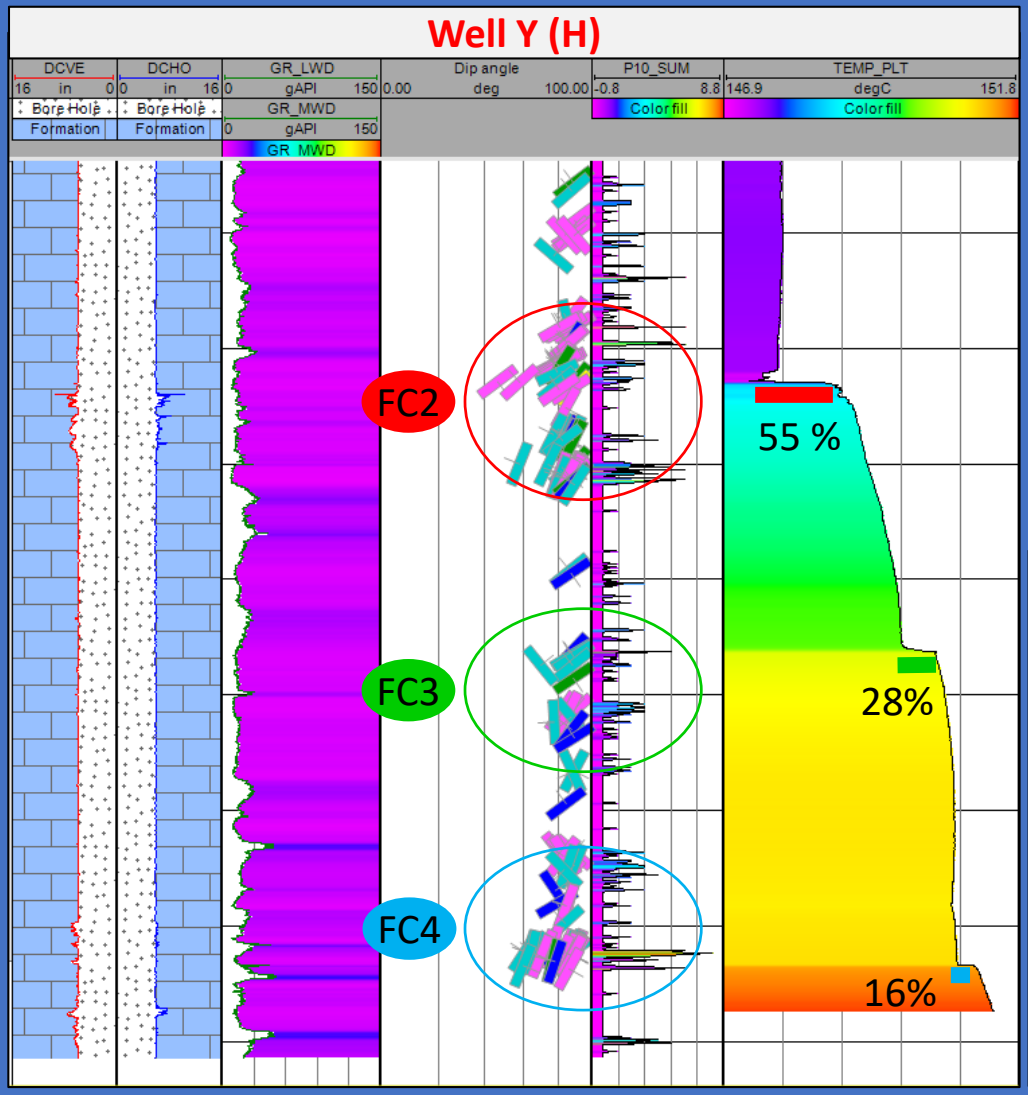


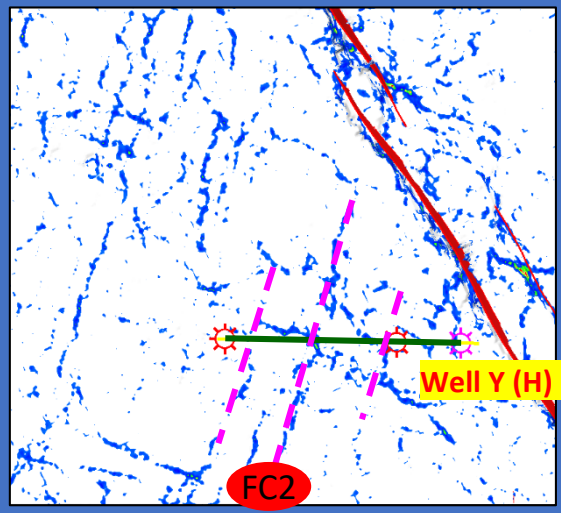


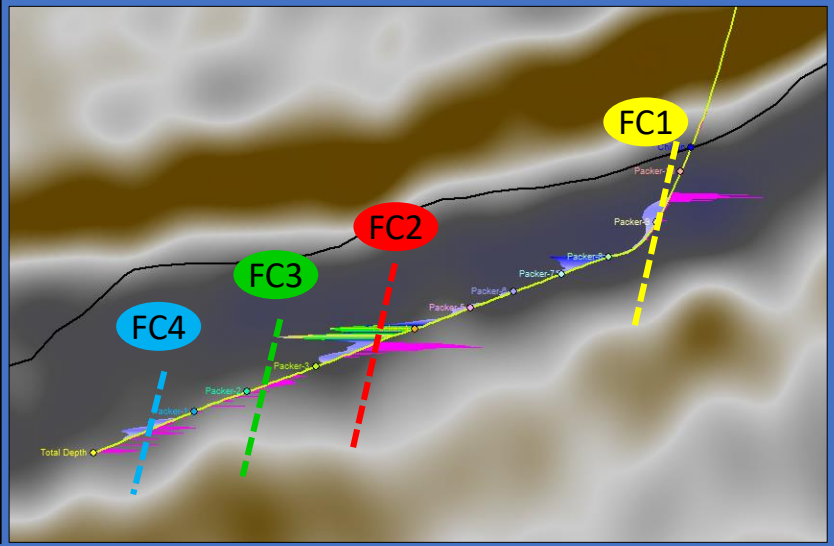

# Conclusions & Recommendations

- Presence and mapping of natural fractures is critical to drain the hydrocarbons from such tight reservoir rocks. Therefore, identify the prospective areas in the basin where natural fractures are present
- Integration of seismic driven fracture maps with well data and regional stress history is key to identify and map the fracture corridors in naturally fractured reservoirs
