Chasing the Faults within a Permian Carbonate Using Wide Azimuth Seismic Data - A Thailand Case Study*

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Search and Discovery Article #41016 (2012)**
Posted September 10, 2012

*Adapted from oral presentation at AAPG Annual Convention and Exhibition, Long Beach, California, April 22-25, 2012

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Abstract

Land seismic data was acquired over a Permian carbonate field with a wide azimuth acquisition template, such that the recorded 3D seismic data is inherently source-to-detector azimuth rich. This geometry allows the data to be subdivided into azimuth sectors, so that stacks of different "illumination" directions can be generated. Subsurface faults and families of fractures are generally better characterized when illuminated normal to their dip, i.e. head on against the faults. The fault and fracture family patterns from each of the sorted shot-to-receiver azimuth sets portray a slightly different illumination of the continuity and development of these faults as shown in time-slices.

The paper will describe the azimuth sorting process, followed by the methodology to sharpen the fault pattern within each dataset. The acquisition of seismic data in a wide-azimuth configuration has shown that with appropriate processing, it is possible to illuminate subtle faulting and fractures quite distinctively within the targeted hard rock reservoir.

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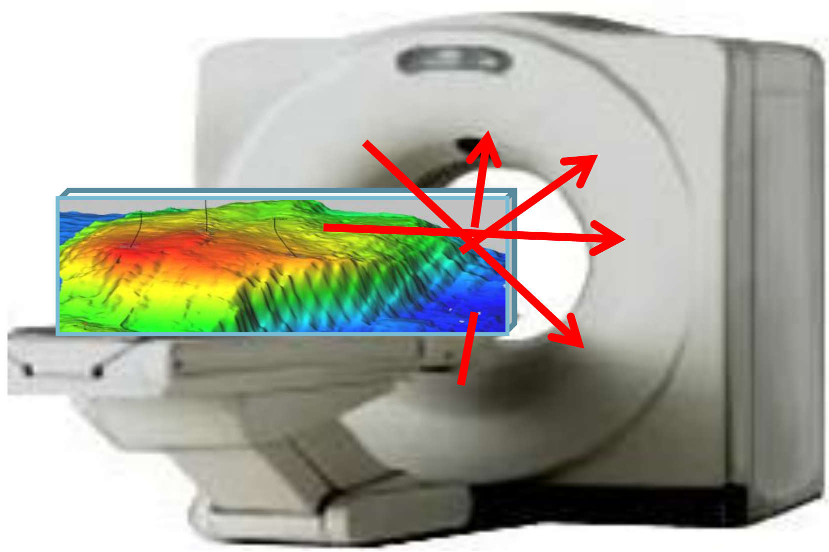

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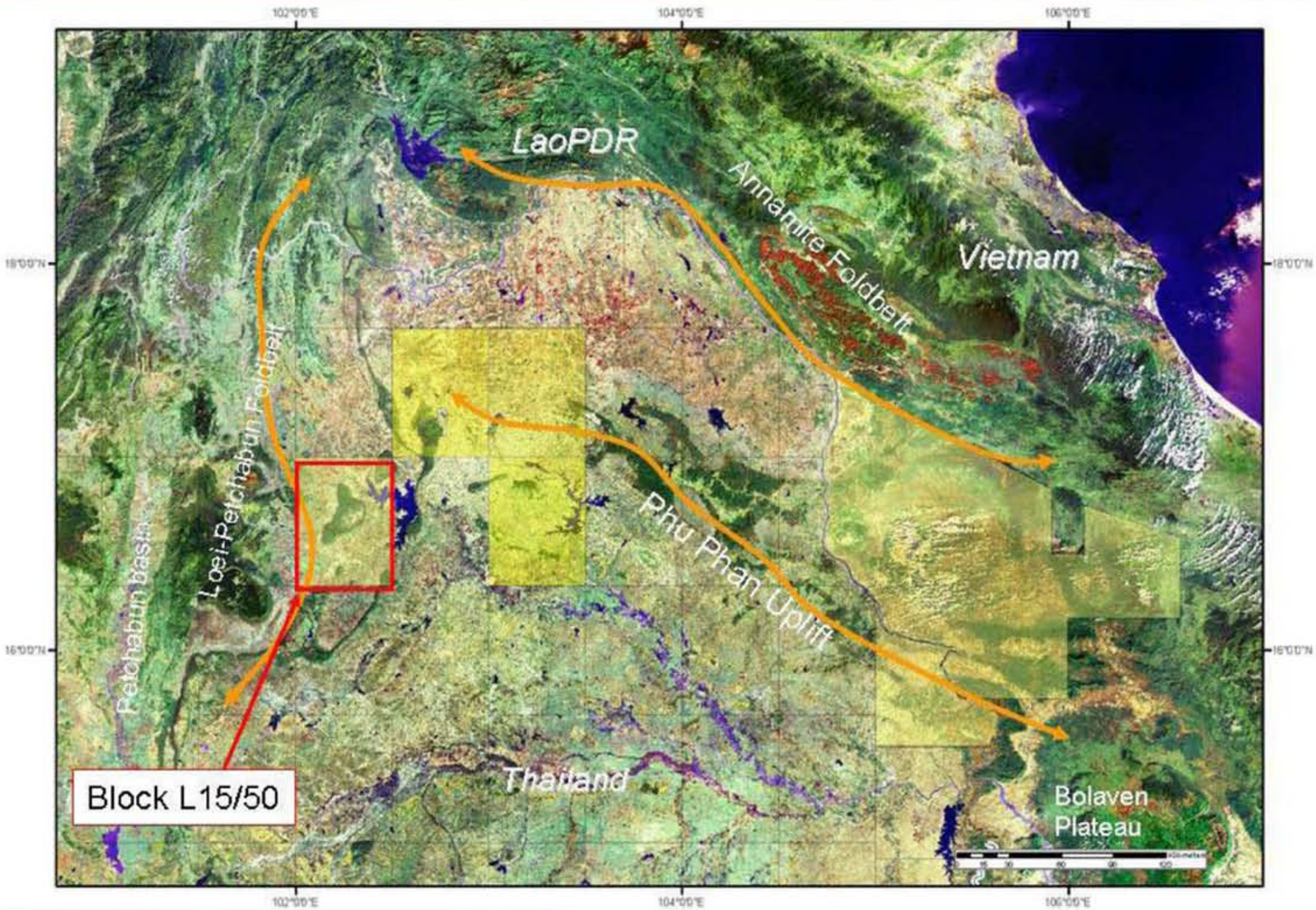
SALAMANDER ENERGY
WesternGeco

Outline

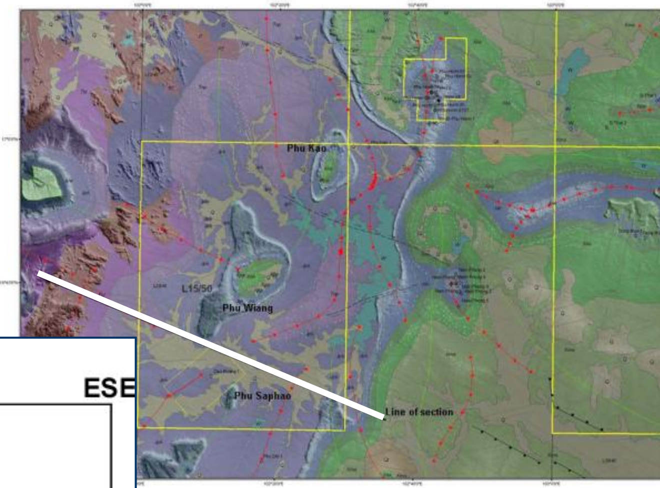
- The Geological Setting
- Wide Azimuth Seismic Data Acquisition
- Sorting the Seismic into Azimuthal Swaths
- Inferences from Geomechanical Properties
- Characterizing the Families of Faults Accordingly
- Conclusion
- Postscript

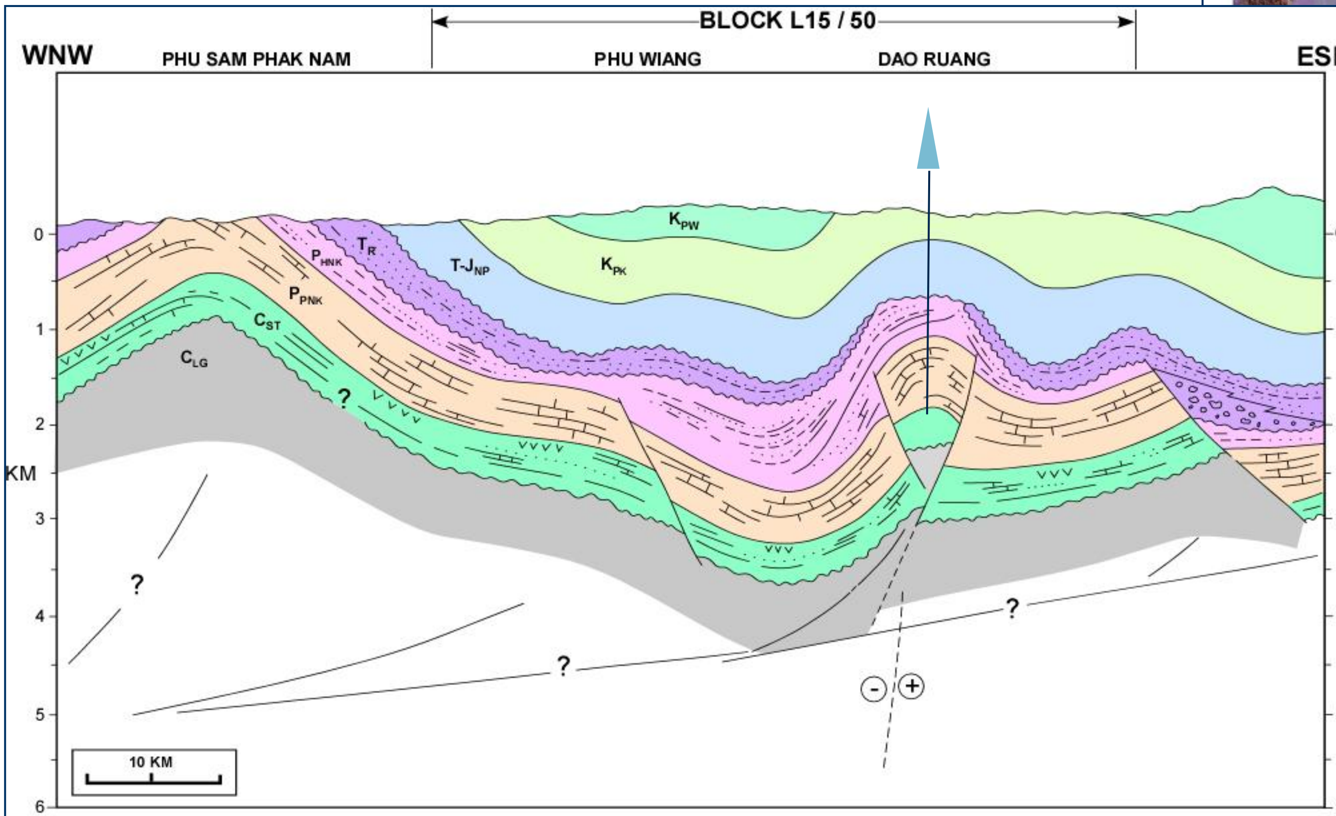
The Geological Setting



Presenter's Notes: Topographical map of the area, with the L15/50 block outlined in red – Petchaburi Limestone.

