Fracture Characterisation of a Complex Carbonate Reservoir: Intelligent Use of Image Logs in a Major Onshore Field, Abu Dhabi, UAE*

Yasmina Bouzida[1], Tim Salter[1], and Fatima Al Darmaki[2]

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Abstract

Characterising the presence and impact of natural fractures is a challenge in many complex carbonate reservoirs. This article describes the successful integration of data across well-bore to field-wide scales of observation, from a Jurassic reservoir, onshore Abu Dhabi. Key to this exercise was the detailed structural and sedimentological analysis of image log data. Maximum value was gained from the image logs by using a customized interpretation framework, and were integrated with open-hole log data and where available, core descriptions. Analysis from key pilot and appraisal wells demonstrated that the reservoir is lithologically heterogeneous, but has a predictable vertical succession of packages, defined by image facies associations that are largely correlatable across the field.

A primary litho-mechanical control from the image facies, recognized a hierarchy of bed-bound and non-bed-bound fractures identification. Most of them will not be extensive vertically and in turn are unlikely to form significant reservoir baffles. Likewise, although some vuggy fractures are observed, they are likely to augment matrix permeability only locally. These fractures density were found to be strongly influenced by well deviation and azimuth, due to relative stratigraphic position and location. This has allowed a hierarchical conceptual model of fracture clustering with range of 10's-100's feet lateral spacing. Structural dip angle is locally increased in the southern and western flanks and correlates with changes in fracture strike and regime. The eastern flank is more affected by reverse faults, while the western flank and the crest are more affected by strike-

slip and traverse faults. The study did provide significant characterization of the many traverse (WNW-ESE and WSW-ENE) faults – that are seen to be laterally discontinuous on the crestal area and typically “en-echelon” and laterally variable in their electrical response. When collated together, all such image log observations have allowed the construction of a conceptual fracture model that links individual wells across the whole field. The intelligent use of the image log data, through a customized interpretation framework, was identified as the key enabler is this process and the exercise has then been repeated for deeper, lithologically differing reservoir units.

Fracture Characterisation of a complex Carbonate Reservoir

Presenter: Yasmina Bouzida [*].
Co-authors: Fatima Al Darmaki [^].
Tim Salter [*].

(^) ADNOC Sour Gas
(*)BAKER HUGHES a GE Company Geosciences & Petroleum Engineering Service.

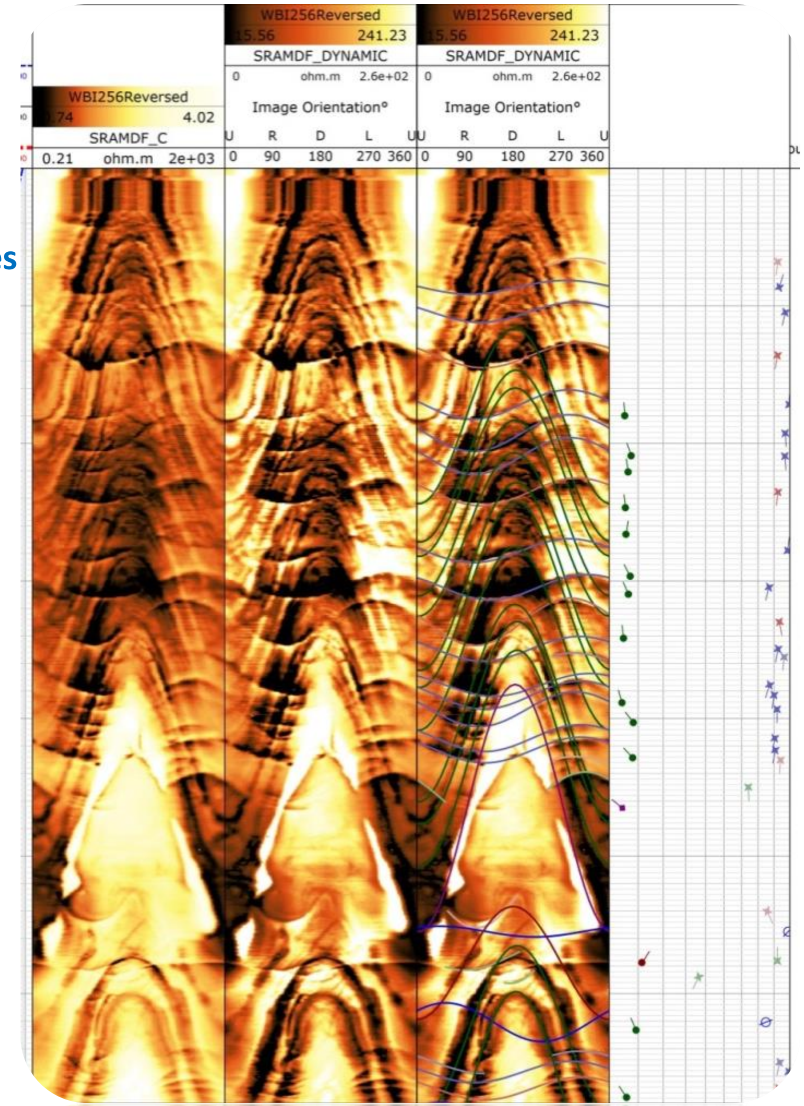
Objectives

Consolidate individual image log reports to **characterise** how **fractures** are distributed within Reservoir A

- Determine **key controls** on fracture presence
- Build a **predictive fracture** (stratigraphy) **model**
- Characterize **scales** of fracture **occurrence/clustering**
- Infer fracture controlled **compartmentalization**

Key Theme:

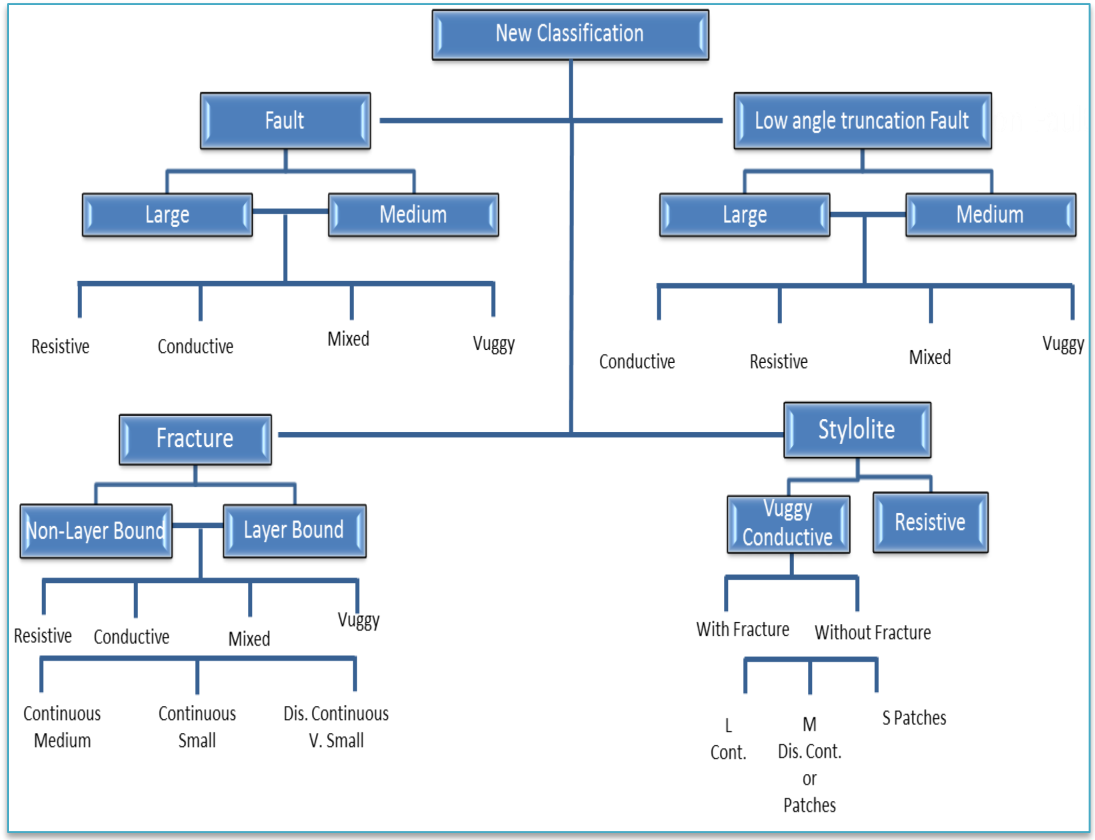
Consistency of original interpretation is essential



Reservoir A Fracture Models

Process

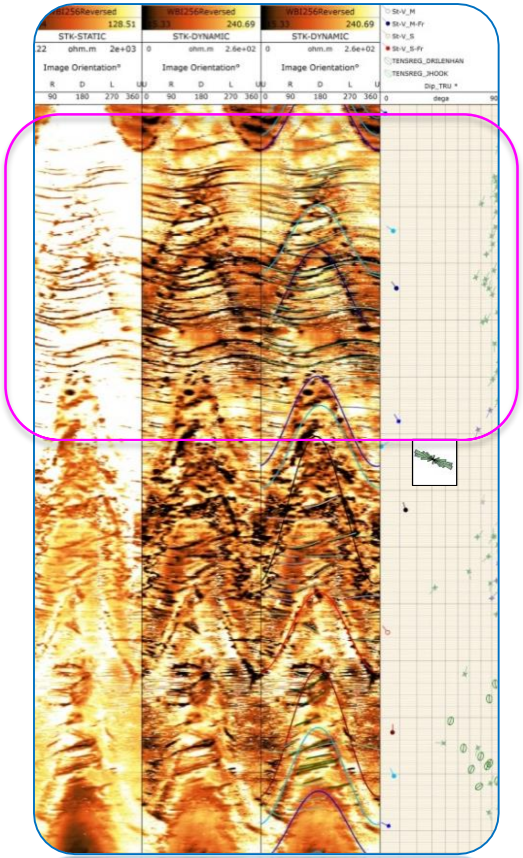
- ❑ Establish interpretation framework
  - ➢ Agreed iteration of dip picking scheme scheme
  - ➢ consistent 'base' interpretation builds later integrated review
  - ➢ consolidate differing data sources
- ❑ Multi technique (walk-out, rose, x-section, correlation) + statistical analysis
- ❑ Proxy templates from near-vertical wells +/- core and log control
- ❑ Extension to horizontal wells with pilot holes
- ❑ Iteration through remaining multi-azimuth horizontals across field



- Consistent classification
- Focus on fractures and fabric

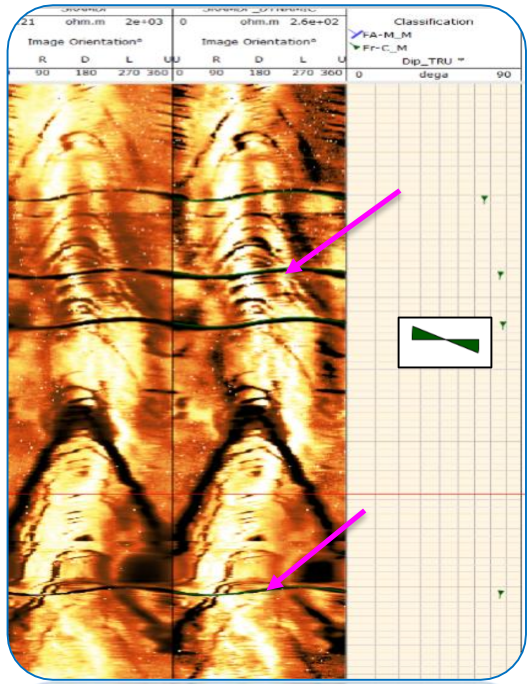
Image examples

Layer bound Fractures



Fracture terminated at bed boundaries

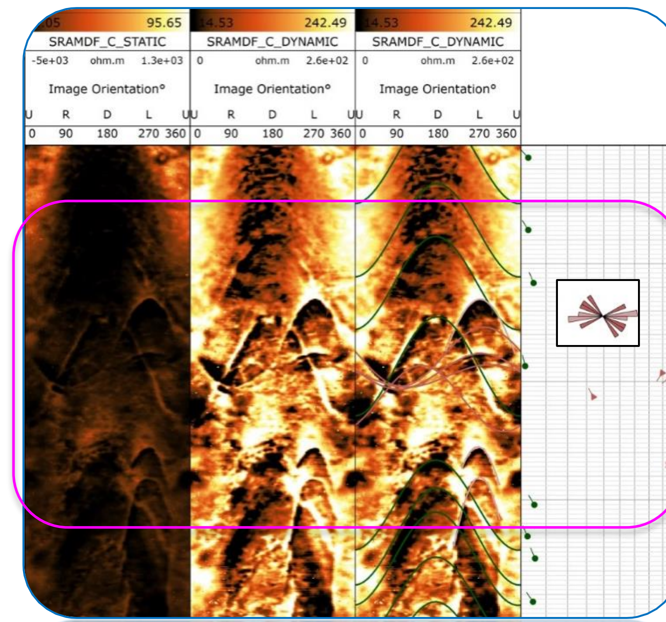
Non Layer bound Fractures

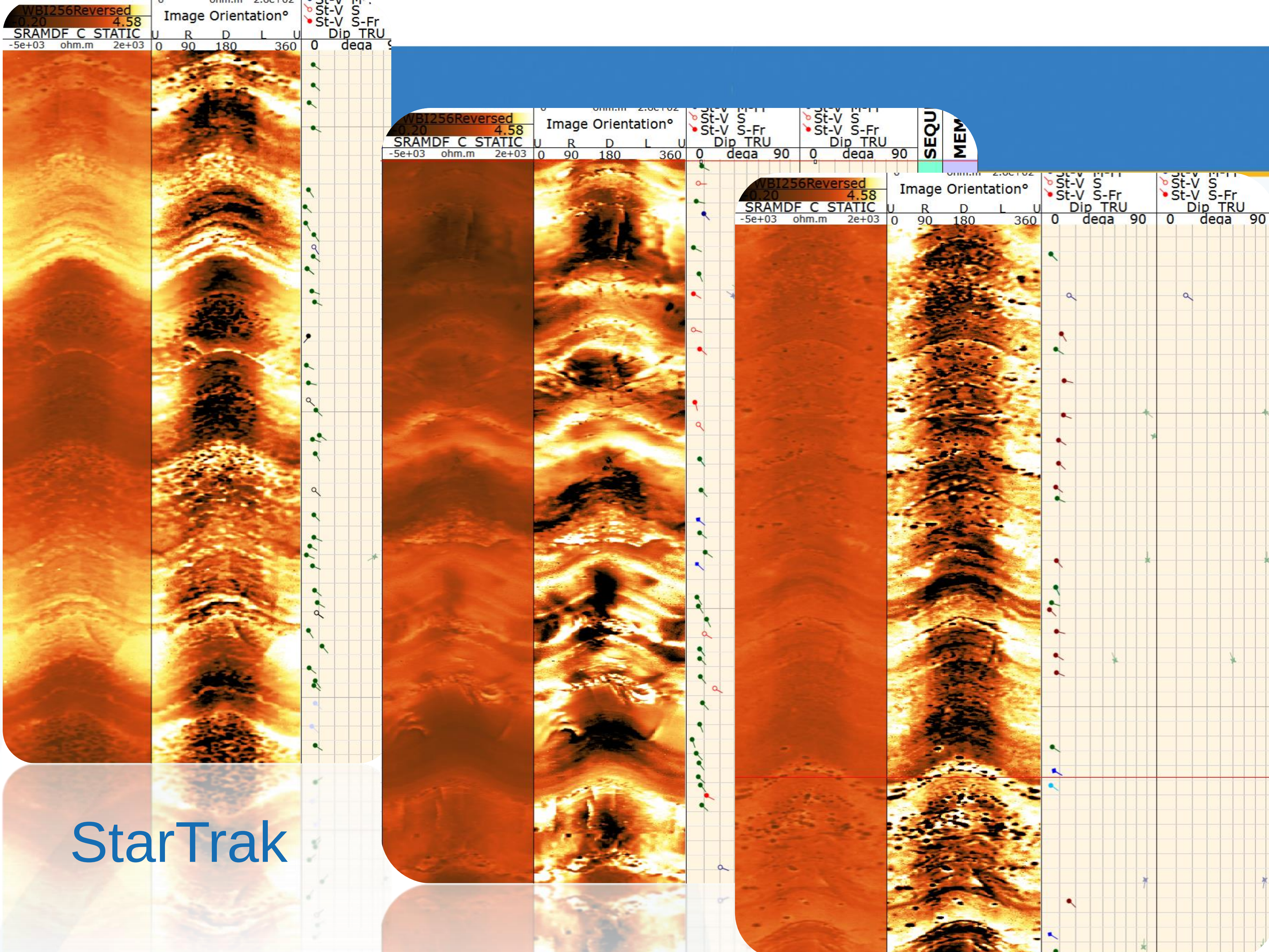


Carbonate bedding cut by high-angle continuous resistive fractures with WNW-ESE & NW-SE strike orientation.