- Well placement in Chiltan Formation is very critical to get hydrocarbon production from tight reservoir. Deviated or horizontal well drilling is recommended to intersect the high permeability zones (natural fractures) for better hydrocarbon productivity
- More well data and its integration with seismic base studies, in future, will help to better understand the reservoir for opening a new play in the Basin

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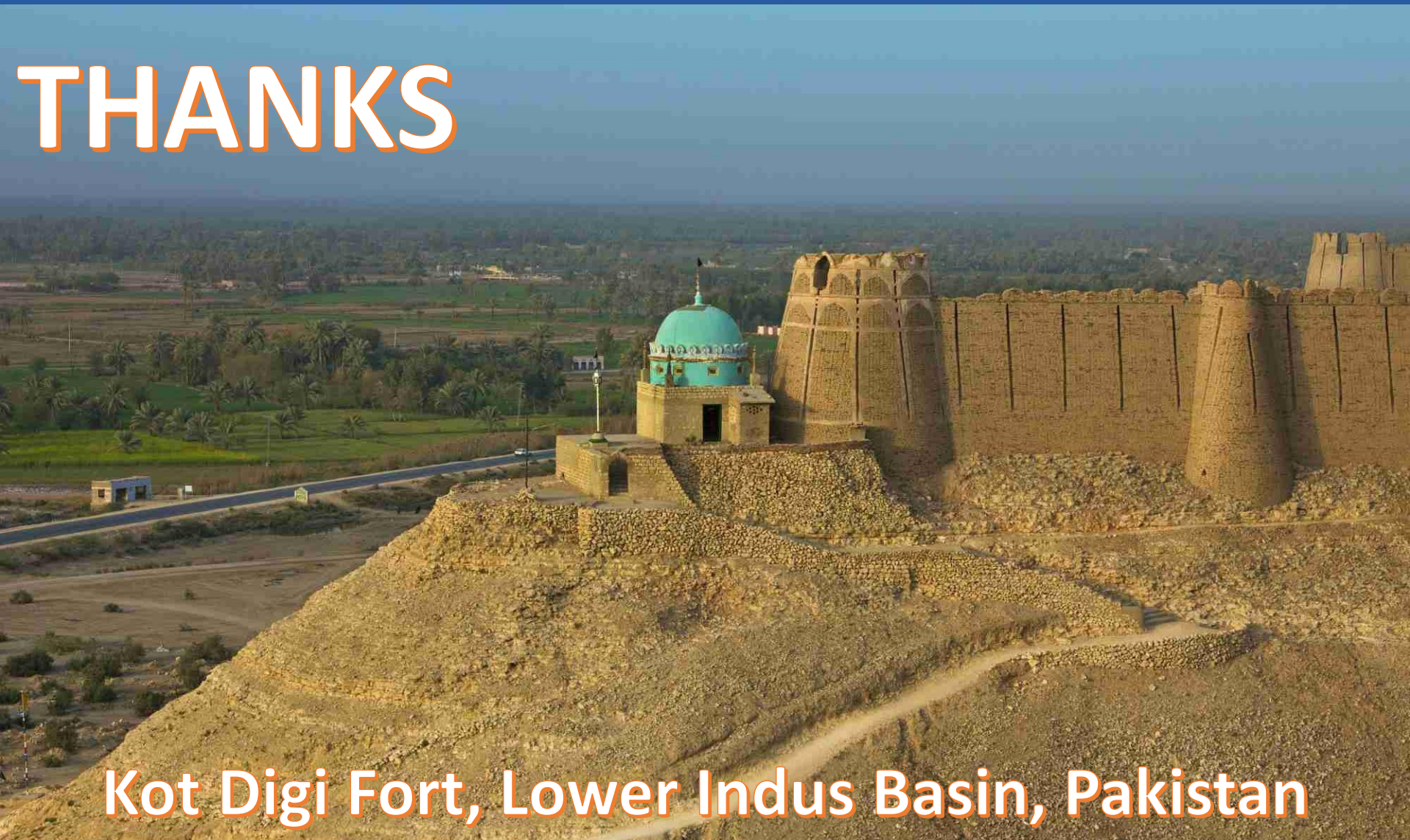
# THANKS



Kot Digi Fort, Lower Indus Basin, Pakistan