The Geological Cartoon – Offset from the Well

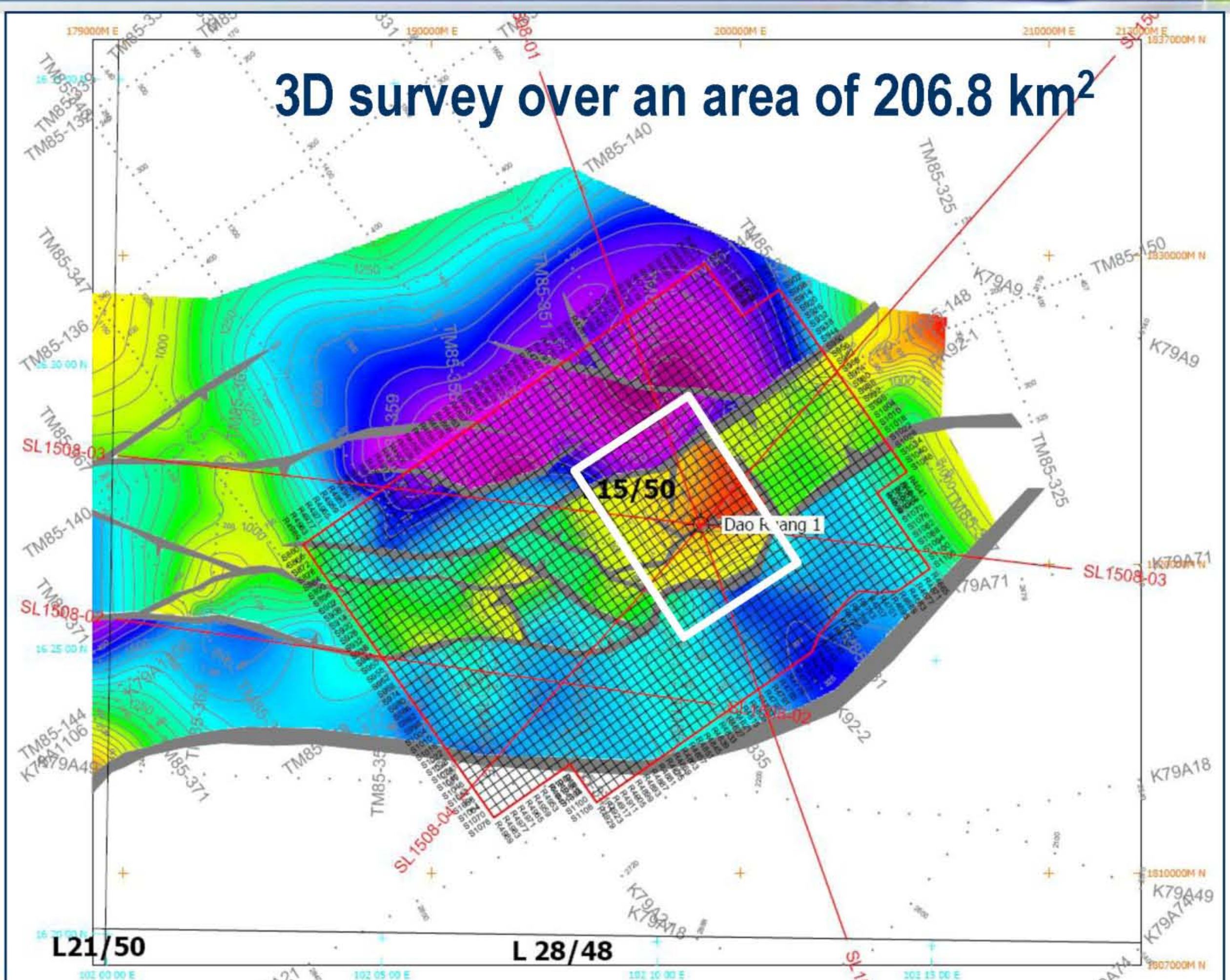




GEOLOGICAL CROSS SECTION ACROSS BLOCK L15 / 50, APPROXIMATELY ALONG HWY 12
6X VERTICAL EXAGERATION

Author : NCS
Drafted: IH, 08Sep2008

Wide Azimuth Land Seismic Data Acquisition



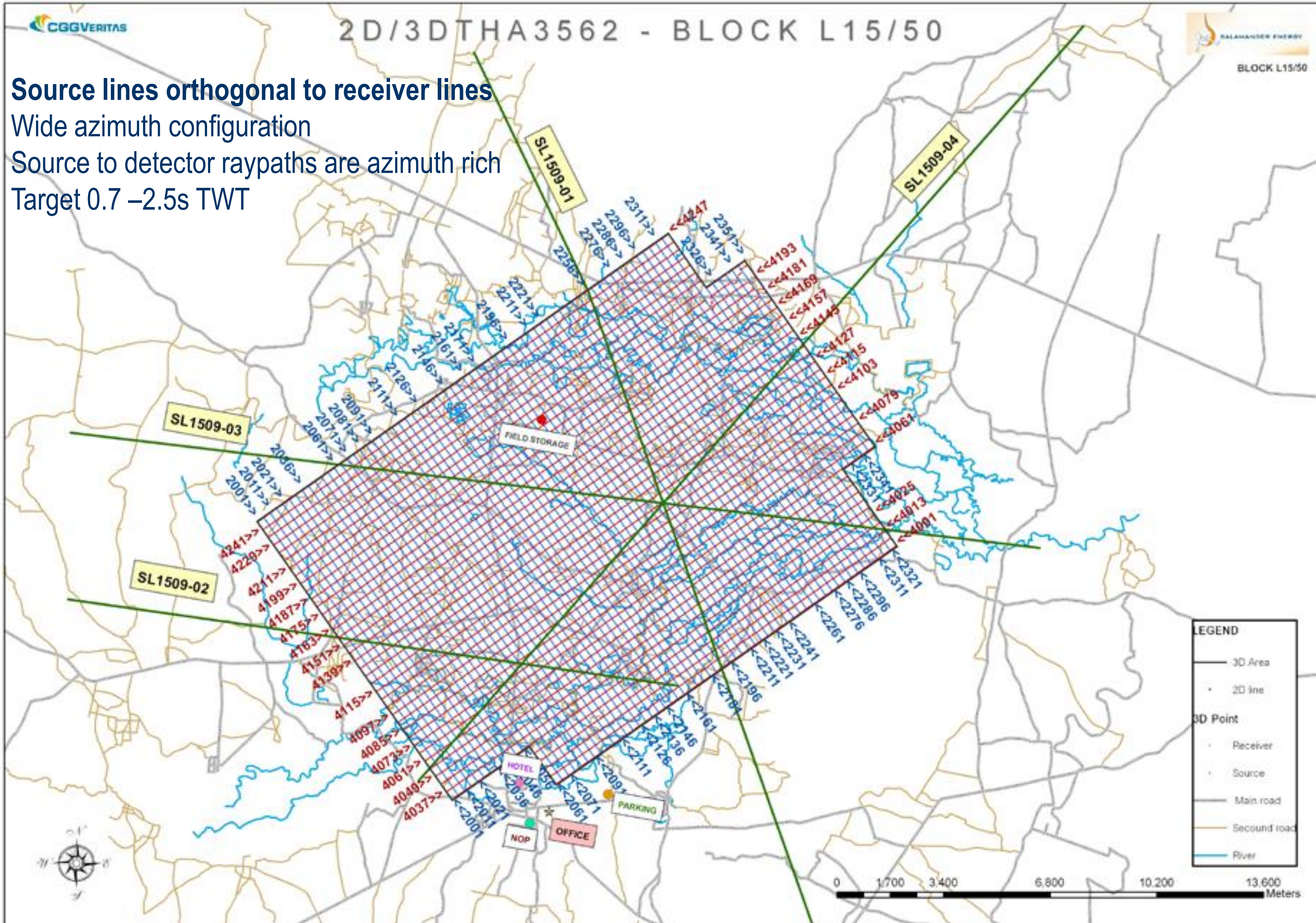
Presenter's Notes: On the 3D Seismic Survey Operation – the coverage area of the 3D, of 206.8 km^2.

