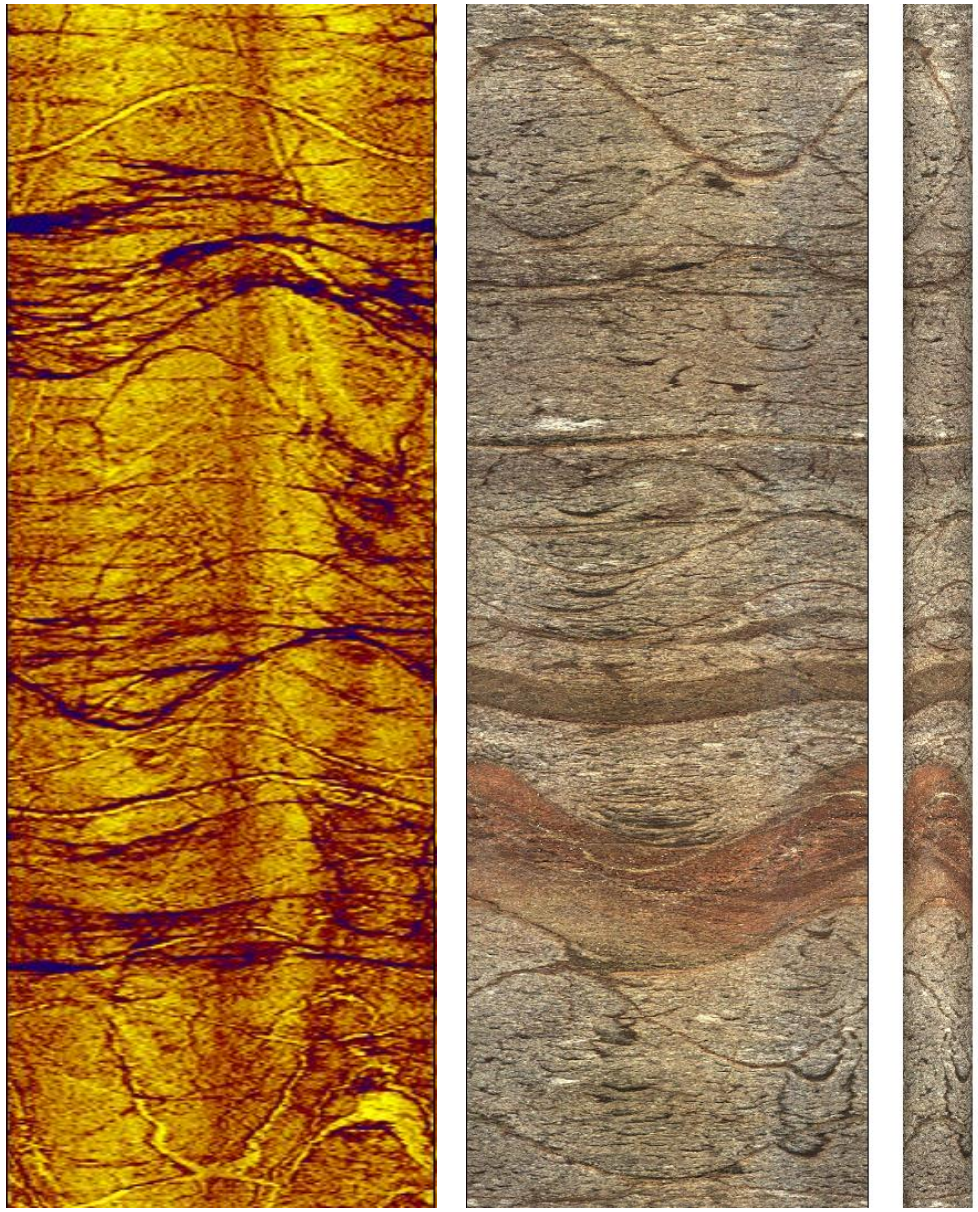


MERC 2023 - Session 4

BOREHOLE IMAGERY AND DATA APPLICATIONS

Session 4 Outline

- Televiewers
  - Optical Televiewer
  - Acoustic Televiewer
  - Features, Fractures and RQD
  - Breakouts and Stress
  - Stress Modelling and Estimation
- Physical Properties Analysis
  - Case Study

Televiewer Surveys

- **Acoustic and Optical Televiewers incorporates;**
  - Orientation measurements
  - Imaging of the borehole
  - Telemetry system

- **Typical Borehole Conditions;**
  - 2”-3” to 20” borehole size – BQ and up – probe diameter ~40mm
  - -90 (Vertical) to -45 with conventional, gravity fed systems
  - Centralization
  - Drilling Method / Rugosity

Televiewer Applications: Oriented Core Alternative

- Drill core is the geologists objective on a diamond drill program.
- However, oriented core from diamond drilling is expensive. Not all drill programs result in oriented drill core.
- Oriented Core allows true strike and dip measurements. Critical for structural modelling.

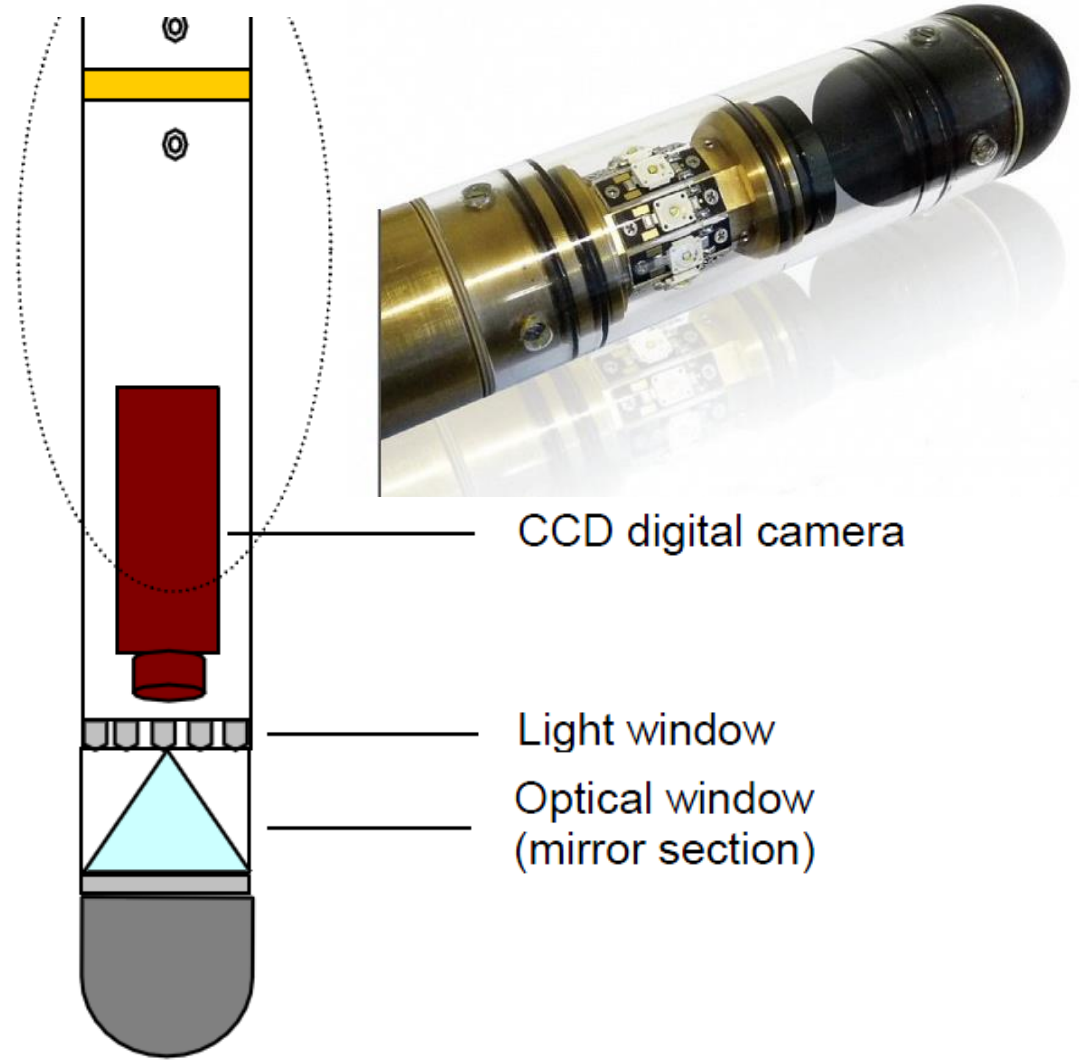
- **Challenge:** What if I now need to do geological modelling?
- **Solution**: Acquire televiewer data to take advantage of *already-drilled boreholes*.

- Quality control for oriented core.

Accurate inputs for structural modelling, and hence true orientations, are critical for the geologist. Especially in more complex geological environments.

Optical Televiewer (OTV)

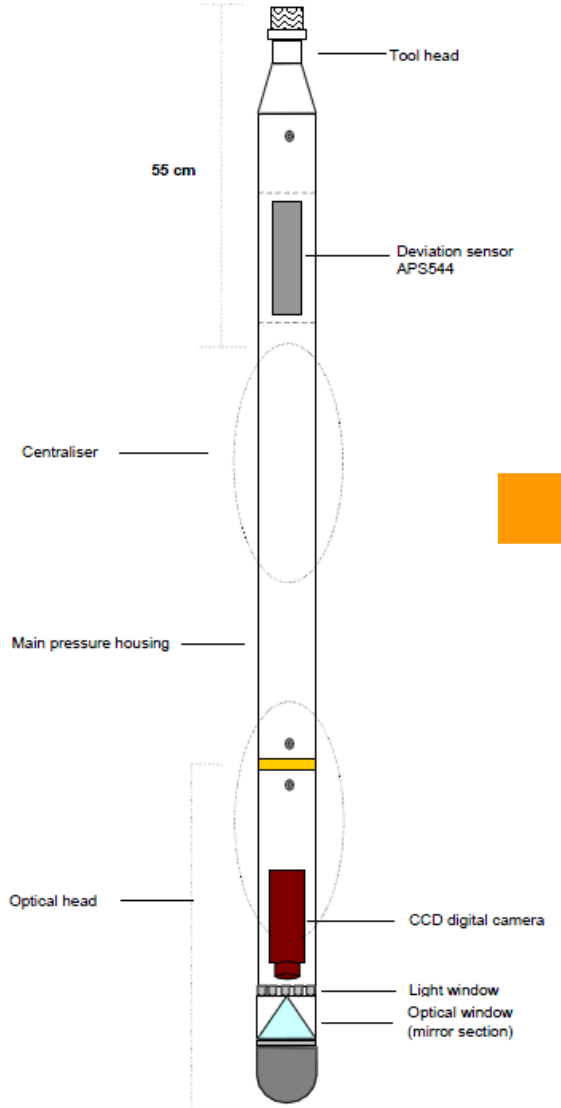
- **Theory of Operation:**
  - CCD digital camera captures the reflection of the mirror providing a 360° image of the surrounding borehole
- **Probe Parameters:**
  - Pixel height and width
  - Light level
  - White balance
  - Exposure
- **Limitations:**
  - Image clarity, magnetic interference, centralization



Optical Televiewer (OTV)

Optical Televiewer Imaging Applications

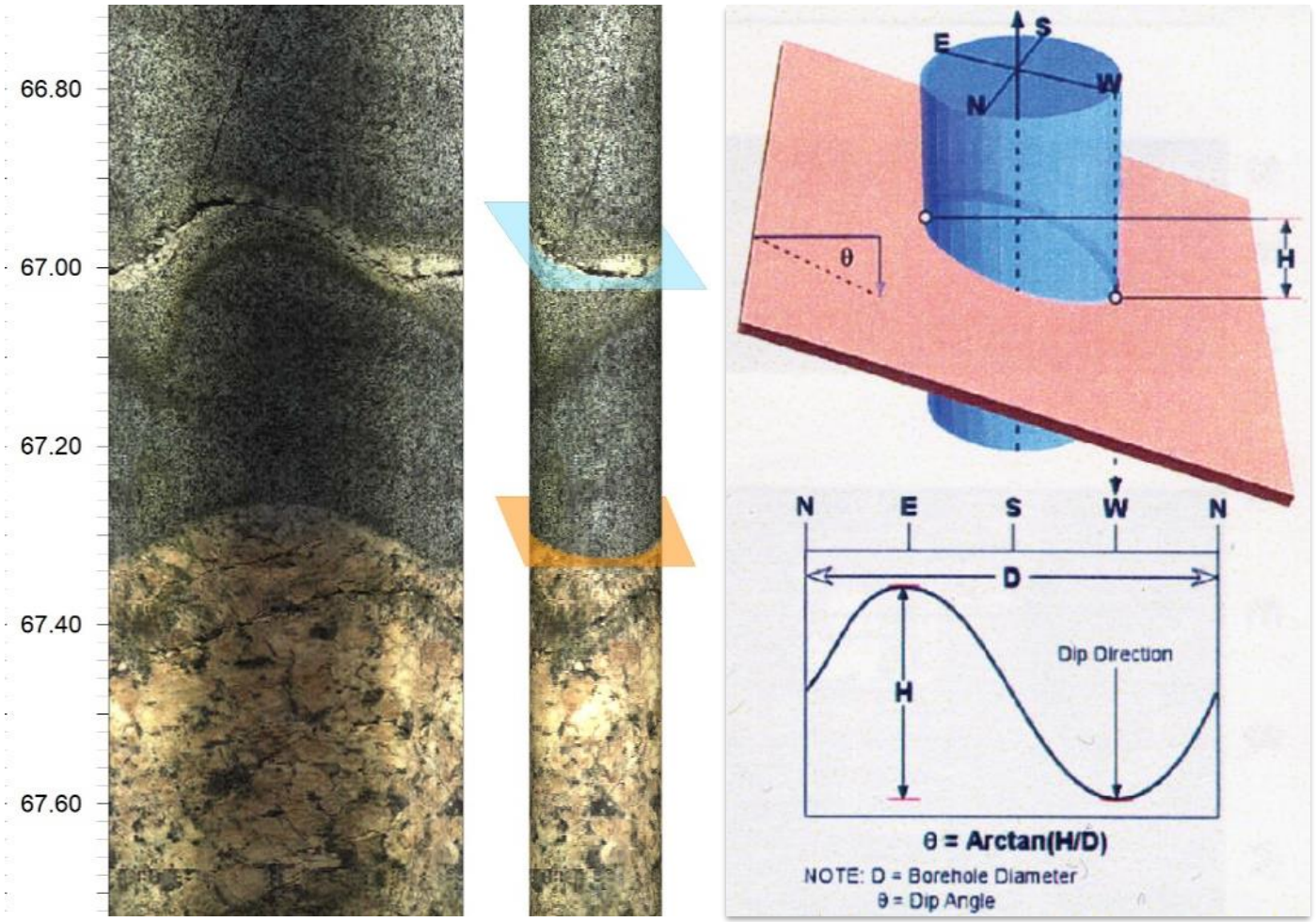
Oriented Core Alternative
RC and Blast Holes
Low RQD Zone Core Recovery
True Strike and Dip
Bedding/Banding/Foliation
Shear Zones
Fault Orientation
Fold Geometry
Fracturing
Contacts
Veins



VIRTUAL CORE ACQUIRED IN A RC DRILLED BOREHOLE

Optical Televiewer (OTV)

- Planar geologic features intersect the borehole
- Strike and dip can be measured accurately
- Simultaneously measure borehole path
- Image oriented to a reference point, allowing for oriented structural measurements



