De-risk West of Shetland (WoS) Area Exploration using Generalized Radon Transform (GRT) Depth Imaging and Unsupervised Machine Learning Methods

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Seismic2020

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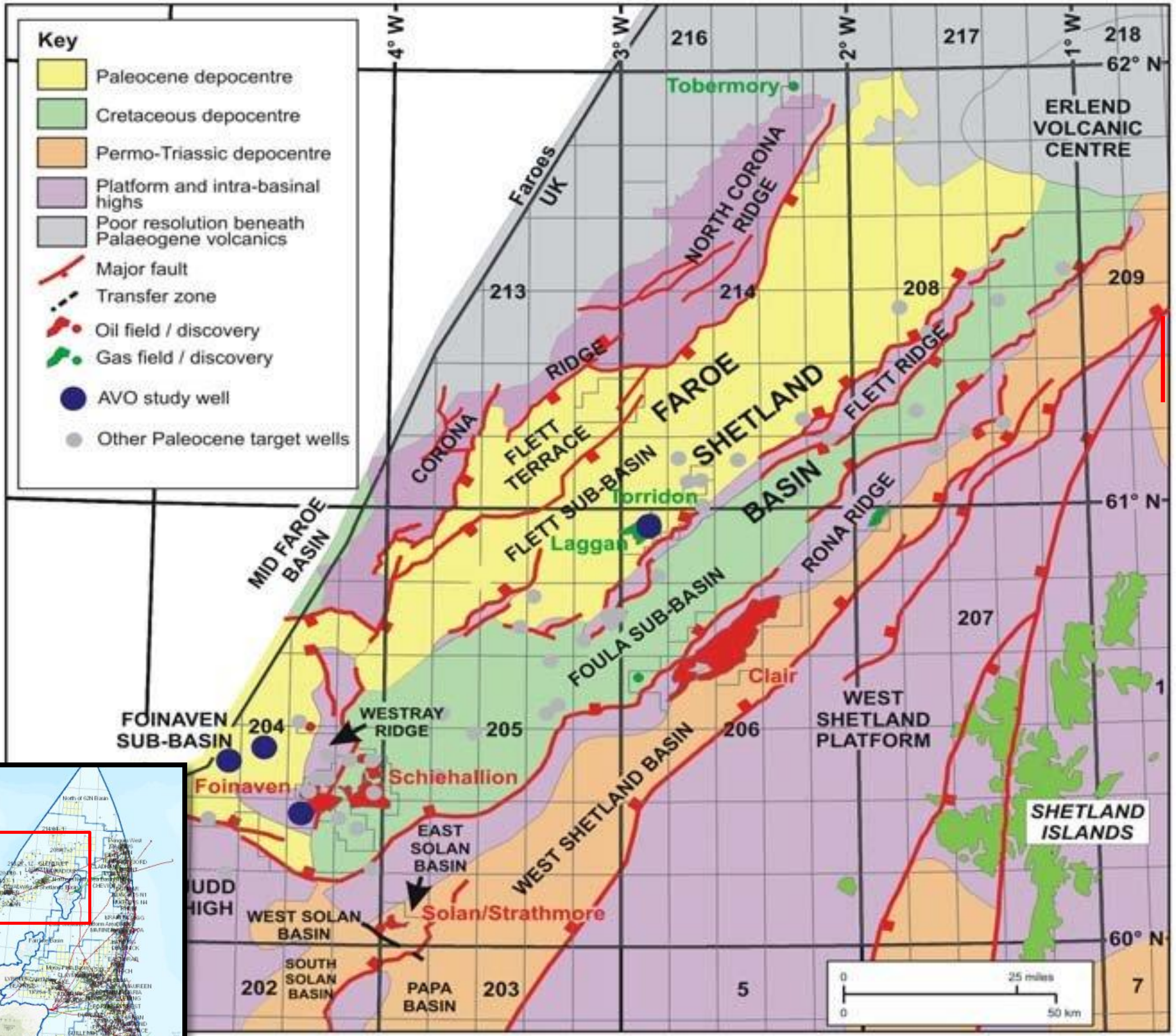
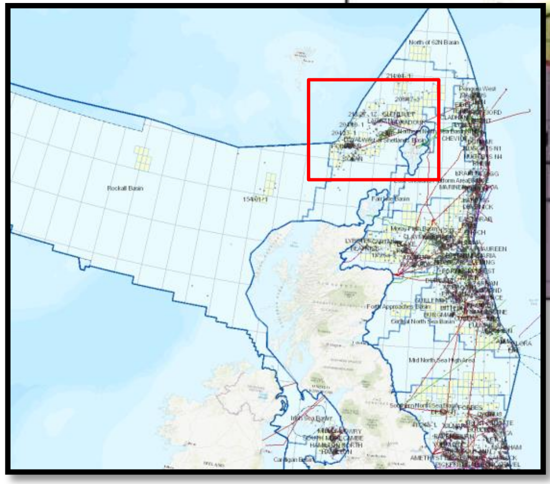
Outline

- **Introduction**
- **Generalized Radon Transform (GRT) Depth Imaging**
- **Unsupervised Machine Learning (ML) Methods and Results from WoS GRT data**
- **Conclusions**

Introduction





(Loizou et al., 2008)

- ➢ **Frontier area**
- ➢ **Less than 200 exploration wells**
- ➢ **About 23 notable discoveries (Paleocene is the most prolific)**

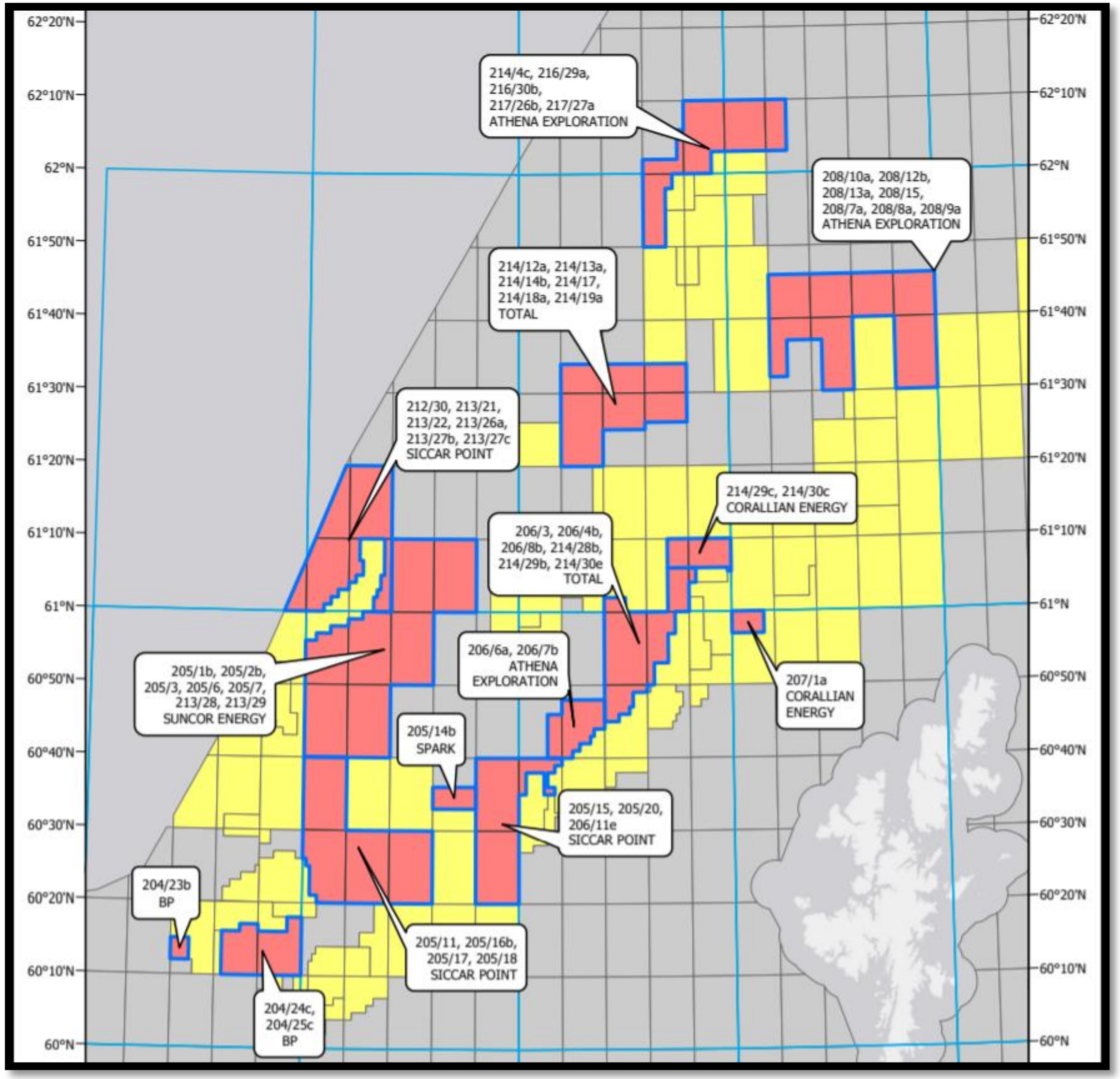
Exploration Technical Issues:

- ❖ **Poorly defined or invalid traps and on prospects that lacked reservoir or poor top seal**
- ❖ **Complex rifting and magmatism**
- ❖ **Misinterpretation of high-amplitude features especially when the amplitude anomalies were inferred in proximity of up dip limit/pinch-out edges of reservoirs**
- ❖ **Faults system of Fractured basement plays**

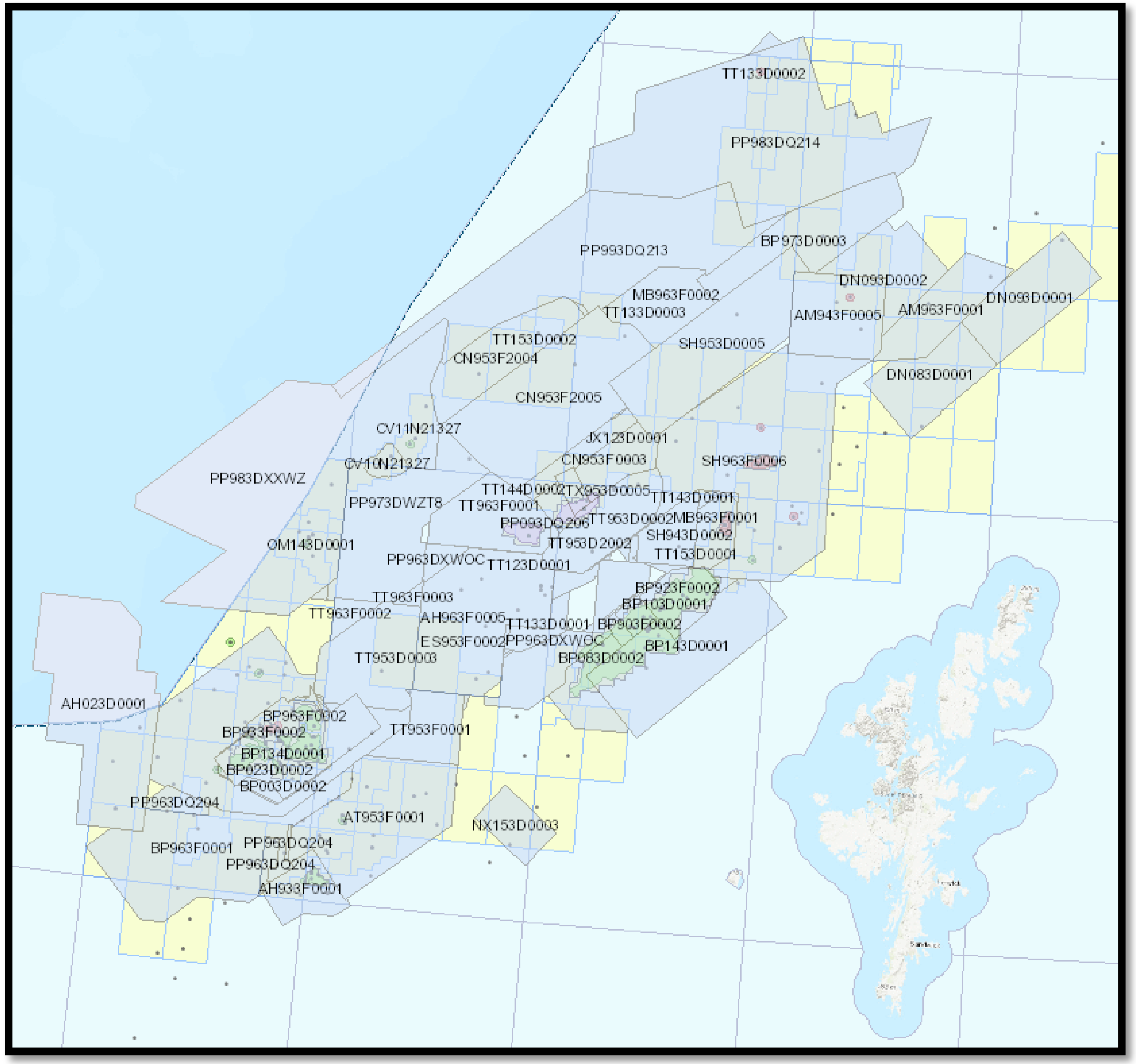
(Edited from Austin et al., 2014)