Source lines orthogonal to receiver lines

Wide azimuth configuration

Source to detector raypaths are azimuth rich

Target 0.7 –2.5s TWT



2009 3D Survey Essential Parameters

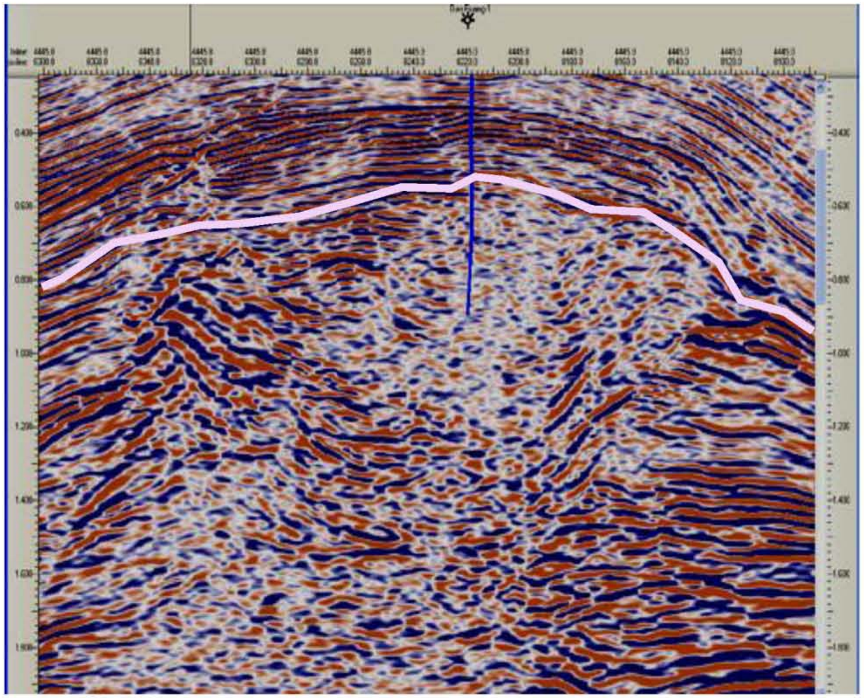
Number of active receiver lines	20 live, split spread
Stations live /receiver line	96 (48-0-48 split spread)
Total stations live	1920
Record length	6 seconds
Receiver Interval	50 meters
Receiver line Interval	250 meters
Shot point Interval	50 meters
Shot line Interval	300 meters
Shot hole drilling	Single hole between 5m and 9m
Sample rate	2 ms
Source	Explosives - 1.5 kg charge
Fold taper method	Roll-On / Roll-Off
Fold	80

Presenter's Notes: The 3D survey essential parameters – Being Land survey it was possible to have shots and receiver lines laid out from a number of relative azimuths, such that many azimuthal shot to receiver angles were recorded. (As compared to marine seismic surveys where generally the shots are inline with the receivers restricted to a narrow angle range).

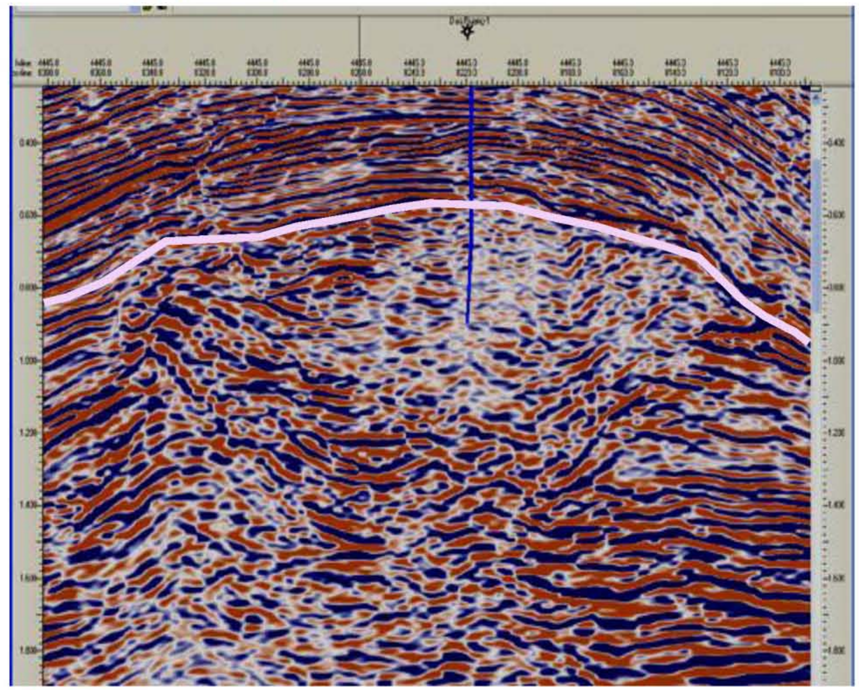
Sorting the Seismic into Azimuthal Swaths

Stages of Processing the 3D Seismic Data :

1. *Pre-Stack Time Migration (PSTM)*
2. *Pre-Stack Depth Migration (PSDM)*
3. **Wide Azimuth Processing (WAZ)**



PSTM



PSDM

Presenter's Notes: The 3D processing: Regular processing – sorted out in inlines and crosslines regularized. Two different processing routes were done; Prestack Time migration and Prestack Depth migration. The comparison profiles show differences in the seismic events being imaged.

The Azimuthal Anisotropy Pre-Stack Migration Processing Route:

- Input SEGY Pre-Regularization CDP Gathers
- **Splitting of CDP gathers into 80 Offset Vector Tiles (OVT)**
- Velocity Analysis
- OVT Noise Attenuation
- Anomalous Amplitude Attenuation
- Random Noise Attenuation
- Pre-Stack Time Migration
- Gather into Azimuth Groups:
  - **AZ1: 235-280 (center 257.5 degrees)**
  - **AZ2: 280-325 (center 302.5 degrees)**
  - **AZ3: 325-10 (center 347.5 degrees)**
  - **AZ4: 10-55 (center 32.5 degrees)**
- Output 30 km^2 Migrated Volumes for Each Sector

Presenter's Notes: This is the summary of the WAZ processing sequence. The main emphasis here is the use of Offset Vector Tiles (OVT) early on in the processing steps, and run the processing sequence along the offset vector tiles groups. After the Prestack time migration stage, these OVTs are gathered into the four Azimuth Groups as shown. This being a kind of test run, only 30 km^2 of the 3D survey was chosen for this WAZ processing.

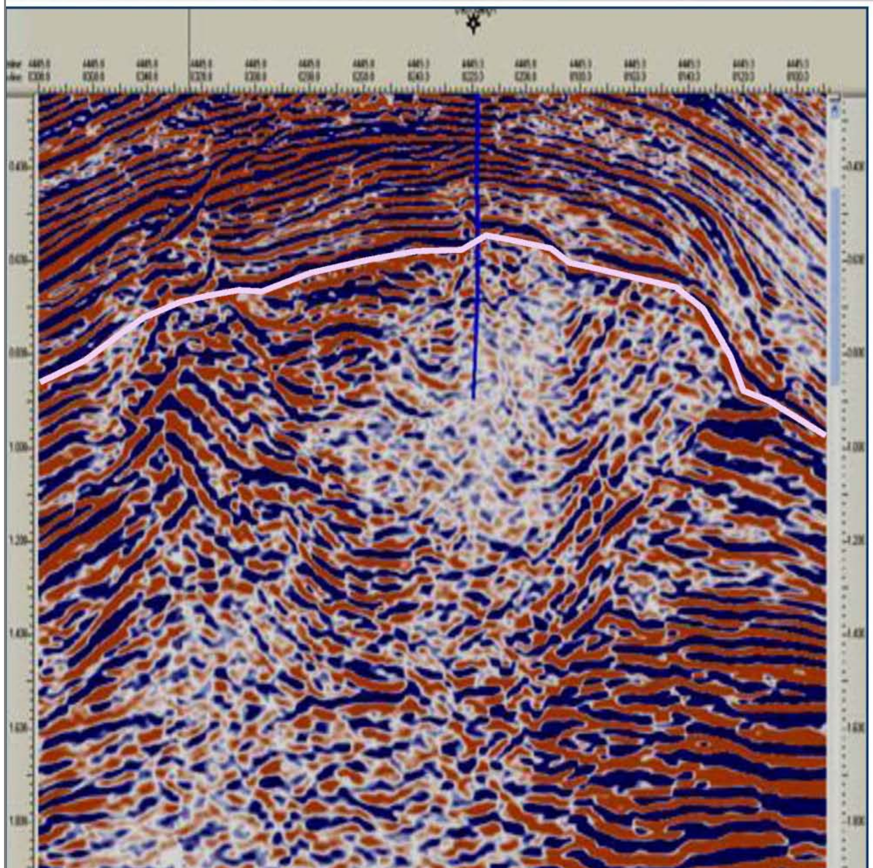
Why Offset Vector Tile Methodology *Instead of Azimuth Sectors*?

- Less Primary Reflection Damage is Done During Noise Attenuation
- CMP Cells in the OVTs are Better Populated Before Migration, Yielding a Better Migrated Image

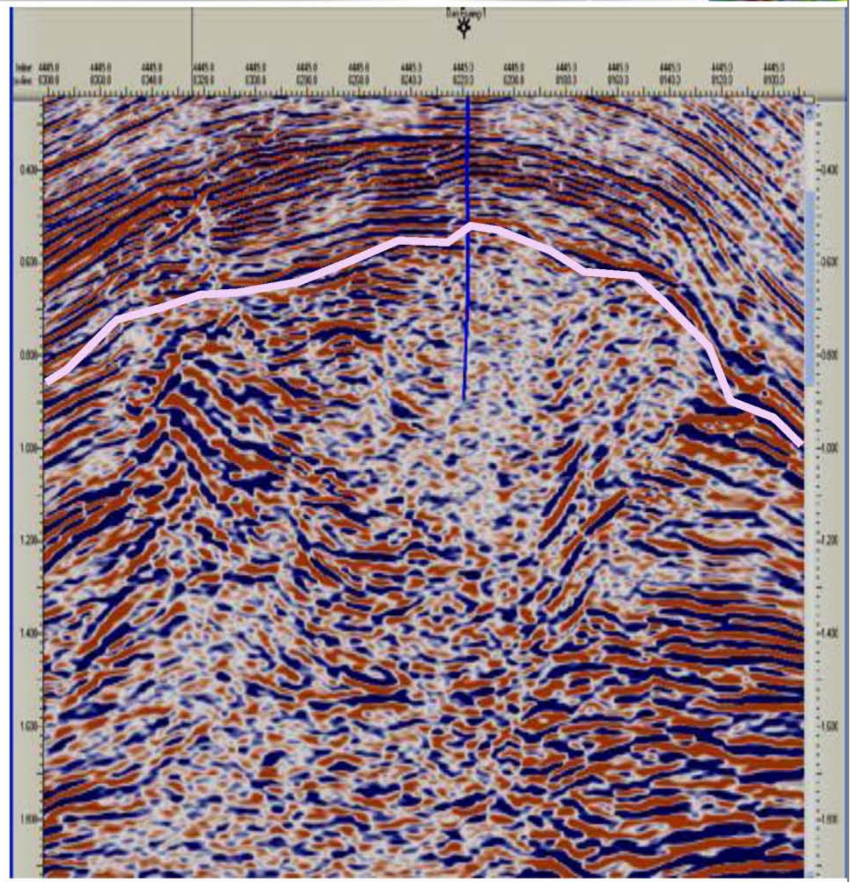
(For comparison the azimuth sector/common offset was chosen to be close to the center of the corresponding OVT)

Presenter’s Notes: Through the WAZ processing tests the Offset Vector Tile method was considered superior to the more conventional azimuth sector sorting, for the 2 reasons of 1) less primary reflections are damaged in the noise attenuation step, 2) the population and signal to noise ratio is enhanced prior to the prestack time migration step, to yield better migration results.