UNWRAPPED 360-VIEW OF BOREHOLE WALL

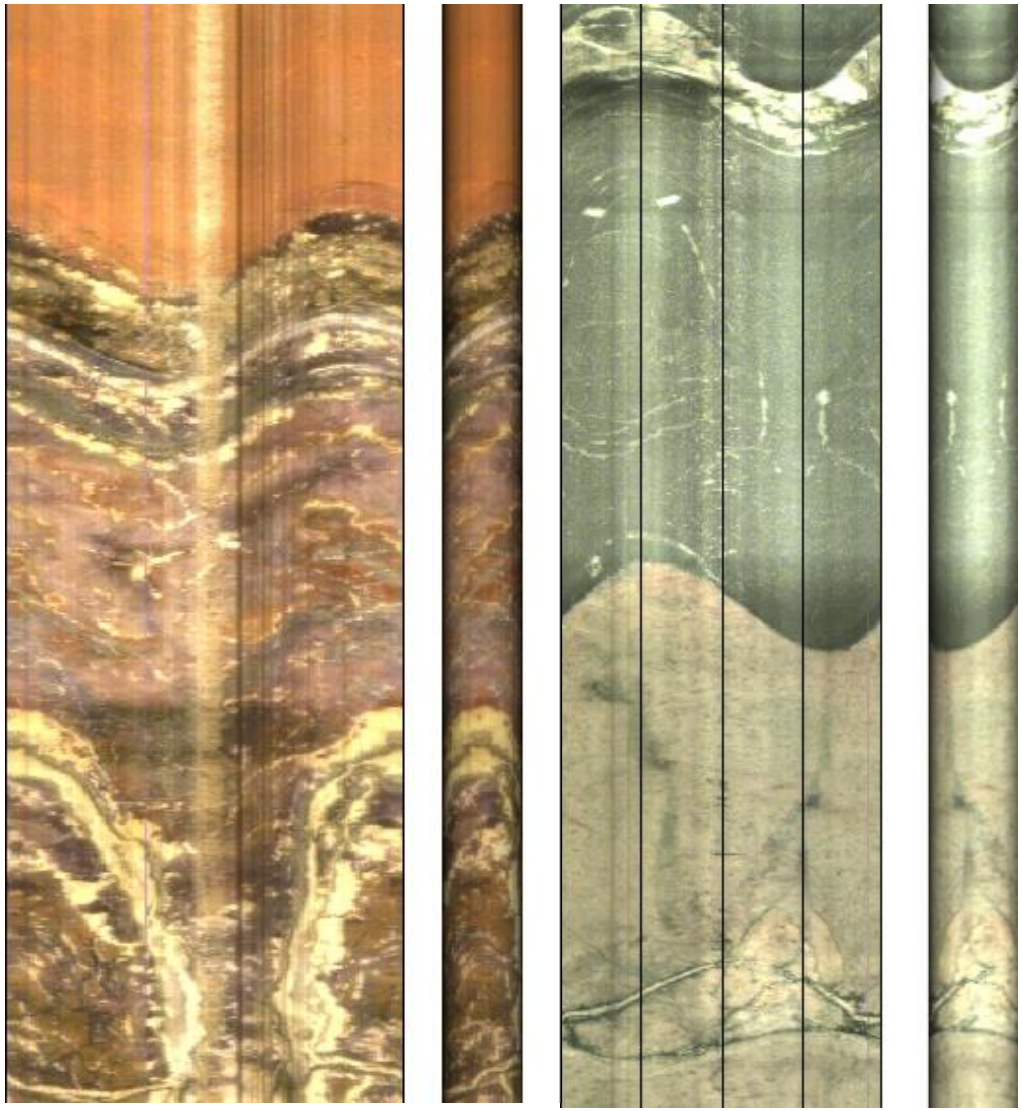
VIRTUAL 3D CORE

Sample Optical Televiewer (OTV) Images

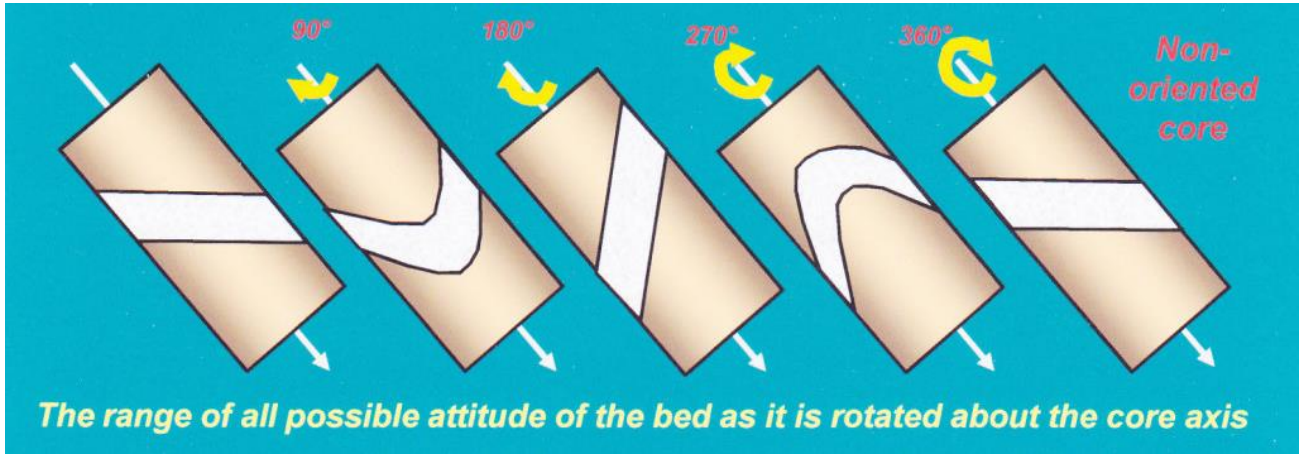
Major Benefits

- Oriented image
- Measure fractures, veins, contacts, foliation, bedding, faults, etc.
- Relative to core axis or converted to true co-ordinates
- Acquire for the entire hole
- Does not need borehole fluid

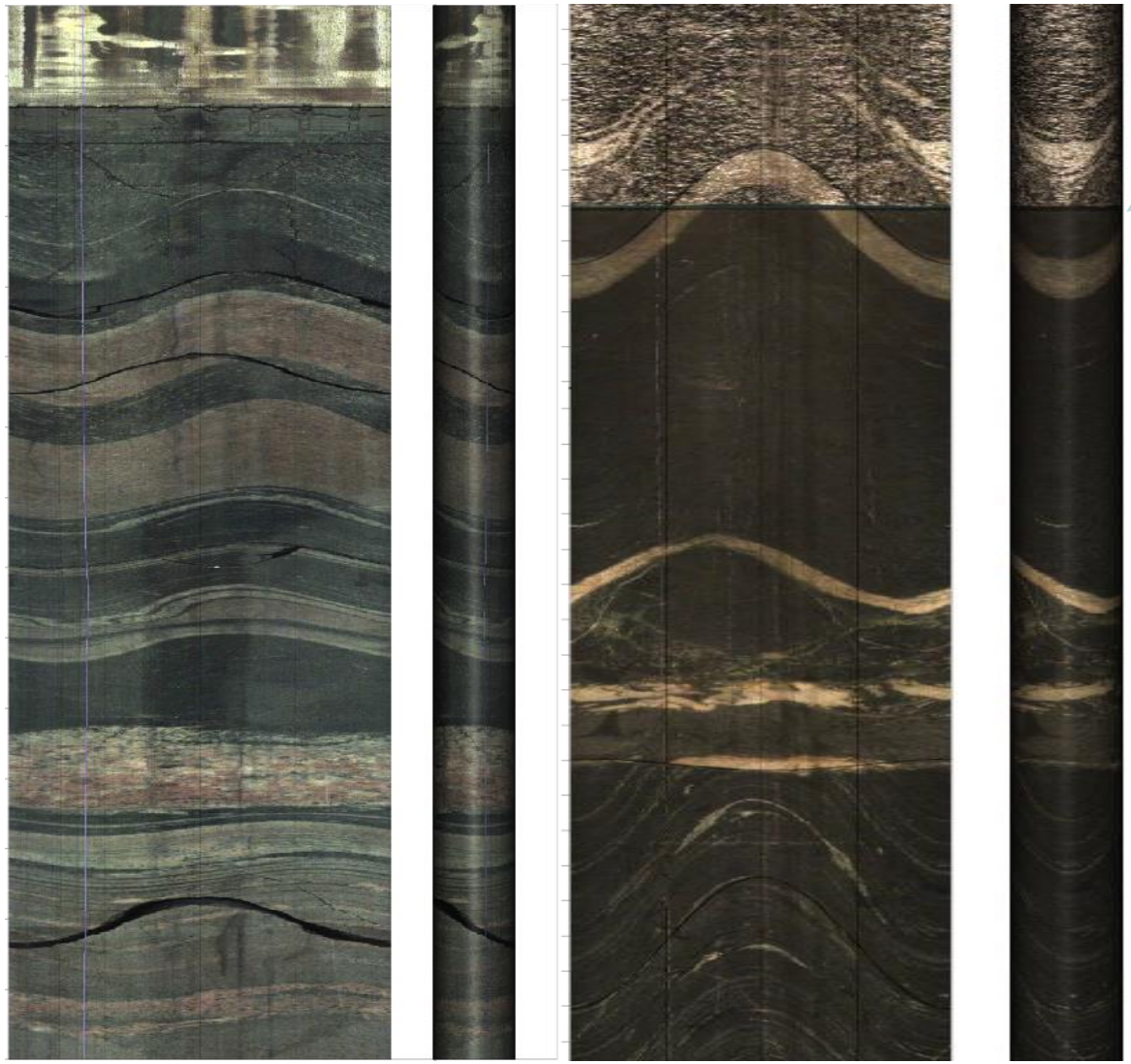
Structural Information: True Dip and Dip Direction



- **Purpose**
  - Obtain a high resolution, oriented, image of the borehole wall and features
  - Optimal for structural applications and the measurement of veins, bedding and contacts
  - Joints identifiable, but acoustic is preferred method
  - Obtain in current or previously drilled holes



Cored versus Non-Cored Drilling



Cored

Percussion Drilled

Televiewer Applications: RC Drilling

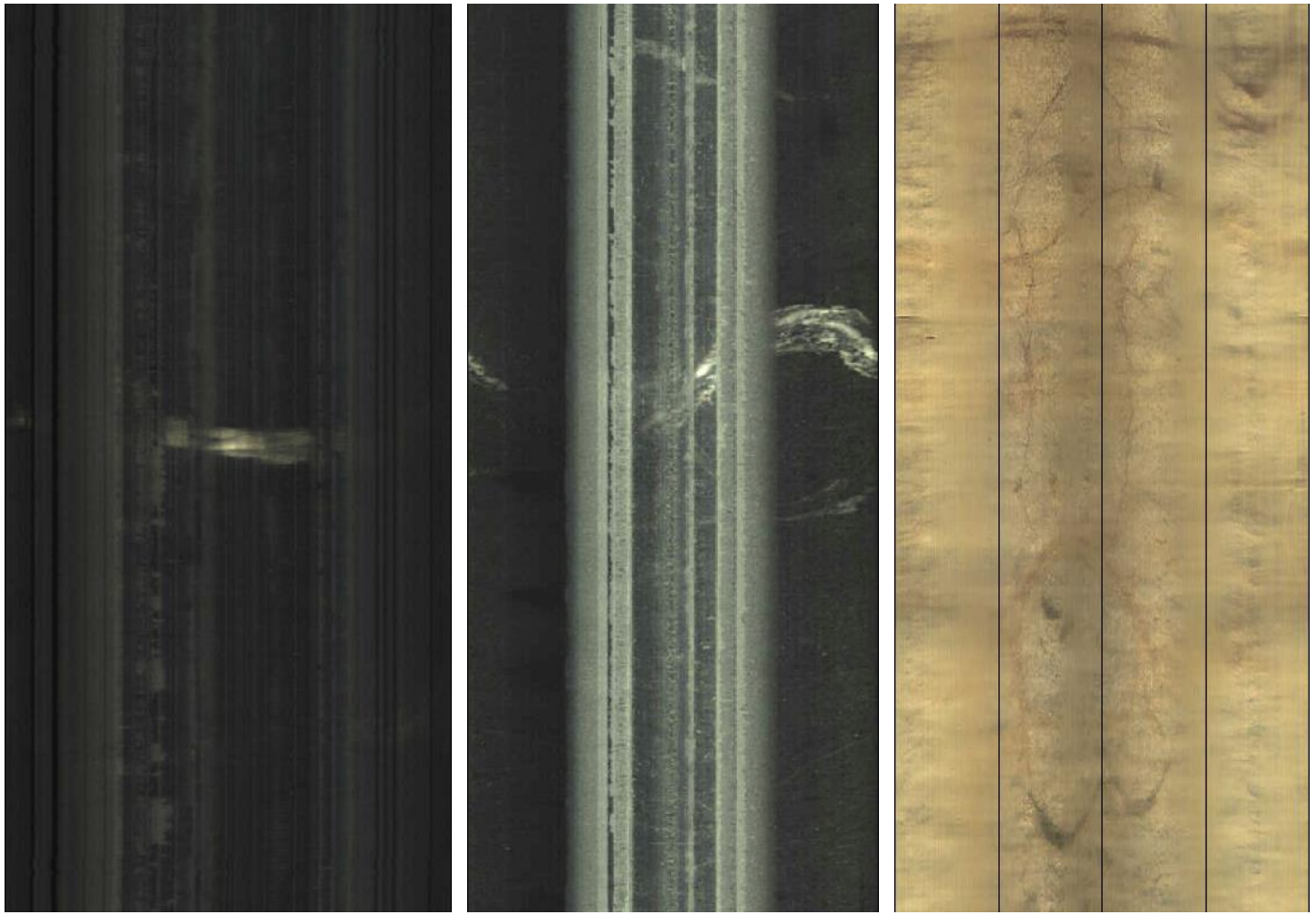
RC DRILLING CHIPS: FAST, CHEAP, NO RECOVERABLE CORE.

Obtain structural measurements from Reverse Circulation drilling

Diamond drilling oriented core strike and dip alternative

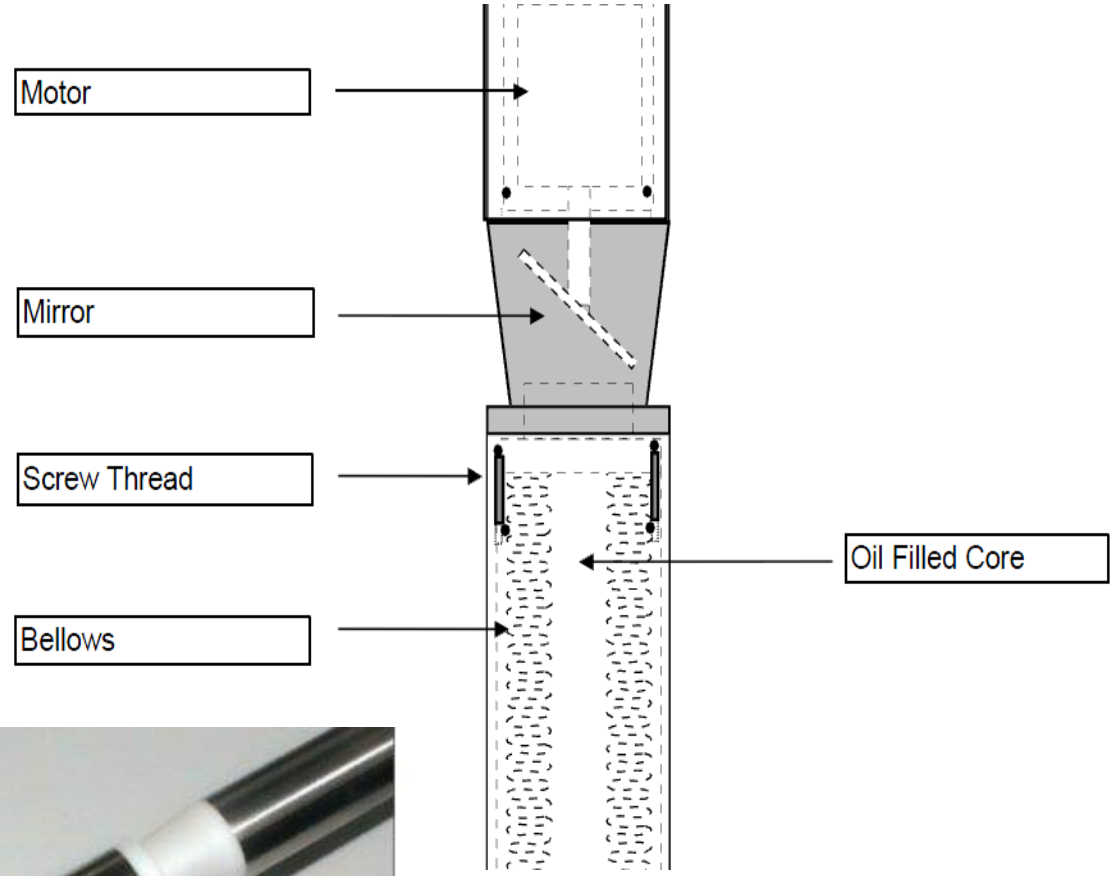
Borehole Conditions

- Fluid/borehole quality
  - Flushing
  - Flocculant
  - Brushing
- Smearing/Grease
- Aquifer interaction

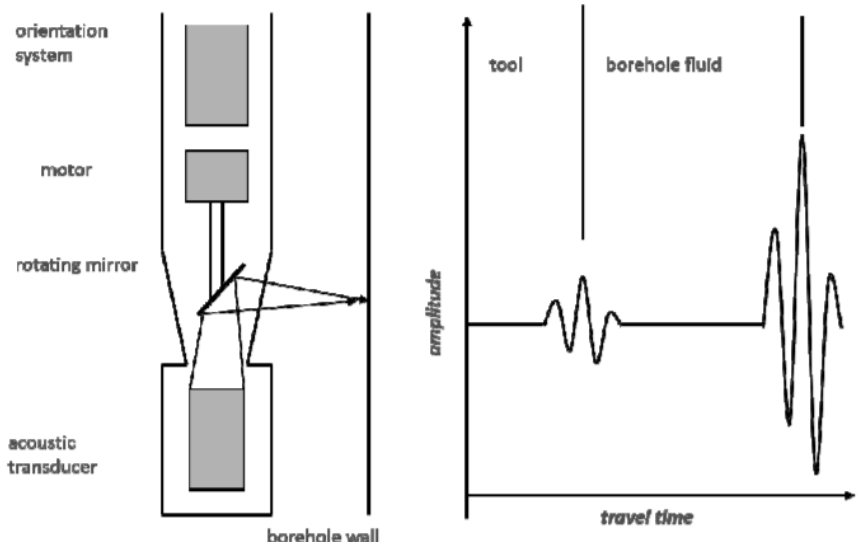


Acoustic Televiewer (ATV)

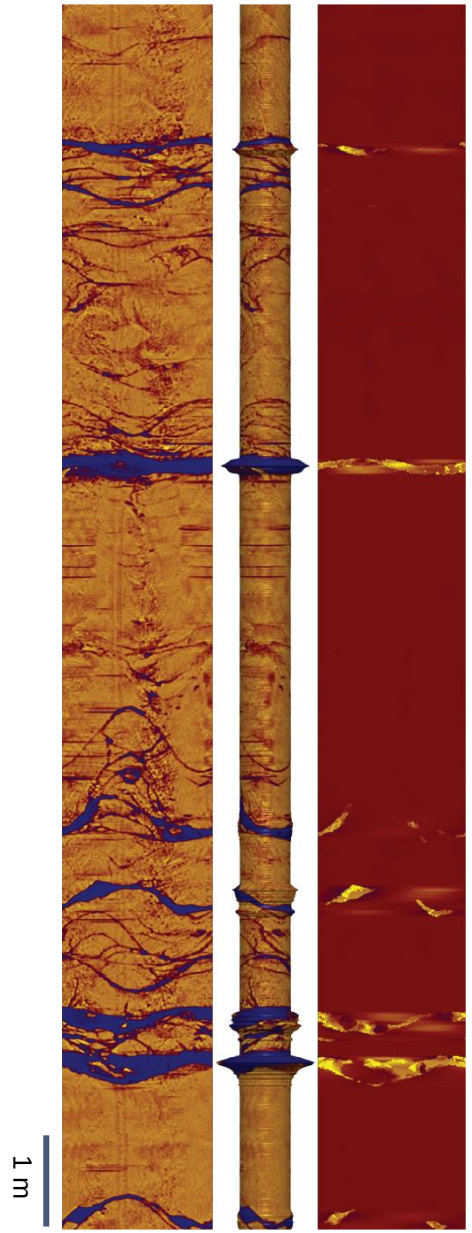
- Theory of Operation:
  - Image is generated by a rotating sensor that emits ultrasound pulses and records the amplitude and travel time
- Probe Parameters:
  - Azimuthal Resolution
  - Echo Processing
- Ability to see behind casing
- Limitations:
  - Fluid required
  - Magnetic Interference
  - Centralization