Introduction

Offer of award Blocks of 32nd License Round



Released Seismic Surveys in WoS Area



(from OGA web)

Introduction- Data Processing and Imaging Workflow Comparison

Industry Typical Processing Flow

1. Geometry
2. Designature
3. Gain
4. Denoise
5. Deghosting (S-R)
6. SRME
7. SWD
8. TPDecon S-R
9. Radon
10. Regularisation
11. FXY decon
12. Velocity & anisotropy
13. PSTM (Kirchhoff)
14. PSDM -> tomography
15. Footprint removal
16. RMO
17. Radon
18. Stack
19. Amp-Q
20. DAS
21. Filter

SIP Workflow

1. Geometry
2. Denoise
3. ePEG (M1 -> M5)
4. Velocity & anisotropy
5. PSTM/PSDM (Kirchhoff)
6. PSDM GRT
7. Radon
8. Stack
9. Amp-Q

Key Messages:

Multiples: Attenuated in a single pass. Mixing of modelling and statistical techniques is not good

Residual Noise: Attenuated in the imaging condition

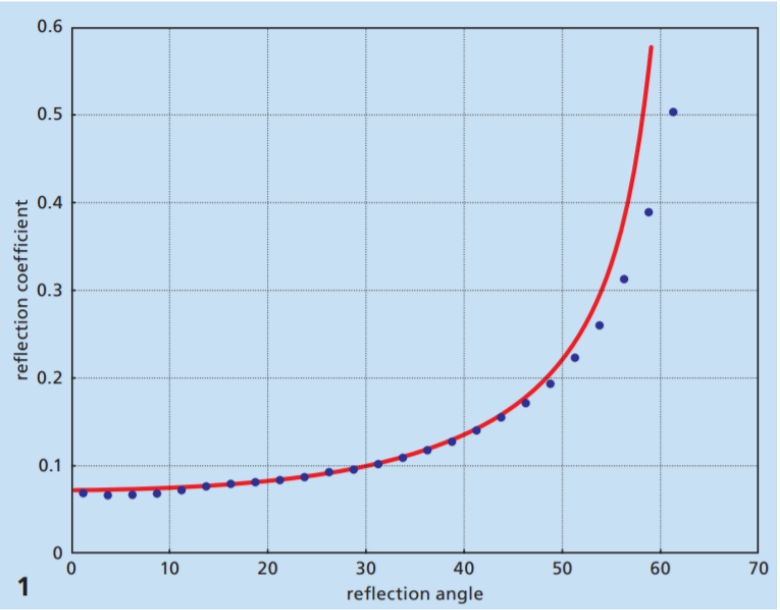
Regularisation: Not required for GRT
Cycle time: Massively Reduced
Cost: Effective
Results: Far Superior

Generalized Radon Transform (GRT) Depth Imaging

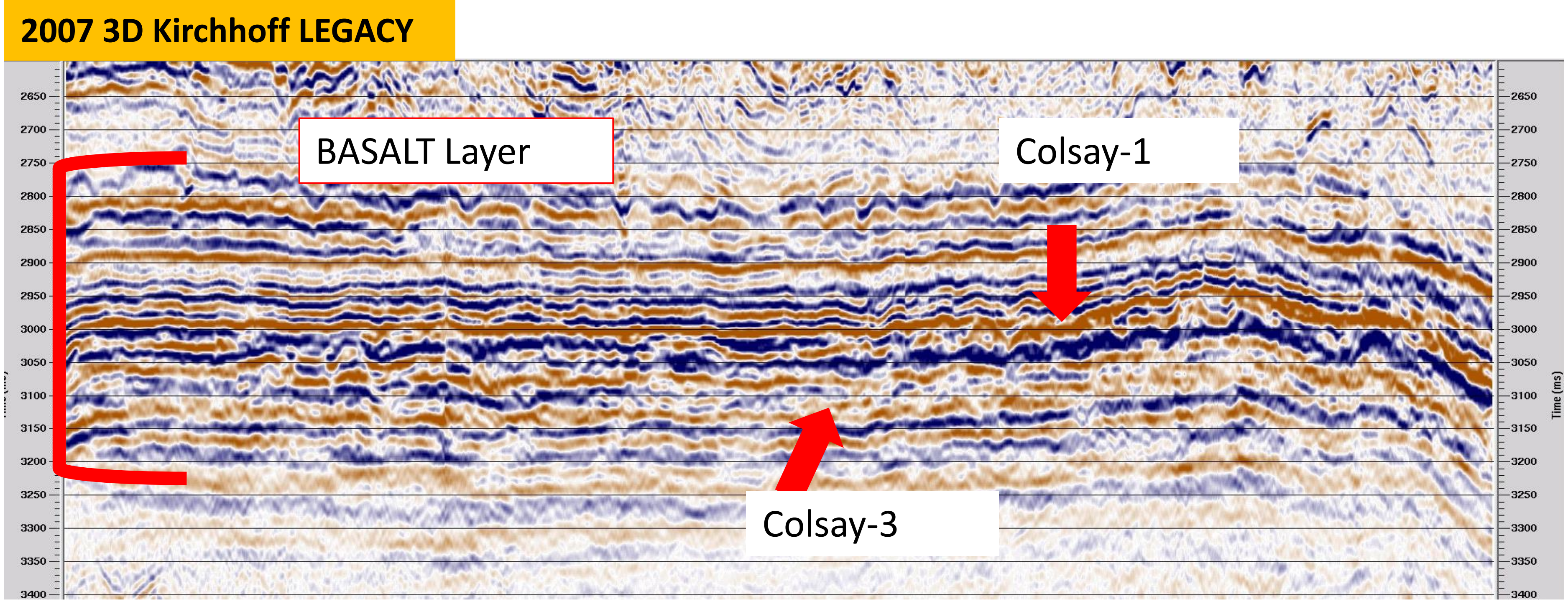
GRT Depth Imaging- Summary of GRT description

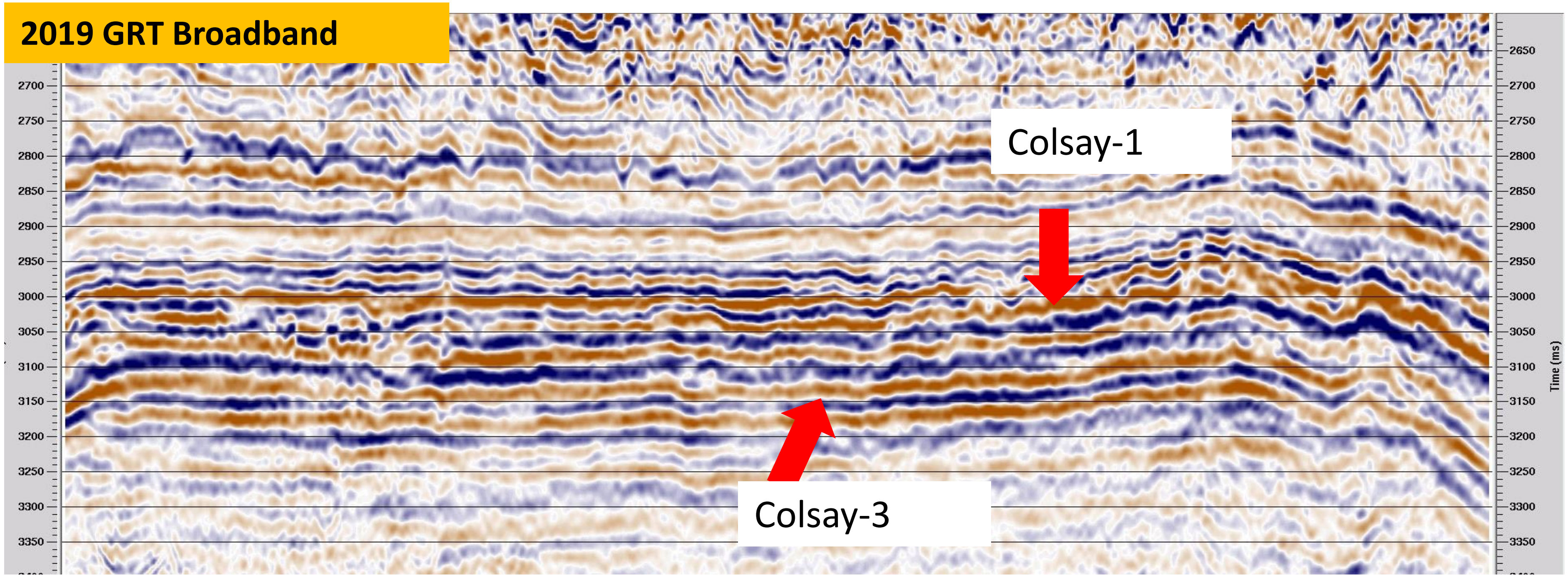
Ray-based migration schemes, carried out in the angle domain, offer several advantages over conventional Kirchhoff migration methods:

1. The migration result is generated in dependence on incidence angle. No explicit knowledge of true local dip or post-migration mapping between offset and angle is required.
2. There is no need for regularizing the input data.
3. True-amplitude weighting is applied to the seismic trace amplitudes. Migration amplitudes are, thus, proportional to the local angle- and azimuth-dependent reflection coefficient.
4. By identifying rays in the angular domain, GRT solves problems in situations of multi-pathing in a natural way while Kirchhoff migration has severe problems in storing and accessing multiple ray events. GRT is, thus, essentially an all-arrival migration.



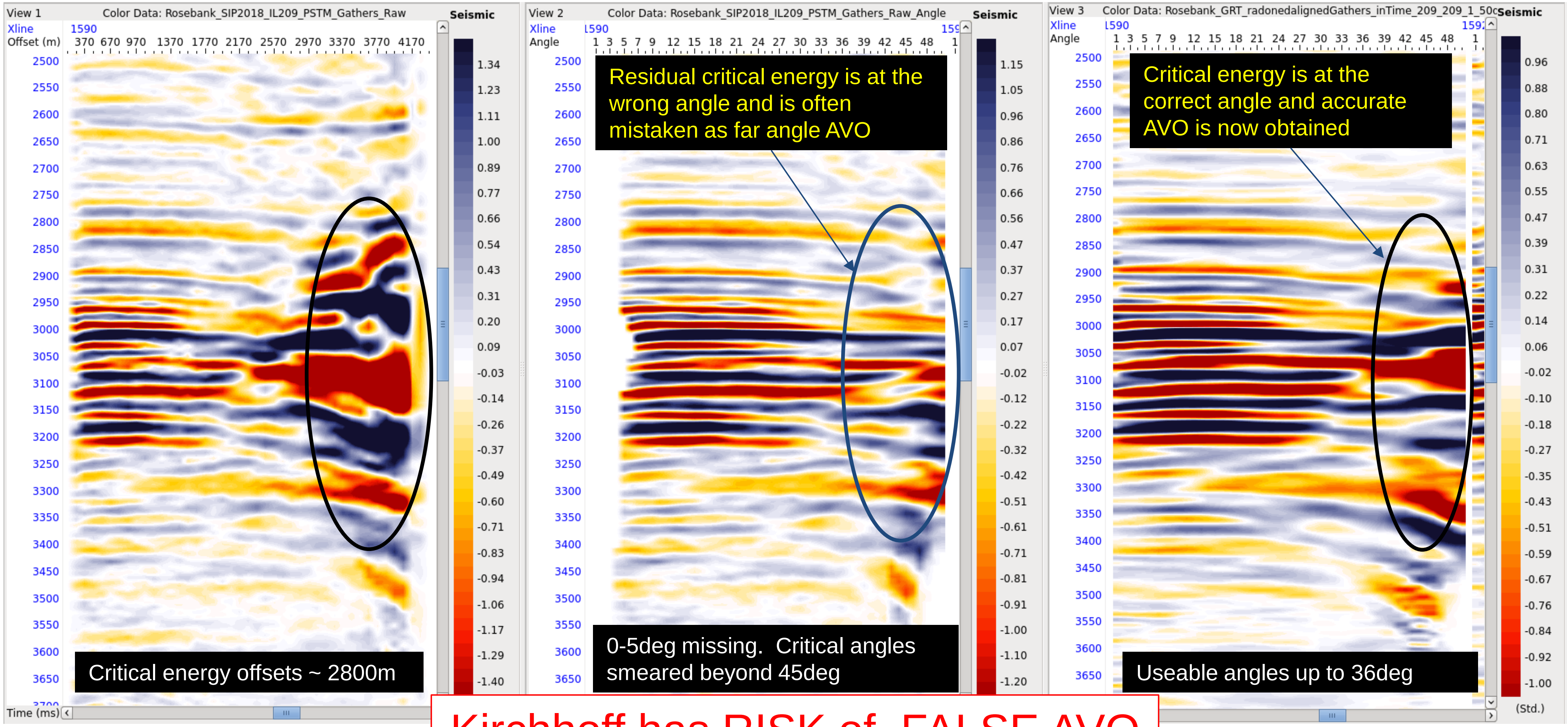
Reflection coefficient from GRT gathers (blue)
Exact curve (red)


2007 3D Kirchhoff LEGACY
BASALT Layer
Colsay-1
Colsay-3
Time (ms)
2650 2700 2750 2800 2850 2900 2950 3000 3050 3100 3150 3200 3250 3300 3350 3400