Attention to fracture continuity and aperture

Shear Fractures: Fault (Image scale fault)

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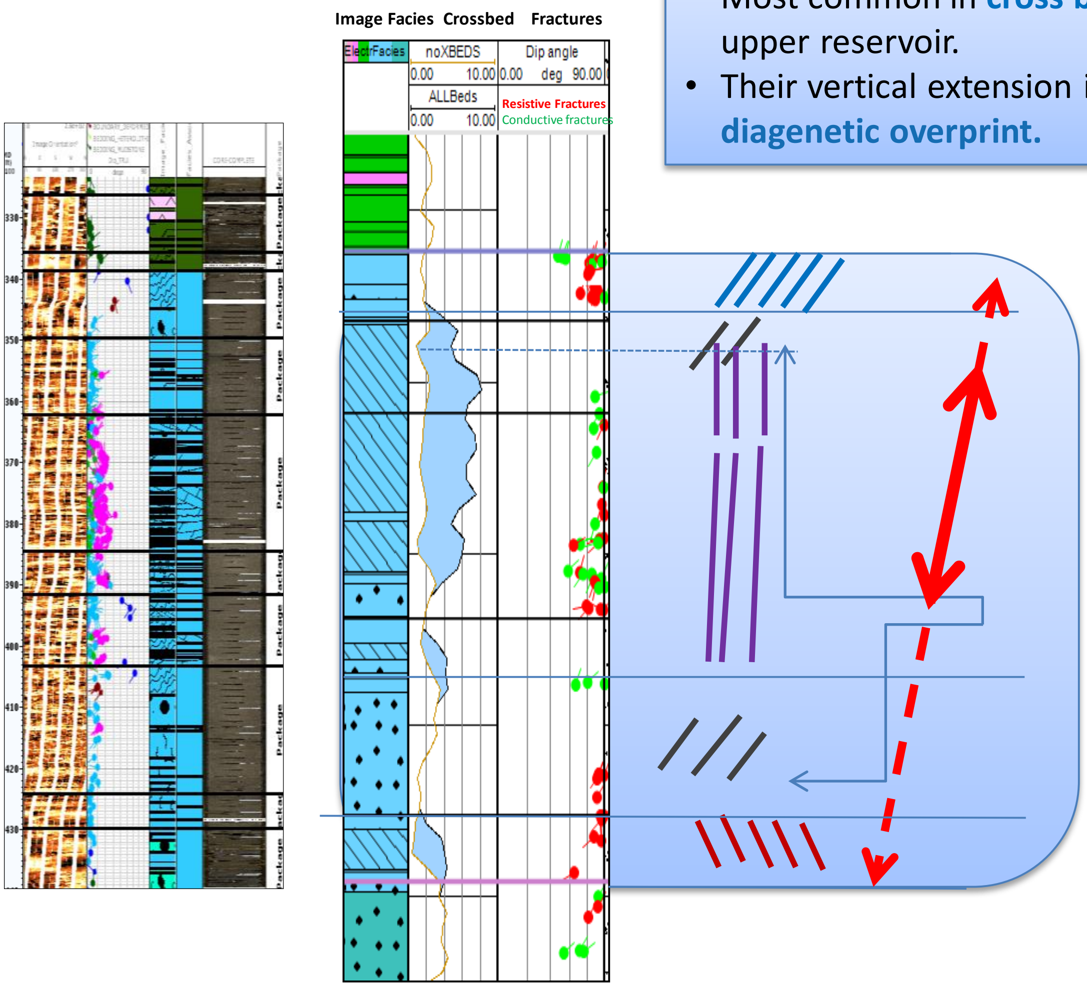
Fracture schematic for a deviated well

- Fractures are **lithologically controlled**
- Most common in **cross bedded** and **massive** intervals within the mid-upper reservoir.
- Their vertical extension is controlled by **the bed thickness** and **diagenetic overprint.**



- **Uppermost Reservoir:**
Brecciated interval. Very fractured, high dispersion but low vertical extension, dominantly resistive.

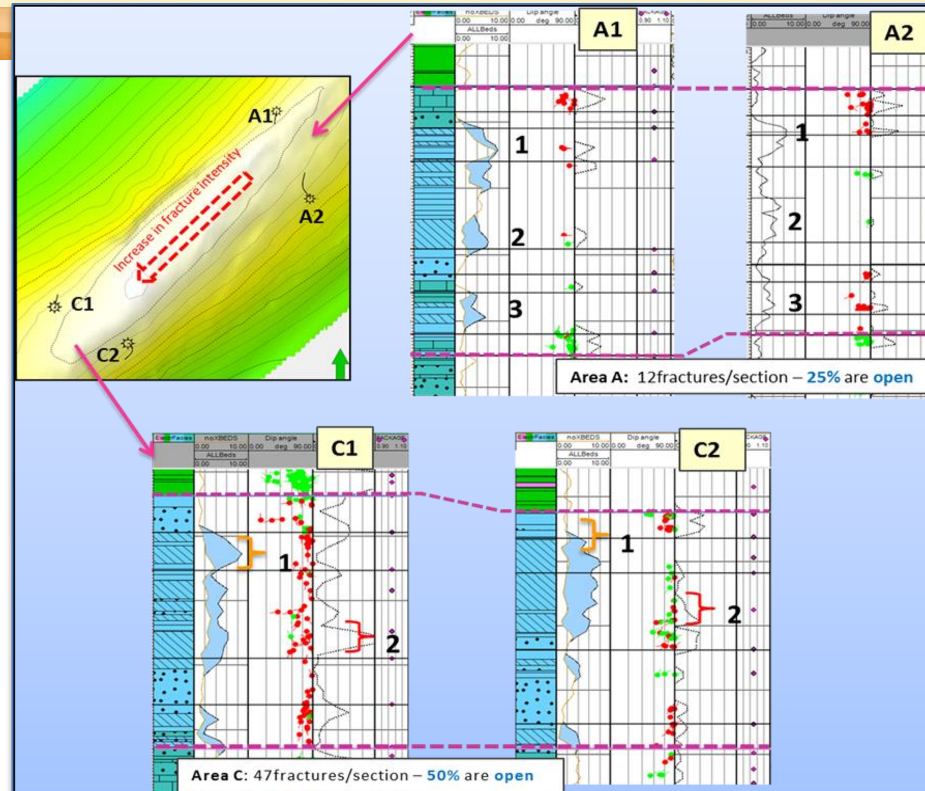
Shear fractures in the middle part of reservoir are most probably the most extensive fractures .. they seem to be "en-echelon".

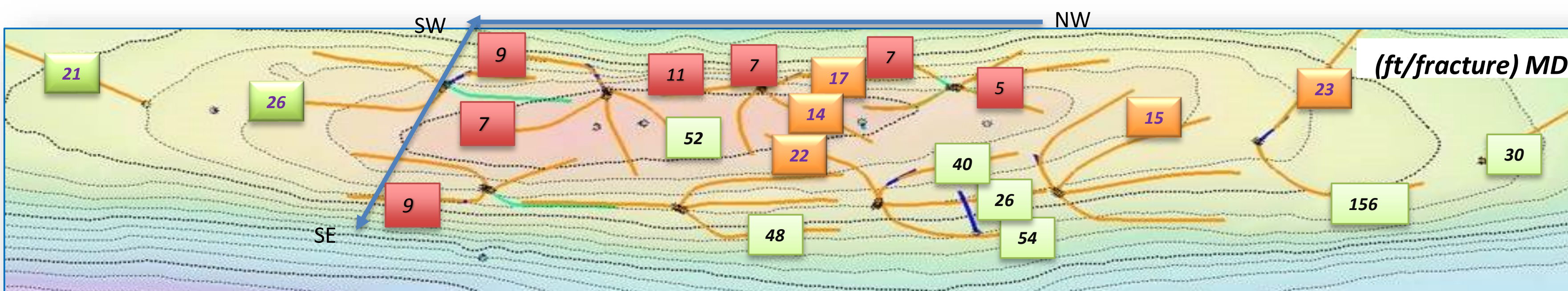
- **Middle reservoir:**
Open and closed fractures present, Vuggy fractures related to bioturbated and bioclastic rich layers. Intersecting sets noted.

- **Lower Reservoir:**
Fractures are most probably related to stylolites and therefore have limited vertical extension.

Areal Fracture Trends

well data suggests more fractures in the south (and especially SW) - with trends matched apparently related to presence of cross-bedding.



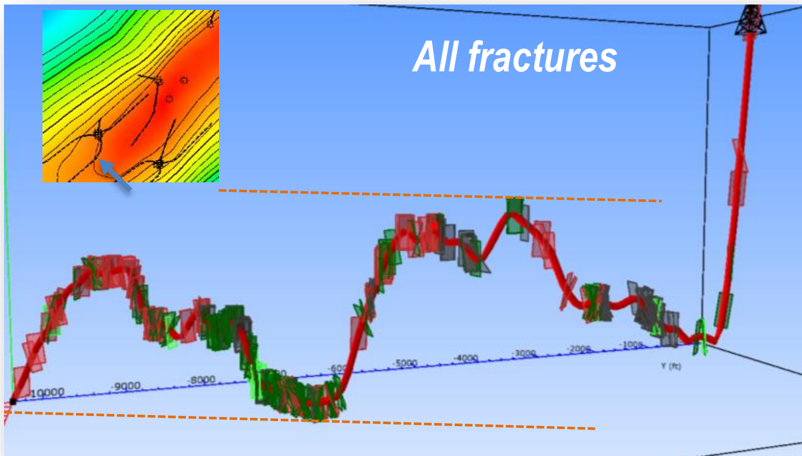


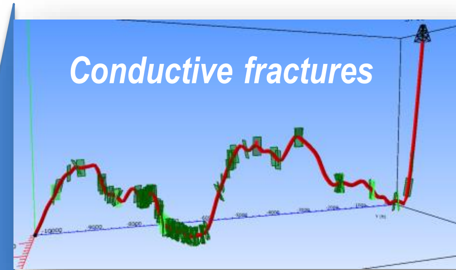
Model of fracture density from vertical wells is less clear in horizontals due to impact of varying well placement & relative data quality… knowing where the horizontal is positioned to make this conclusion

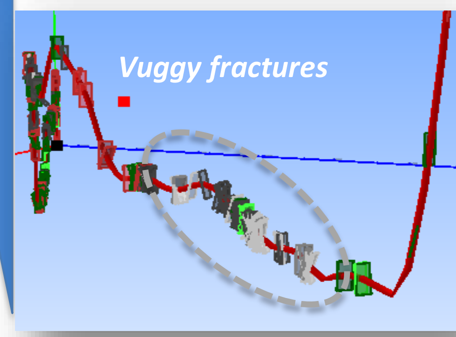
But observations are that higher fracture density areas may be more localised:

- in a NW-SE axis across SW of Field & along W flank.

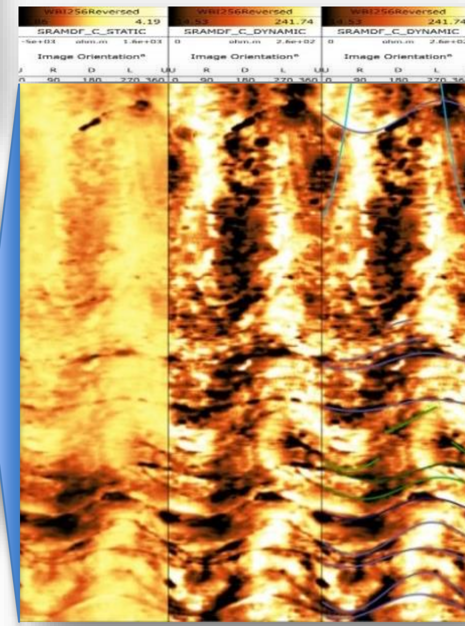
Fracture style relationships







Fractures distribution appears lithologicaly controlled:
The along hole variation in conductive vs resistive features ties to approx. stratigraphic position.