Acoustic Televiewer (ATV)



- An acoustic image is produced by recording echoes of the acoustic signal
- Works independent of borehole water quality
- Creates synthetic caliper



Acoustic Televiewer Imaging Applications

Geotechnical Analysis

Hazard Detection

Rapid RQD and Fracture Frequency

Breakout Analysis

Stress Modelling

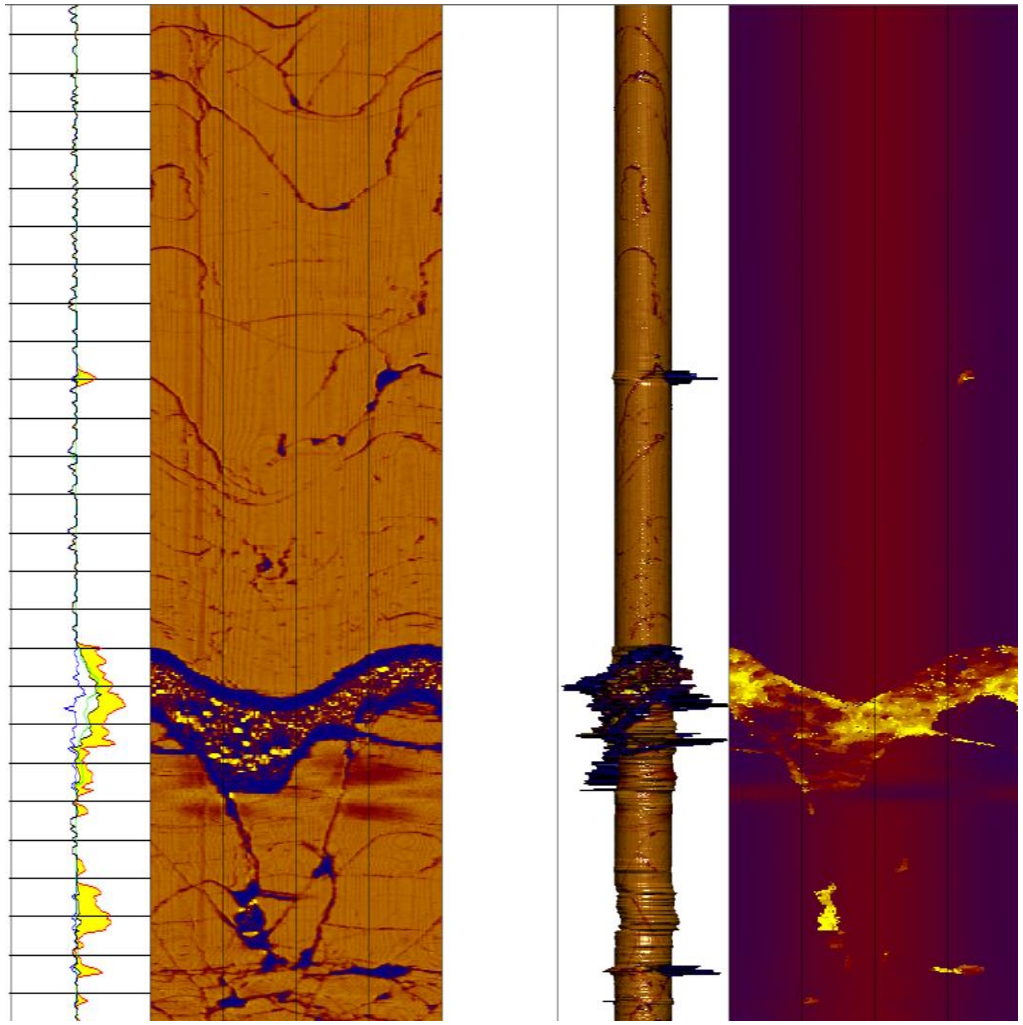
Pastefill Inspection

True Strike and Dip

Fault Orientation

Fracturing

Acoustic Televiewer (ATV)



Amplitude

Travel Time

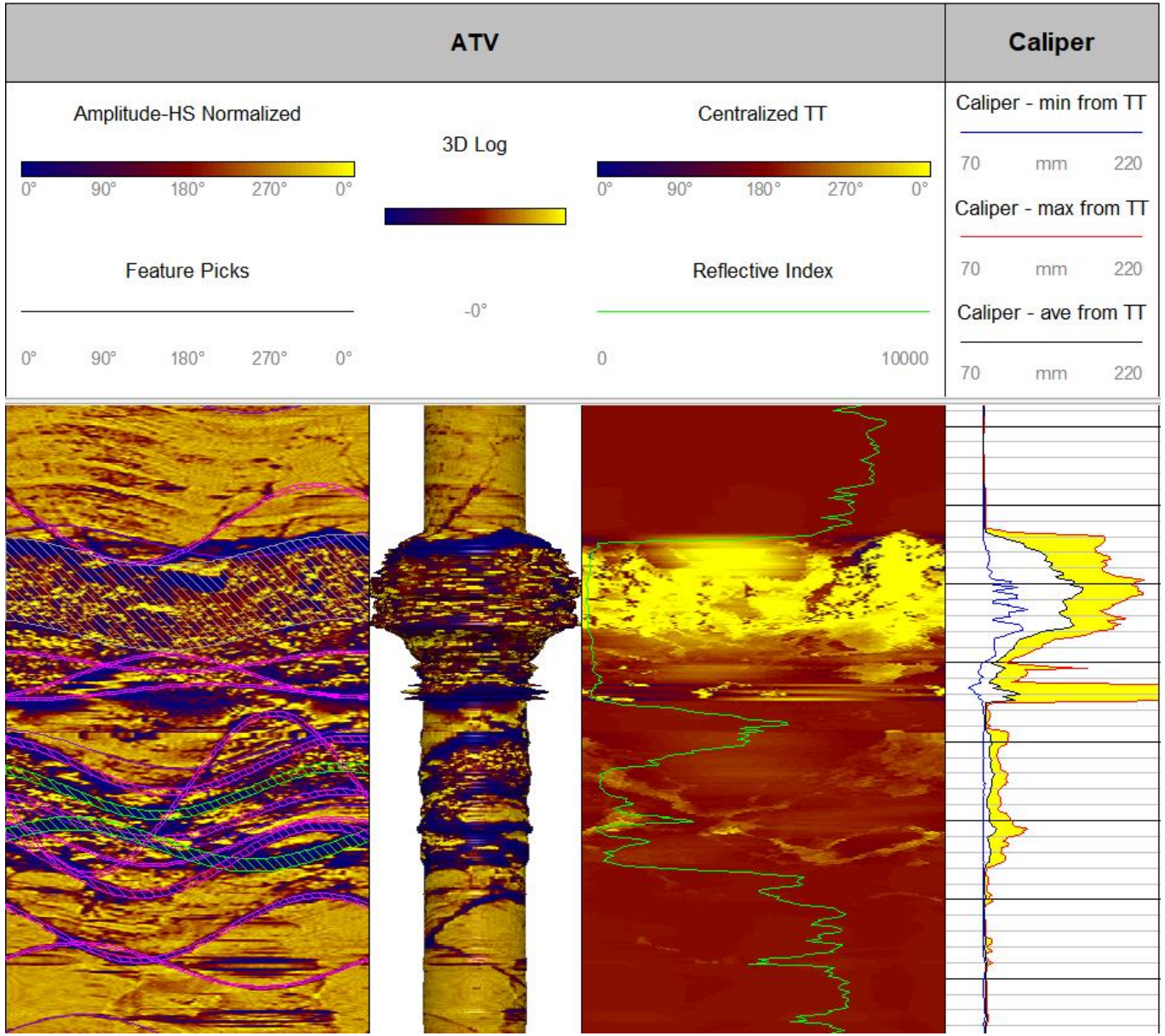
- Image based on amplitude and travel time of acoustic pulse
- Energy absorbed in fractures, voids
- Geotechnical and rock mechanics applications
- Complete core recovery
- Oriented image – true dip and dip direction of features in situ

Benefits of Televiewer

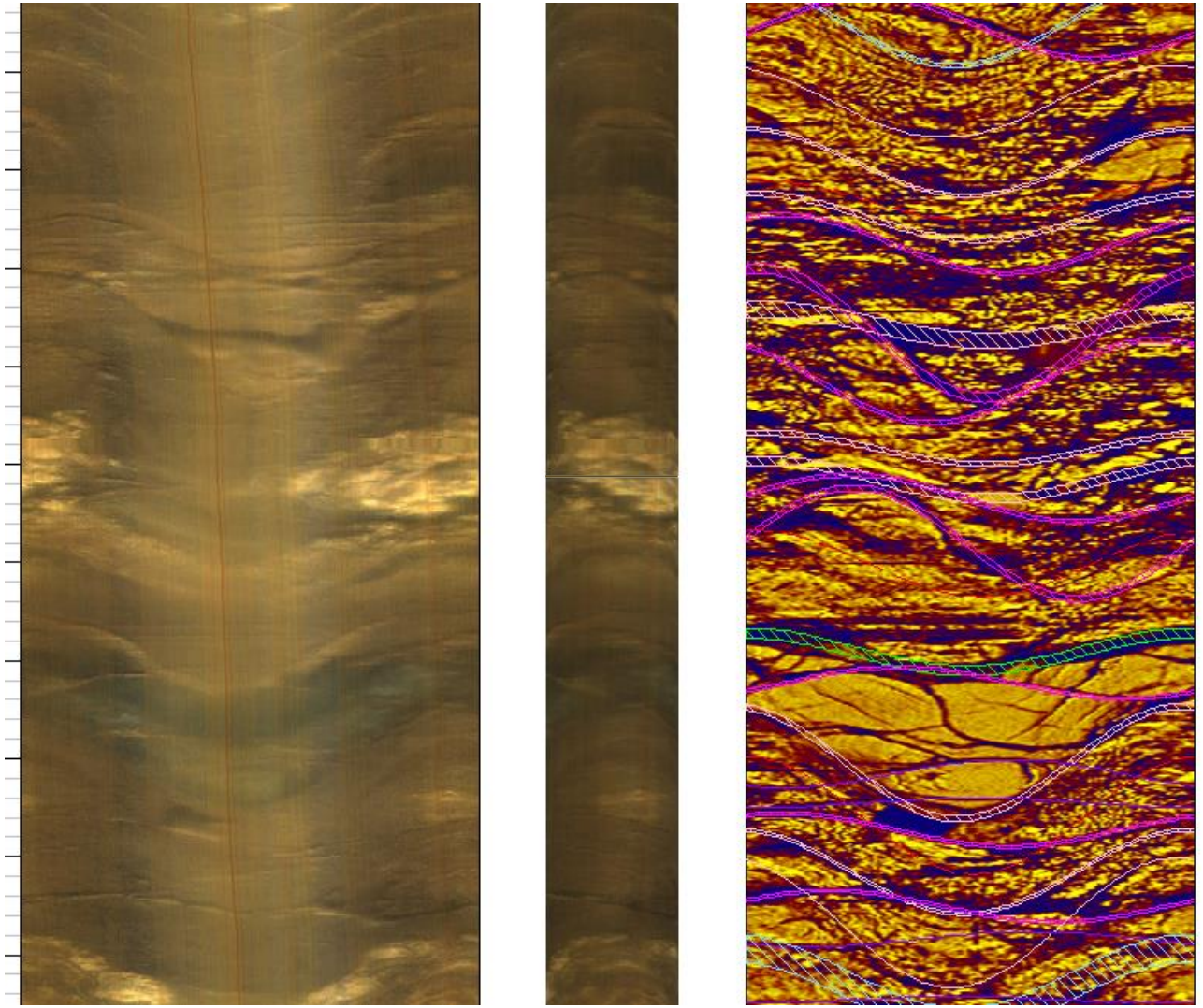
- True Dip and Dip Direction from the Entire hole
  - No missing data due to broken core, disking, rubble in the core box etc
- Measure orientation and stress magnitude of breakouts
- No concerns about interference with the core
- Digital Record
  - Permanent record
- Rapid
  - Data processed in days

Synthetic Caliper

- Acoustic Televiewer can create an synthetic caliper
- Good QAQC of caliper or back up if caliper is broken
- Faster and therefore cheaper

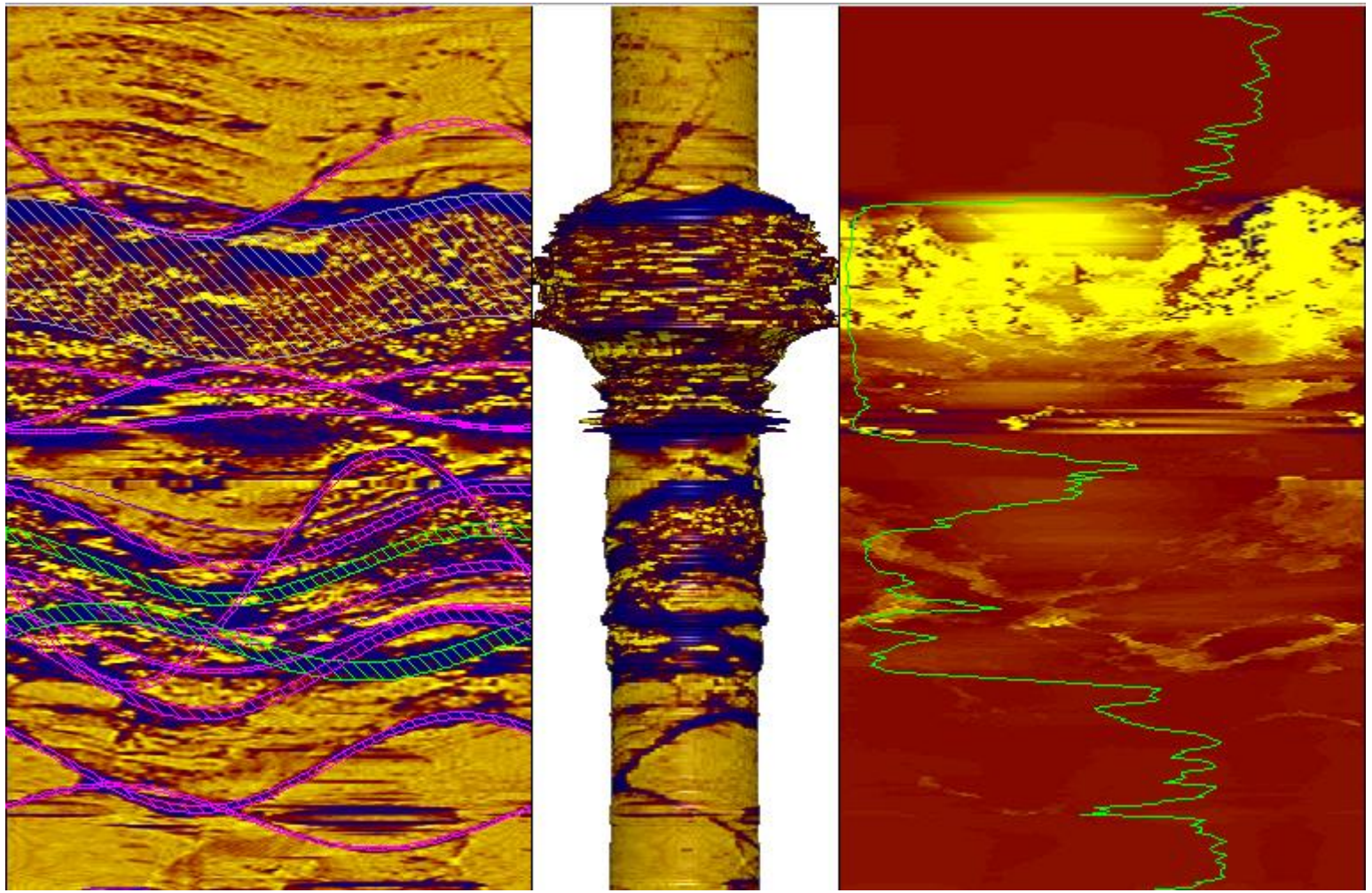


Feature Picks



- **Borehole features appear as sine waves:**
  - **Dip Angle:** Amplitude
  - **Dip Direction:** Radial position of sine wave minimum
- **Common Features Picked:**
  - Veins
  - Bedding/Banding/Foliation
  - Fractures/Joints
  - Lithological Contacts