2019 GRT Broadband
Colsay-1
Colsay-3
Time (ms)
2650 2700 2750 2800 2850 2900 2950 3000 3050 3100 3150 3200 3250 3300 3350

GRT Depth Imaging- Examples

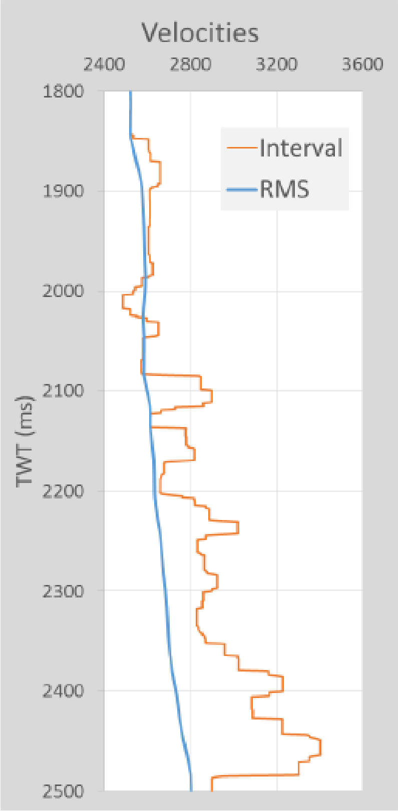
Kirchhoff Gathers (offset) | **Kirchhoff Gathers Angles** | **GRT Gathers Angles**

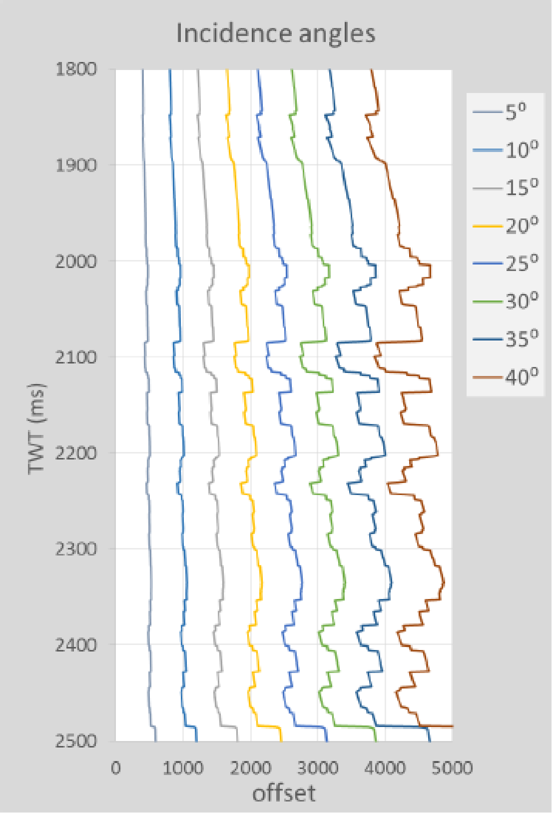


Kirchhoff has RISK of FALSE AVO

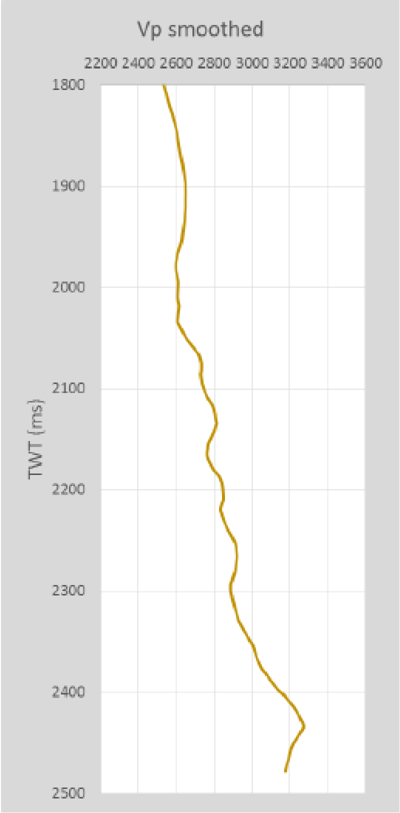
angle estimation errors

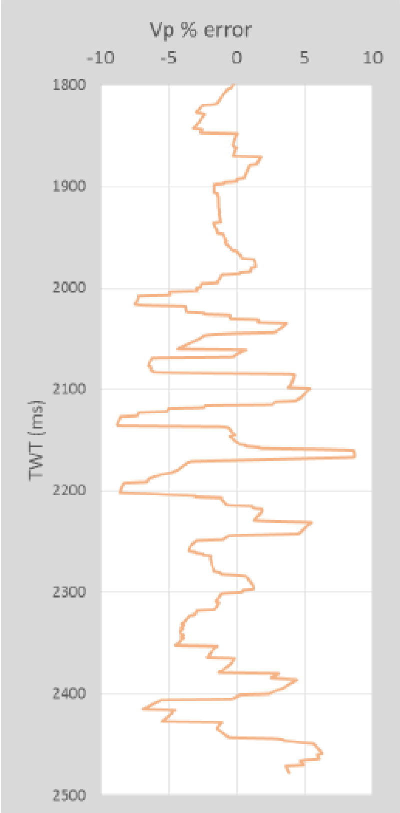
% angle error ≈ % local interval velocity error





velocities from sonic log:





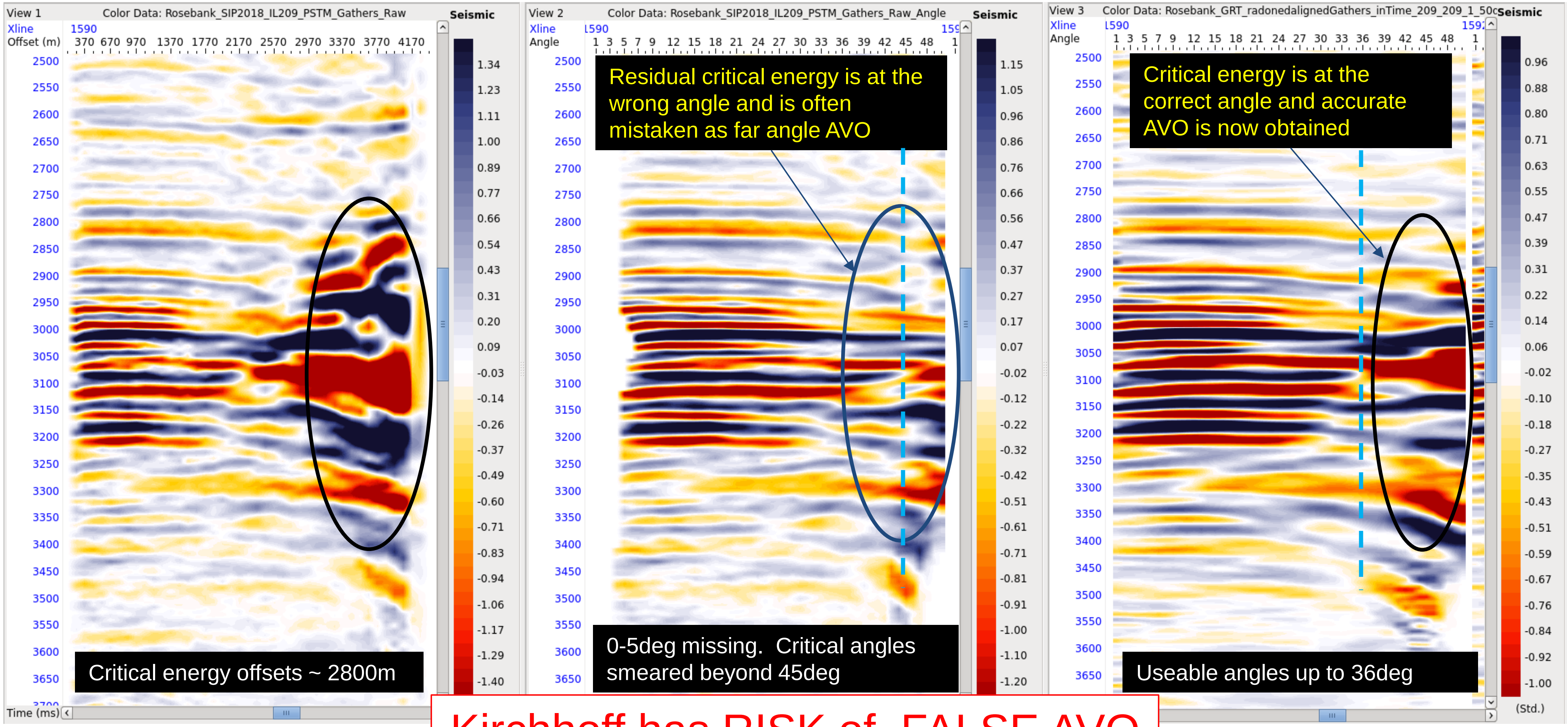
seismic velocities

error = ± 10%

(From Patrick Connolly, 2020)

GRT Depth Imaging- Examples

Kirchhoff Gathers (offset) | **Kirchhoff Gathers Angles** | **GRT Gathers Angles**



Kirchhoff has RISK of FALSE AVO

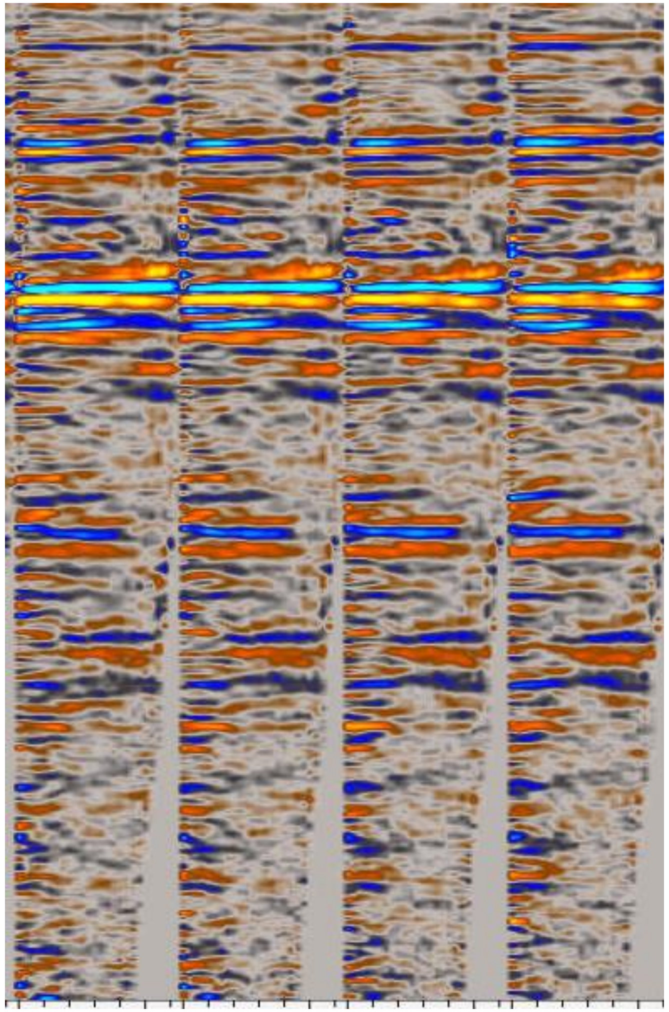
GRT Depth Imaging Examples

West of Shetlands Exploration Areas

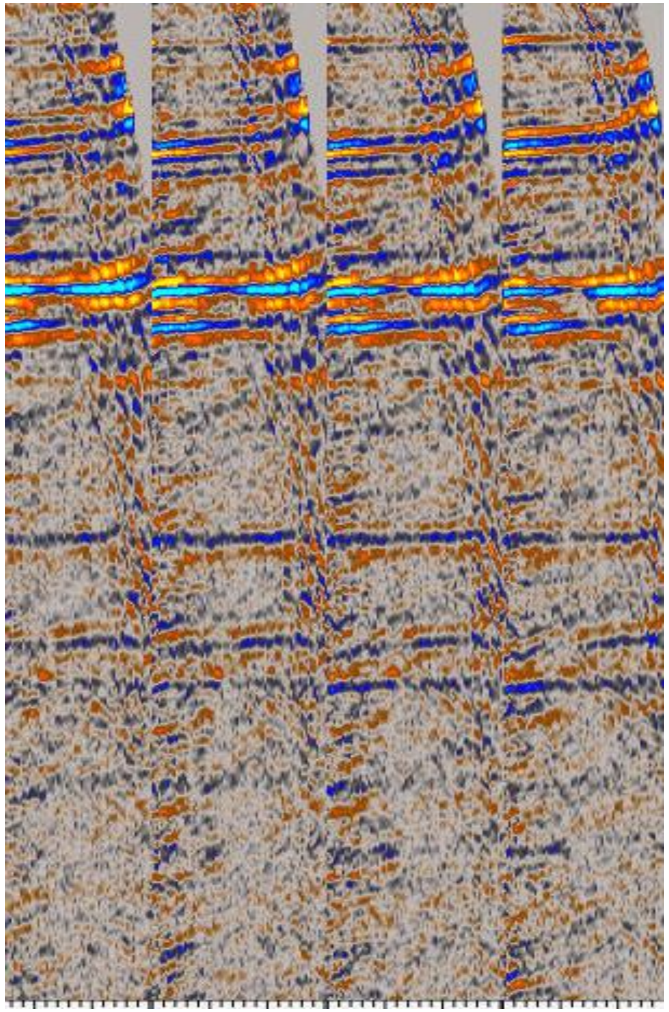
1. GRT vs Kirchhoff migrated gathers comparison
2. Beam tomography derived velocity model
3. GRT vs Kirchhoff EEI fluid slice comparison