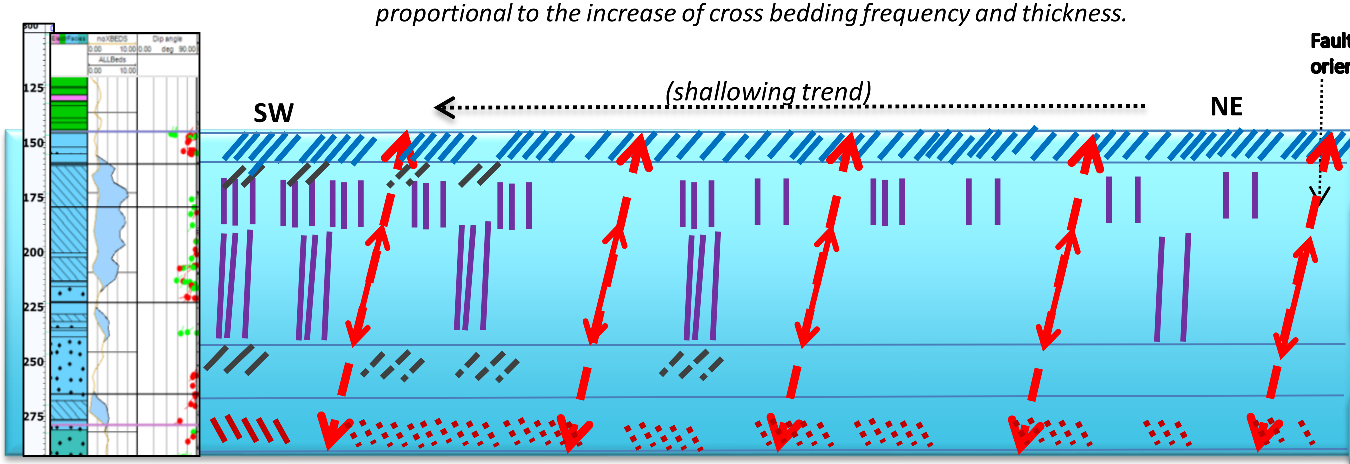


W & SW flank of the field host the most dissolution (vuggy) features
Initial though that vuggy fractures may be important in contribution to reservoir– but actually quite localised in mid-lower Reservoir A and number < 1 in 5 of all fractures

Fracture Schematic extended in a strike section

Increase in fracture intensity towards the W and SW. Fracture intensity is proportional to the increase of cross bedding frequency and thickness.

Faults have different spacing. It depends on orientation and location within the field.



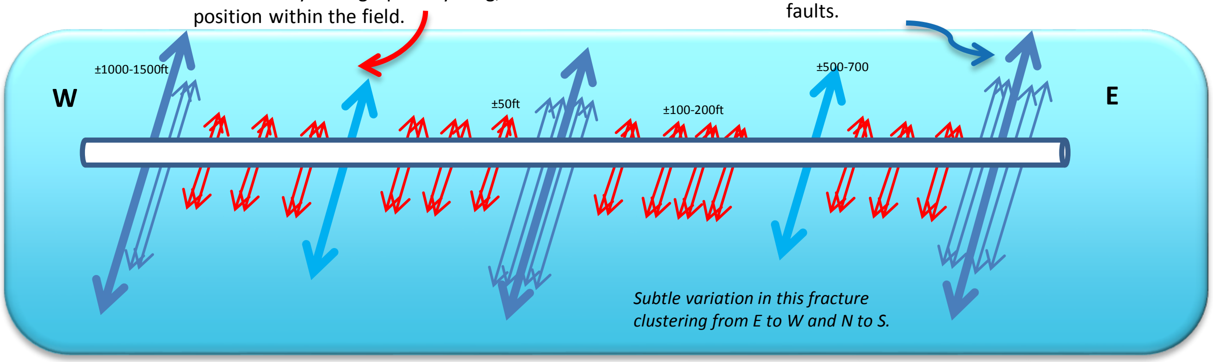
uppermost reservoir unit fractured across entire field

Mid reservoir A fractures are lithologically controlled and most common in x-bedded intervals. Their vertical extension is controlled by bed thickness and diagenetic overprint.
Vuggy fractures are developed more locally within bioclastic rich layers and possibly bioturbated intervals.

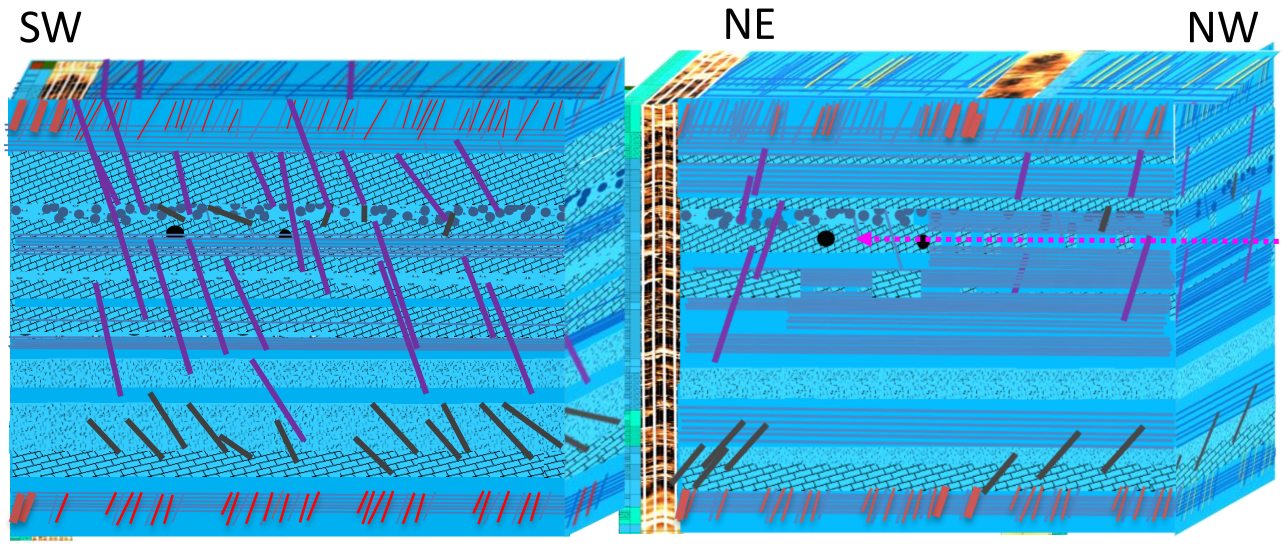
lowermost reservoir fractures may enhance communication with deeper reservoir units in the southern field areas where units are discomformable.

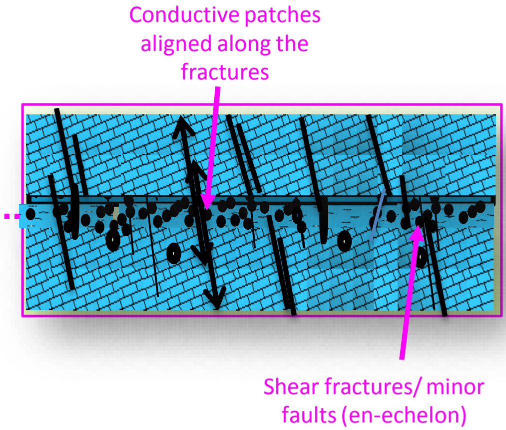
Small - medium fracture cluster spacing are controlled by stratigraphic layering, well azimuth and position within the field.

Fracture clusters and image log faults with spacing over 500 -1100ft distances may correspond to seismic (grid) faults.



Linkage of Predictive Fracture Model and Lithology

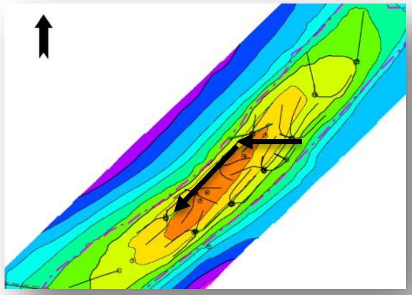




Significant increase of cross bedding and bioturbation and skeletal layers towards the West and South West.

Bedded limestone. Only rare cross beds are seen on the North East flank

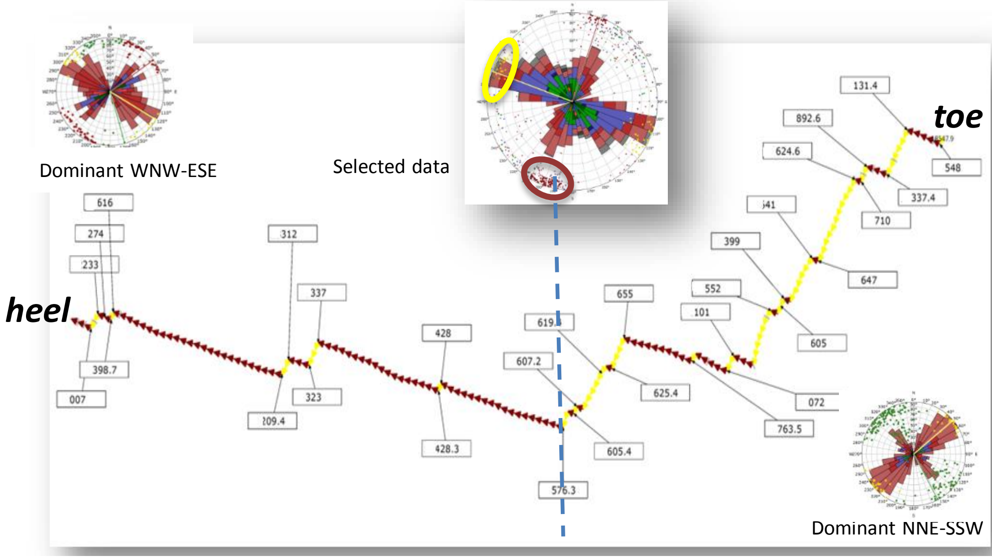
depositional dip

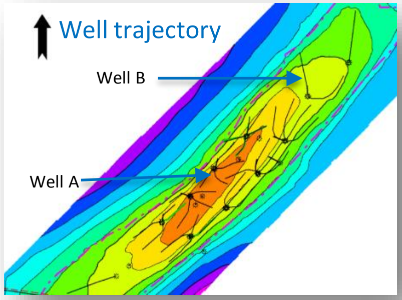


Fractures are stratigraphically controlled but at reservoir zone scale
They are **mainly resistive** but **vertically dis-continuous** – so unlikely to be complete baffles

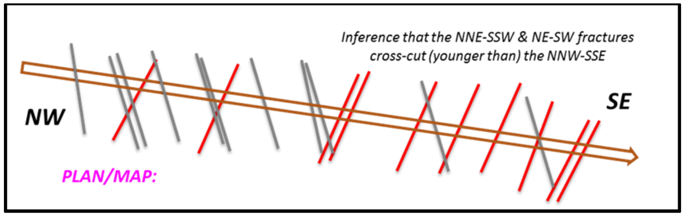
Note use of differing image datasets

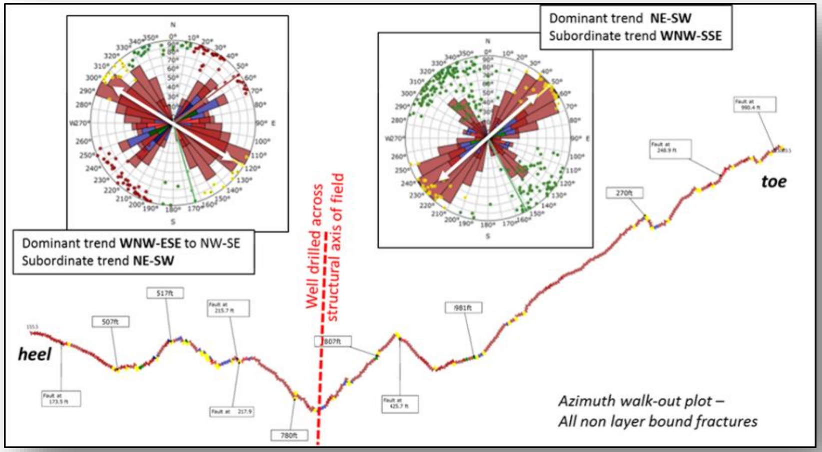
Fracture strike orientation across the axis of the field. (non layer bound fractures)





Fractures strike and frequency follows fold axis and change in structural dip

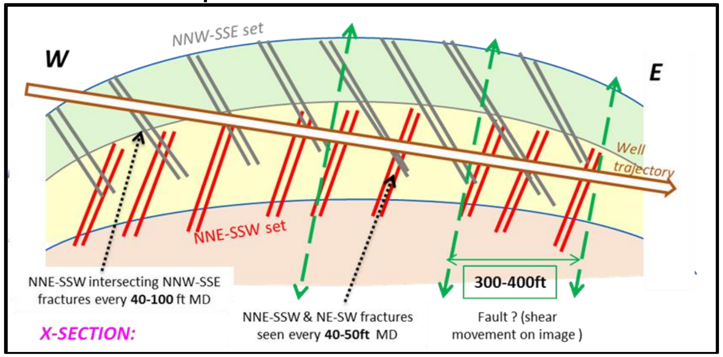


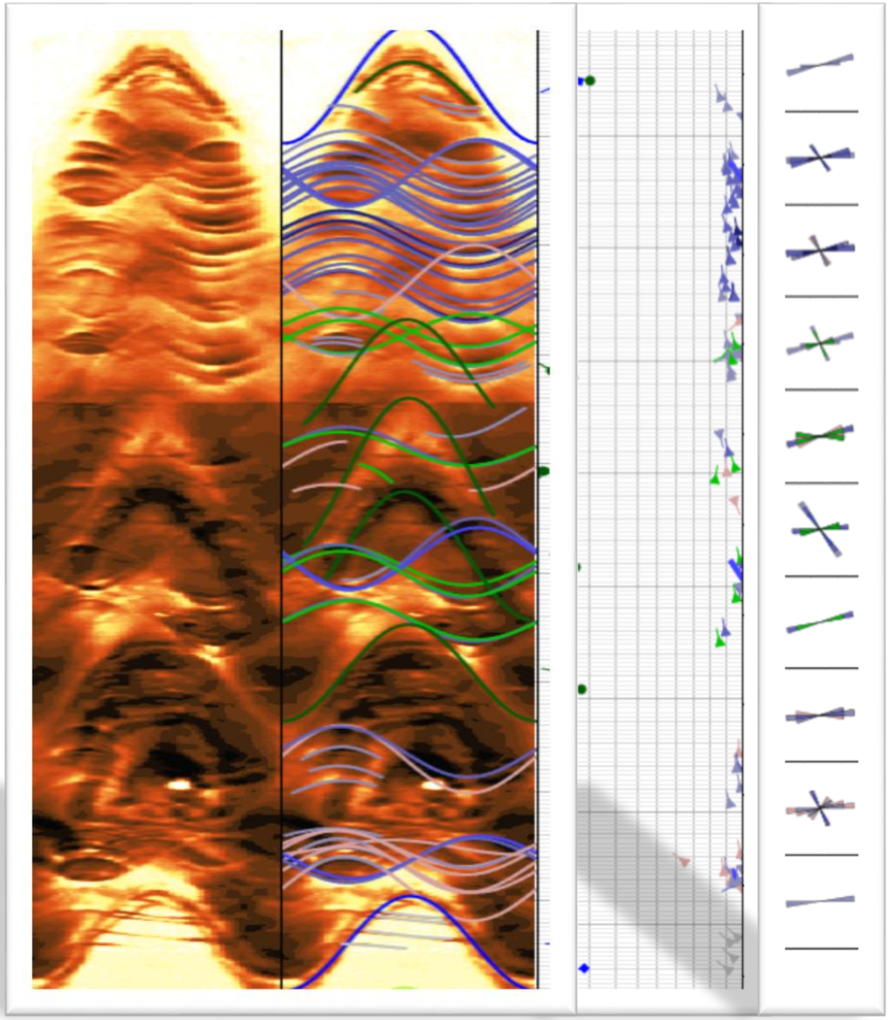


Key here is that distilling fractures by looking only at features closely aligned to the mean 'set' azimuth reveals a more systematic spatial change in fracture presence and orientation from West to East of the crestal area….