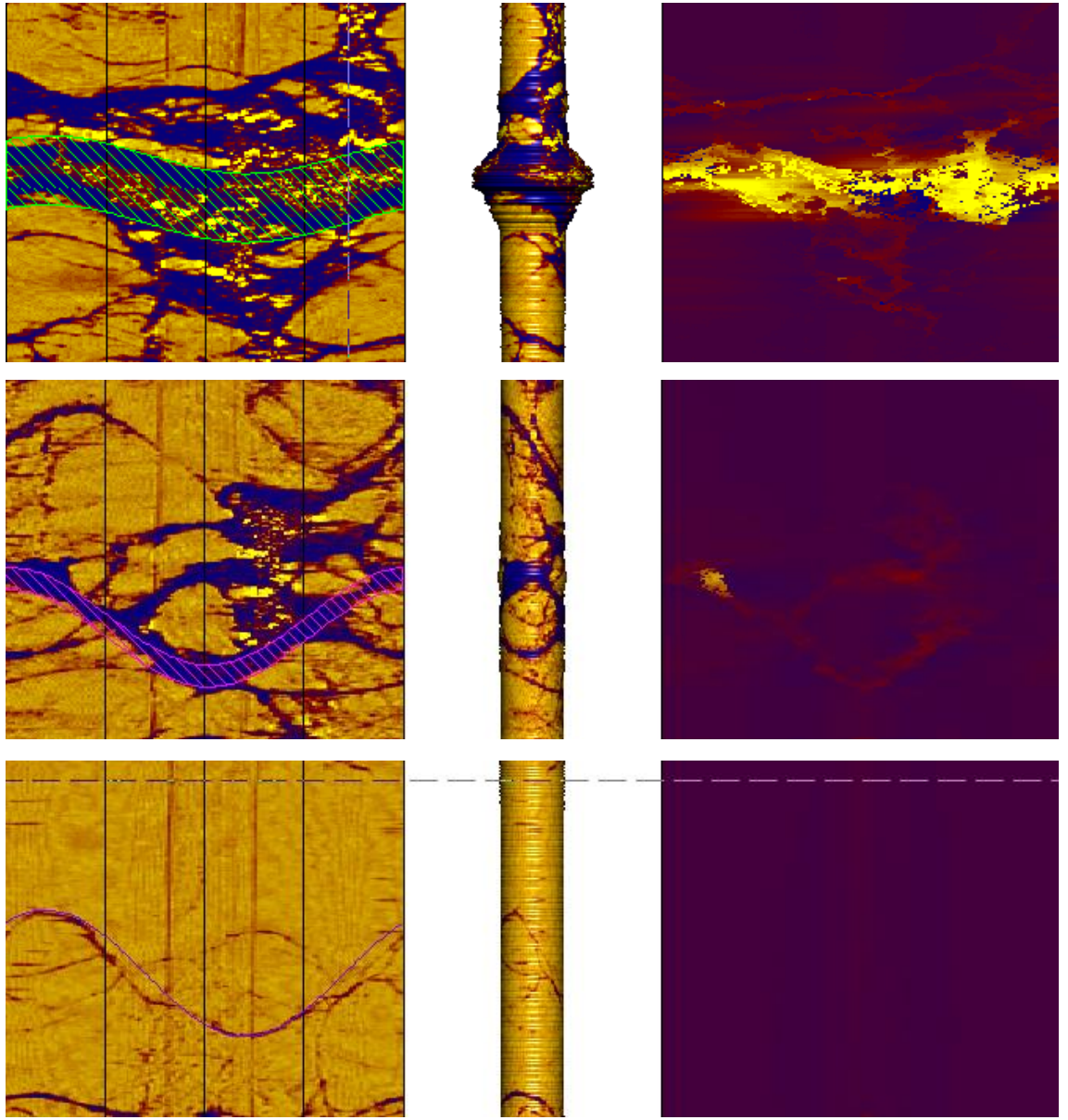
Feature Picks



- Fully customisable
- Bespoke Deliverables
- Can focus on one geological component e.g., veins
- Easier to pick out features
- Are orientated and therefore can be used for analysis

Classification - Example

- **Major Open Fracture** (complete visibility in travel time log)
  - These features are often seen in the OTV where inside of the feature is visible. Major open joint/fractures have an aperture greater than 5 mm.
- **Partially Open Fracture** (incomplete visibility in travel time log)
  - Partially open joint/fractures have an aperture between 1 and 5mm.
- **Minor Fracture** (no visibility in travel time log)
  - Minor joint/fractures have an aperture between 0 and 1mm.

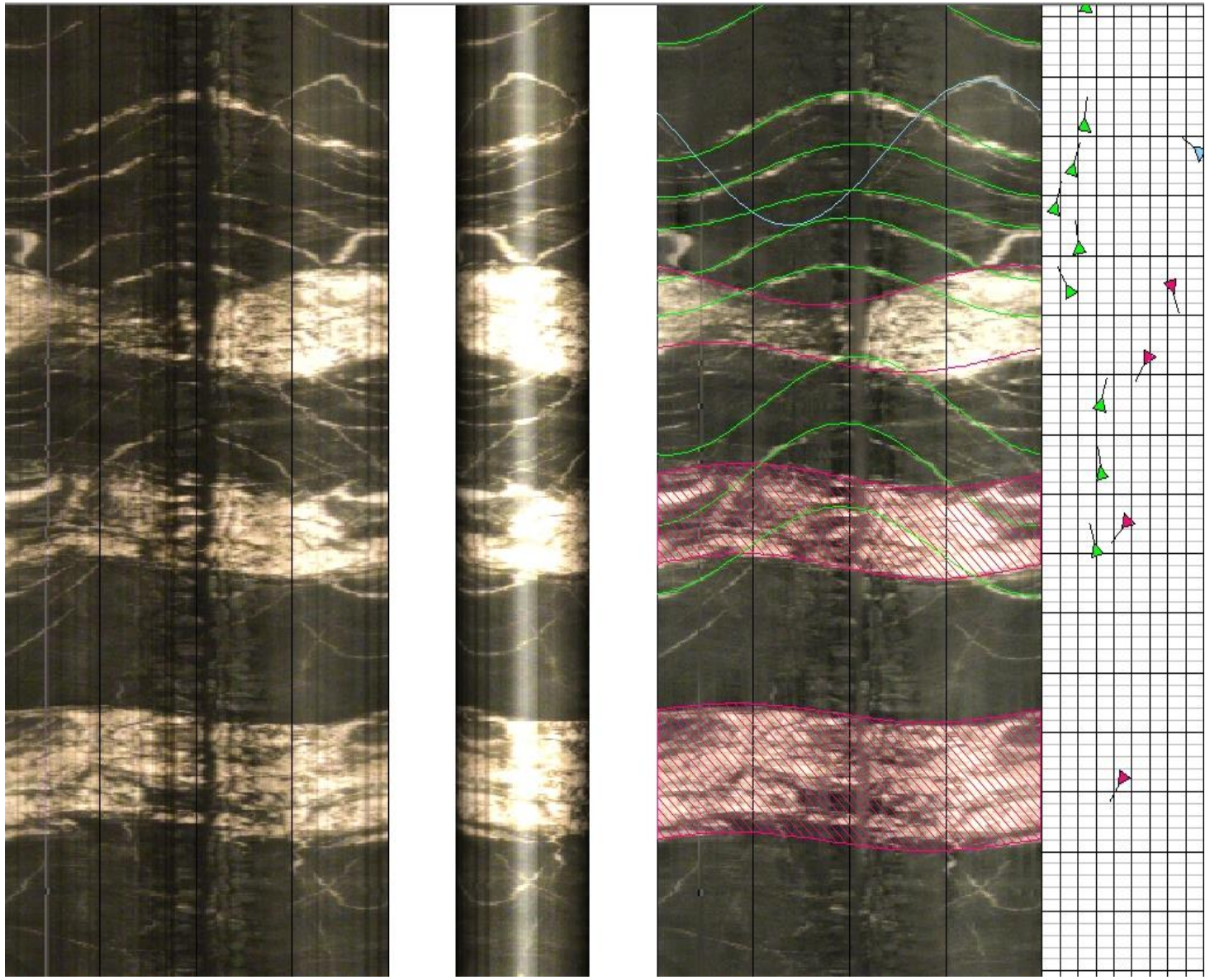


Feature Picks

- Sinusoidal features picked
- Three visible vein generations

Quartz Vein - generation 1
Quartz Vein - generation 2
Quartz Vein - generation 3

- Working in conjunction with the geologist to determine generations



Tadpoles

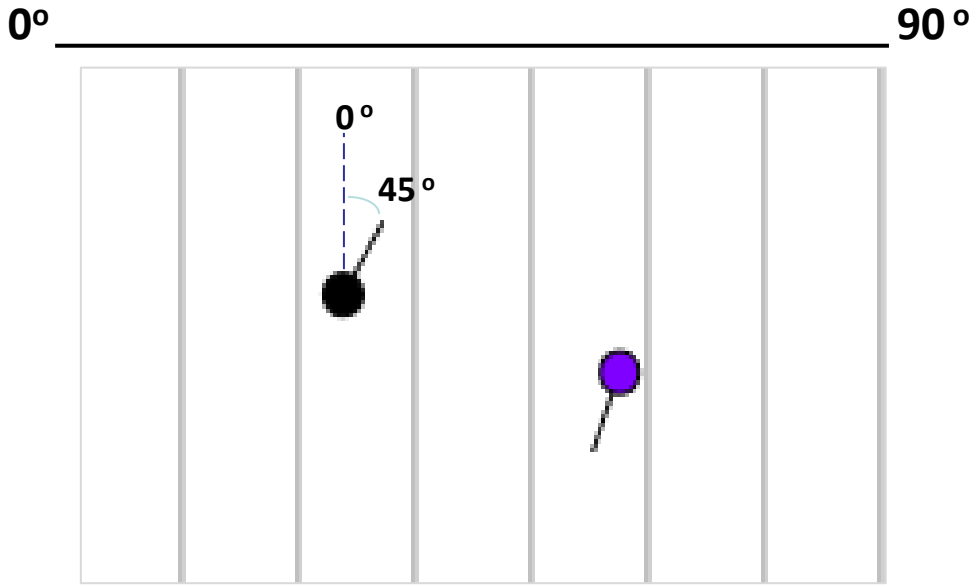
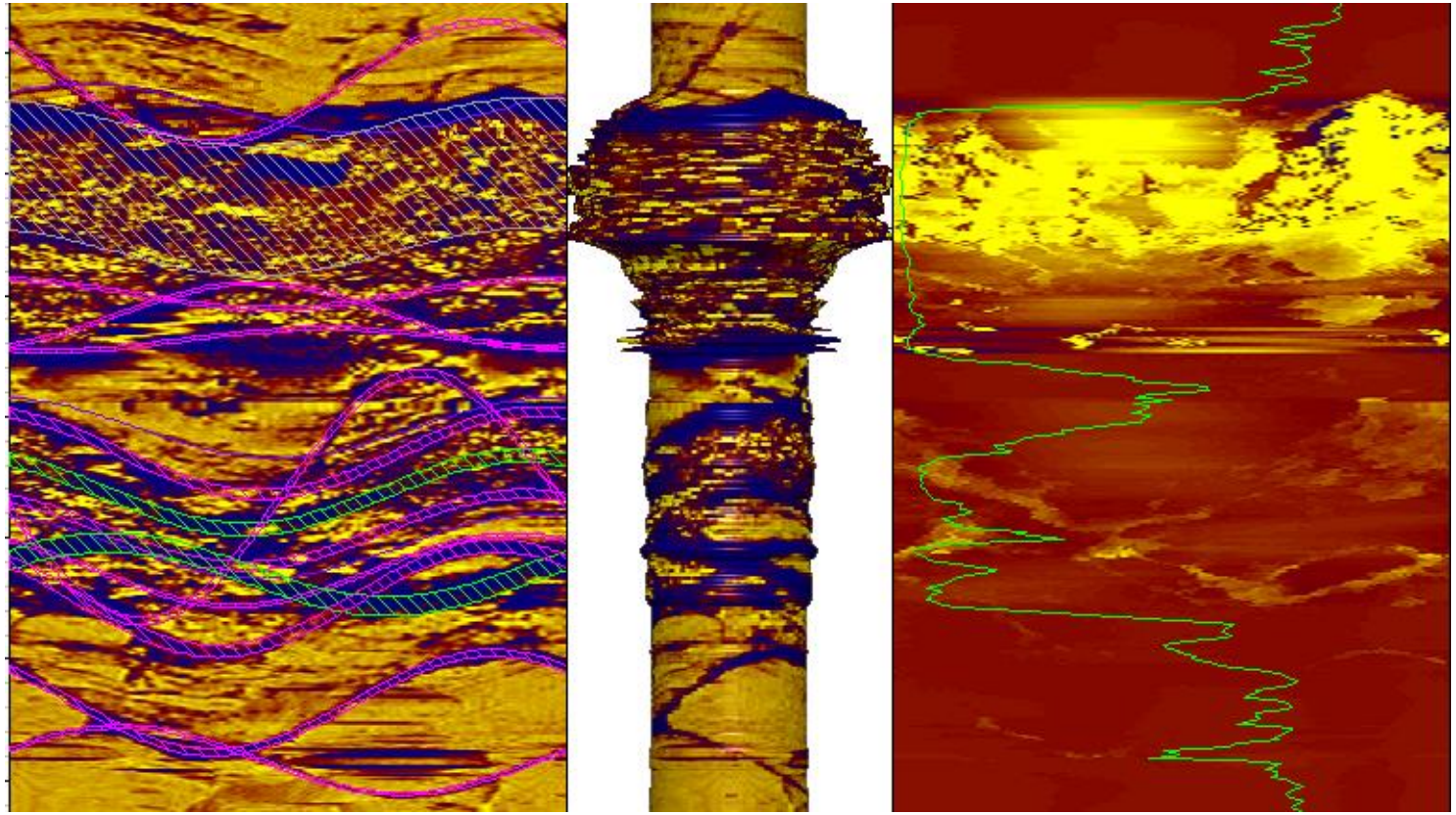


Figure: section of a tadpole log. The black tadpole has a dip and dip direction of 24/45.

- Tadpoles are used to represent the dip and dip direction of structural features.
- The horizontal position of the tadpole represents the dip, while the radial position of the ‘tail’ represents the dip direction.
- The colour of the tadpole indicates the type of feature.

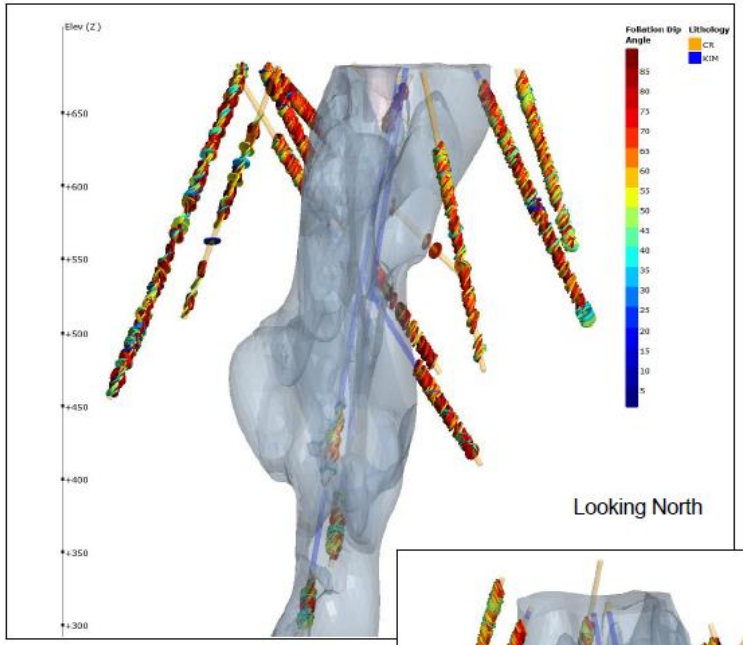
Feature Aperture/Width

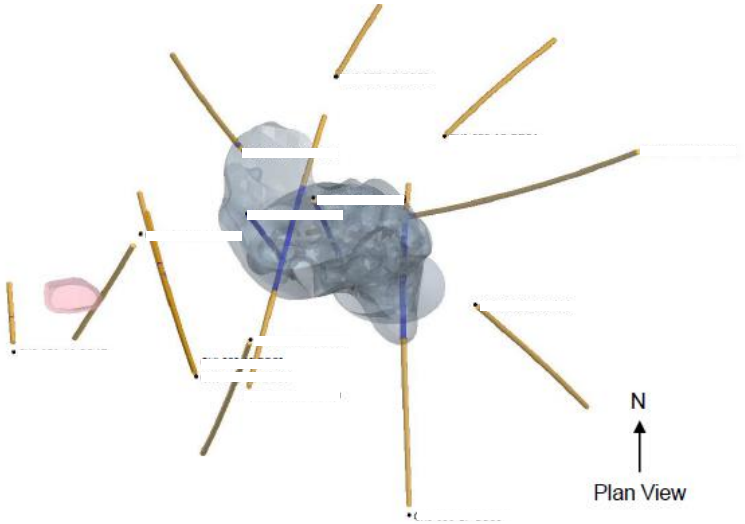
- CSV, Las, excel etc., exports
  - Export aperature, width, orientation, type, depth etc
- Can then be imported into Geological interpretation and modeling software
  - E.g., Leapfrog