GRT Depth Imaging- Examples

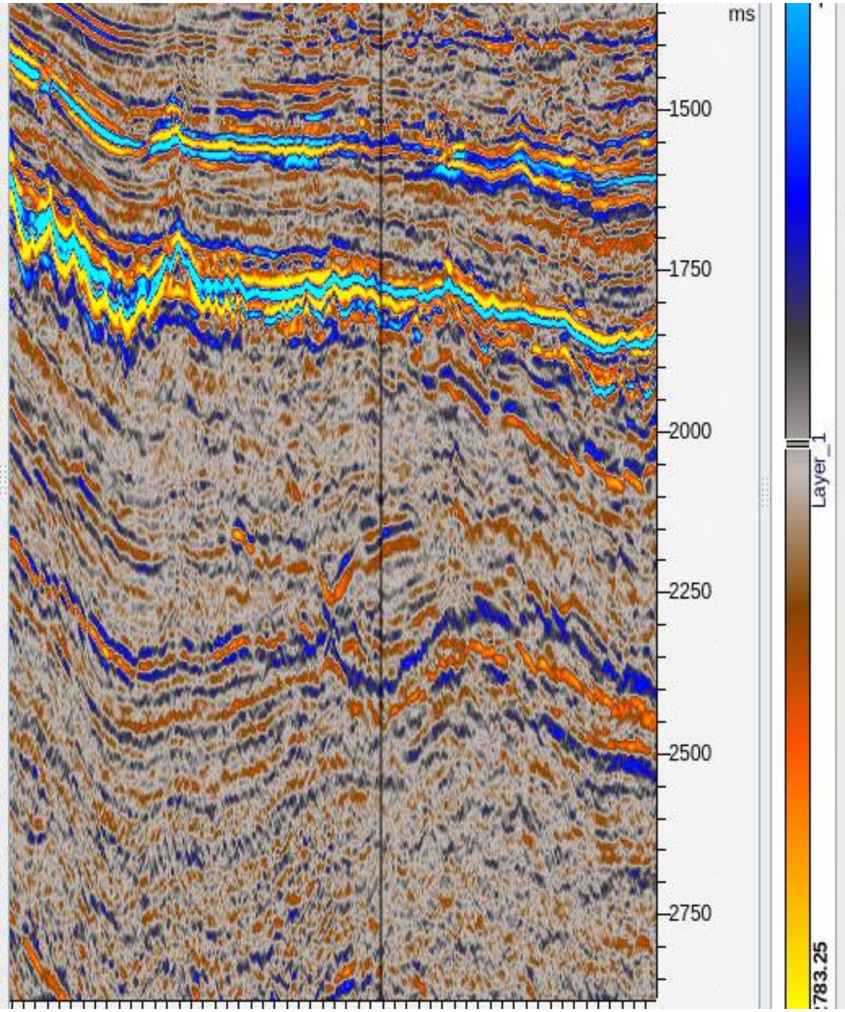
GRT Gathers



Kirchhoff Gathers

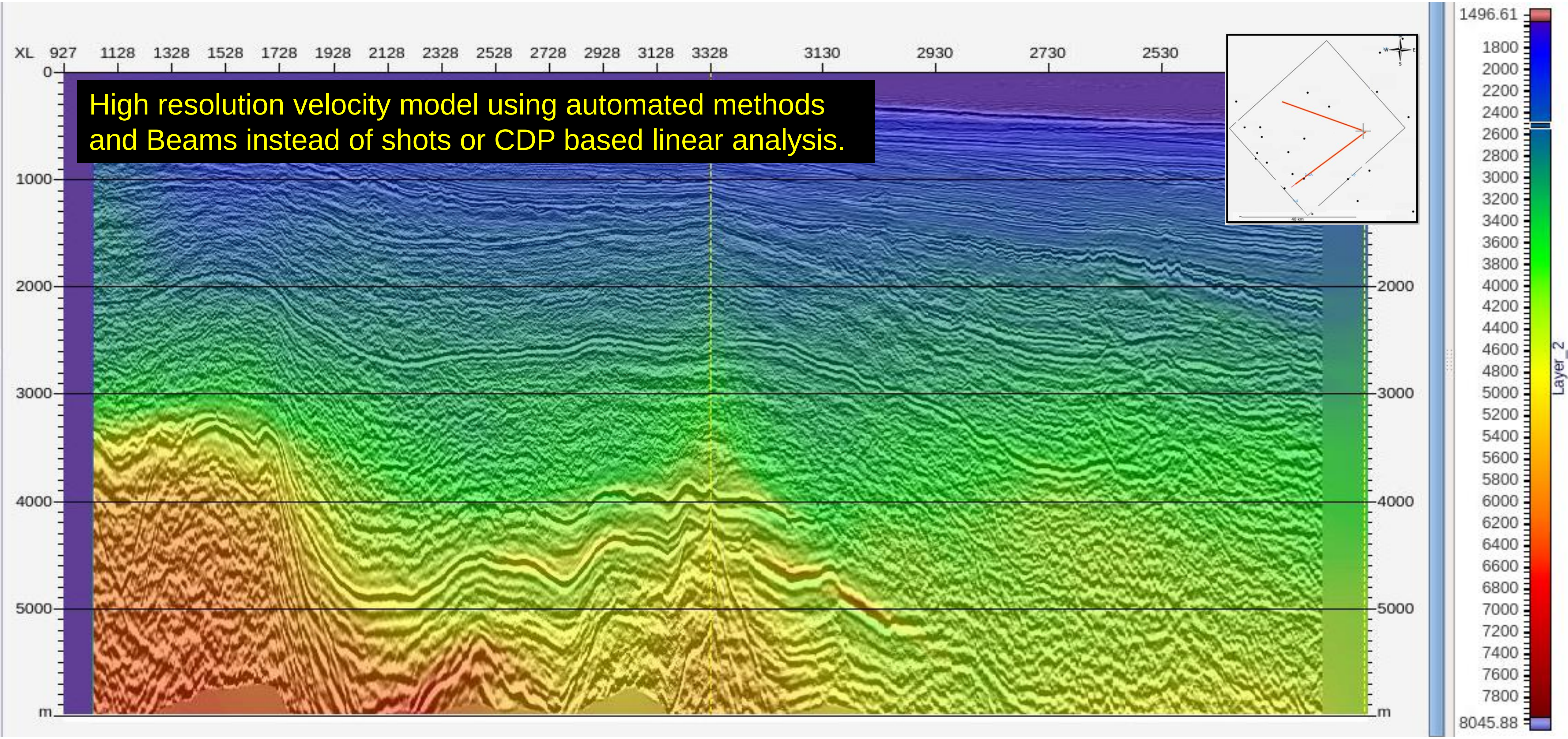


Gathers Location

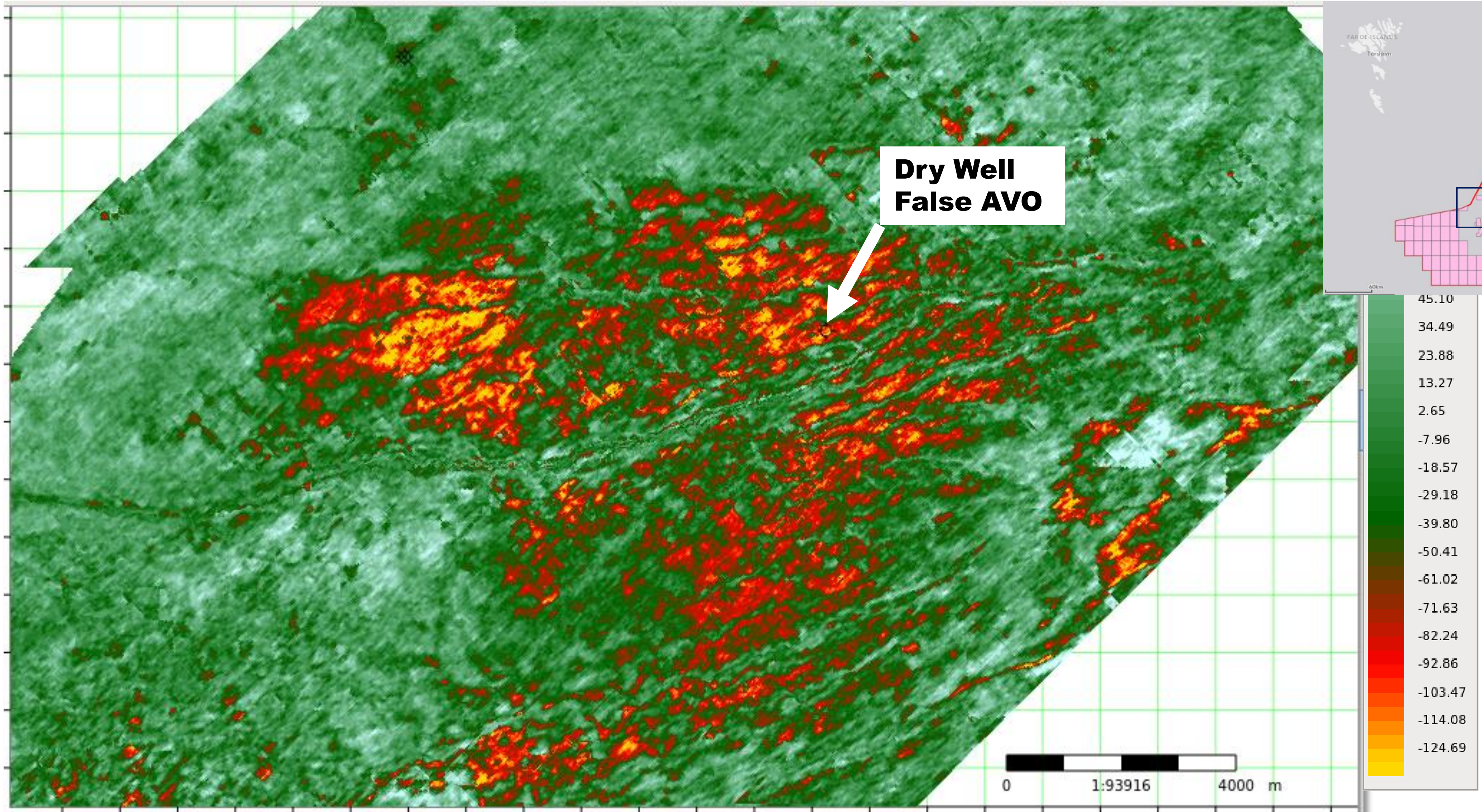


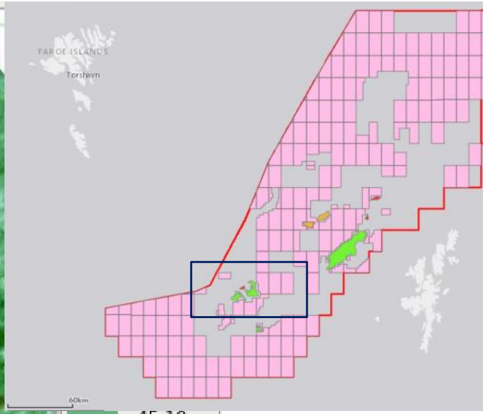
Most aspects in terms of “AVO “ are poor using Kirchhoff migration