Comparison of Processing Results



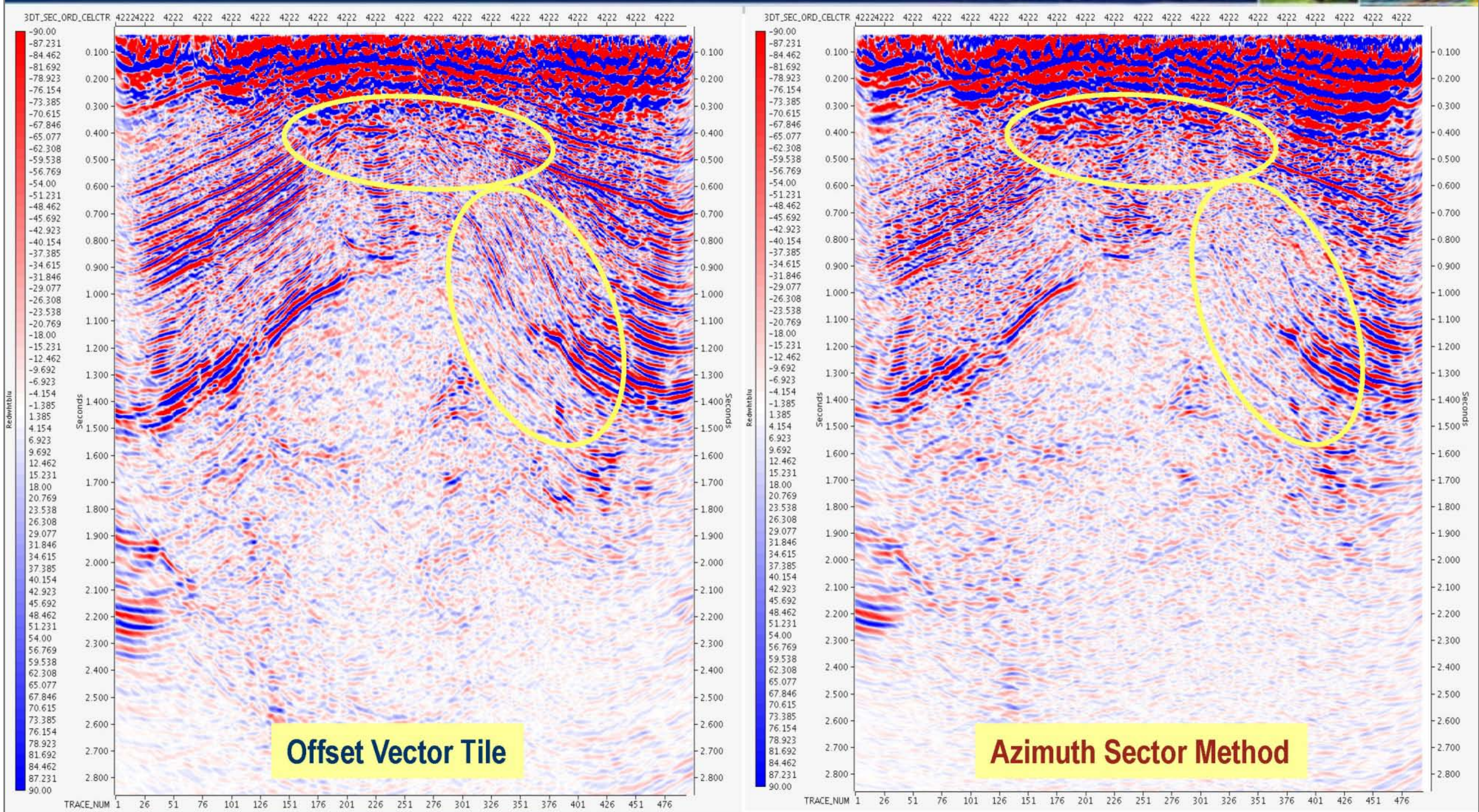
Wide Azimuth Processing (WAZ)



Original PSTM

Presenter's Notes: Following the regular processing the data was processed with the Wide Azimuth (WAZ) methodology – where the different swaths of shot to receiver angles were grouped into a number of azimuthal bands.

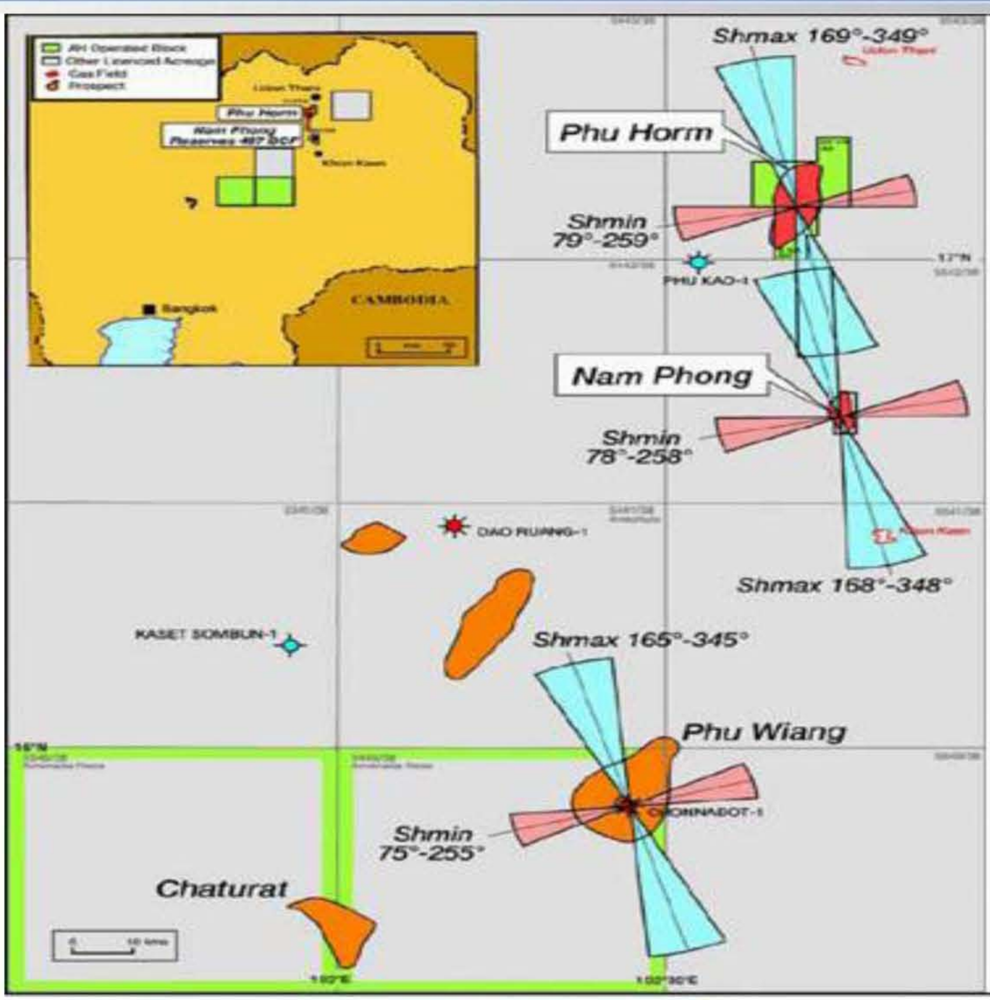
A Better Migrated Image : Unconformity Definition & Steep Dips



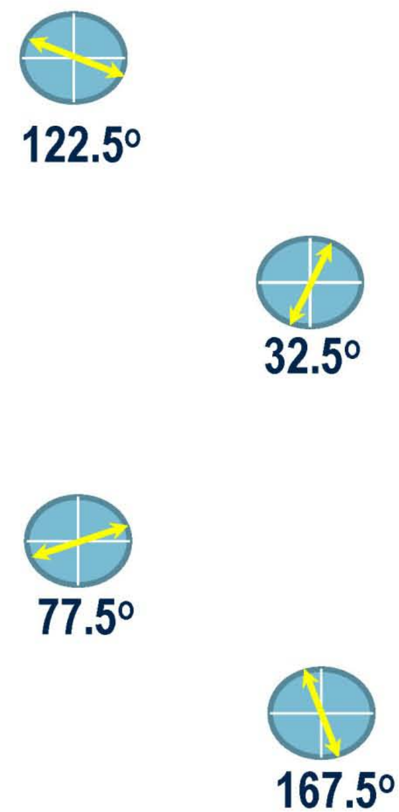
Presenter's Notes: A comparison test profile of using the Offset Vector Tile method over the Azimuth Sector method. The OVT product gave a much cleaner and coherent image.