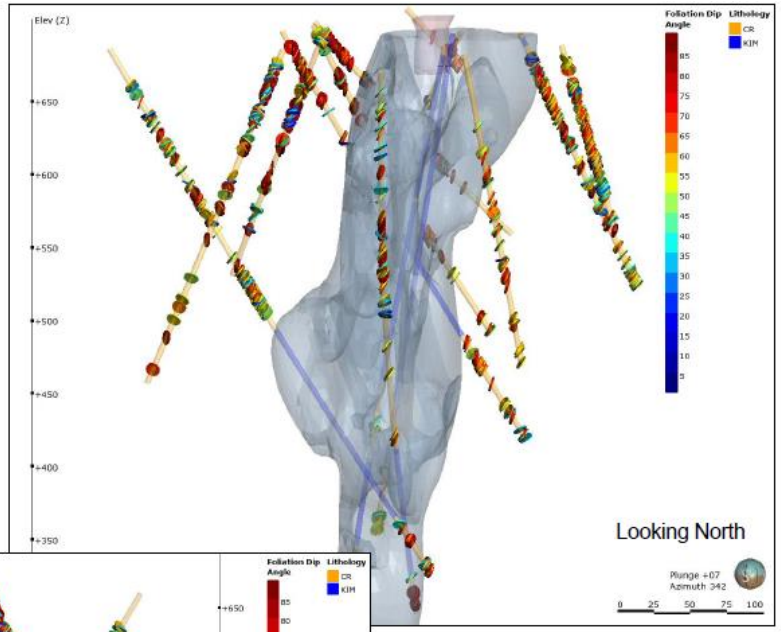


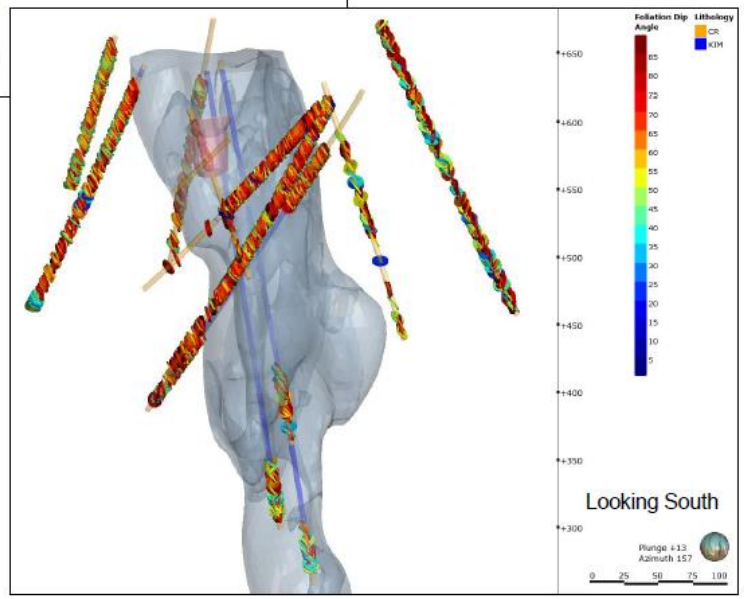
Depth [m]	Dip Direction [deg]	Dip [deg]	Aperture [mm]	Type	Description
28.51	96.51	50.46	0	F4	Joint/Fracture - Tight (0-1mm)
28.85	347.37	66.75	3.9	F3	Joint/Fracture - Open (1-10mm)
28.89	82.51	42.47	0	F4	Joint/Fracture - Tight (0-1mm)
29.02	17.42	43.02	165.21	F1	Joint/Fracture - Wide Open (30mm+)
29.2	27.32	31.26	4.85	F3	Joint/Fracture - Open (1-10mm)
29.23	194.85	44.3	4.03	F3	Joint/Fracture - Open (1-10mm)
29.27	247.26	17.67	5.6	F3	Joint/Fracture - Open (1-10mm)
29.42	30.38	49.92	0	F4	Joint/Fracture - Tight (0-1mm)
29.46	20.22	58.61	9.76	F3	Joint/Fracture - Open (1-10mm)
29.53	10.72	55.18	13.6	F2	Joint/Fracture - Moderately Open (10-30mm)

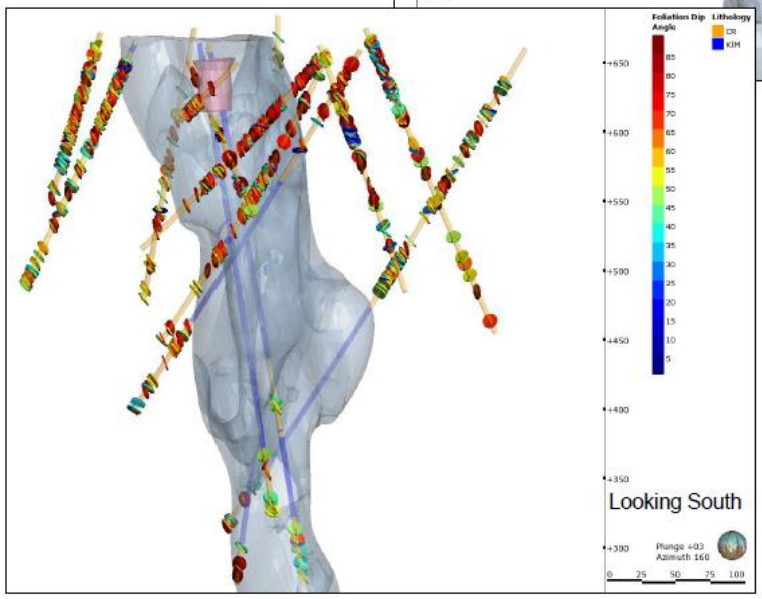
3D View


Looking North

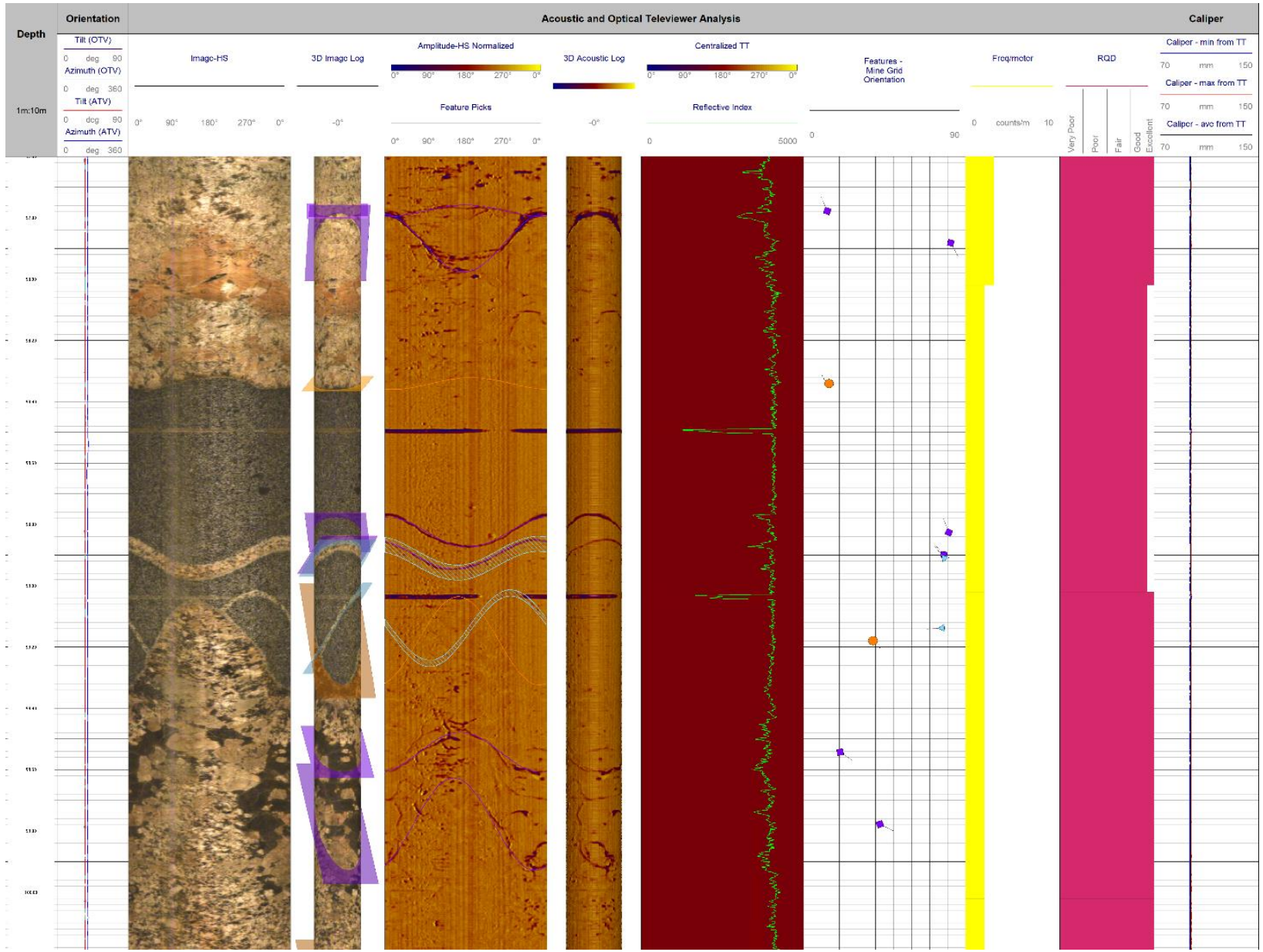

N
Plan View


Looking North


Looking South


Looking South

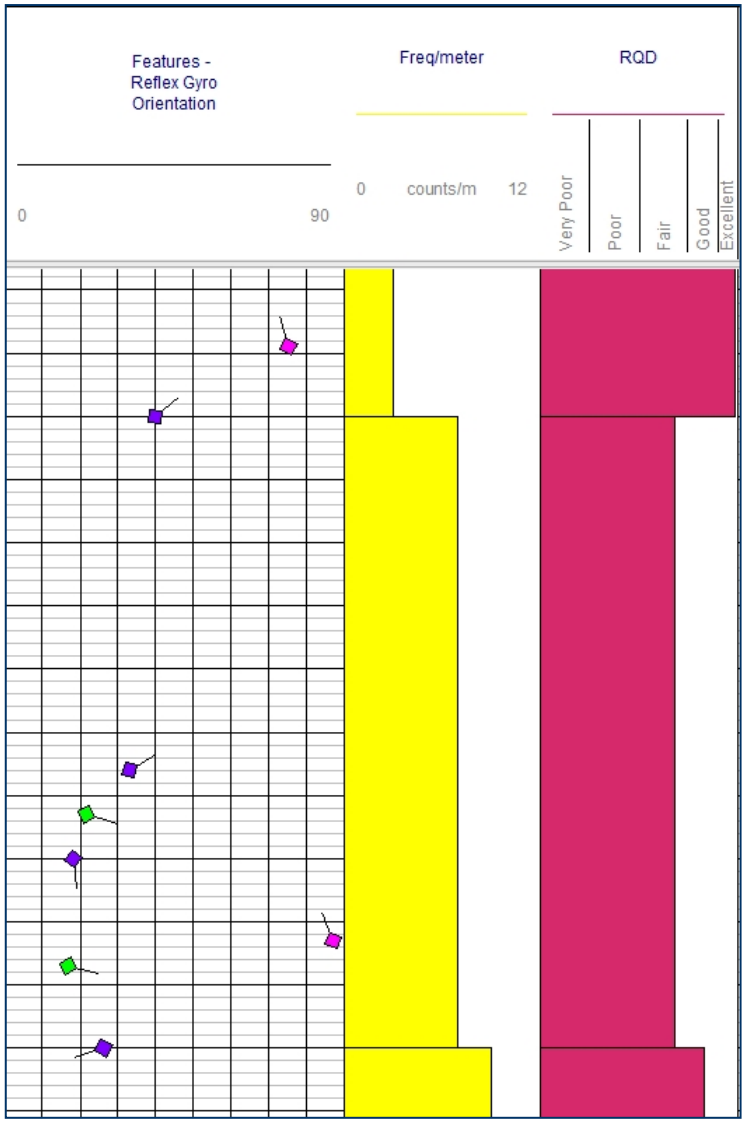
SRK



Acoustic and Optical Televiewer

- Used in conjunction to maximise benefits
- Negates any issues encountered such as poor water conditions or no water!
- Visually powerful

Derived RQD from ATV Features



- **Freq/meter**
  - Fracture frequency per 1m. The number of occurrences per meter.
- **PSUDO RQD**
  - Rock Quality Designation (RQD) which is a measure of the drill core quality or intensity of fractures. This is measured as a percentage of drill core in length of 0.1 meters. High-quality rock as an RQD of more than 75%, low quality rock of less than 50%

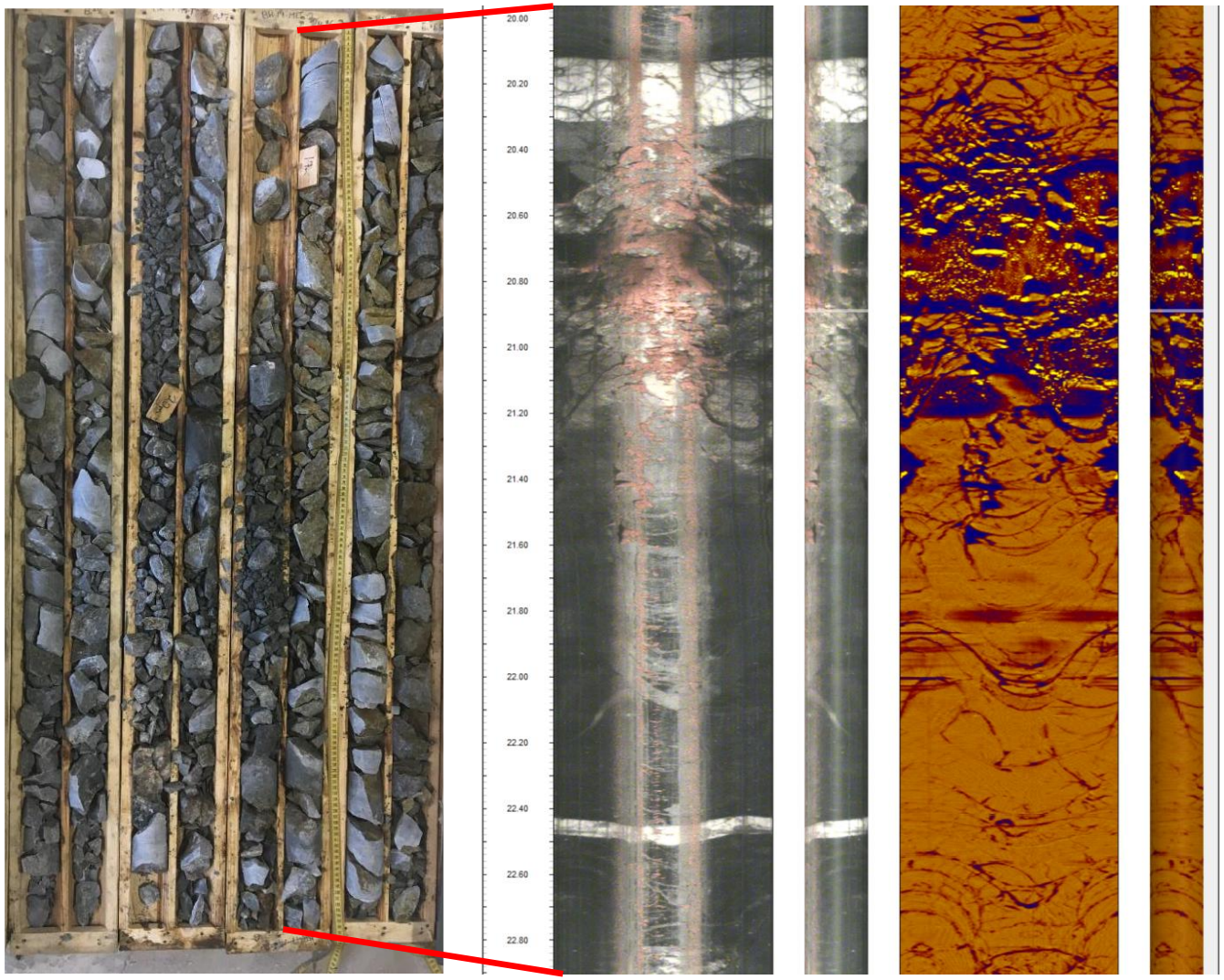
RQD (ROCK QUALITY DESIGNATION)	DESCRIPTION OF ROCK QUALITY
0-25 %	VERY POOR
25-50 %	POOR
50-75 %	FAIR
75-90 %	GOOD
90-100%	EXCELLENT

Televiewer Applications: Low RQD Zones

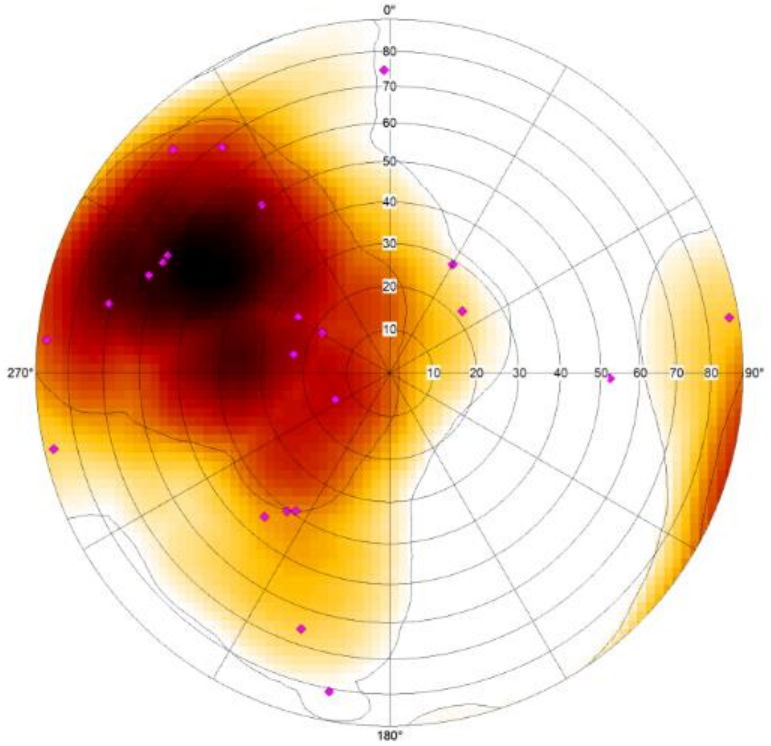
Challenge: How do you get accurate strike and dip measurements?