From Fractures to Faults

Conceptual Fracture Set Models

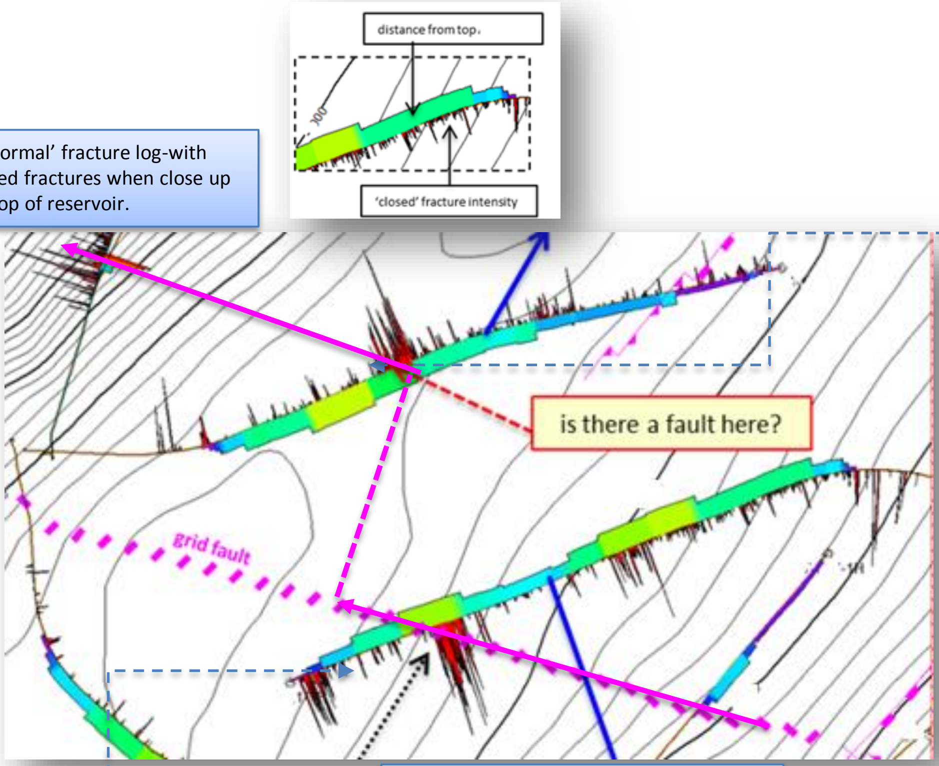


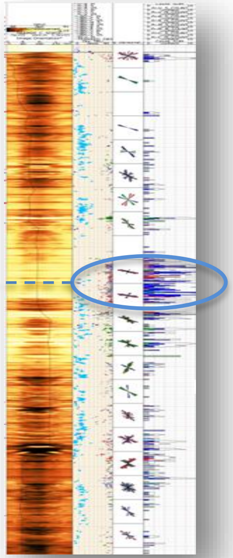


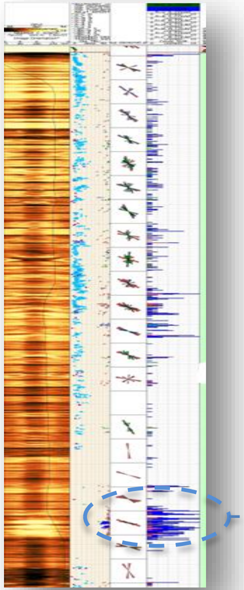
1: Fracture densities as a marker for Faults

*fracture density on image logs indicate WNW-ESE faults are "**en-echelon**".*

Looks like "normal' fracture log-with increase in closed fractures when close up to top of reservoir.



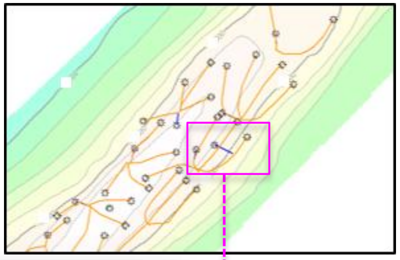




Increase in closed fractures in mid Reservoir A: good justification for a fault or maybe just base of reservoir?.

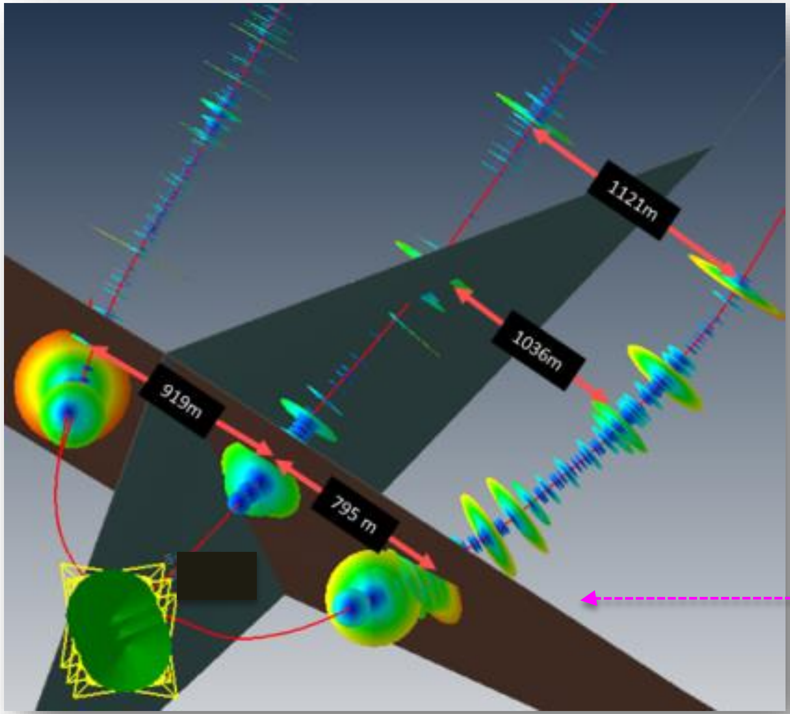
2: Lateral change of the resistivity character of Grid Fault.

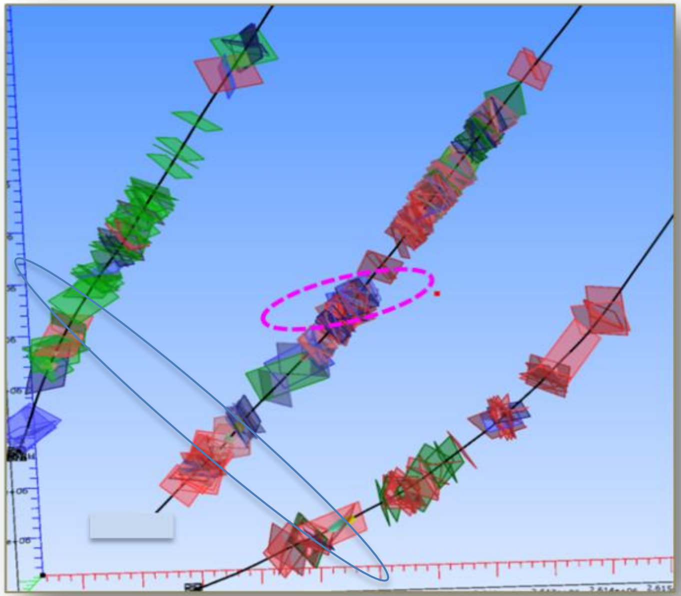
All these 3 Wells pass through a 'grid' fault in their heel sections – in each case the fault could be tied to an adjacent fracture cluster



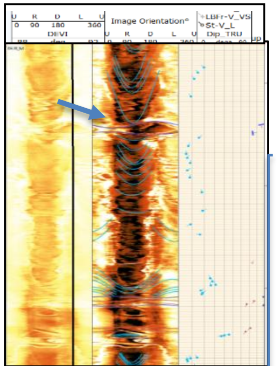
The (fracture) resistivity character of the fault **changes** between laterals:

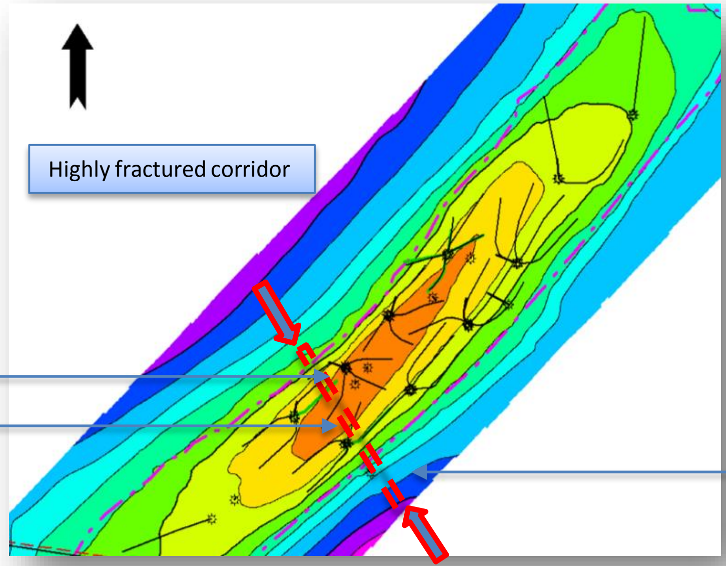
- may depends on which unit is intersected
- but indicative of laterally variable/terminating faults



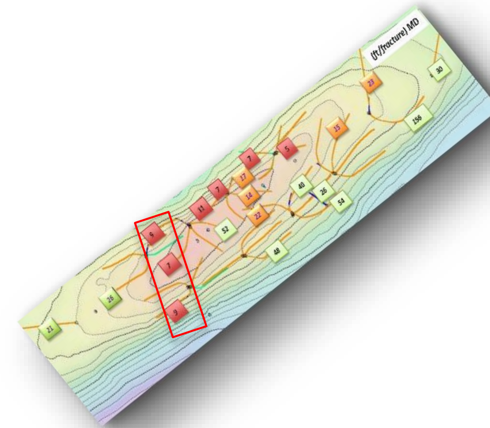


3: Lateral variation of fault strike orientation across the axis of the field



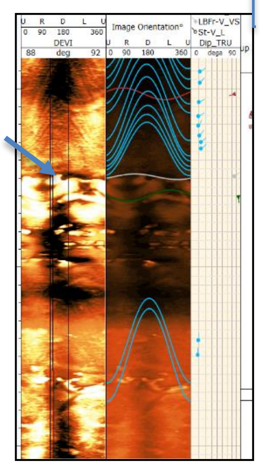


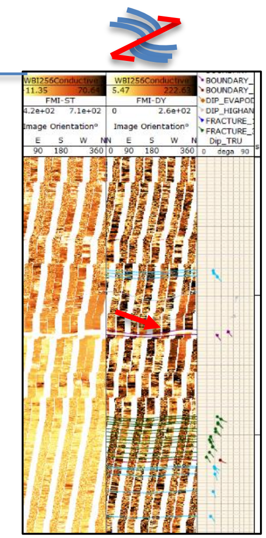
Highly fractured corridor

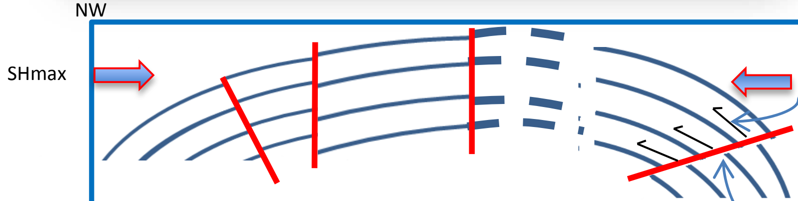


WSW-ENE Low angle truncation fault (20-40°)

Normal and Strike-slip faults





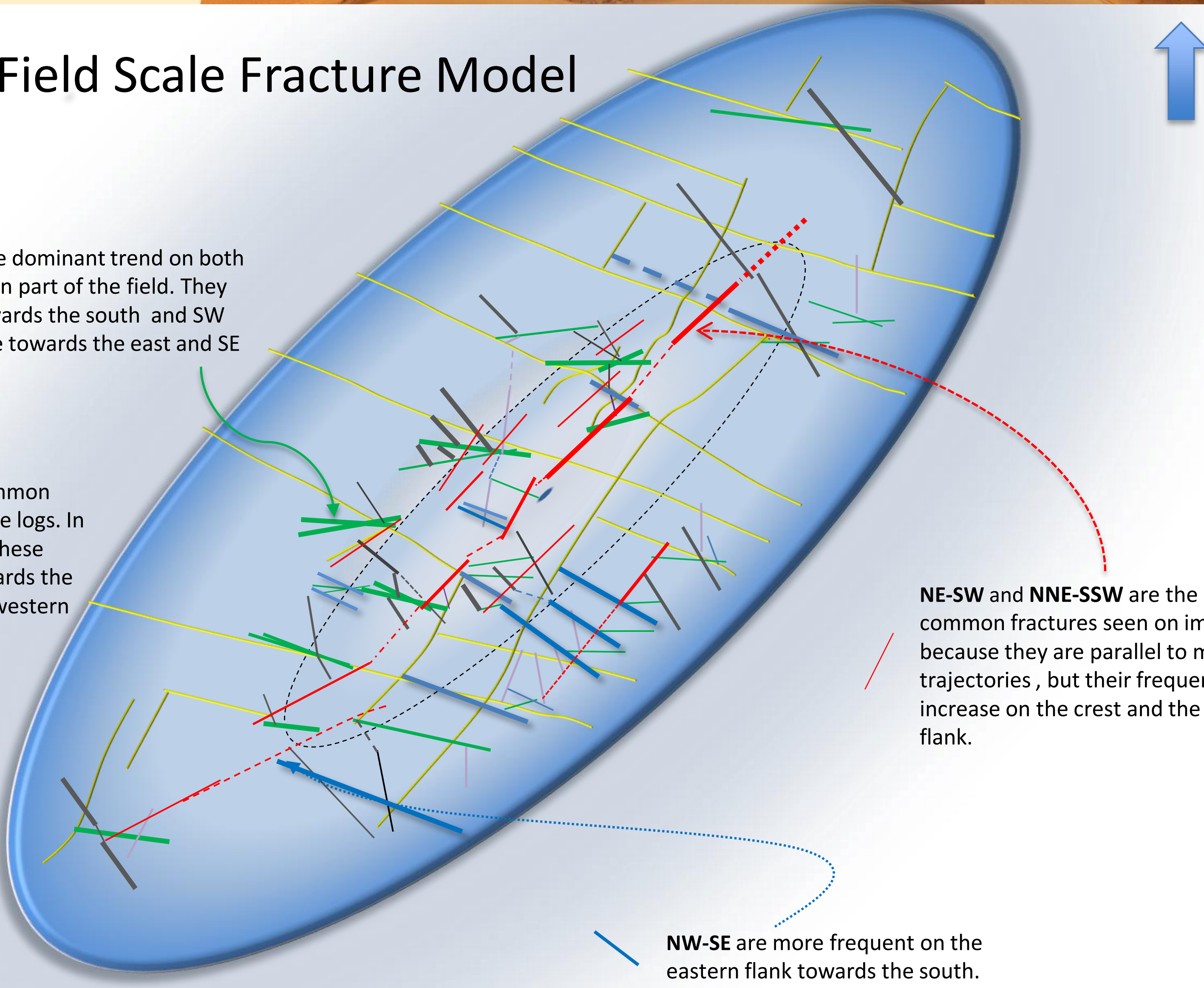


Shear movement along bed boundaries, mainly observed between mudstone and anhydrite

Low angle truncation fault (<40˚)

Faults are different from SE to NW flanks and crestal area.
East flank may be more affected by compression regime.