GRT Depth Imaging- Examples



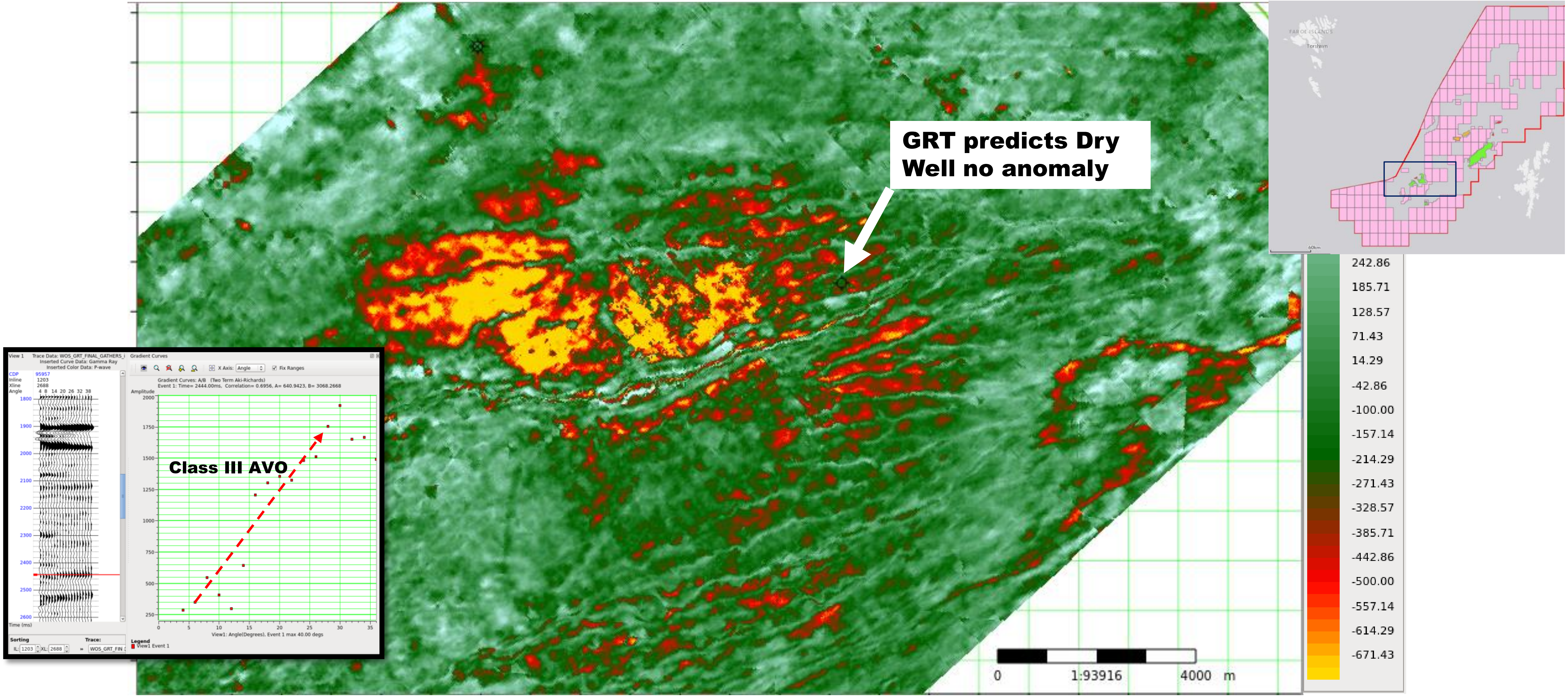
Kirchhoff: EEI Chi 20^o Fluid Response at T31





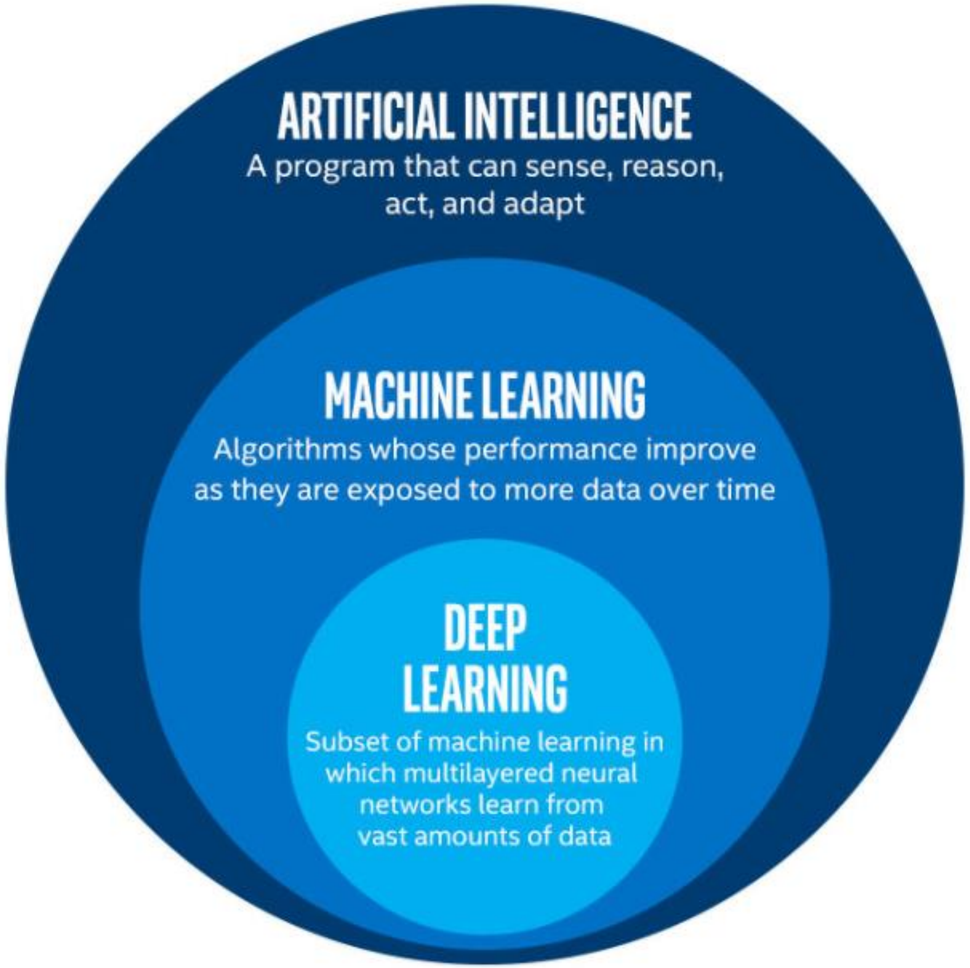
The fluid slice at T31 is very noisy on Kirchhoff data. Not consistent with structure.

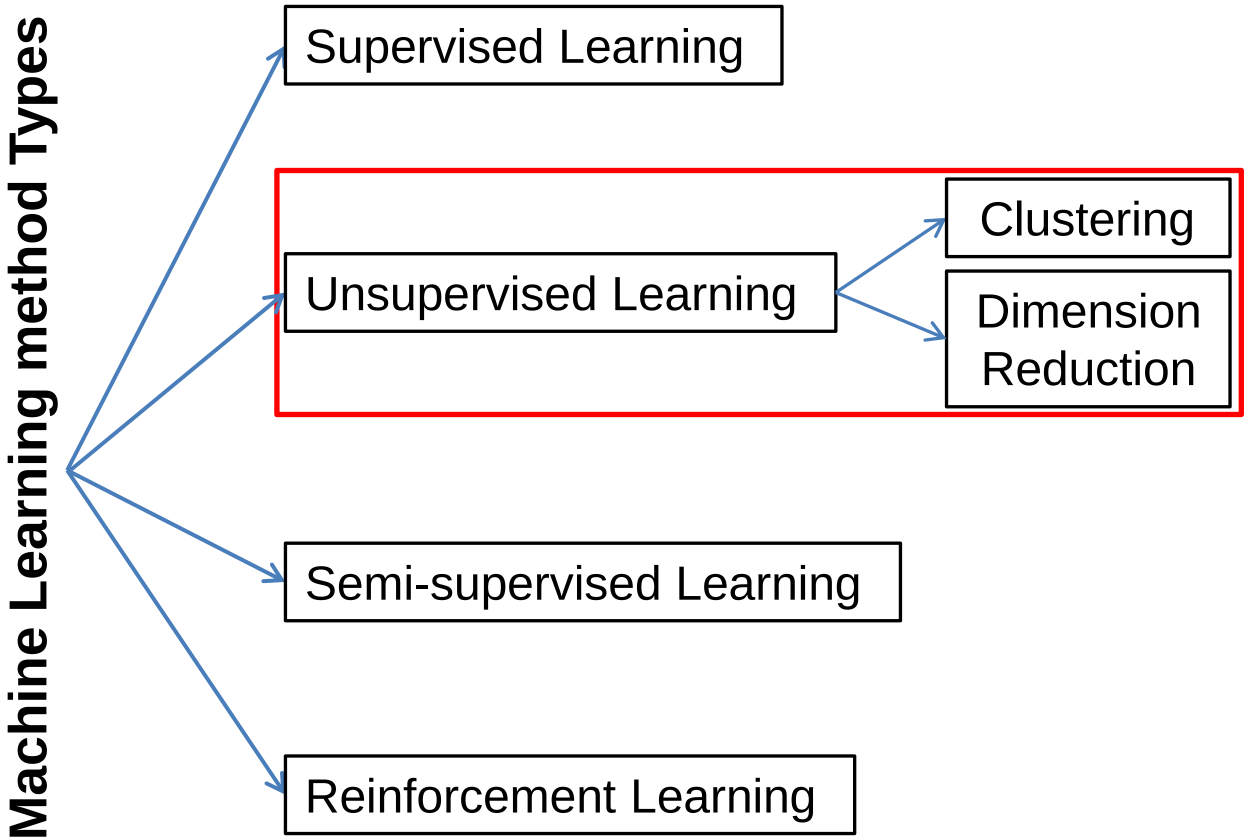
GRT: EEI Chi 20^{o} Fluid Response at T31



The fluid slice at T31 is very clear on GRT data, it can be used for analysis and is consistent with structure.

AI - Machine Learning (ML) Methods

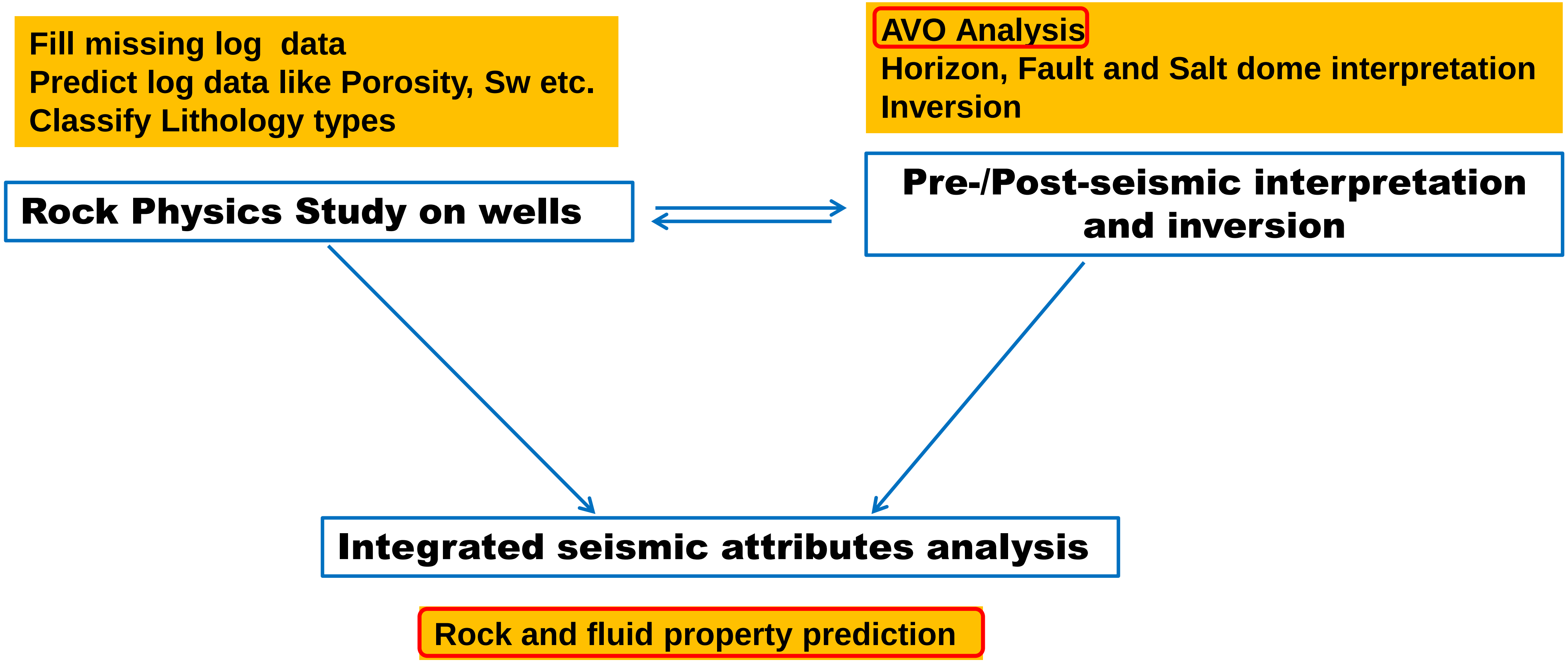




(from medium.com)

AI - Machine Learning (ML) Methods

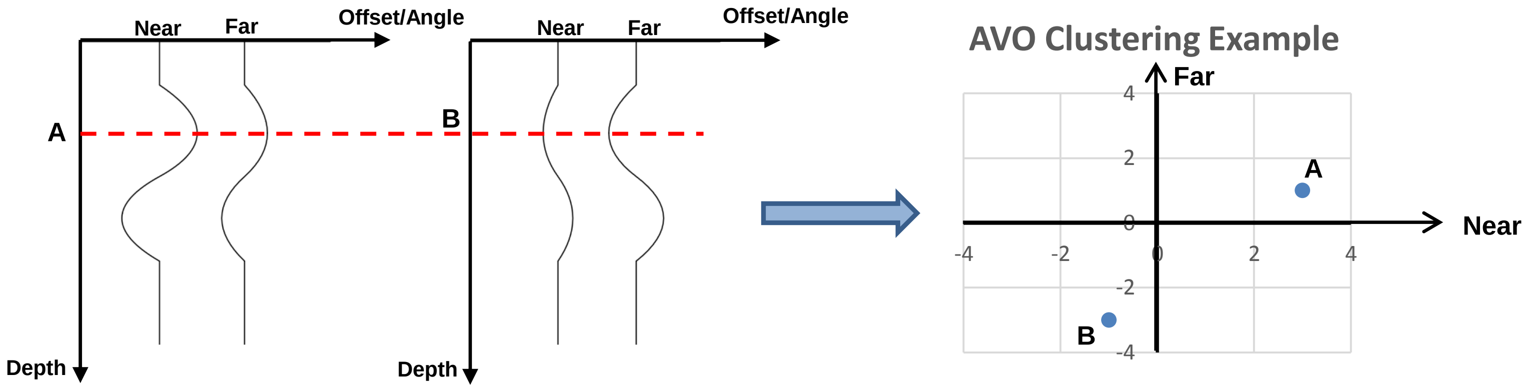
General QI Workflow integrated with Machine Learning