Acoustic Televiewer: RQD, Fracture Frequency, Fracture/Joint Set Orientations

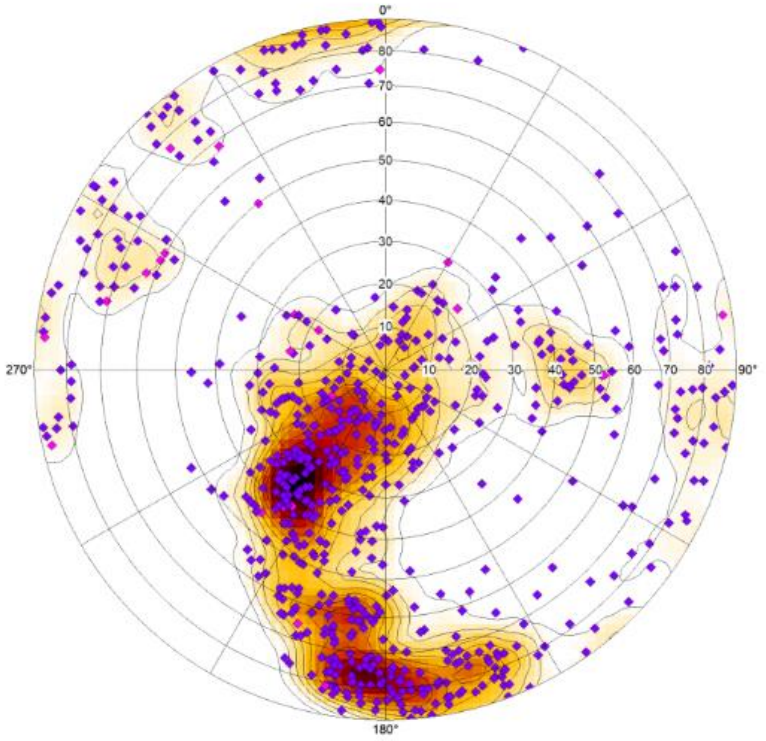
- QAQC mechanism for core box derived measurements.
  - Compare televiewer derived RQD to core derived RQD. Some breaks can be mechanical/due to core handling by the drillers.
  - Orientations visible in the core but not in televiewer may indicate mechanical fracturing being measured as natural fracturing.



Televiewer Applications: Low RQD Zones



Orientations from Core

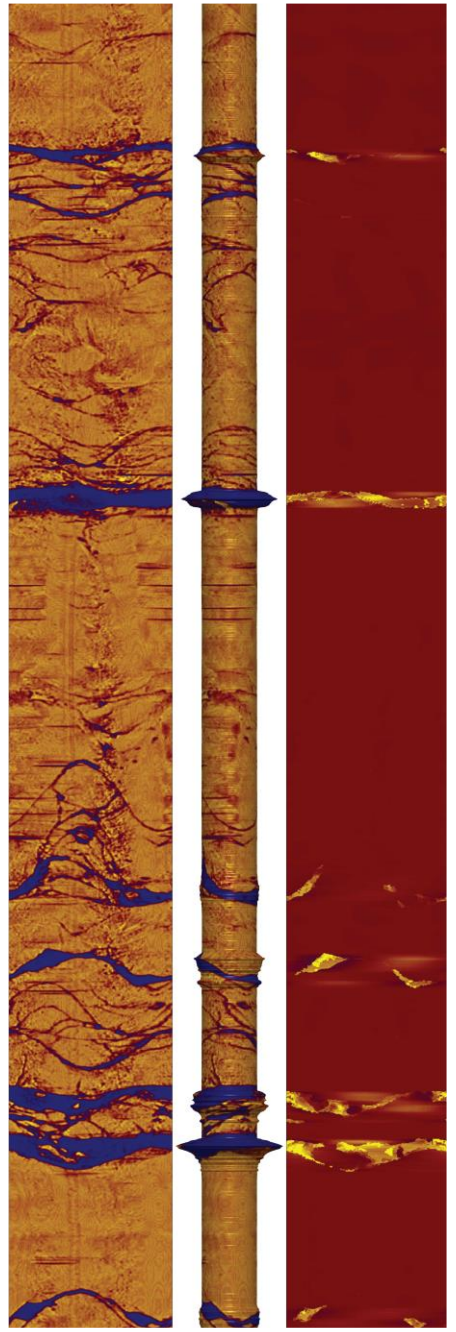


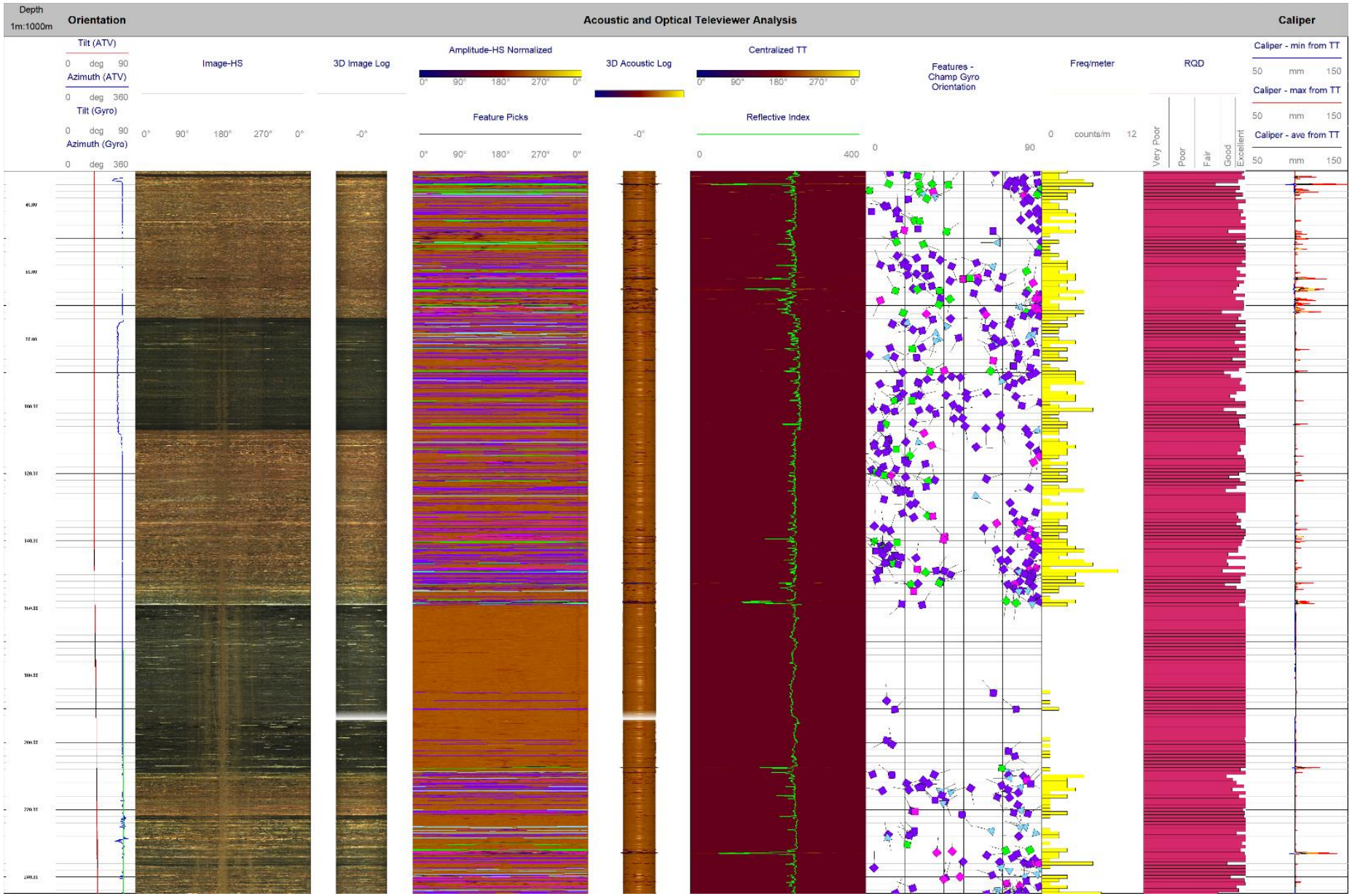
Orientations from Televiewer

- Not having enough data can result in an incomplete geological picture.
- Especially problematic if a key lithology has low RQD.
- Need less boreholes to acquire the same confidence in orientations.

Acoustic Televiewer: RQD, Fracture Frequency, Fracture/Joint Set Orientations

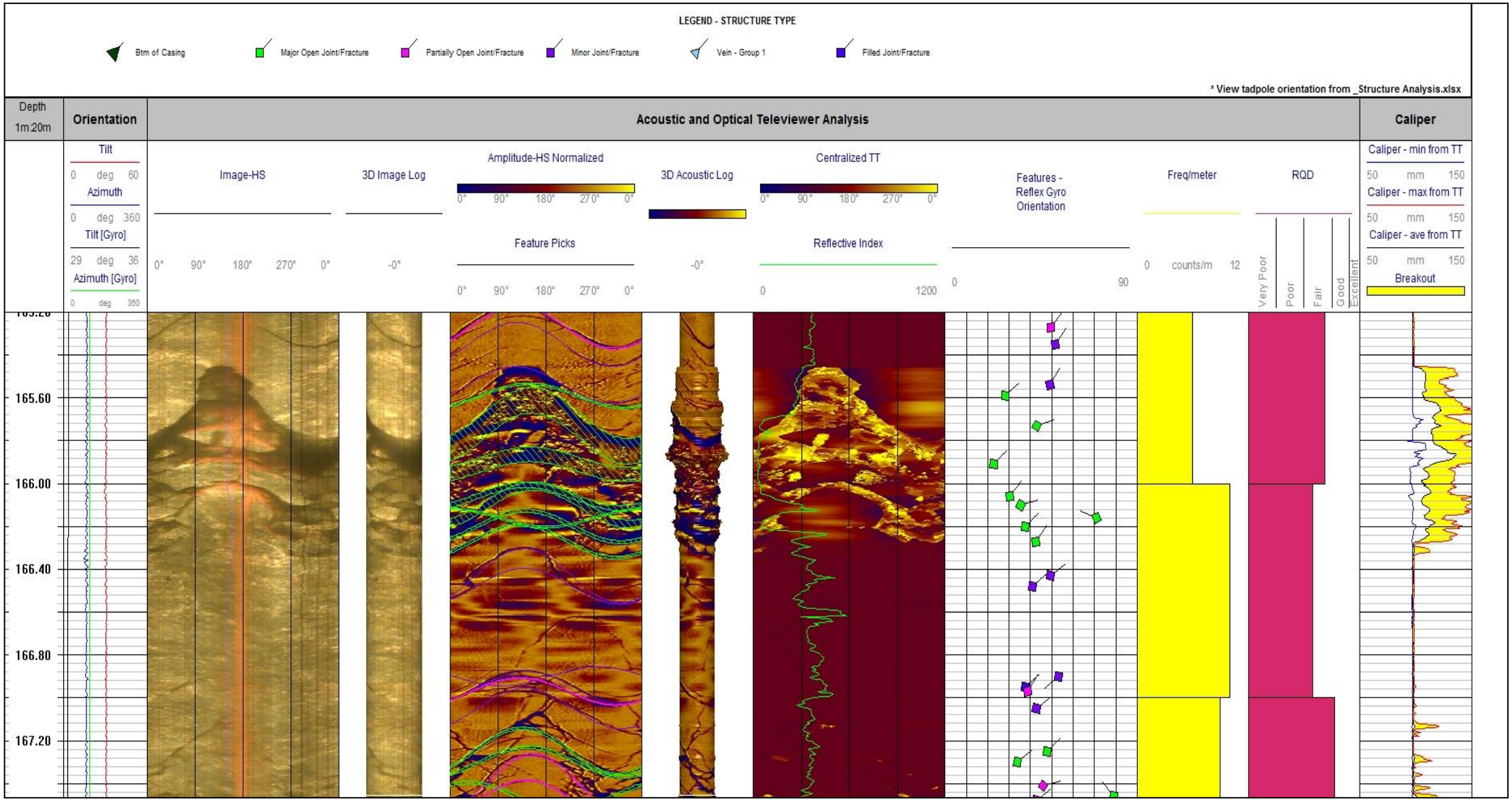
- Determining RQD and fracture frequency in a rapid and accurate manner.
- Rock-quality designation (RQD) is a rough measure of the degree of jointing or fracturing in a rock mass, measured as a percentage of the drill core in lengths of 10 cm or more.
- Used in geotechnical, engineering and rock mechanics studies.
- **Important to be accurate:** over or underestimating both have unwanted consequences when designing infrastructure.
- RQD and freq/m from core can be subjective and time consuming:
  - How to distinguish mechanical breaks from natural fracturing? (weathered v fresh surface)
  - How to handle highly weathered zones, rubble etc?





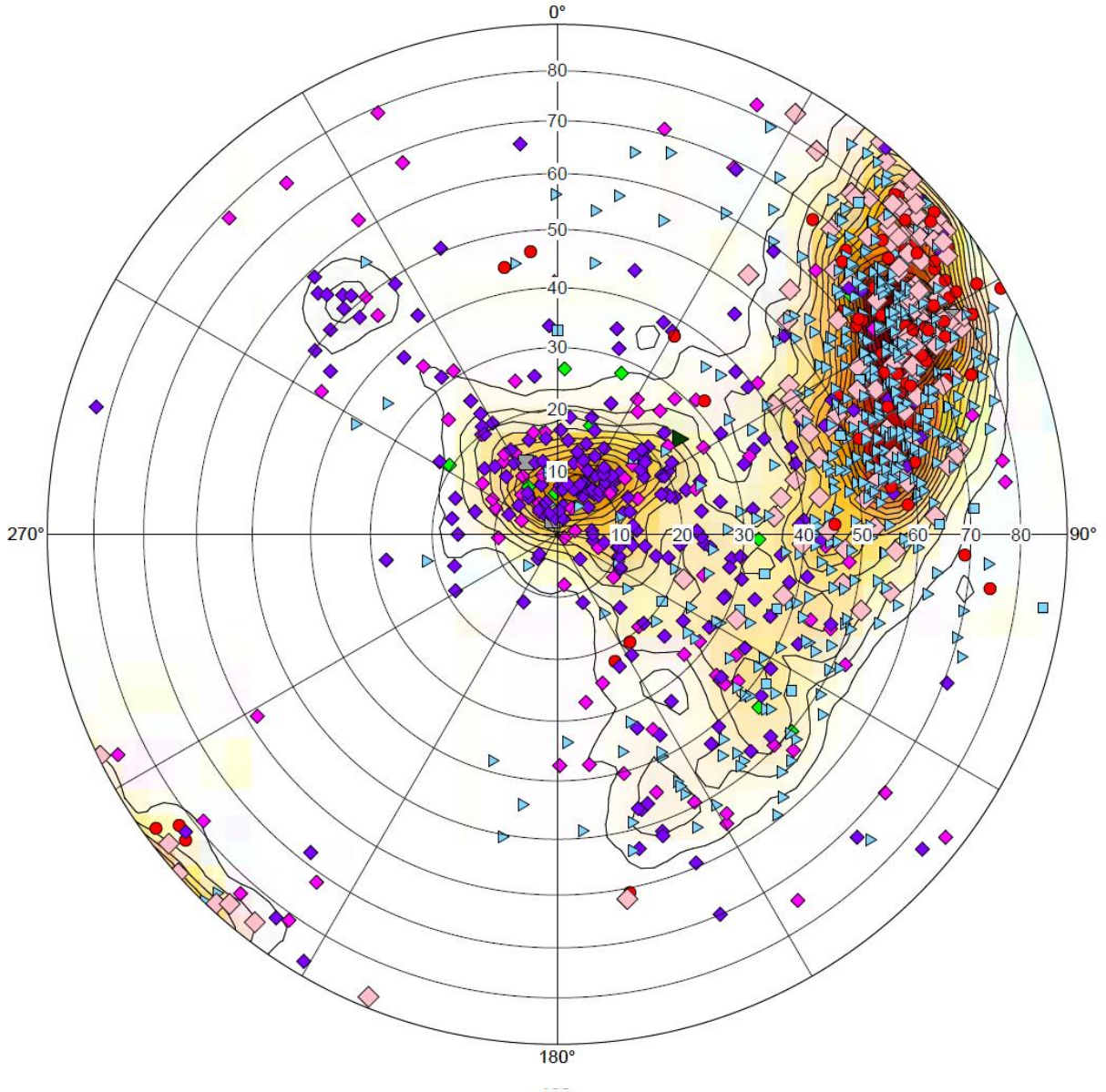
- Combine all parameters to maximise deliverables

Deliverables



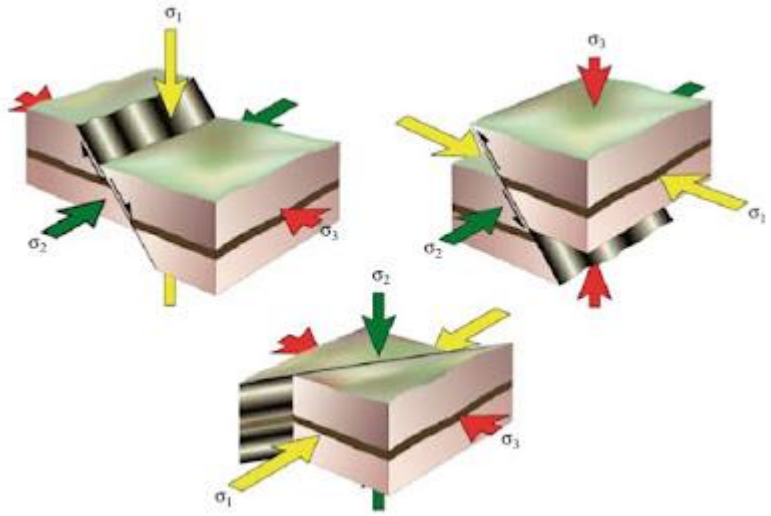
Televiewer: Schmidt Plot

- A Schmidt plot is used in structural analysis to represent numerous structural features graphically.
- A Schmidt plot allows an individual to quickly discern any trends in veins, bedding/foliation, lithological contacts and/or fractures.