Inferences from Geomechanical Properties

Structure and Geomechanics from Neighboring Wells

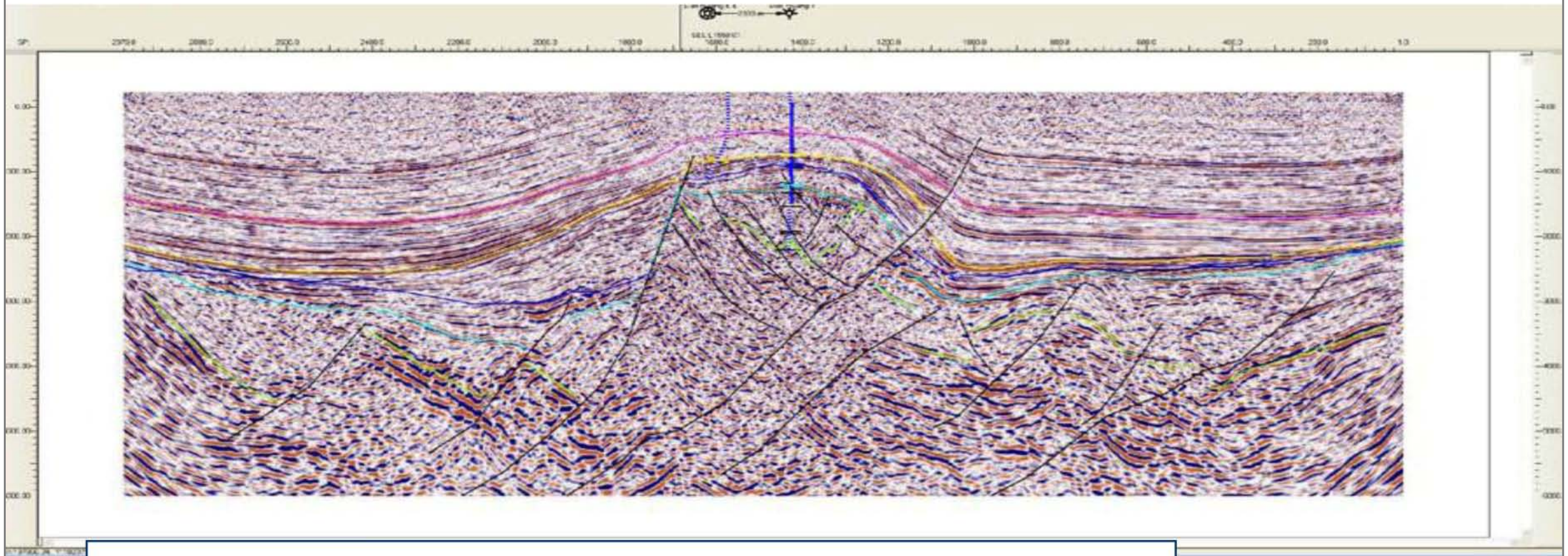


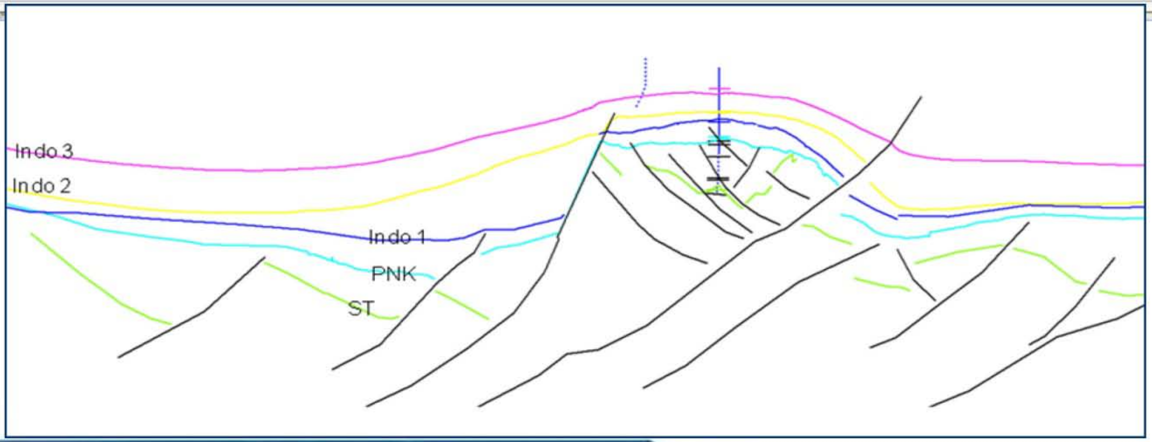
"Chosen Azimuths"



Presenter's Notes: Drawing on the principal stress components measured in other surrounding wells.

Characterizing the Families of Faults Accordingly



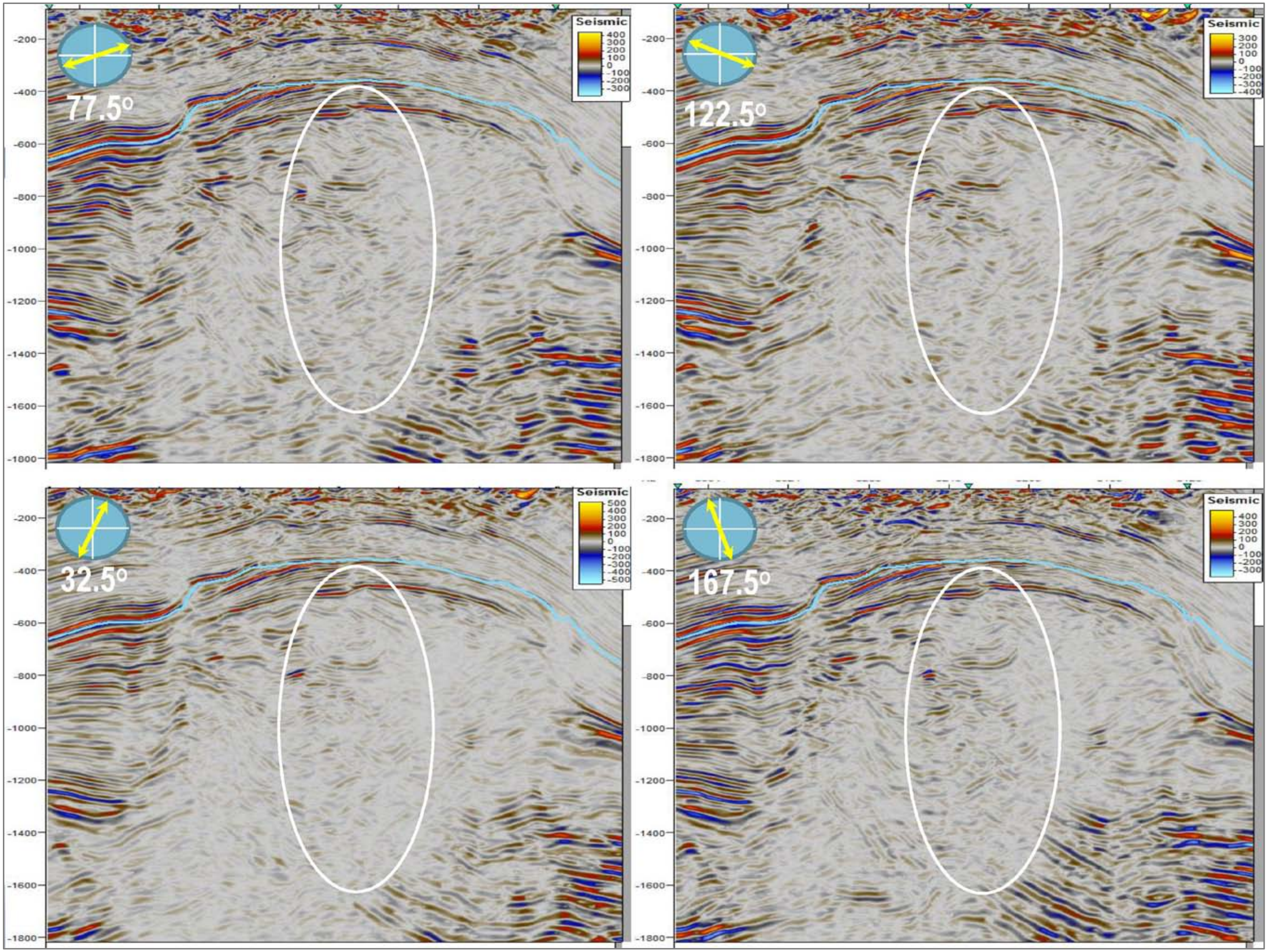


Presenter's Notes: After the WAZ seismic processing where the final data are sorted into the four Azimuthal sectors we applied the fault/fracture tracking technique to characterize and visualize the faulting patterns. This slide show a seismic profile from the conventional processing with structure and faults interpretation. The crestal part of the structure is interpreted as heavily faulted, and hence the WAZ azimuthal sector separations should illuminate and emphasize the faults better from the different angles of view.

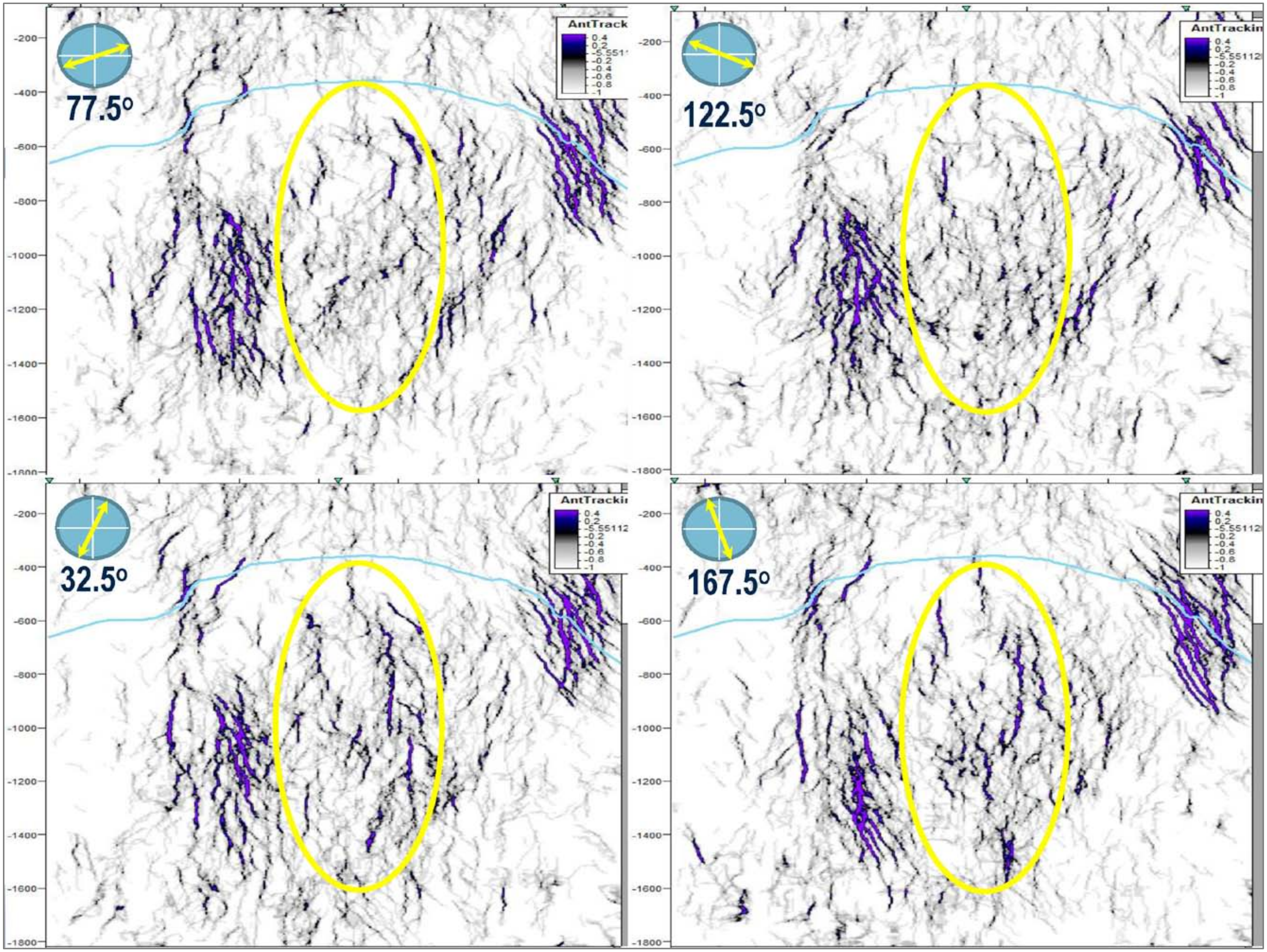
The Fault/Fracture Analysis Route:

- **Enhance the Faults Termination – Edge Detection**
- **Run Variance/Coherence Analysis on Each of the Sorted Azimuthal Vector Data Set**
- **Perform Ant-Tracking on the Variance Output of Each Set**
- **View Profiles and Interpret Time Slices of Each of the Ant-tracked Volumes**

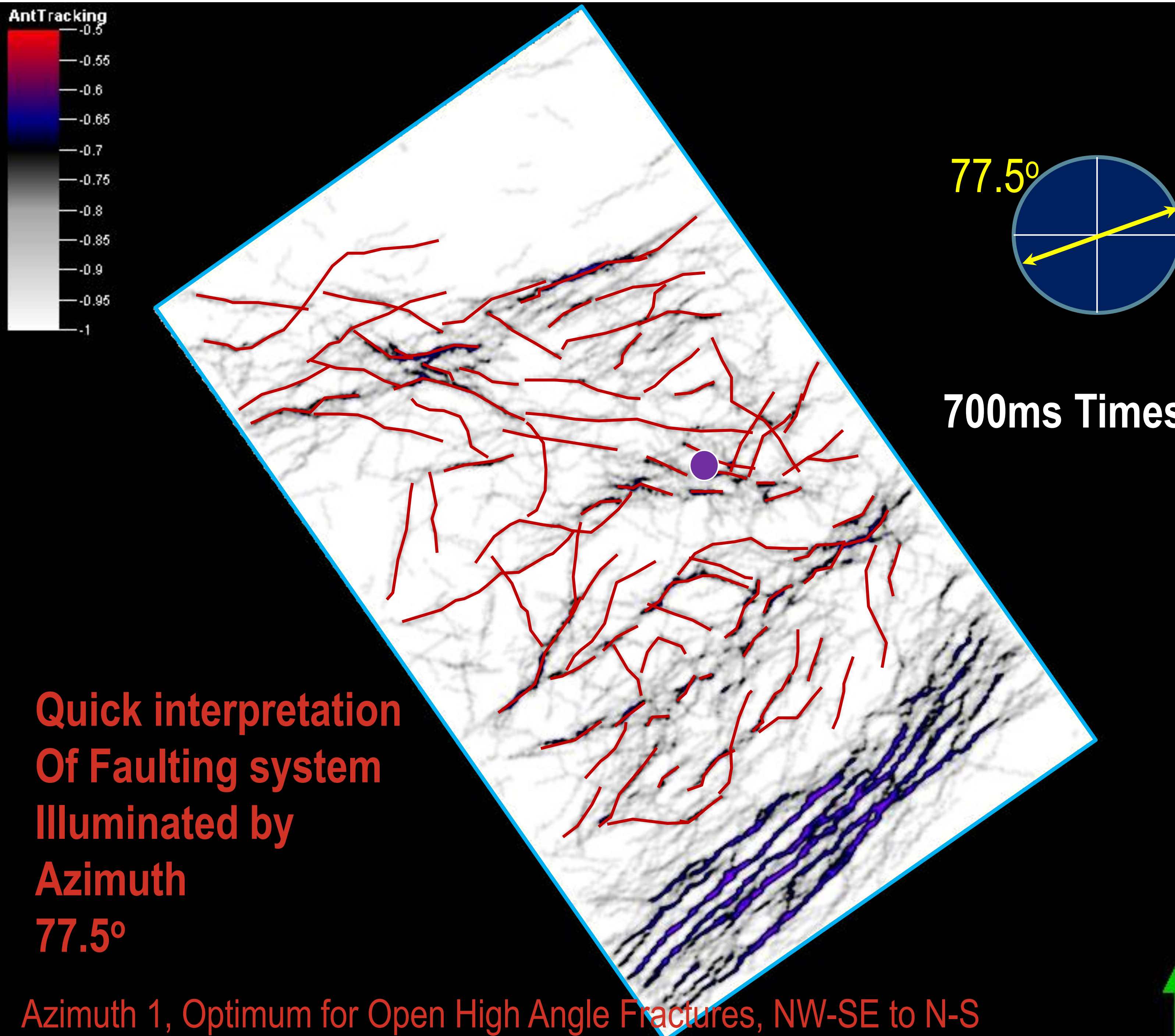
Presenter's Notes: The main steps of faults/fractures analysis following the WAZ processing results. Since we have four azimuthal sectors, the same analysis route is made identical for each of the four seismic inputs to observe the results unbiased.



Presenter’s Notes: The same profile illuminated from the different azimuth sectors – visually we observe differences in events and discontinuities emphasis.



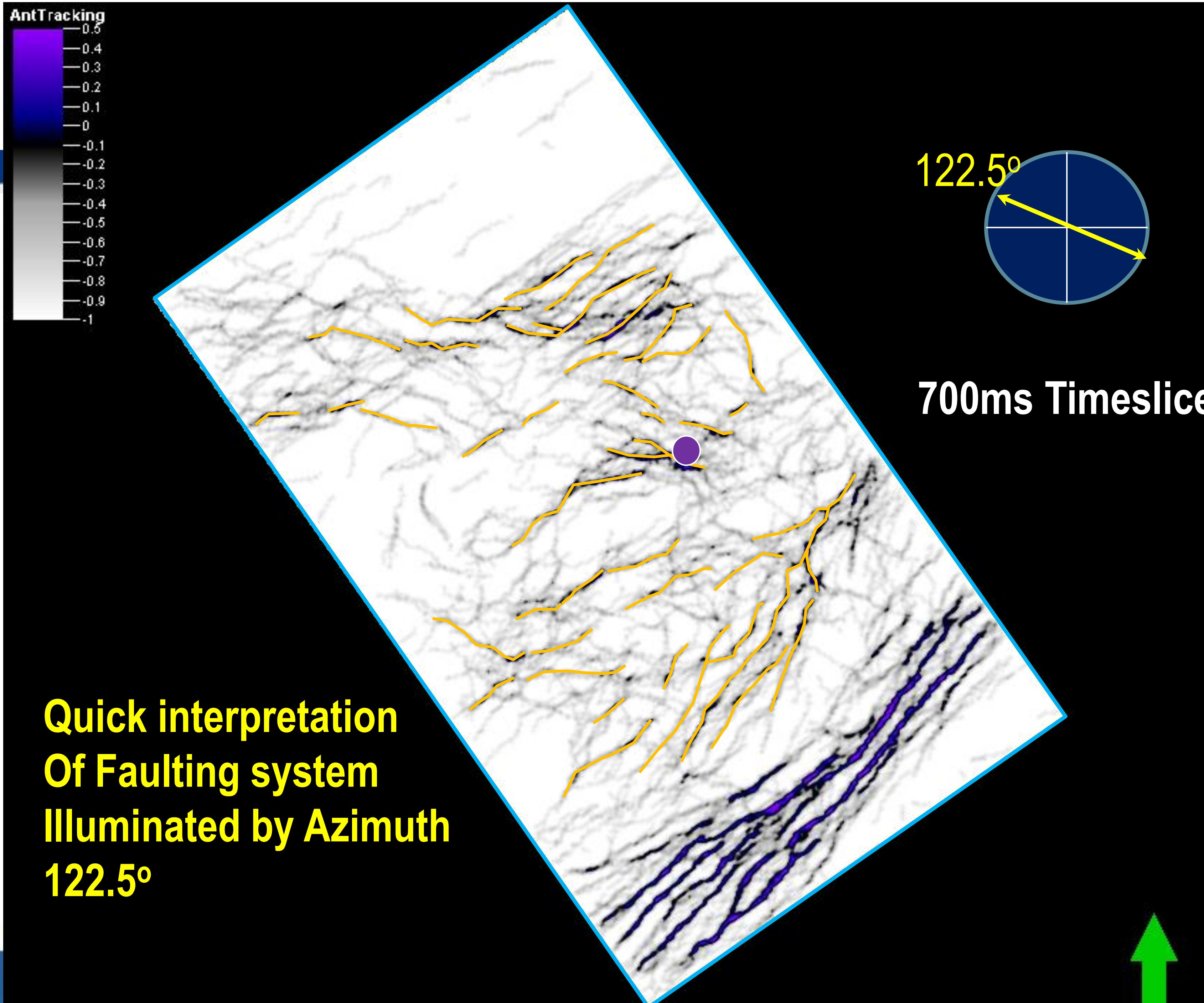
Presenter's Notes: The same profile illuminated from the different azimuth sectors – the Ant-track results. The profiles show the emphasis of the faults cluster varying with azimuthal sectors. The following slides would show the same time's time-slice for each of the azimuthal sectors, with an overlay of some quick faults interpretations.