Composite Field Scale Fracture Model



WNW-ESE/ ENE-WSW are dominant trend on both edges, and in the western part of the field. They increase significantly towards the south and SW Their frequency decrease towards the east and SE

NNW-SSE are the most common fractures seen on the image logs. In general the frequency of these fractures are increase towards the North of the field. On the western half of the field.

NE-SW and **NNE-SSW** are the least common fractures seen on images because they are parallel to most well trajectories , but their frequency increase on the crest and the east flank.

NW-SE are more frequent on the eastern flank towards the south.

Reservoir Fracture Model Conclusions

- Fracture intensity increases towards the SW and seems proportional to an increase in cross-bed thickness
- Vertical fracture extent is thought controlled by the bed thickness and diagenetic overprint
- Vuggy fractures are least common fracture type - they are localized within some layers and more common in the West and SW of the field.
- Fractures noted across a variety of scales – ordered into different "clusters" – that are recognized with spacing of 40-50, 80-100, 200, 500-700 and 1000 (MD) ft.
- 'Seismic' faults generally not confidently linked to obvious image fault clusters/shear features
    - they may be identified equally by an increase in fracture density/alignment or by a single (mainly resistive /mixed) shear fault plane or damaged zone.
- Number of fractures and faults vary with location in the field but also significantly (for horizontals) due to borehole azimuth and deviation
- It is suggested that both fractures and seismic (faults) will not be critical as either enhancing or degrading features
    - Both show lateral constrained dimensions, variable character and absence of strong 'damage zone' linkage

Acknowledgements

- The authors would like to thank ADNOC Sour Gas (Subsurface Division) for providing the data and support. The authors would like also to acknowledge Abu Dhabi National Oil Company (ADNOC) and Occidental Oil and Gas Corporation (OXY) for permission to present this work.

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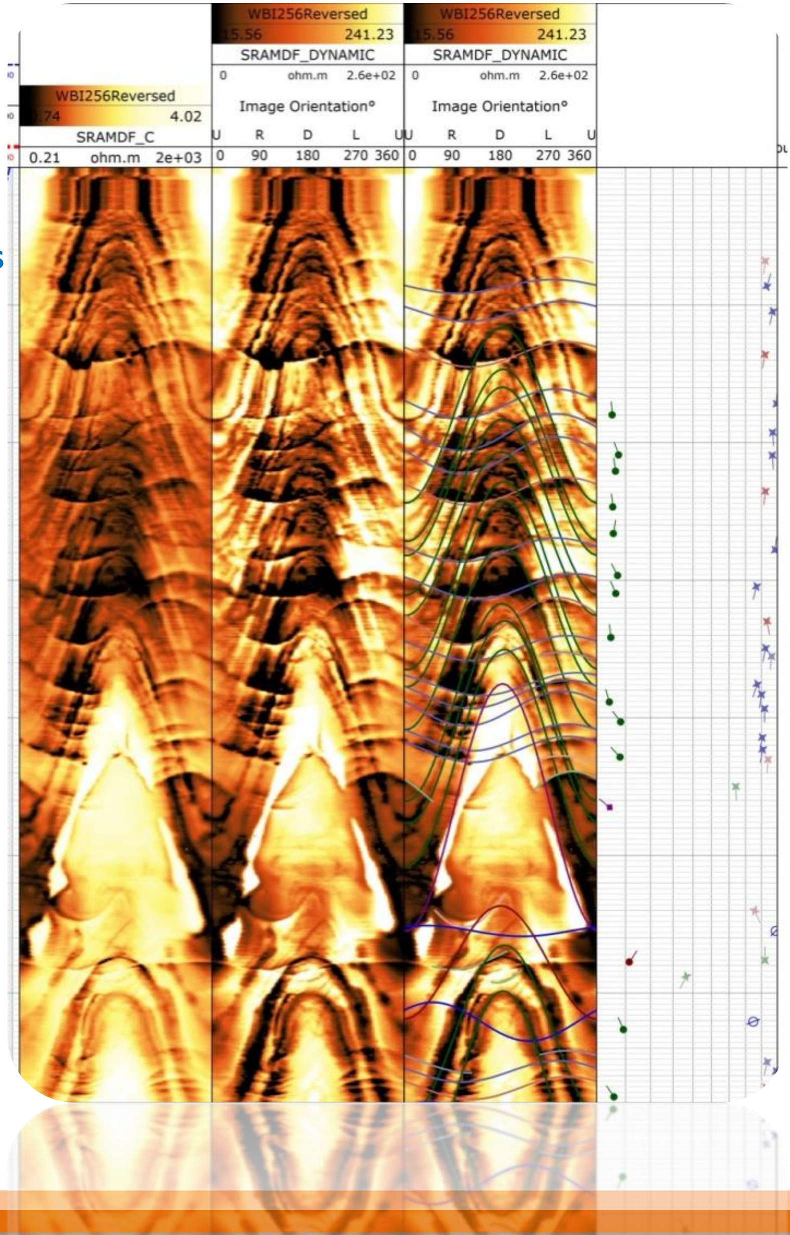

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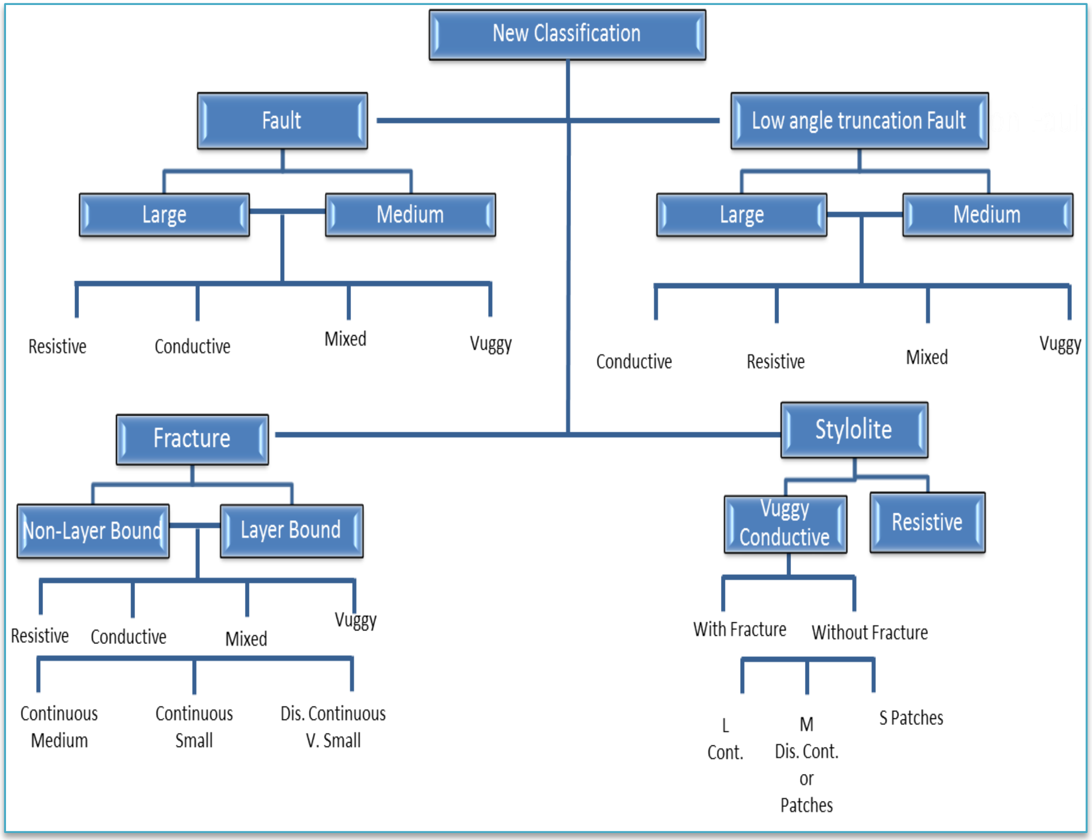

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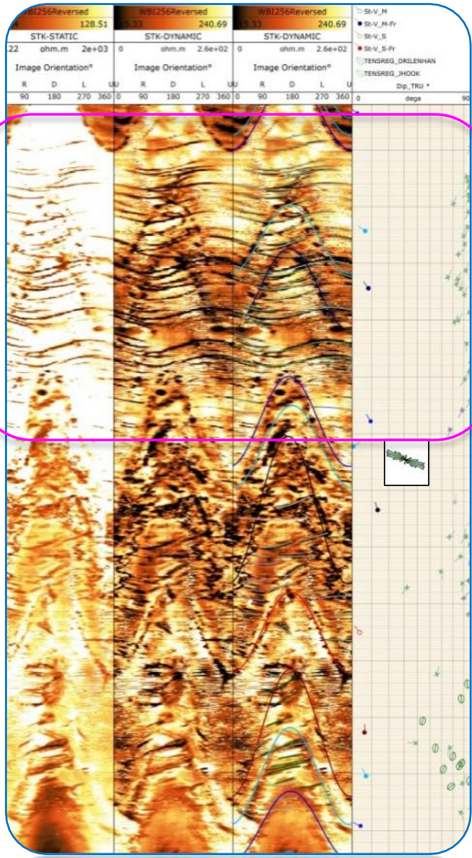

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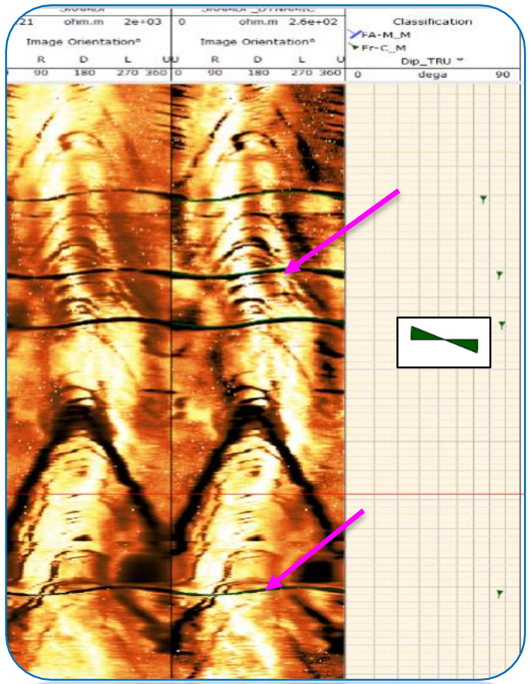

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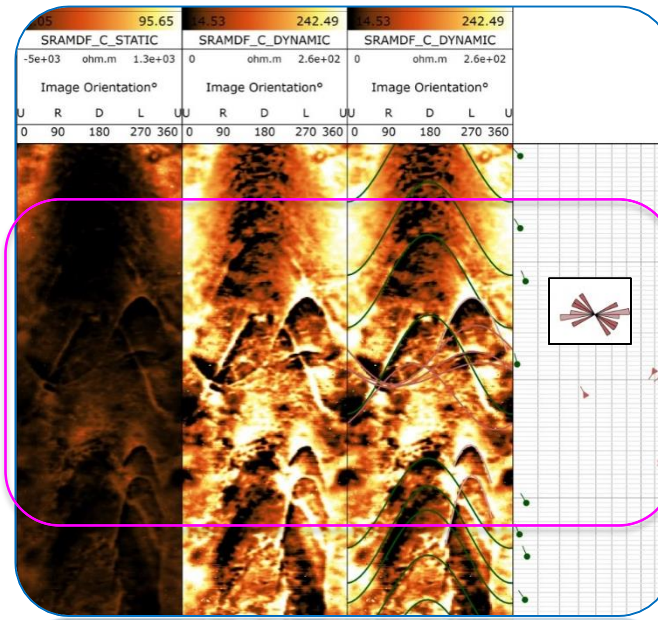