Geologic Stress

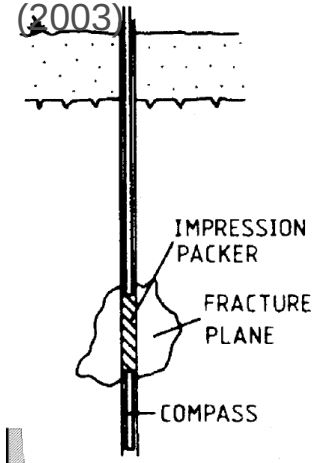
- Understanding the state of stress is important for many geological engineering problems
- Stress is represented mathematically by 3 orthogonal vectors (σ_1 σ_2 σ_3)
- Text-book stress models consider gravity and tectonic forces that are generally vertical or horizontal.
- Actual stresses can be complex due to local effects.
  - Loading, excavation, paleofractures, groundwater, geothermal gradients, etc
- *In-situ* stress measurements are helpful to understand local stress directions & magnitude



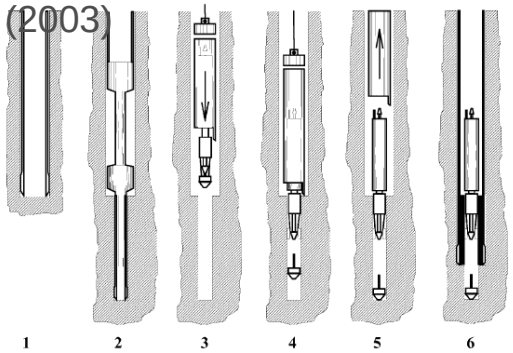
Stress Estimation from Breakouts

- Stress is traditionally a challenging property to measure because:
  - It can be highly variable across region of interest.
  - The available methods for measuring it can subject to **high levels of uncertainty**, **sparse, low success levels, time consuming** and **expensive**.
    - Overcoring (Field)
    - Acoustic Emission Kaiser Effect (Laboratory)
    - Mini Hydraulic Fracture (Field)
    - Microseismic Moment Tensor Inversion (Field)
    - Microseismic – Geomechanics (Field)

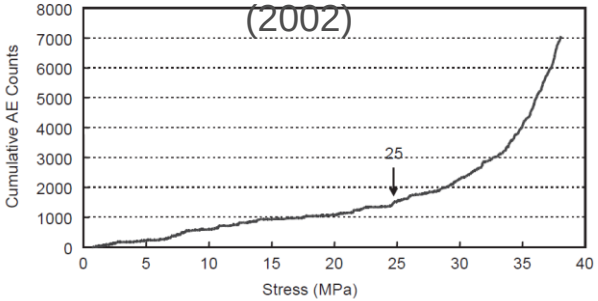
Ljunggren et al. (2003)



Ljunggren et al. (2003)

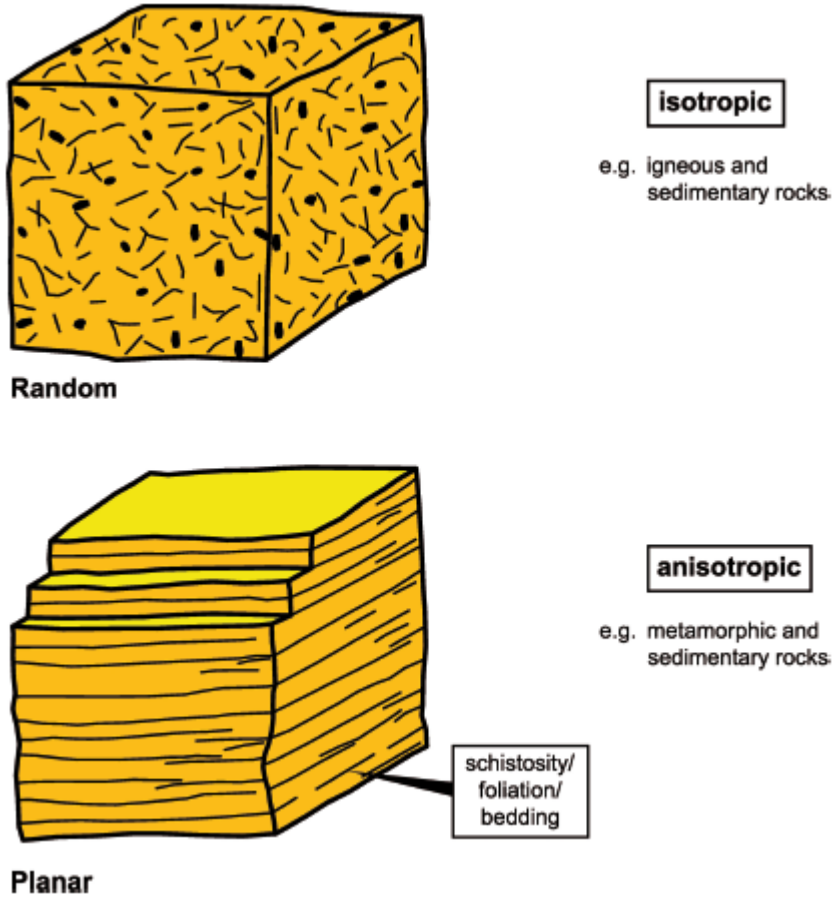


Villaesusa et al. (2002)



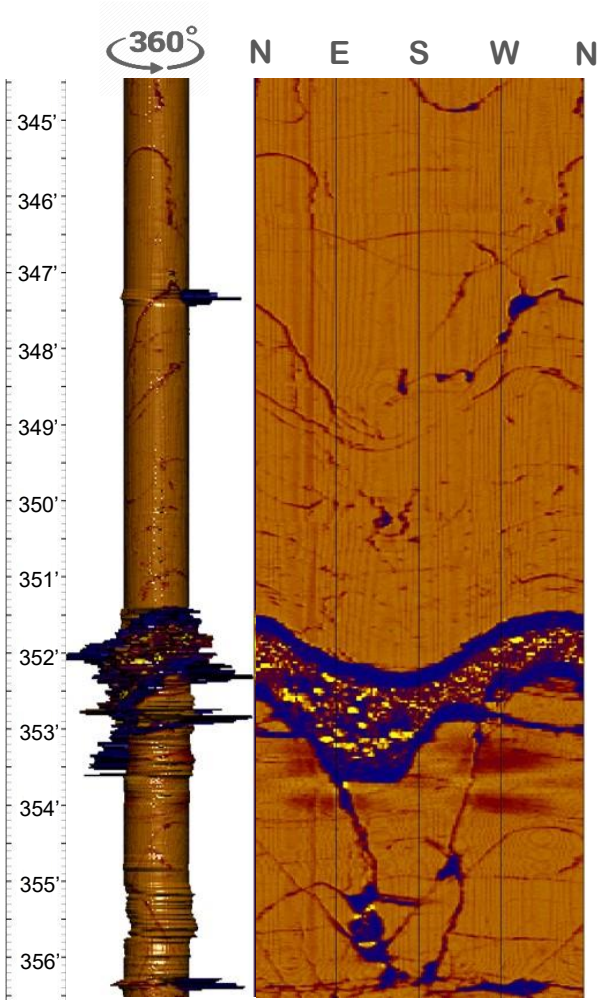
Anisotropic Rock

- A main assumption of the stress estimation methodology is the rock is an isotropic homogenous medium, such that the rock is uniform and the observed breakouts occur due to regional stresses and not local structure.