AI - Machine Learning (ML) Methods

AVO Anomaly Analysis using Unsupervised Machine Learning

➢ **AVO anomaly analysis can be considered as a clustering process, different AVO classes can be put into different clusters.**



➢ **This is unsupervised machine learning task (Clustering).**

➢ **Fuzzy c-means clustering can be used to solve the problem quickly.**

Input Data
Pre-stack Gathers
Partial Angle Stack Volumes
Number of Clusters

→ **Fuzzy C-Means Clustering** →

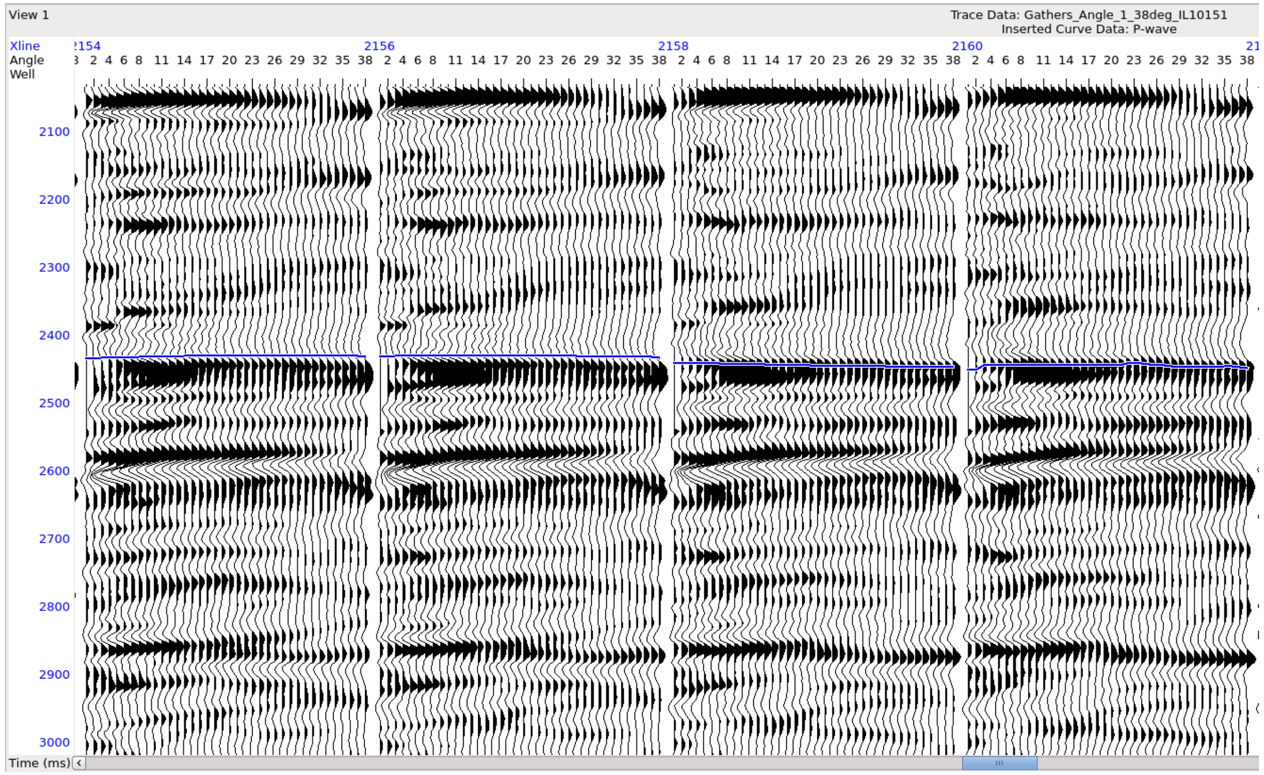
Outputs
- **Labelled Cluster volume**
- **Probability of Cluster Membership Volume for Each Cluster**

A "soft clustering" technique, which allows one piece of data to belong to two or more clusters.
Membership grades are assigned to each of the data points. These membership grades indicate the degree to which data points belong to each cluster.

(Edited from Laura et al., 2018)

AI - Machine Learning (ML) Methods- **Example of AVO scanning**

Angle Gathers Example

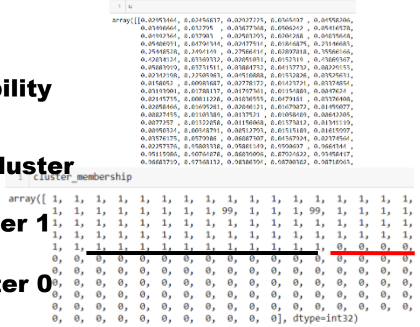


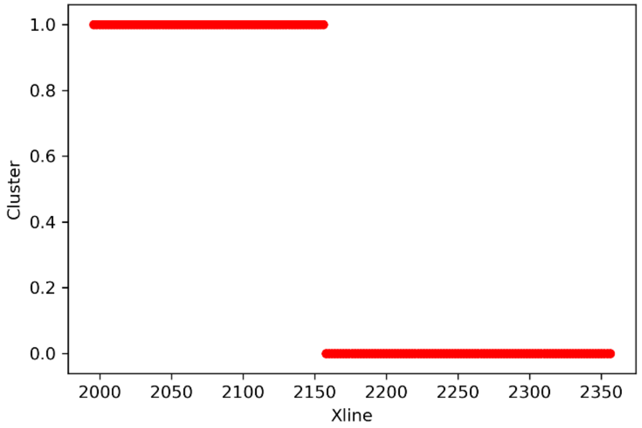
Probability

Labelled Cluster

Cluster 1

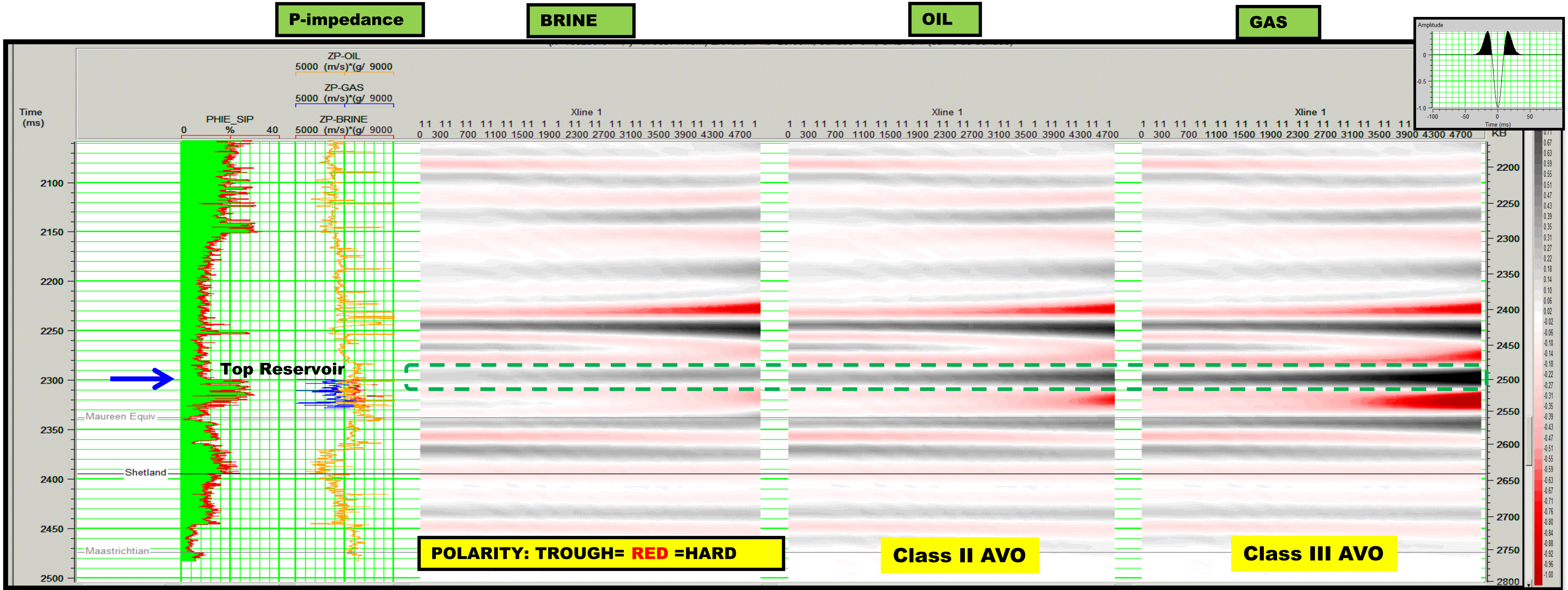
Cluster 0





AI - Machine Learning (ML) Methods

AVO Synthetics from Dry Well log data

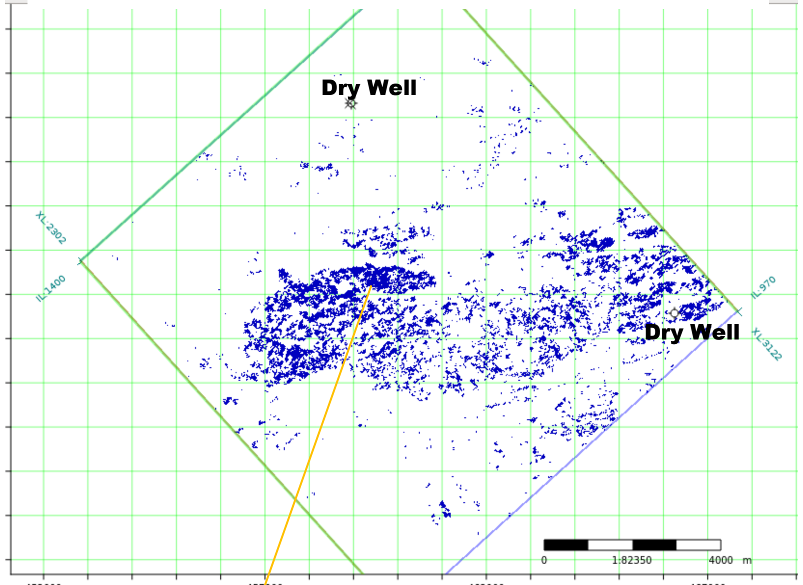


The top reservoir brine (BLUE arrow) response is a soft event of low amplitude with a slight increasing AVO. For the oil case the near offset response is similar (though very slightly brighter), but there is now a distinct increasing AVO response from about 2000m offset and higher. In the gas case both the near and far offsets brighten and there is a distinct increasing AVO response associated with the reservoir.

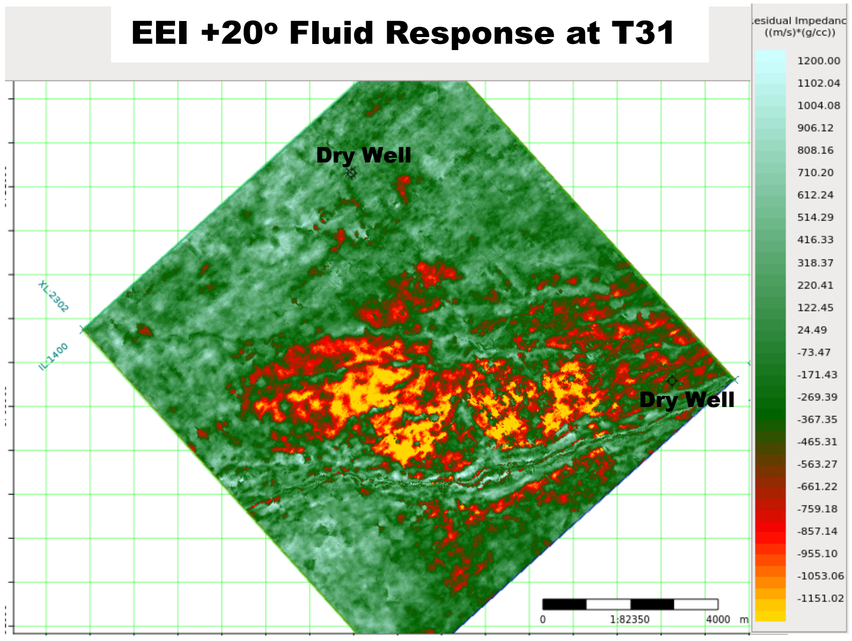
AI - Machine Learning (ML) Methods

Results of AVO Scanning

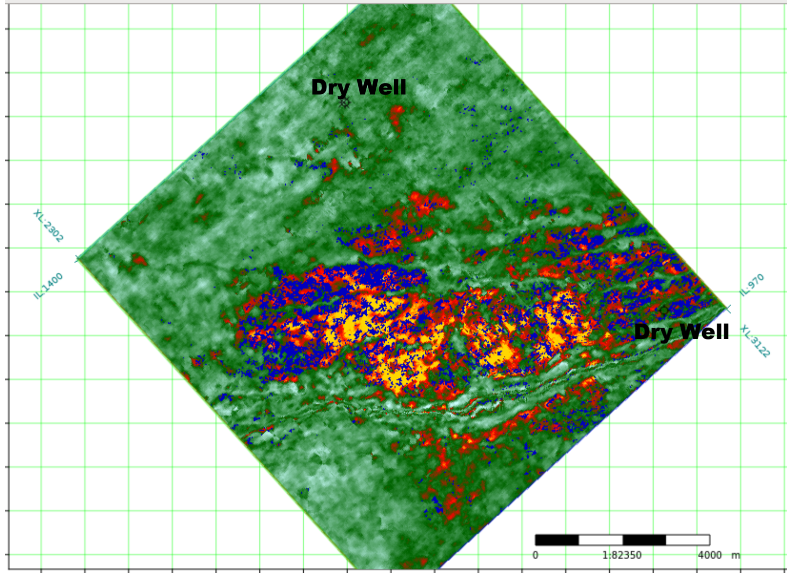
Machine Learning Scanned AVO Cluster AVO Class II/III at T31