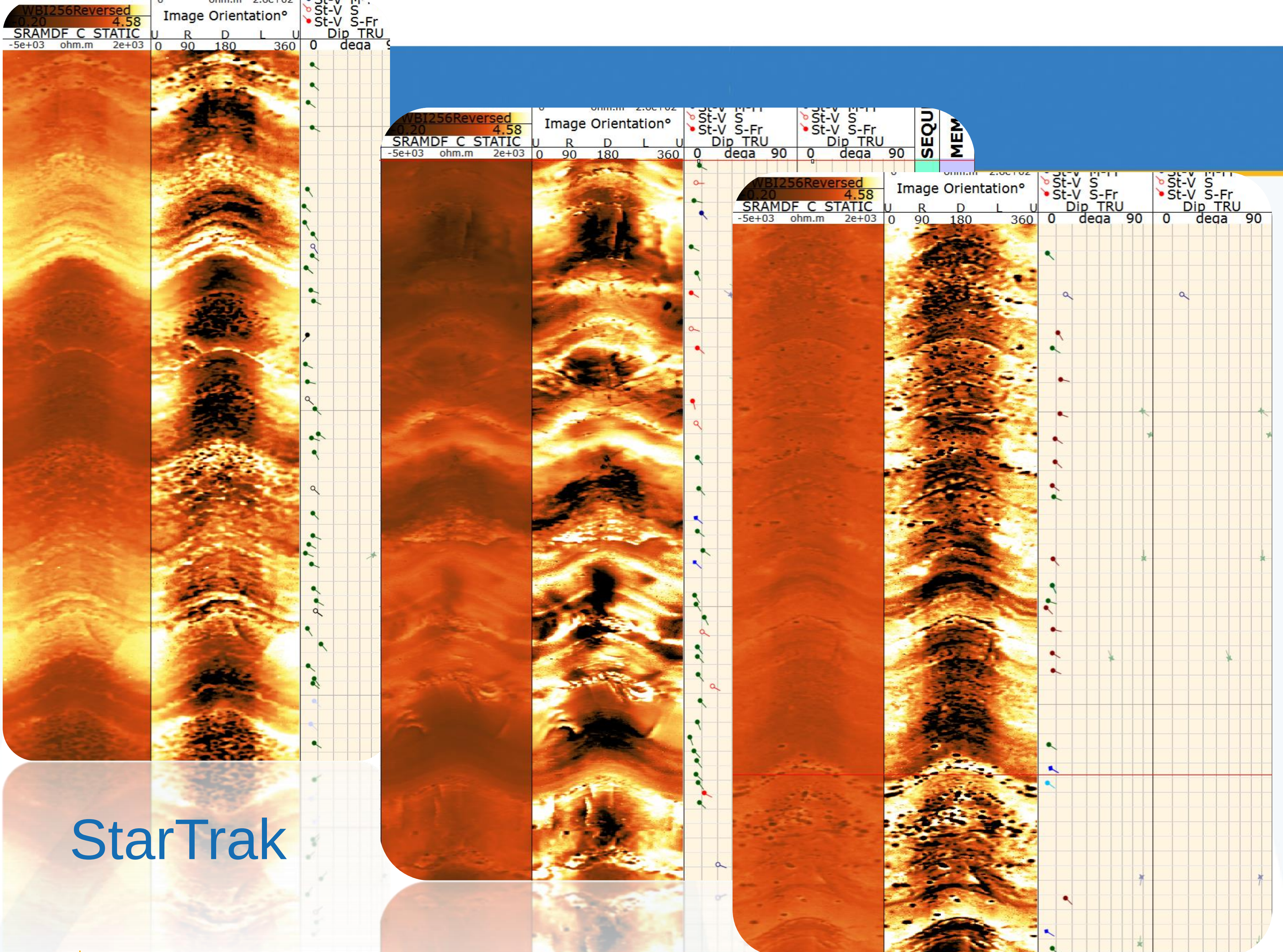
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StarTrak

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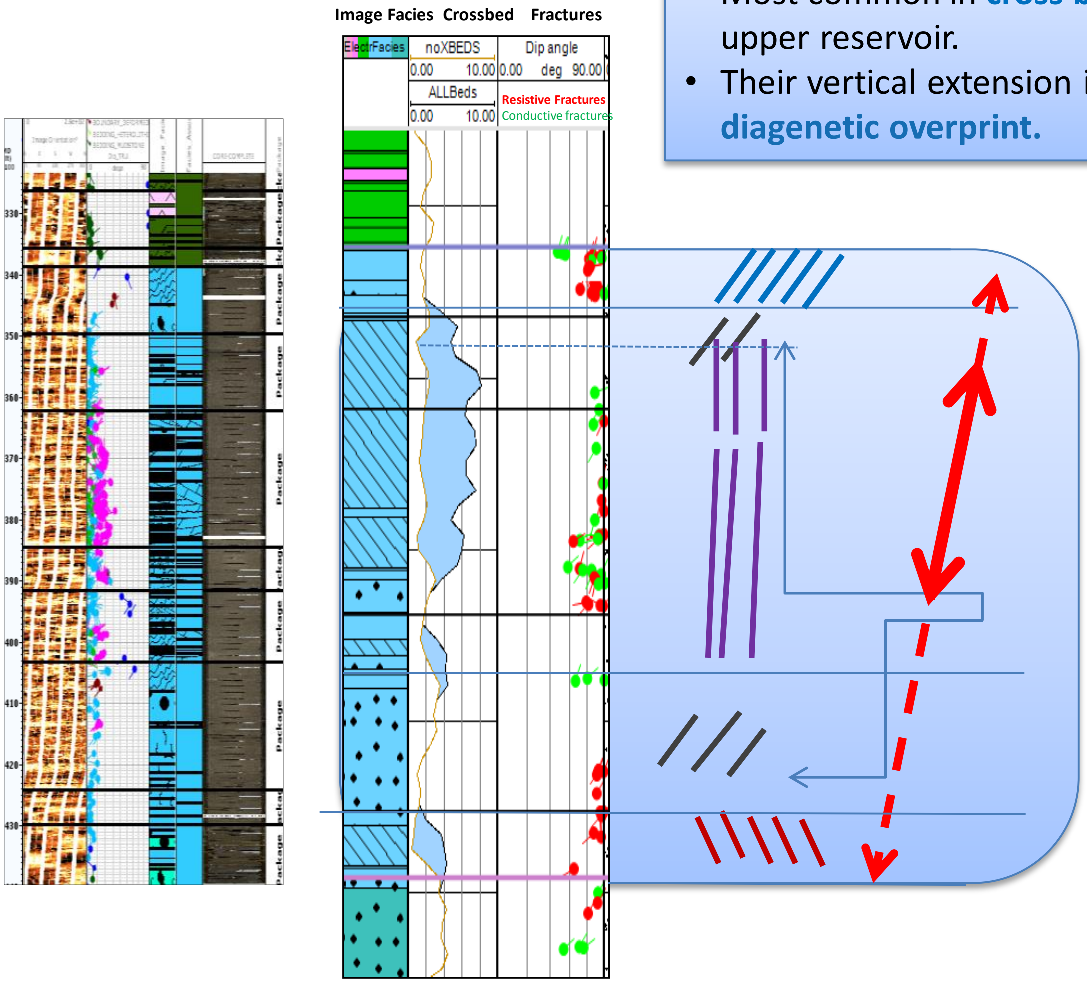

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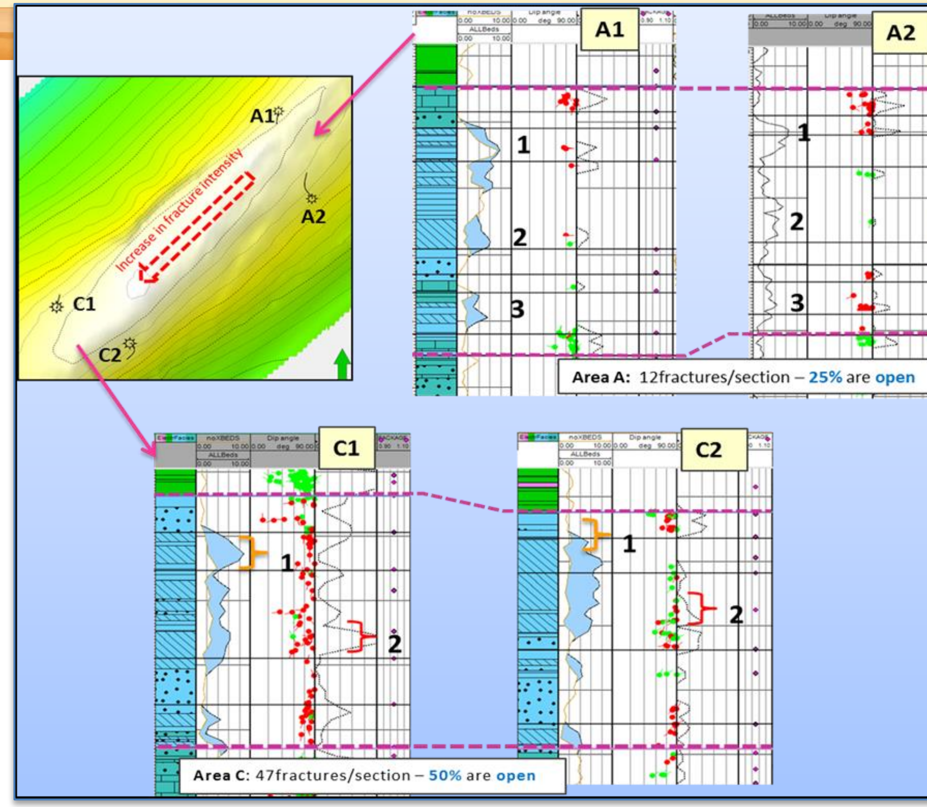
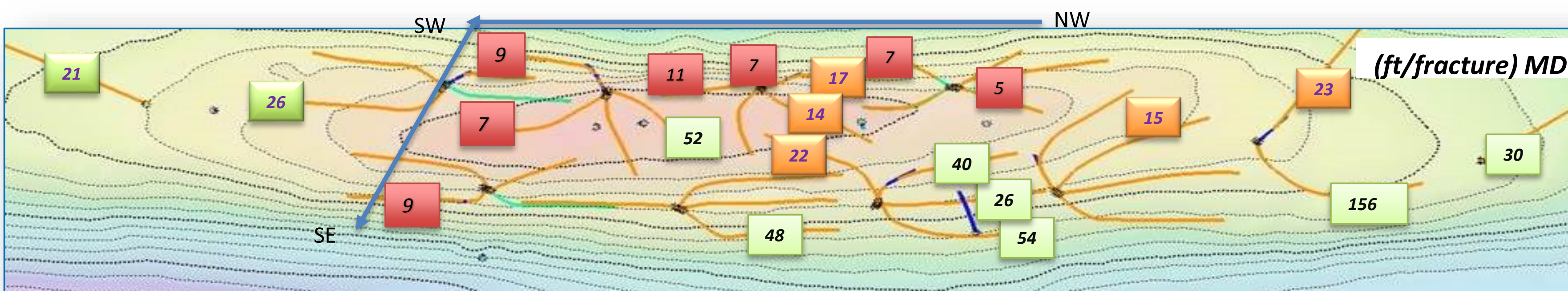
well data suggests more fractures in the south (and especially SW) - with trends matched apparently related to presence of cross-bedding.



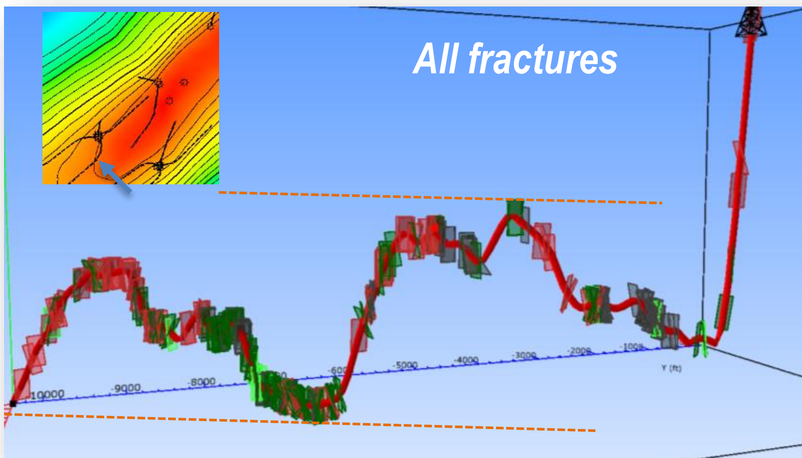


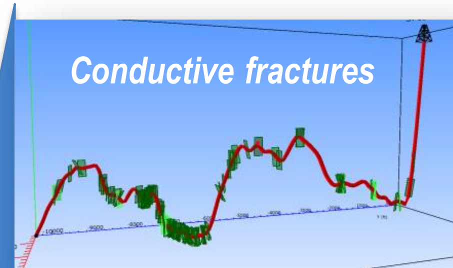
Model of fracture density from vertical wells is less clear in horizontals due to impact of varying well placement & relative data quality… knowing where the horizontal is positioned to make this conclusion

But observations are that higher fracture density areas may be more localised:

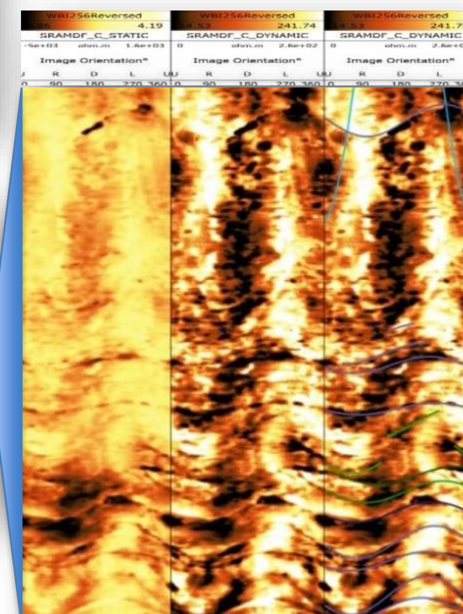
- in a NW-SE axis across SW of Field & along W flank.

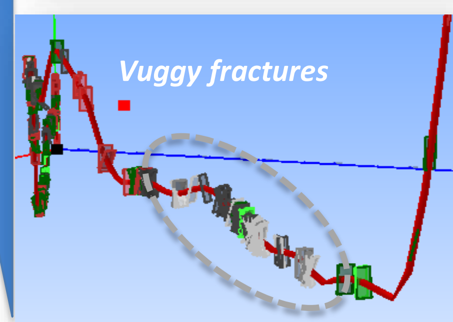
Fracture style relationships





Fractures distribution appears lithologicaly controlled:
The along hole variation in conductive vs resistive features ties to approx. stratigraphic position.

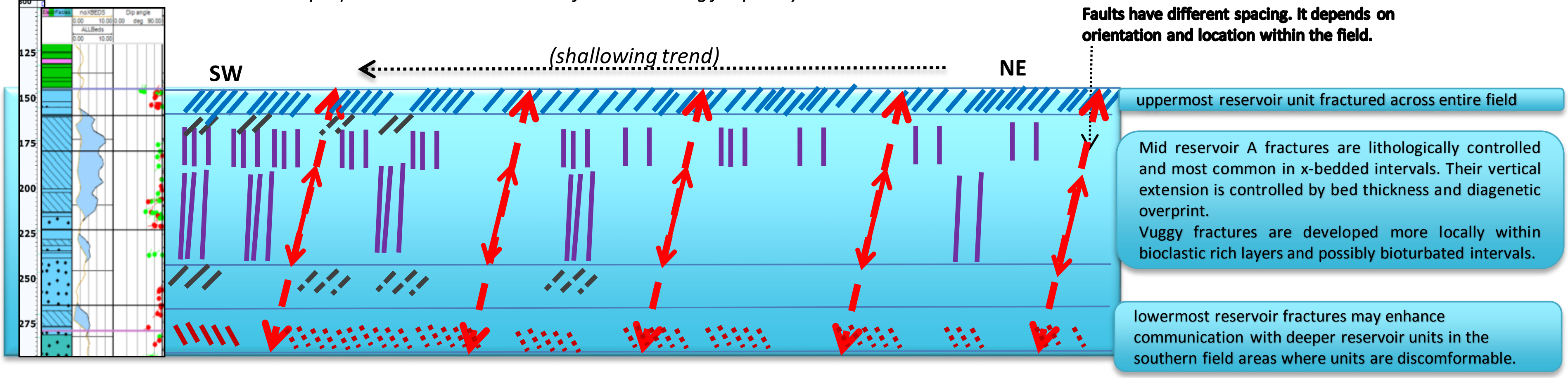




W & SW flank of the field host the most dissolution (vuggy) features
Initial though that vuggy fractures may be important in contribution to reservoir– but actually quite localised in mid-lower Reservoir A and number < 1 in 5 of all fractures

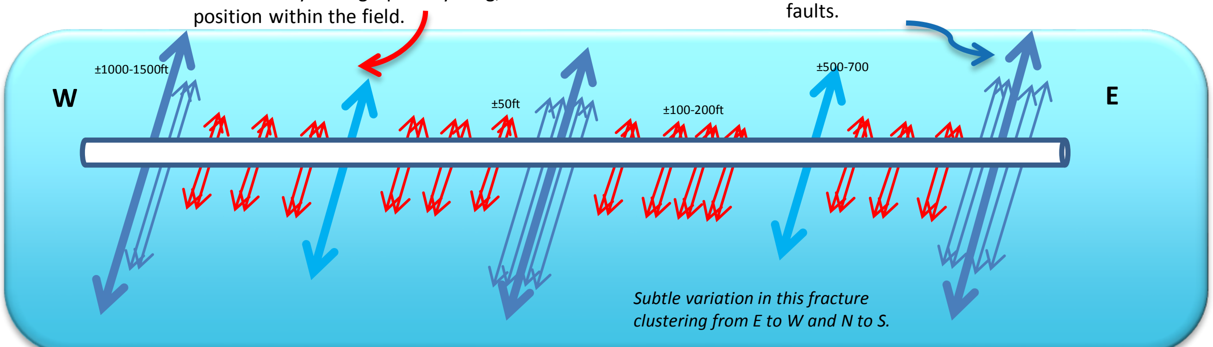
Fracture Schematic extended in a strike section

Increase in fracture intensity towards the W and SW. Fracture intensity is proportional to the increase of cross bedding frequency and thickness.