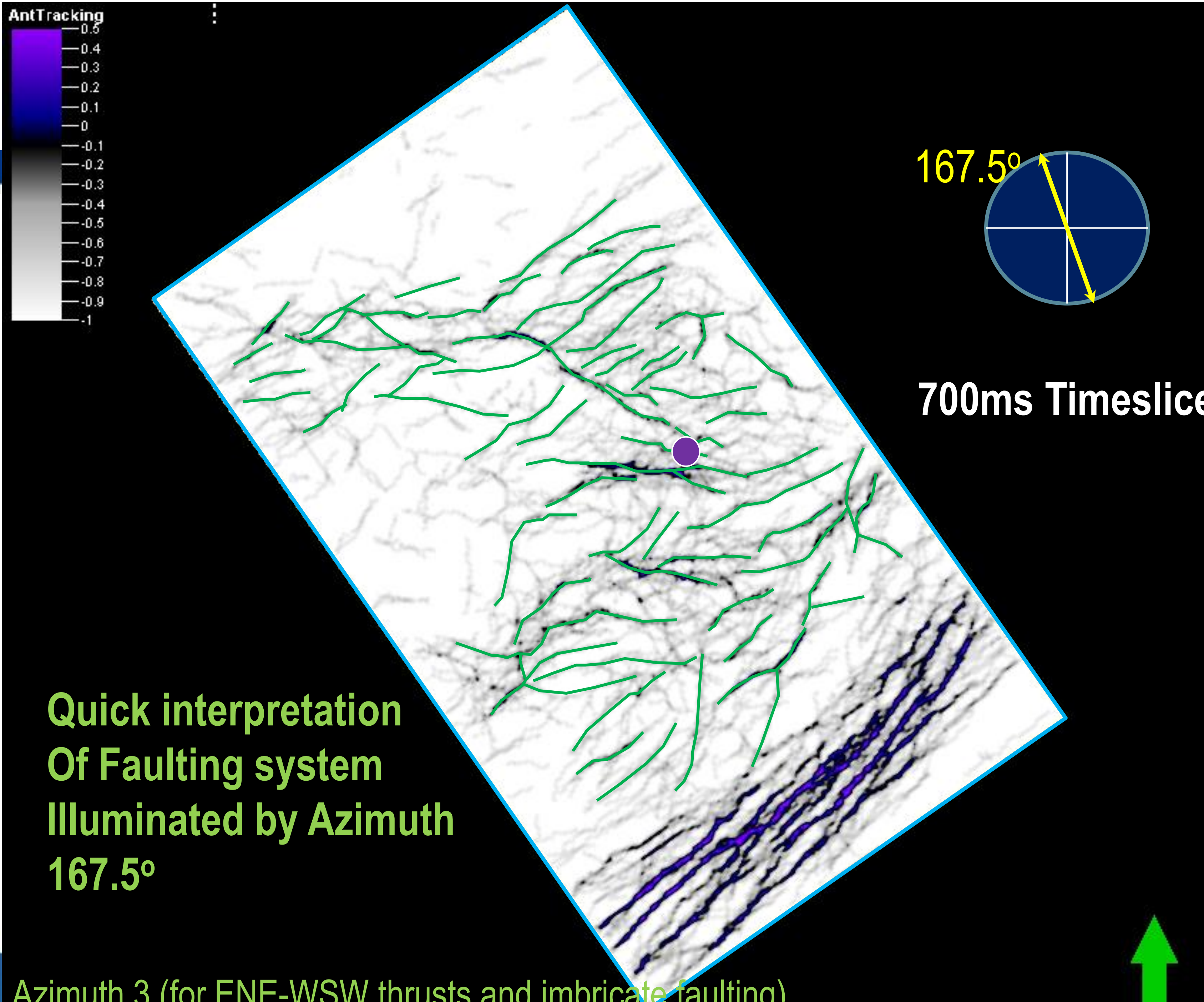


700ms Timeslice

Quick interpretation Of Faulting system Illuminated by Azimuth 77.5º

Azimuth 1, Optimum for Open High Angle Fractures, NW-SE to N-S

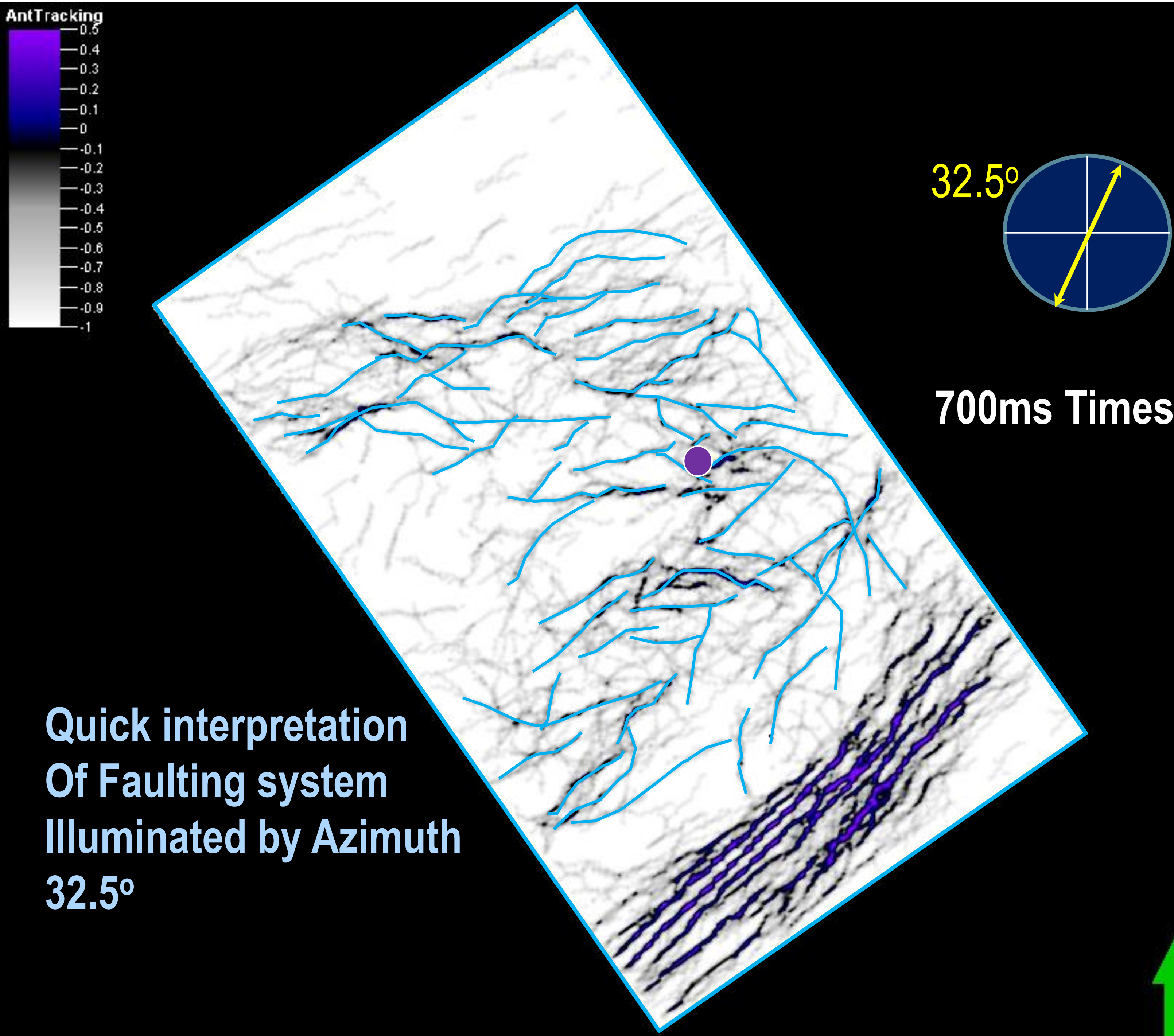

AntTracking
0.5
0.4
0.3
0.2
0.1
0
-0.1
-0.2
-0.3
-0.4
-0.5
-0.6
-0.7
-0.8
-0.9
-1
122.5°
700ms Timeslice
Quick interpretation
Of Faulting system
Illuminated by Azimuth
122.5°



700ms Timeslice

Quick interpretation Of Faulting system Illuminated by Azimuth 167.5°

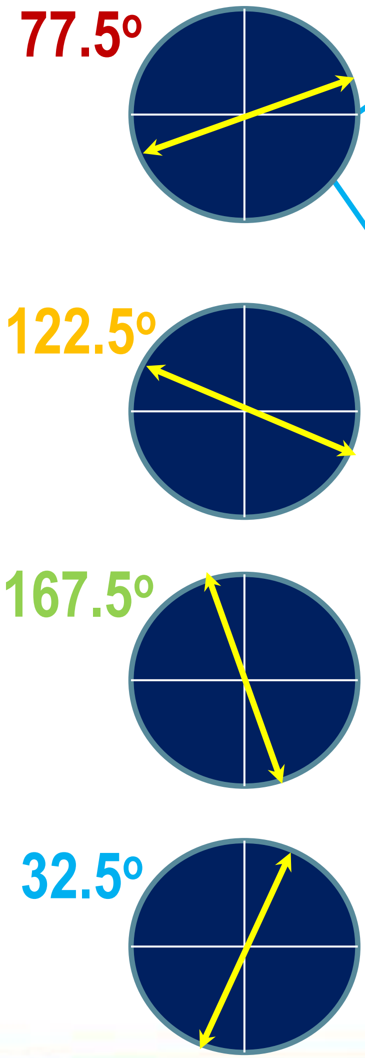
Azimuth 3 (for ENE-WSW thrusts and imbricate faulting)