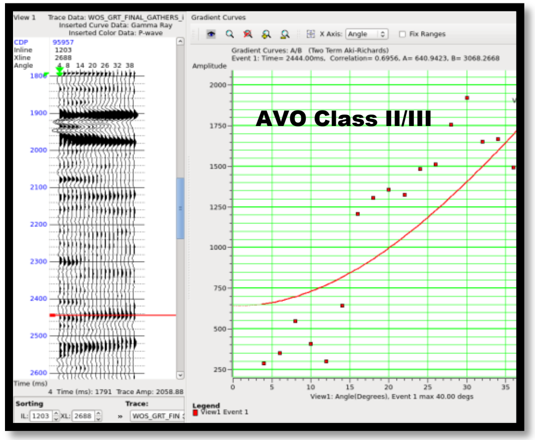


EEI +20º Fluid Response at T31



AVO Class II/III overlay on EEI +20º Fluid Response at T31





One gather AVO gradient analysis at T31

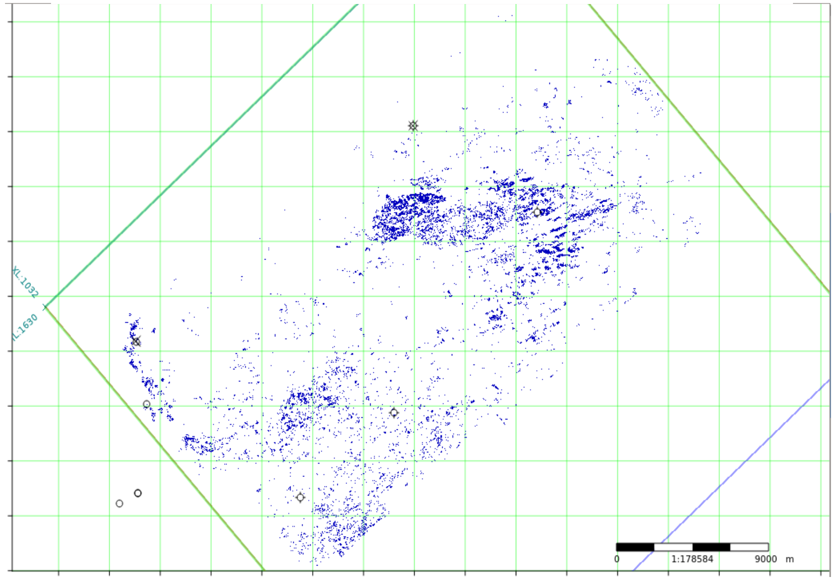
The bright colour shows potential fluid distribution area.

AVO Class II/III area matches very well with EEI+20º fluid distribution area.

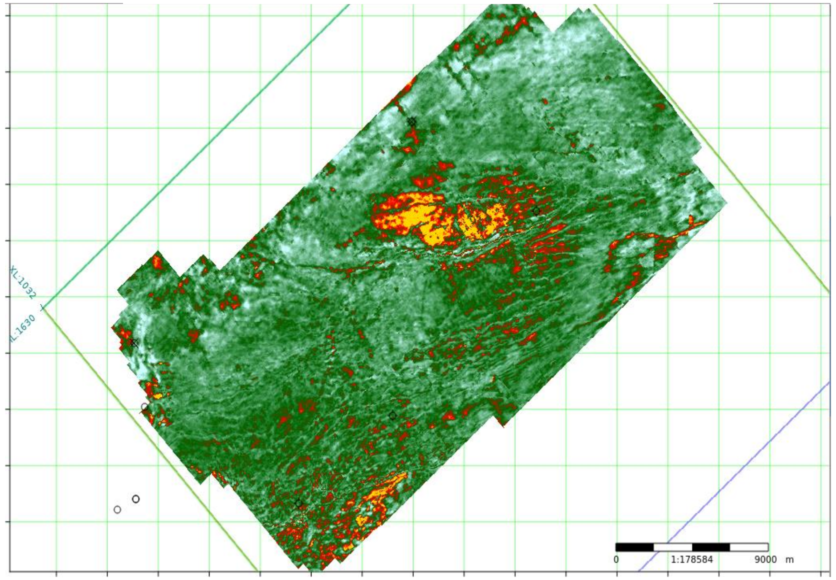
AI - Machine Learning (ML) Methods

Results of AVO Scanning

Machine Learning Scanned AVO Cluster AVO Class II/III at T31

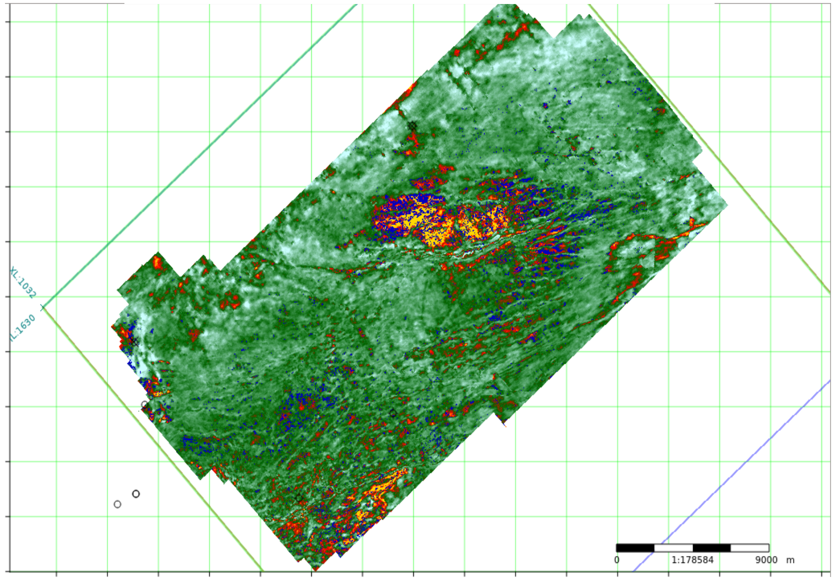


EEI +20º Fluid Response at T31



The bright colour shows potential fluid distribution area.

AVO Class II/III overlay on EEI +20º Fluid Response at T31

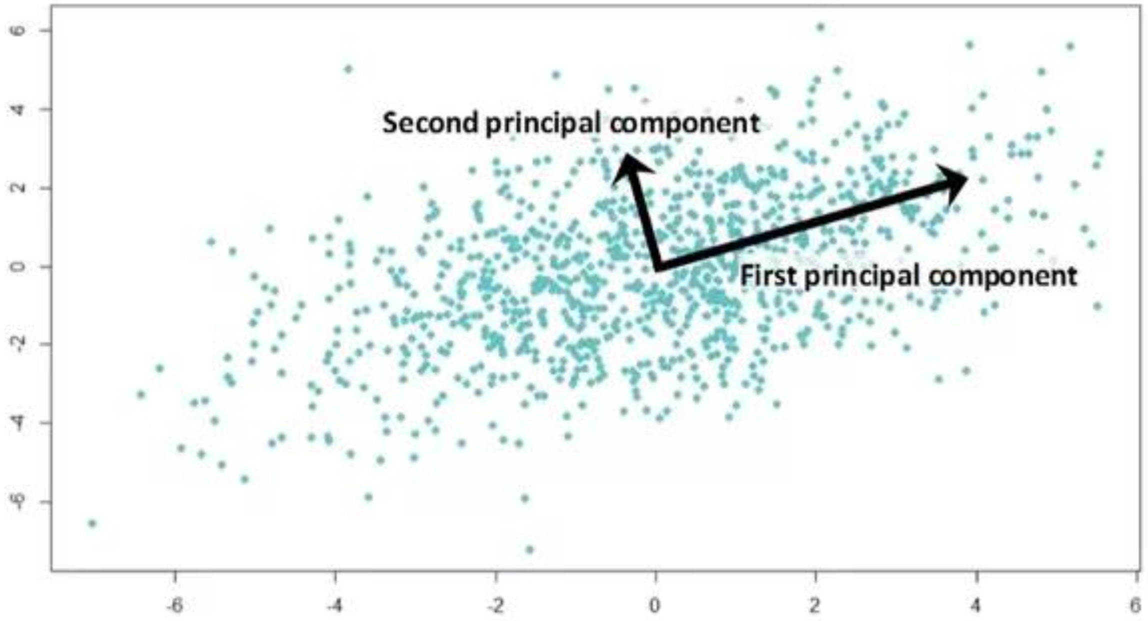


AVO Class II/III area matches very well with EEI+20º fluid distribution area.

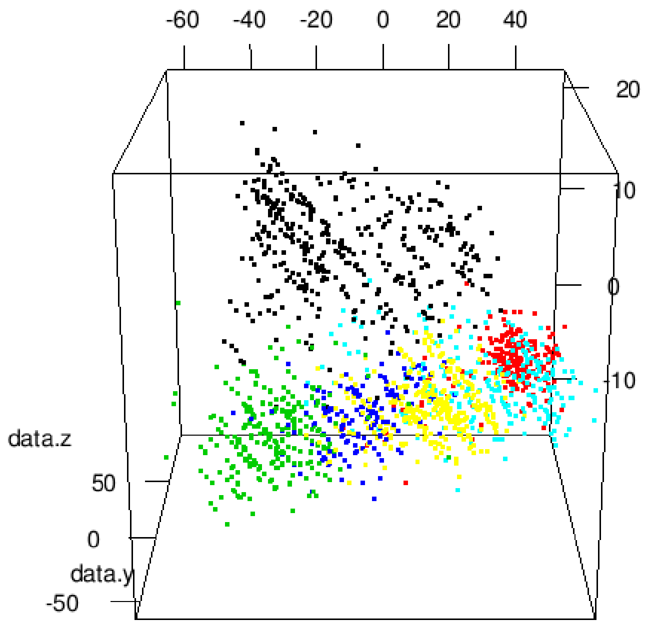
AI - Machine Learning (ML) Methods

Multi-Attributes analysis using Principal Component Analysis (PCA) and Self-Organizing Map (SOM)

PCA is a linear mathematical technique used to reduce a large set of seismic attributes to a small set that still contains most of the variation in the large set (Roden et al., 2015).



(from medium.com)

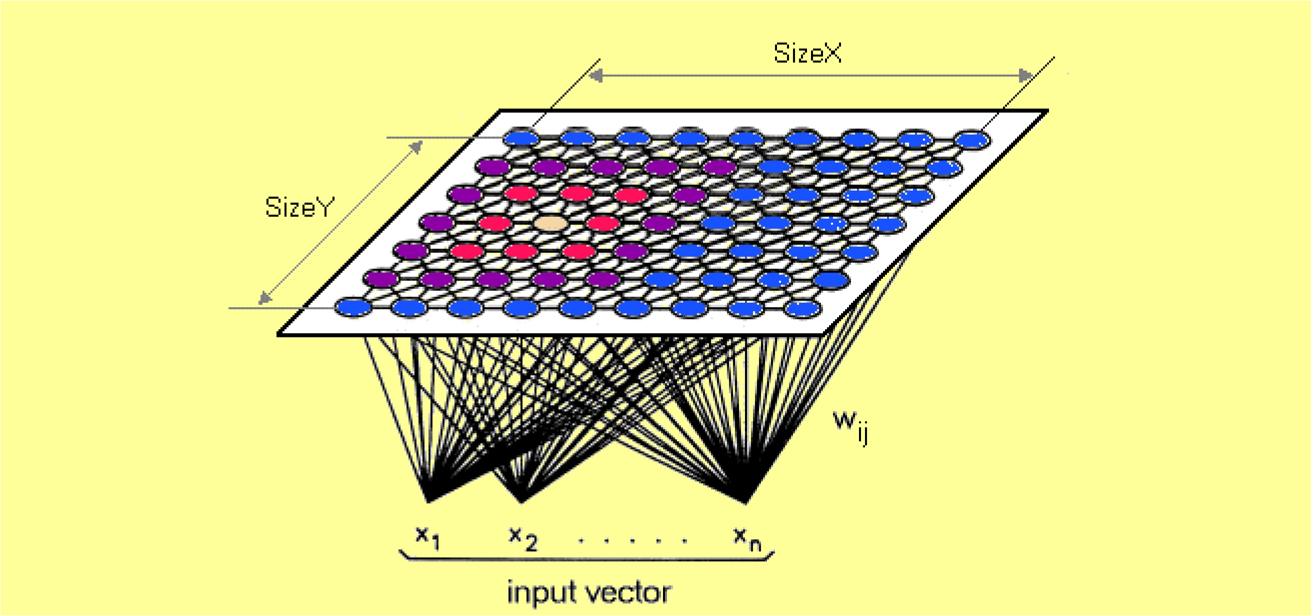


(from giphy.com)