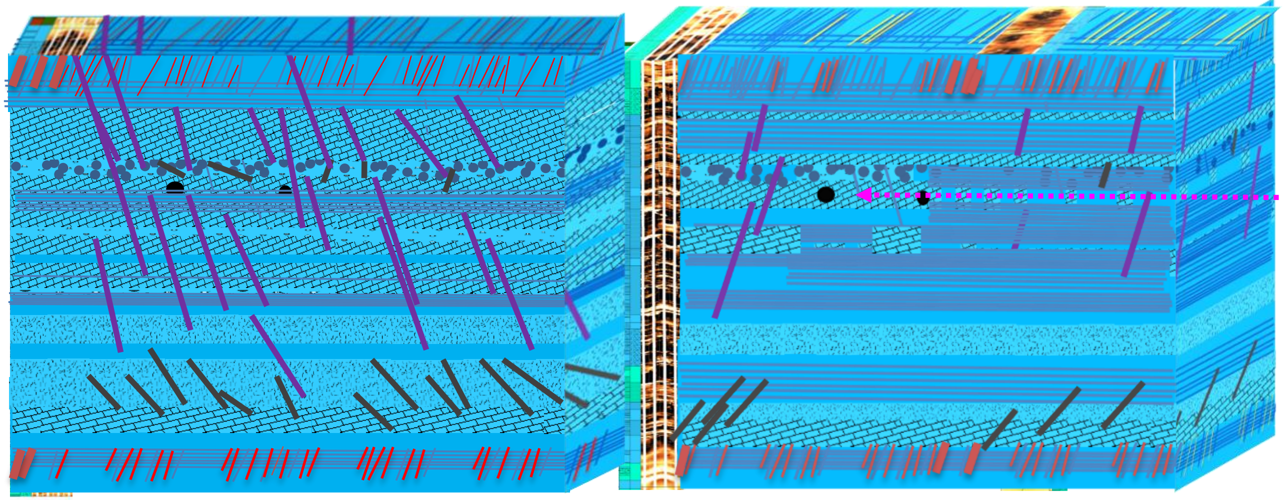


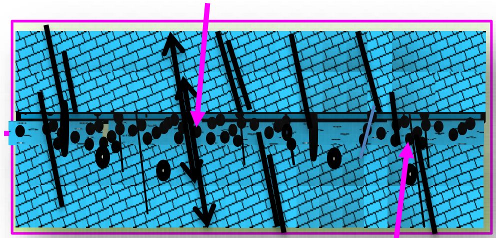
Small - medium fracture cluster spacing are controlled by stratigraphic layering, well azimuth and position within the field.

Fracture clusters and image log faults with spacing over 500 -1100ft distances may correspond to seismic (grid) faults.



Linkage of Predictive Fracture Model and Lithology

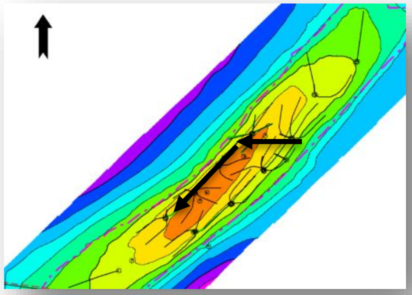




Significant increase of cross bedding and bioturbation and skeletal layers towards the West and South West.

Bedded limestone. Only rare cross beds are seen on the North East flank

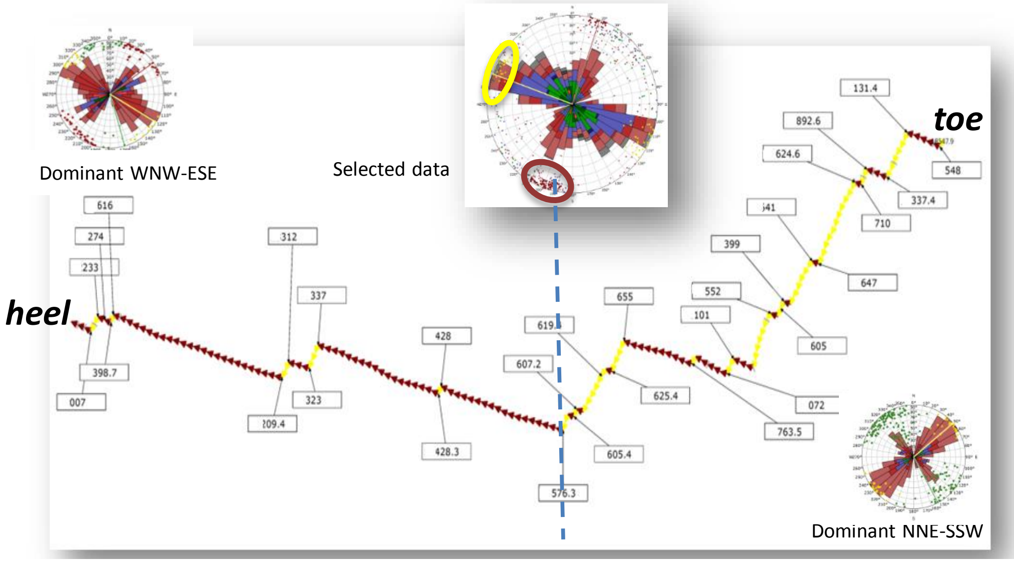
depositional dip

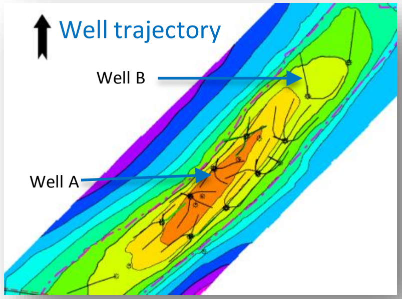


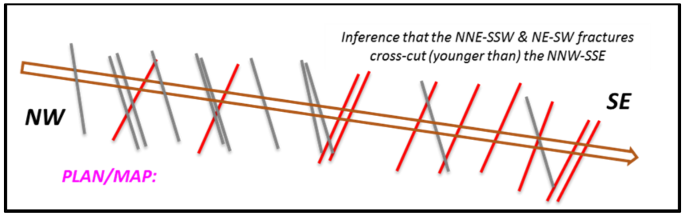
Fractures are stratigraphically controlled but at reservoir zone scale
They are **mainly resistive** but **vertically dis-continuous** – so <u>unlikely to be complete baffles</u>

Note use of differing image datasets

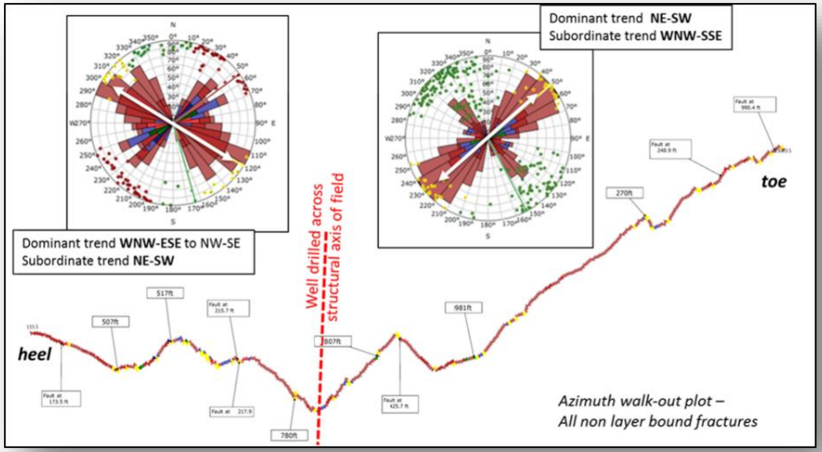
Fracture strike orientation across the axis of the field. (non layer bound fractures)







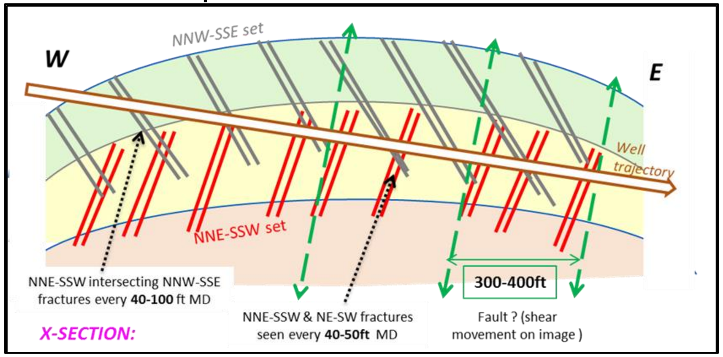
Fractures strike and frequency follows fold axis and change in structural dip

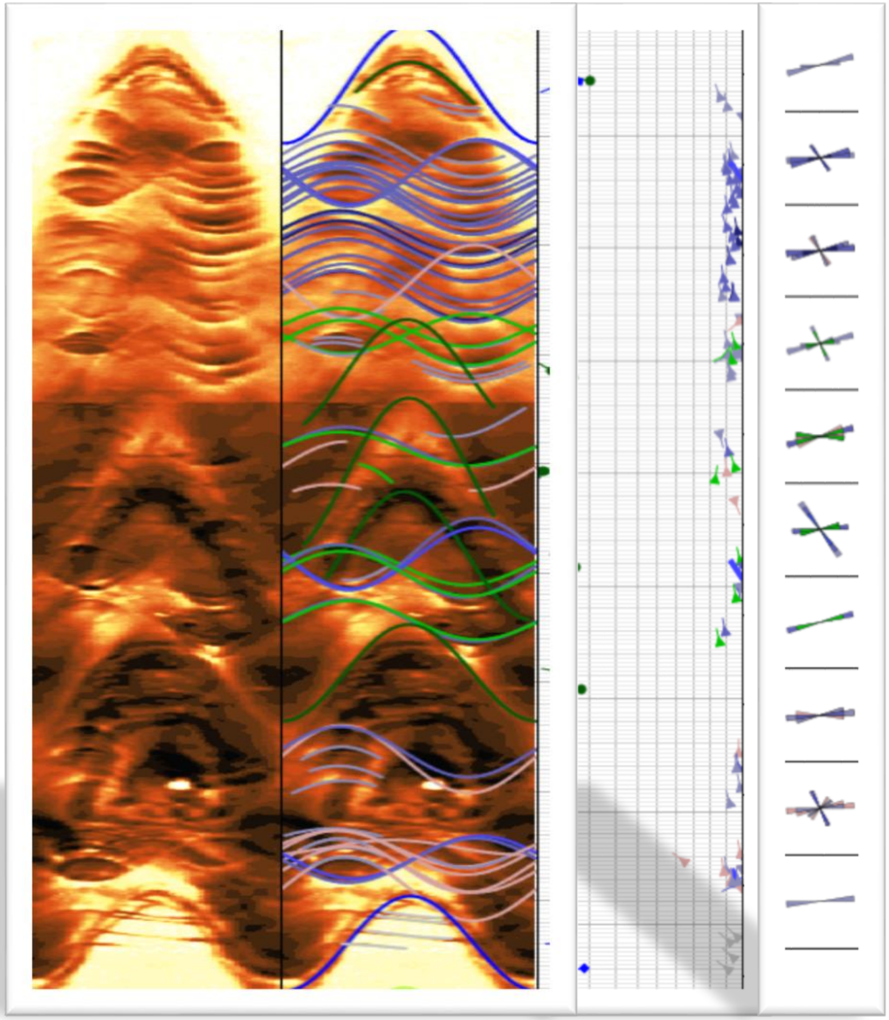


Key here is that distilling fractures by looking only at features closely aligned to the mean 'set' azimuth reveals a more systematic spatial change in fracture presence and orientation from West to East of the crestal area….

From Fractures to Faults

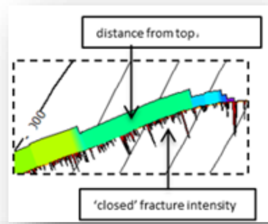
Conceptual Fracture Set Models



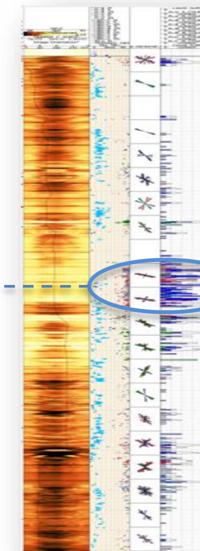


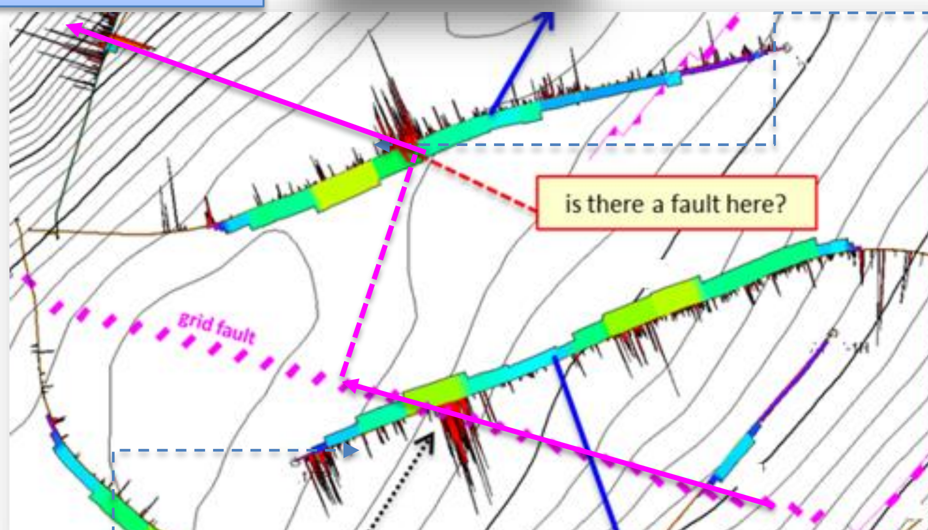
1: Fracture densities as a marker for Faults

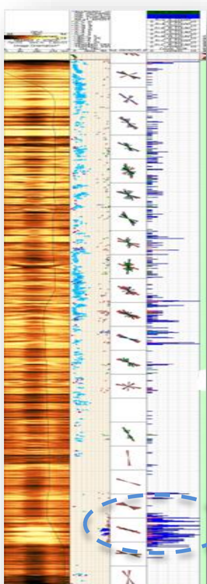
*fracture density on image logs indicate WNW-ESE faults are "**en-echelon**".*



Looks like "normal' fracture log-with increase in closed fractures when close up to top of reservoir.