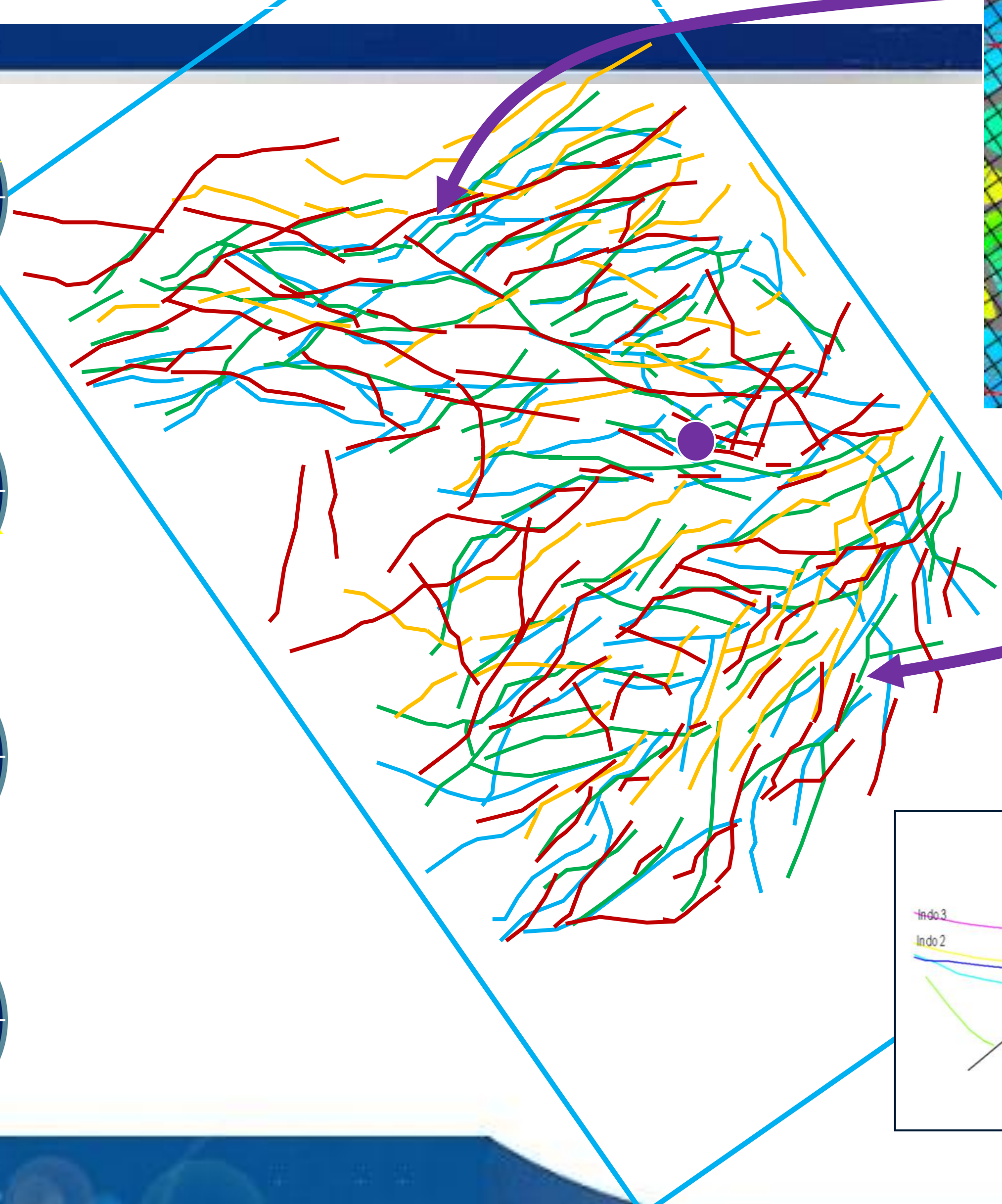


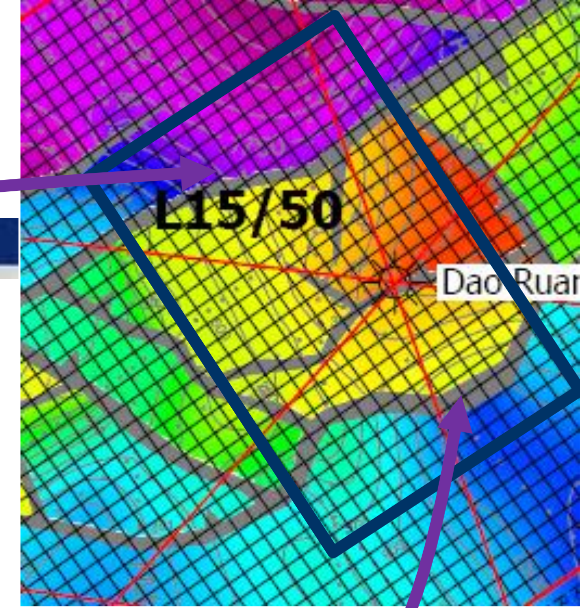
700ms Timeslice

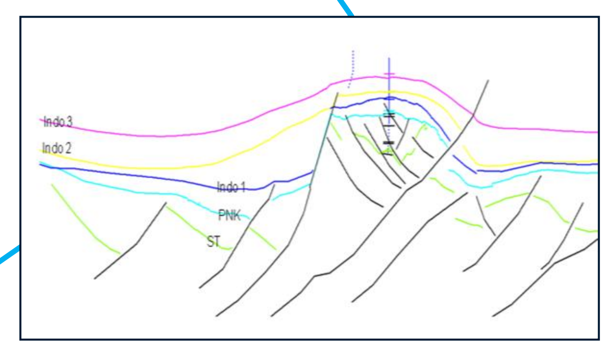
Quick interpretation
Of Faulting system
Illuminated by Azimuth
32.5°

Composite Quick interpretation of Faulting system Illuminated by 4 different Azimuth sets









Conclusions

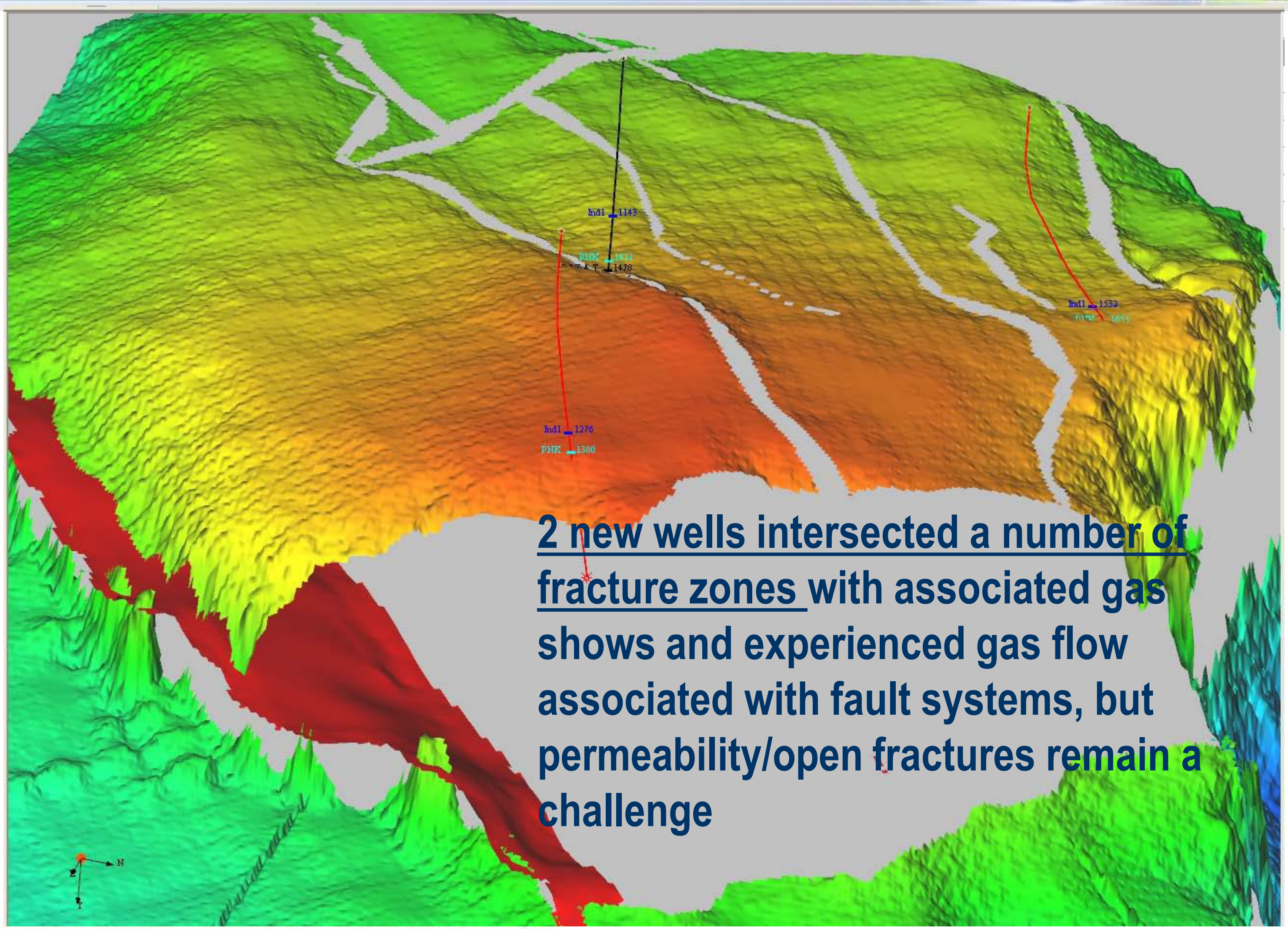
- The Shots and Receiver Lines in Different Orientations Provides the Data for Wide Azimuth Processing (WAZ)

- The WAZ Processing Technique Using Offset Vector Tiles (OVT) Gave an Uplift Over Conventional PSTM 3D Processing and Yielded Optimum Migrated Images for Fault Analysis

- The Ant-tracking on Each of the 4 Azimuth Sectors of the Migrated Seismic Showed Definite Varying Faulting/Fracturing Illumination with Respect to the Azimuthal Angle Range

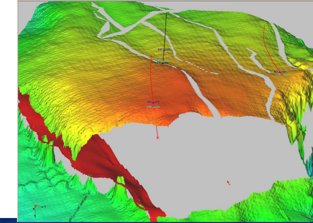
- Tying in the Azimuthal Interpretation with the Geomechanical Analysis from Surrounding Wells, it has been Possible to Identify Areas of the Dao Ruang Structure Where Fault and Fracture Networks may be Preferentially Developed

Postscript



<u>2 new wells intersected a number of fracture zones</u> with associated gas shows and experienced gas flow associated with fault systems, but permeability/open fractures remain a challenge

Conclusions



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