AI - Machine Learning (ML) Methods

Multi-Attributes analysis using Principal Component Analysis (PCA) and Self-Organizing Map (SOM)

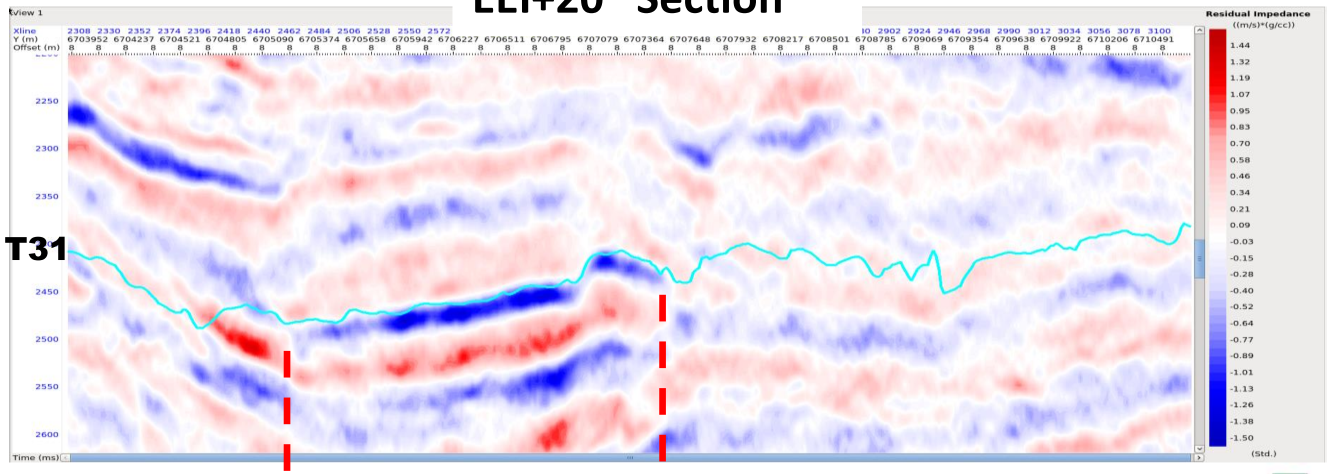
The self-organizing map (SOM) is a non-linear approach reduces the dimensions of data using unsupervised neural networks. SOM reduces dimensions by producing a 2D map that plots the similarities of the data by grouping similar data item together.



(from towardsdatascience.com)

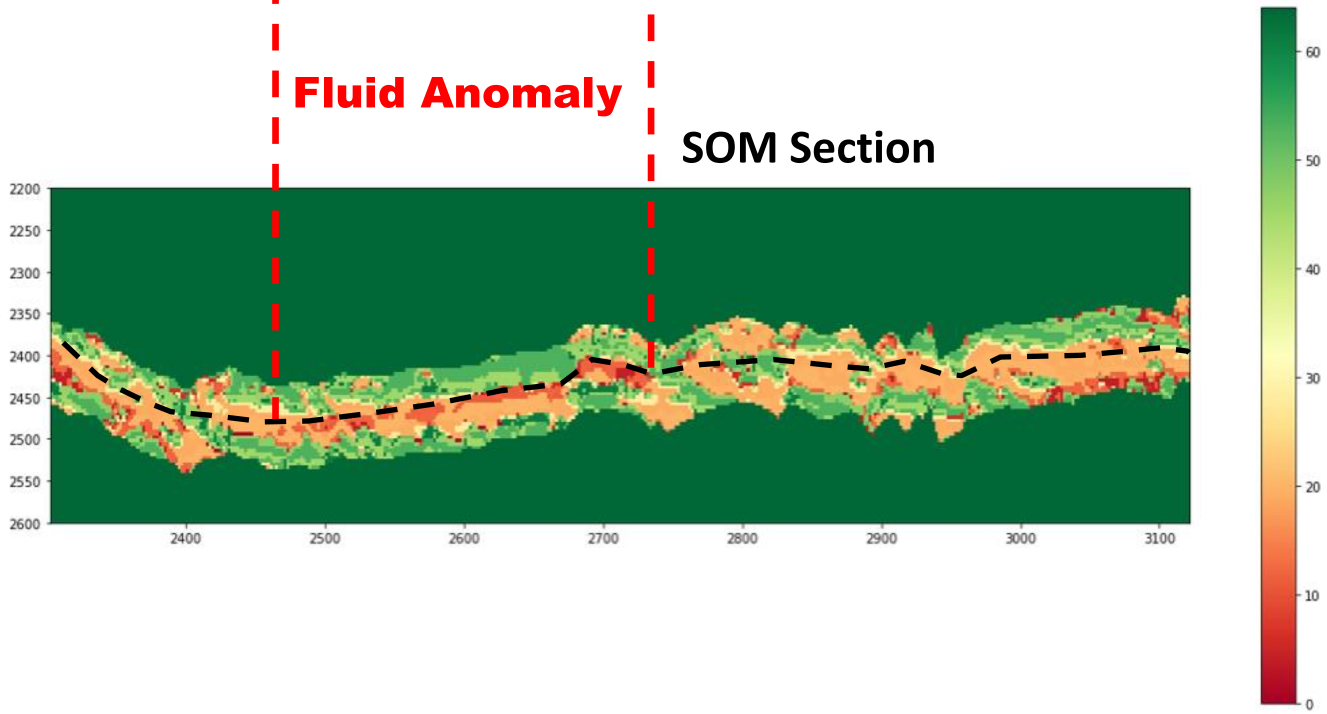
AI - Machine Learning (ML) Methods- **Results from SOM**

EEI+20° Section

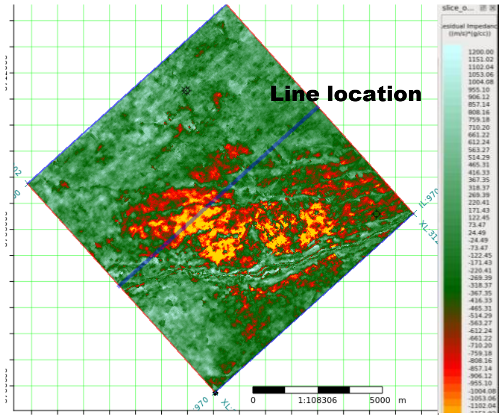


Fluid Anomaly

SOM Section

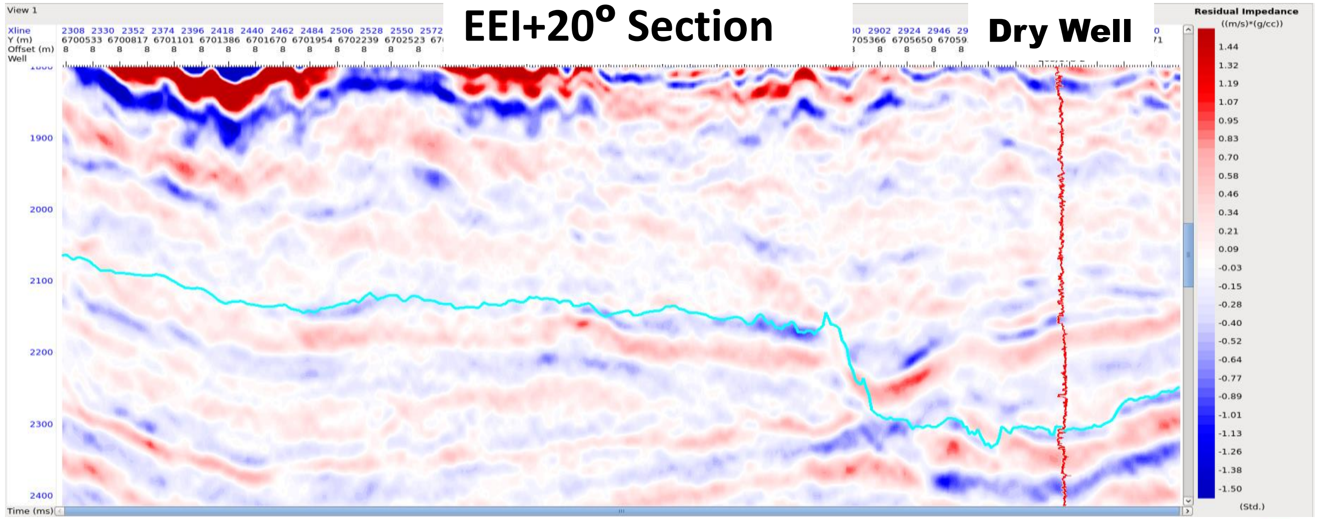


EEI+20° Slice at T31

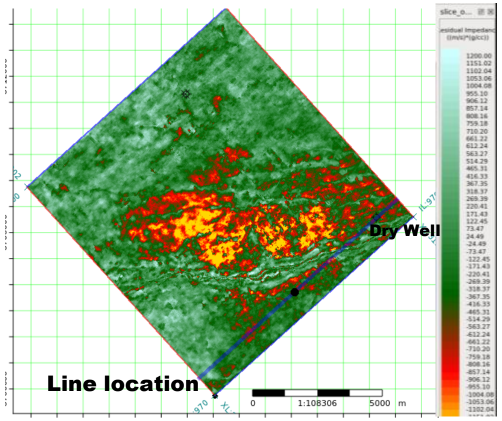


One pattern on SOM section matches very well with fluid anomaly on EEI+20° section but in more details.

AI - Machine Learning (ML) Methods- **Results from SOM**

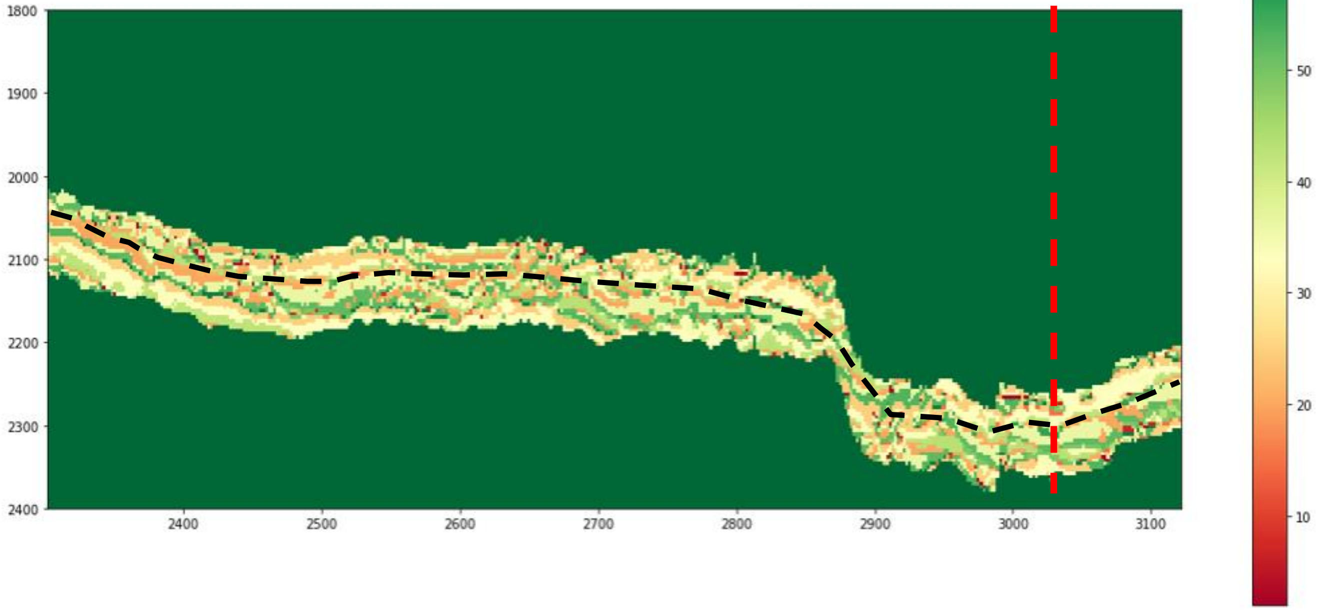


EEI+20° Slice at T31



SOM Section

Dry Well Location



No special pattern shows up on SOM section through dry well.

Conclusions

- SIP broadband processing with GRT imaging reduces the risk of false AVO anomalies and delivers a high-quality velocity model using beam tomography.

- Kirchhoff migration has significant risk for AVO analysis.

- The Fuzzy c-means clustering enables us to quickly scan seismic and find areas of AVO anomalies but only if the input is of the high quality.

- Combining different attributes from the seismic using PCA and SOM we can define more accurately our exploration targets.

- This new SIP integrated migration and AI-Machine Learning workflow is proven to identify and de-risk exploration targets in the West of Shetlands in a time- and cost-efficient manner, whilst generating a high-quality seismic image and associated fluid and lithology attributes.

Acknowledgements

- Suncor UK Ltd

Seismic2020

www.seismicimageprocessing.com