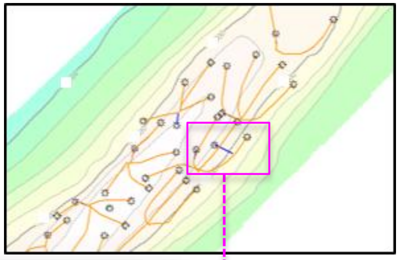




Increase in closed fractures in mid Reservoir A: good justification for a fault or maybe just base of reservoir?.

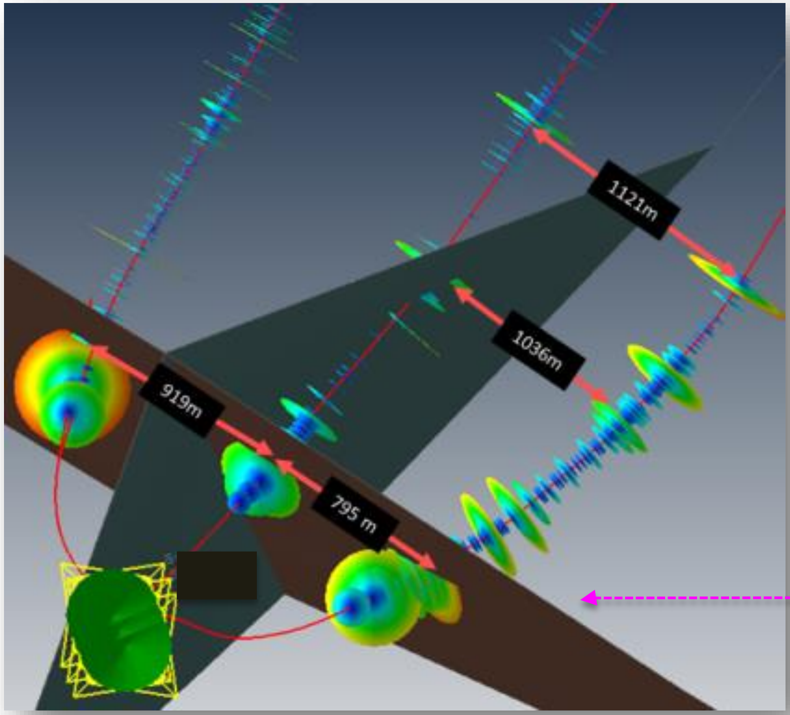
2: Lateral change of the resistivity character of Grid Fault.

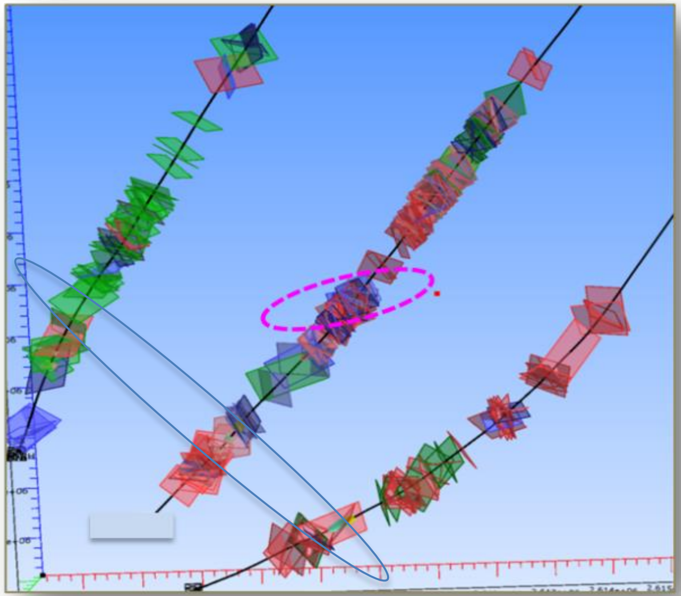
All these 3 Wells pass through a 'grid' fault in their heel sections – in each case the fault could be tied to an adjacent fracture cluster



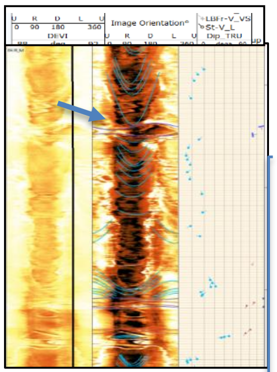
The (fracture) resistivity character of the fault **changes** between laterals:

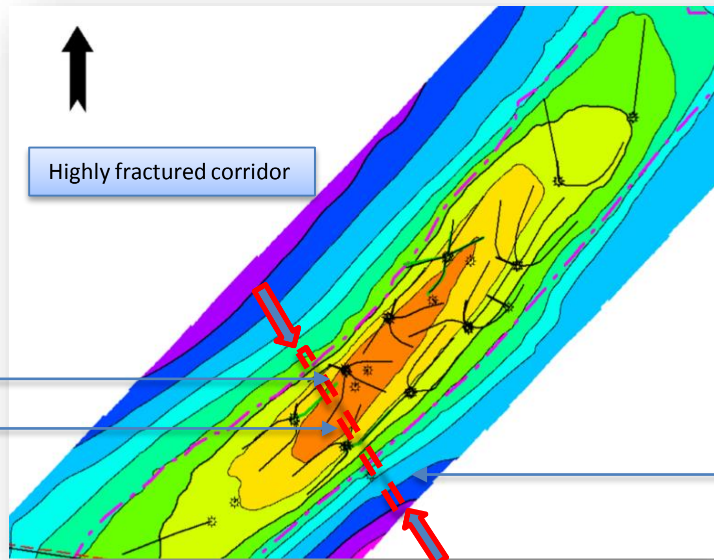
- may depends on which unit is intersected
- but indicative of laterally variable/terminating faults

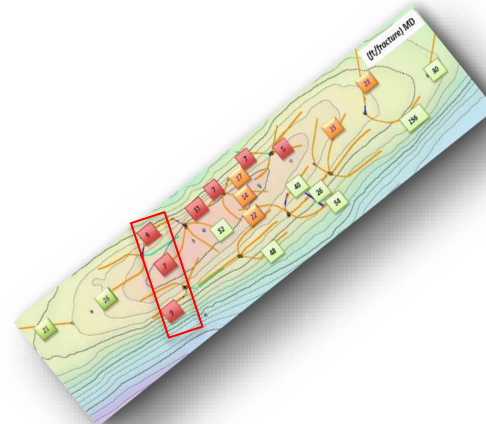




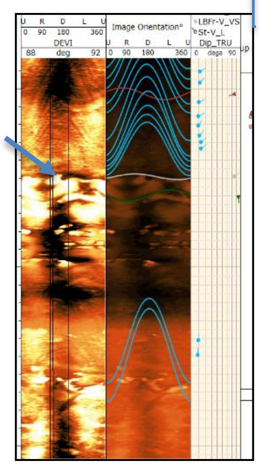
3: Lateral variation of fault strike orientation across the axis of the field



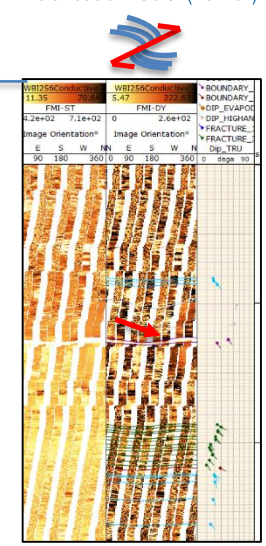


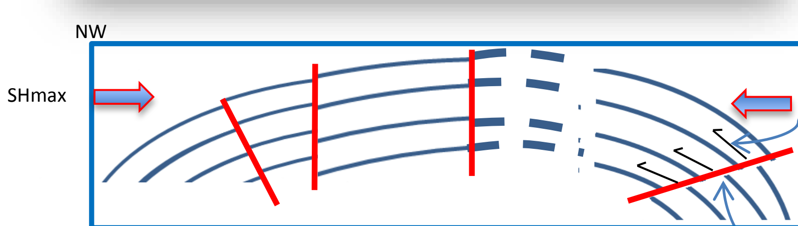


Normal and Strike-slip faults



WSW-ENE Low angle truncation fault (20-40°)





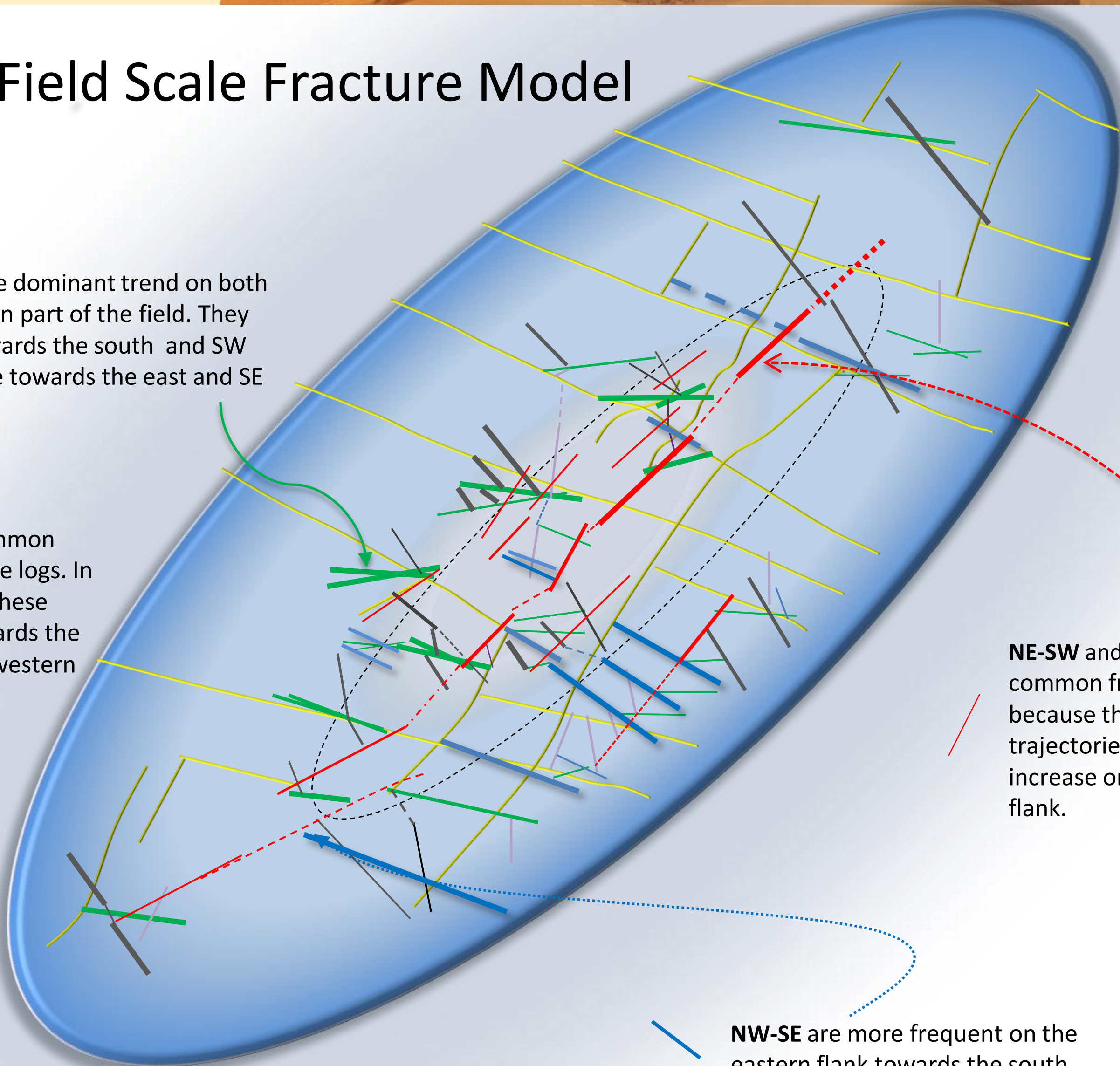
Shear movement along bed boundaries, mainly observed between mudstone and anhydrite

Low angle truncation fault (<40˚)

Faults are different from SE to NW flanks and crestal area.
East flank may be more affected by compression regime.

Composite Field Scale Fracture Model

N



WNW-ESE/ ENE-WSW are dominant trend on both edges, and in the western part of the field. They increase significantly towards the south and SW Their frequency decrease towards the east and SE

NNW-SSE are the most common fractures seen on the image logs. In general the frequency of these fractures are increase towards the North of the field. On the western half of the field.

NE-SW and **NNE-SSW** are the least common fractures seen on images because they are parallel to most well trajectories , but their frequency increase on the crest and the east flank.

NW-SE are more frequent on the eastern flank towards the south.

Reservoir Fracture Model Conclusions

- Fracture intensity increases towards the SW and seems proportional to an increase in cross-bed thickness
- Vertical fracture extent is thought controlled by the bed thickness and diagenetic overprint
- Vuggy fractures are least common fracture type - they are localized within some layers and more common in the West and SW of the field.
- Fractures noted across a variety of scales – ordered into different "clusters" – that are recognized with spacing of 40-50, 80-100, 200, 500-700 and 1000 (MD) ft.
- 'Seismic' faults generally not confidently linked to obvious image fault clusters/shear features
  - they may be identified equally by an increase in fracture density/alignment or by a single (mainly resistive /mixed) shear fault plane or damaged zone.
- Number of fractures and faults vary with location in the field but also significantly (for horizontals) due to borehole azimuth and deviation
- It is suggested that both fractures and seismic (faults) will not be critical as either enhancing or degrading features
  - Both show lateral constrained dimensions, variable character and absence of strong 'damage zone' linkage

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