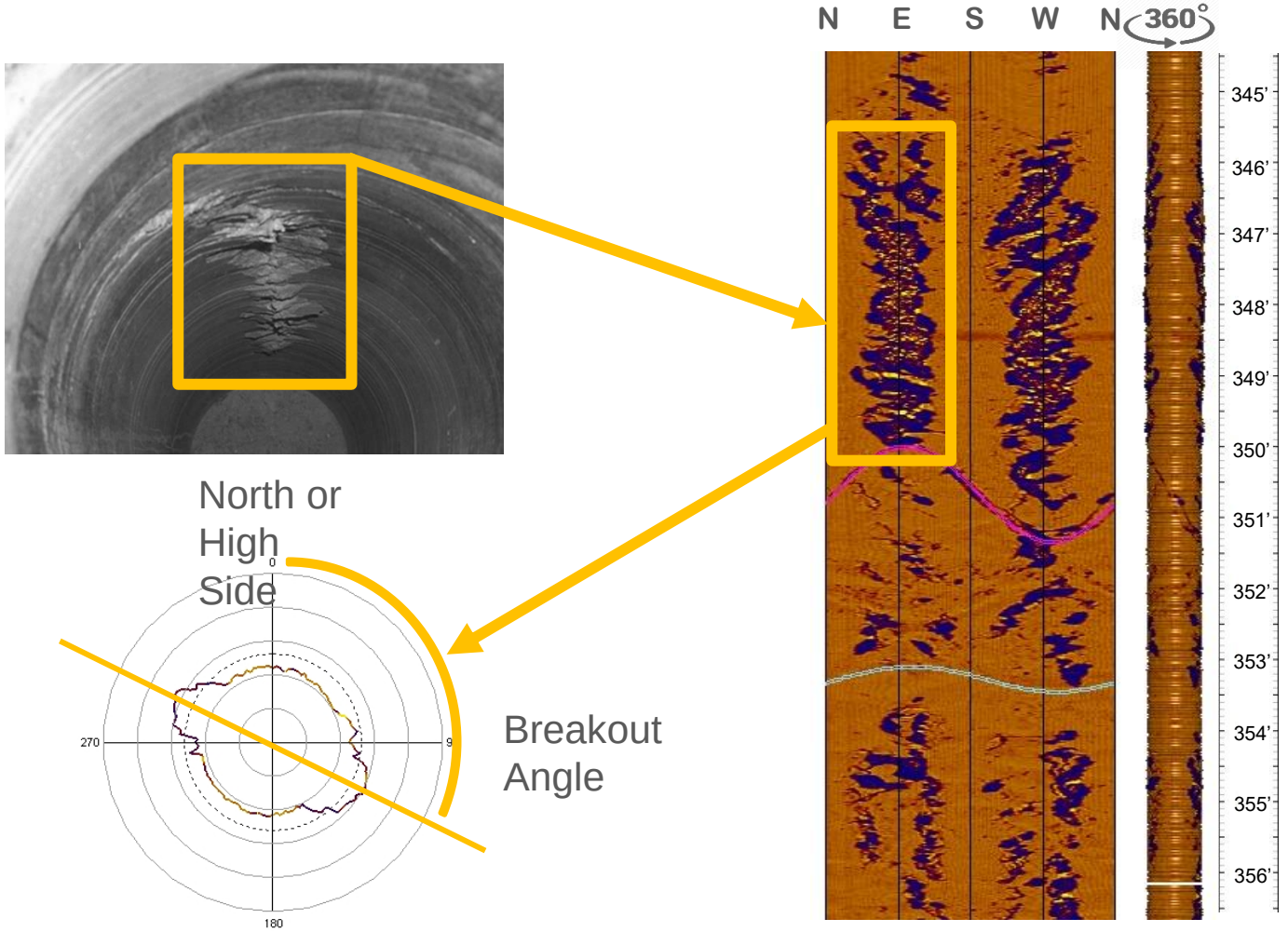


Acoustic Televiewer Data

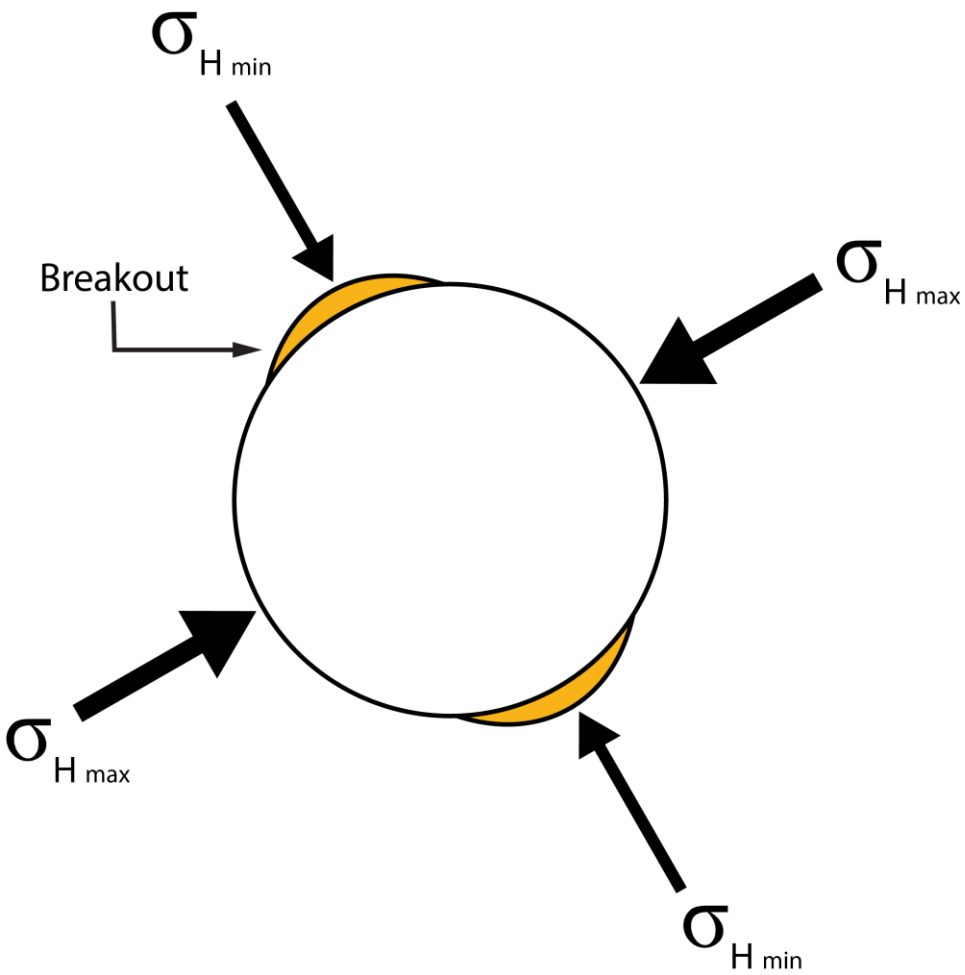
- Fracture Analysis

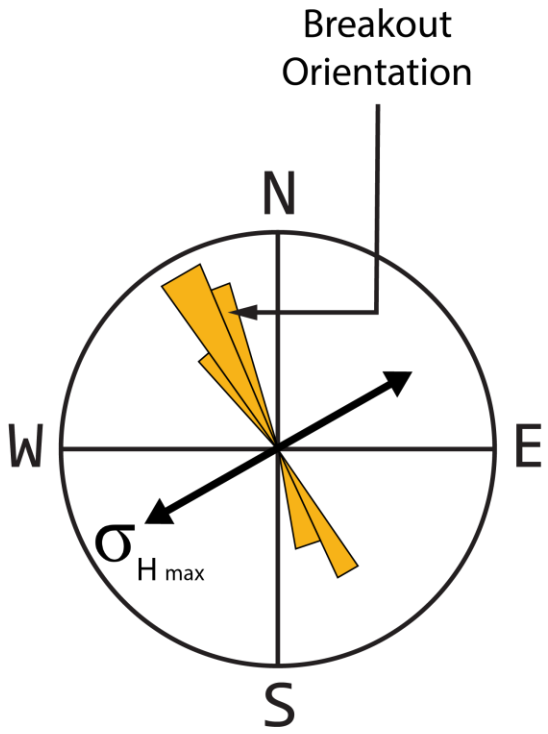


- Breakout Analysis

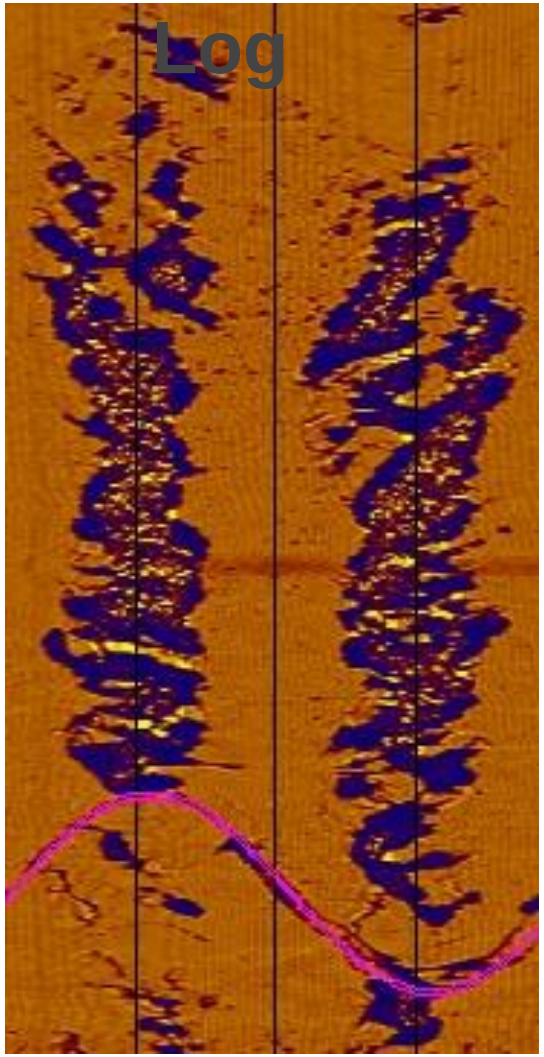


Acoustic Televiewer Data



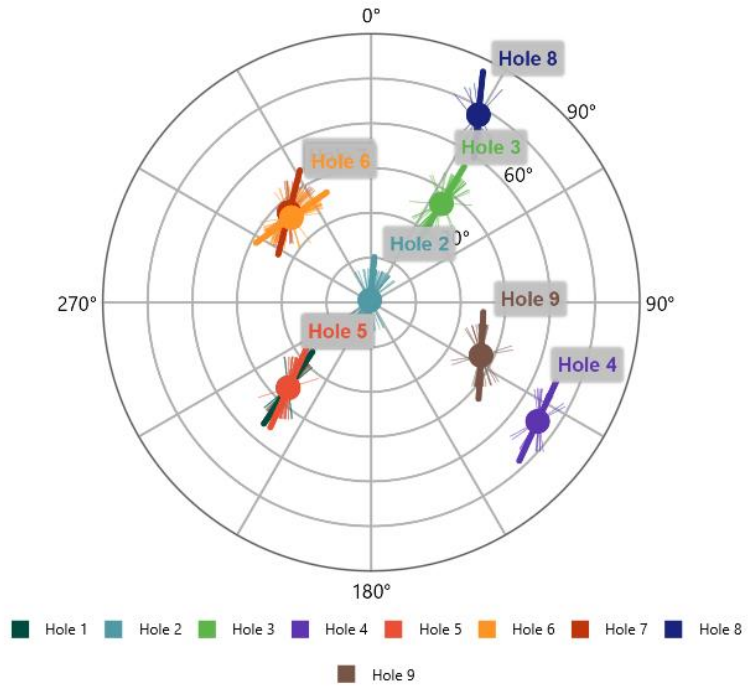


ATV Log

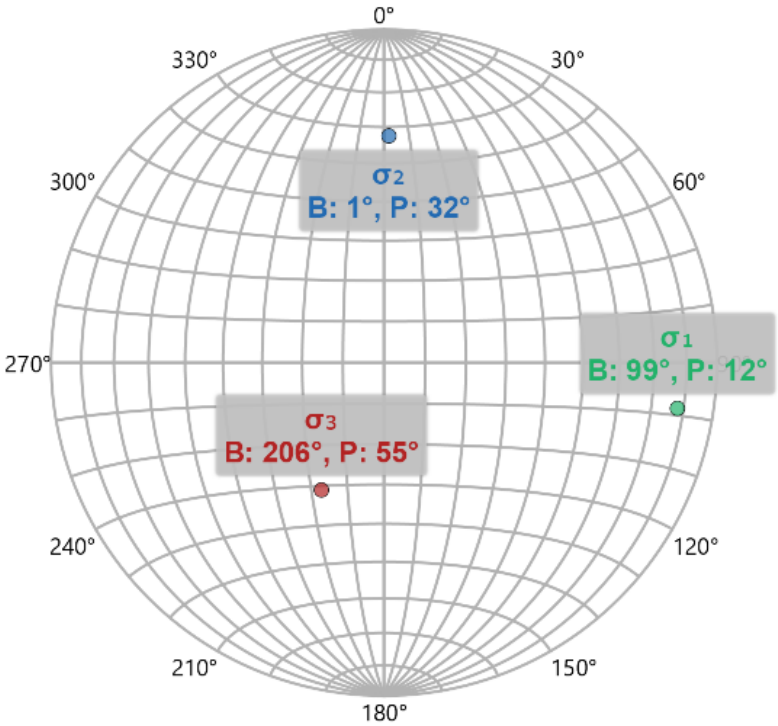


Stress Estimation

Multiple Deviated Holes with Breakout Data



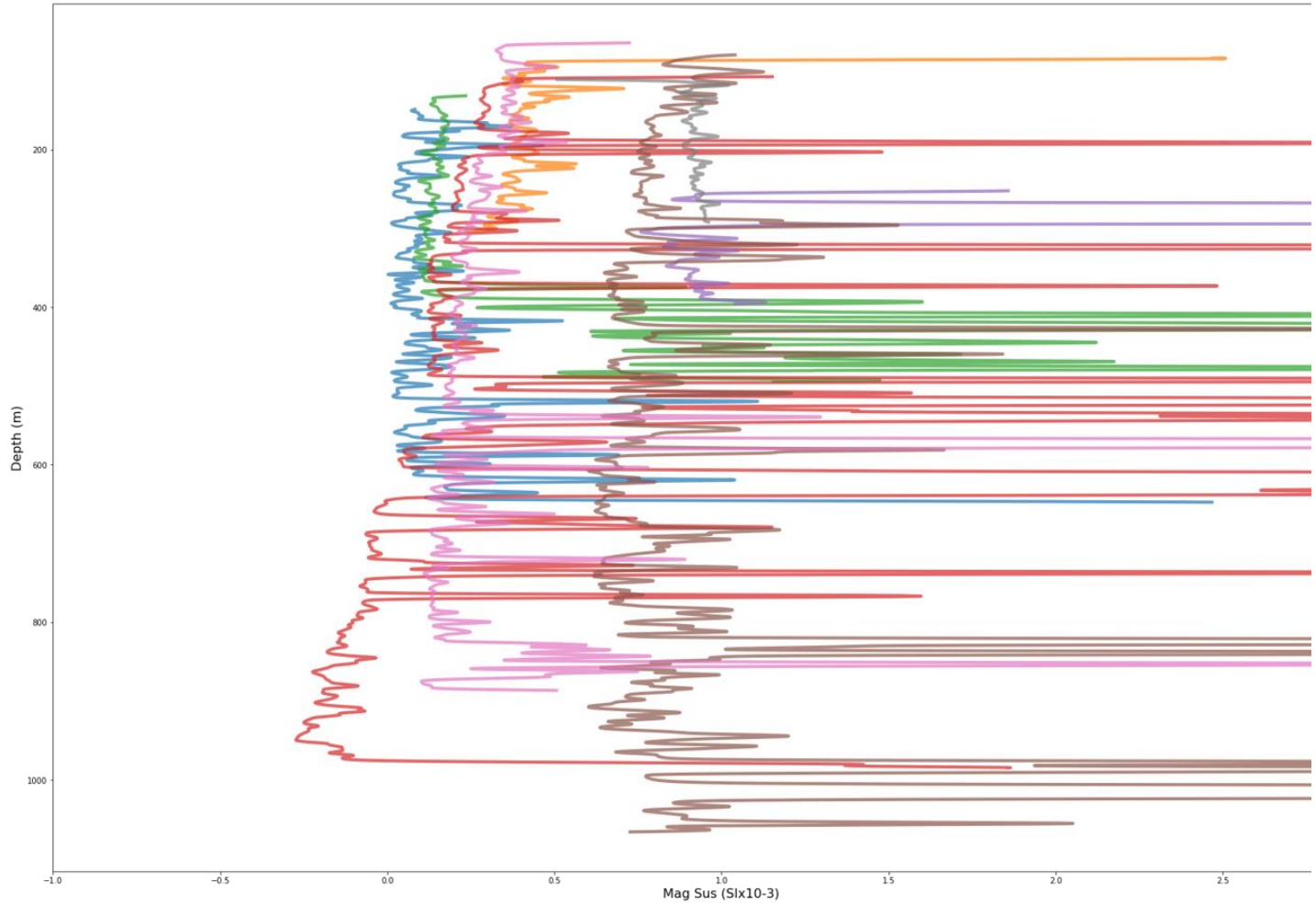
Best Fit Stress Model



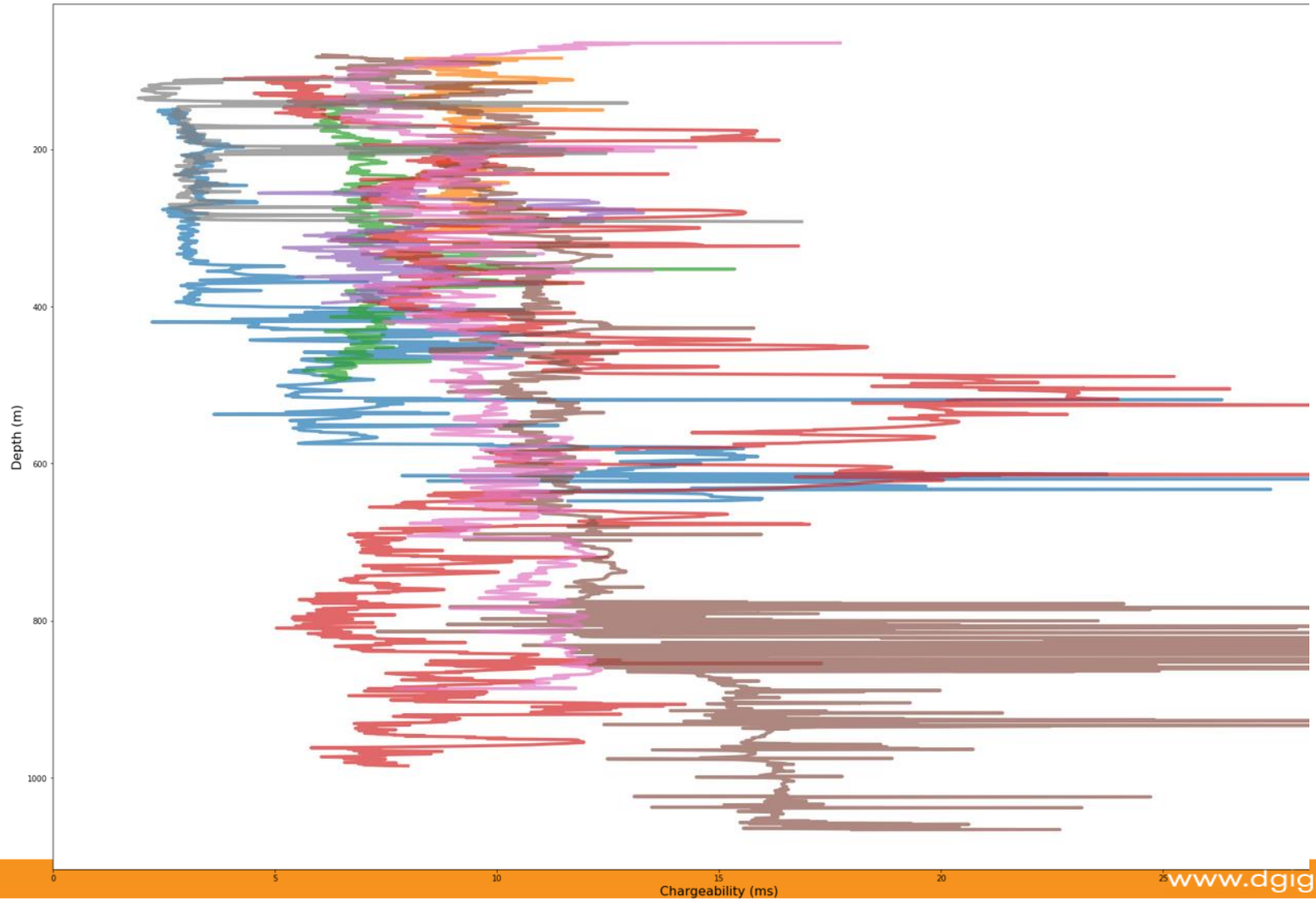
Physical Property Statistical Analysis Case Study

- 11 holes of physical property data acquired by third party with the following parameters:
  - Magnetic Susceptibility
  - Induction Conductivity
  - Induced Polarization
  - Full waveform sonic
  - Spectral Gamma
- Goal of the project was to examine the data quality, examine the relationships between the parameters and geology, and perform a cluster analysis.

Data Quality Check – Magnetic Susceptibility

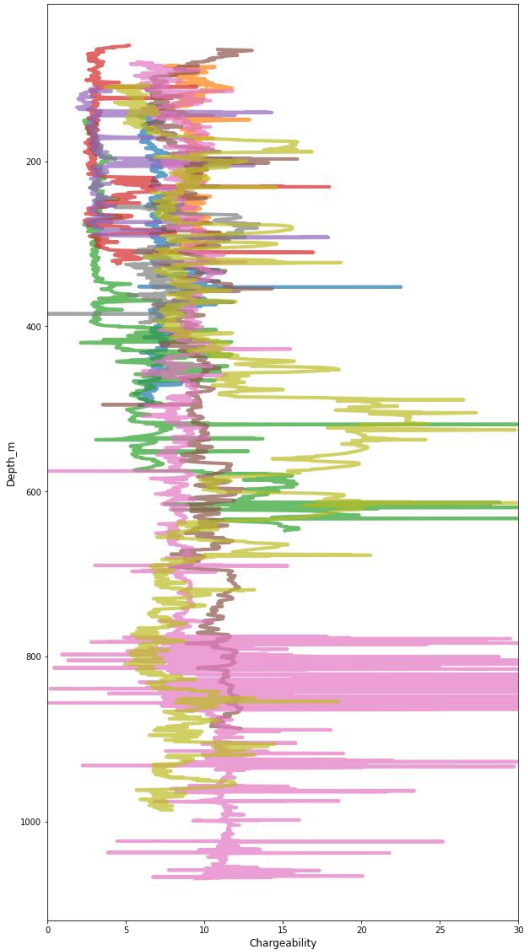


Data Quality Check - IP

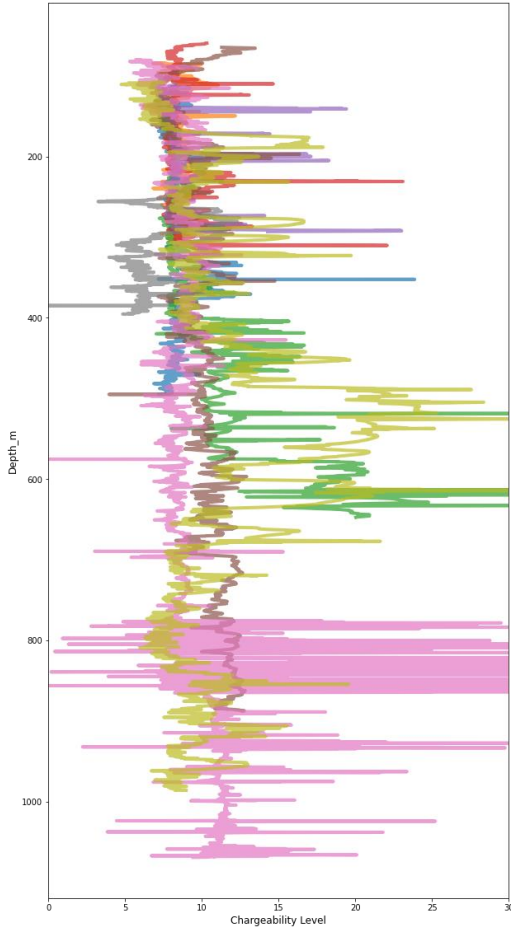


Data Preparation: Level Chargeability Data

Original Data

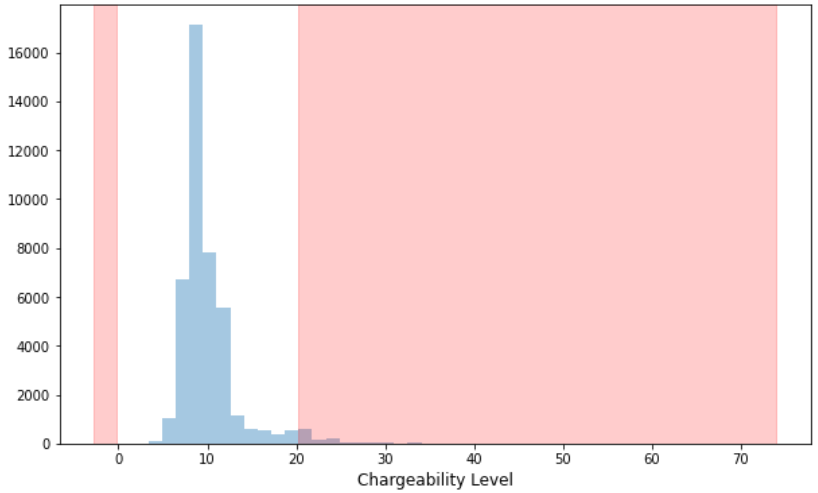


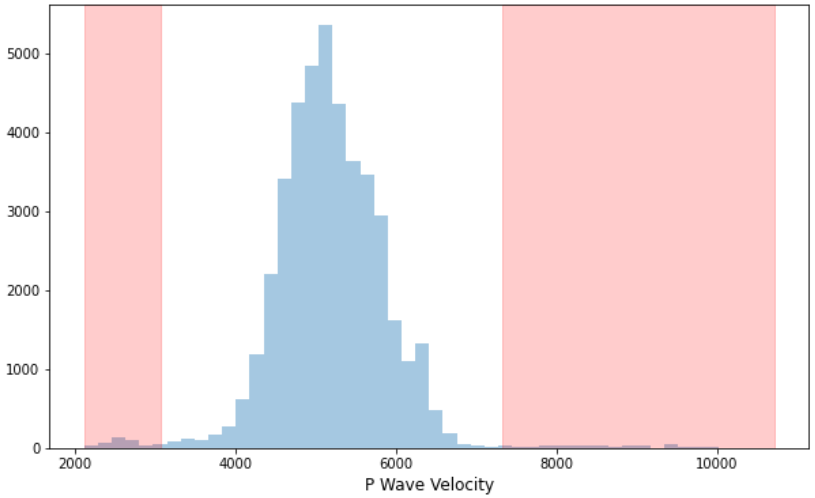
Leveled Data

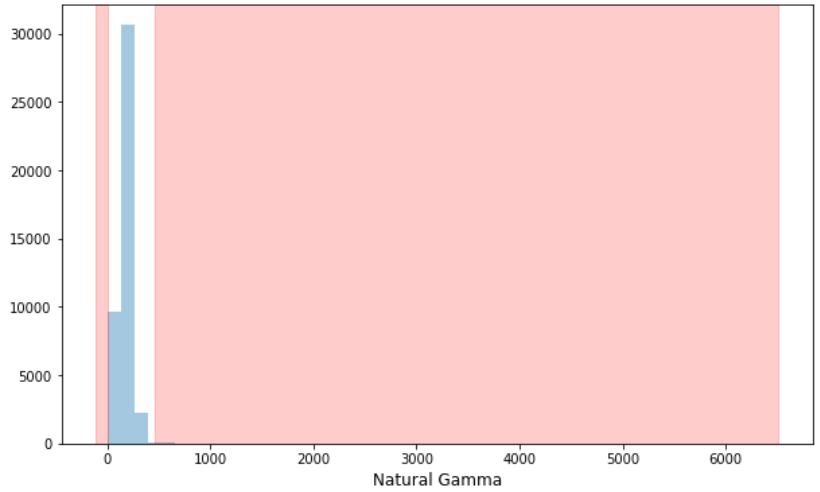


Data Preparation: Capped Values

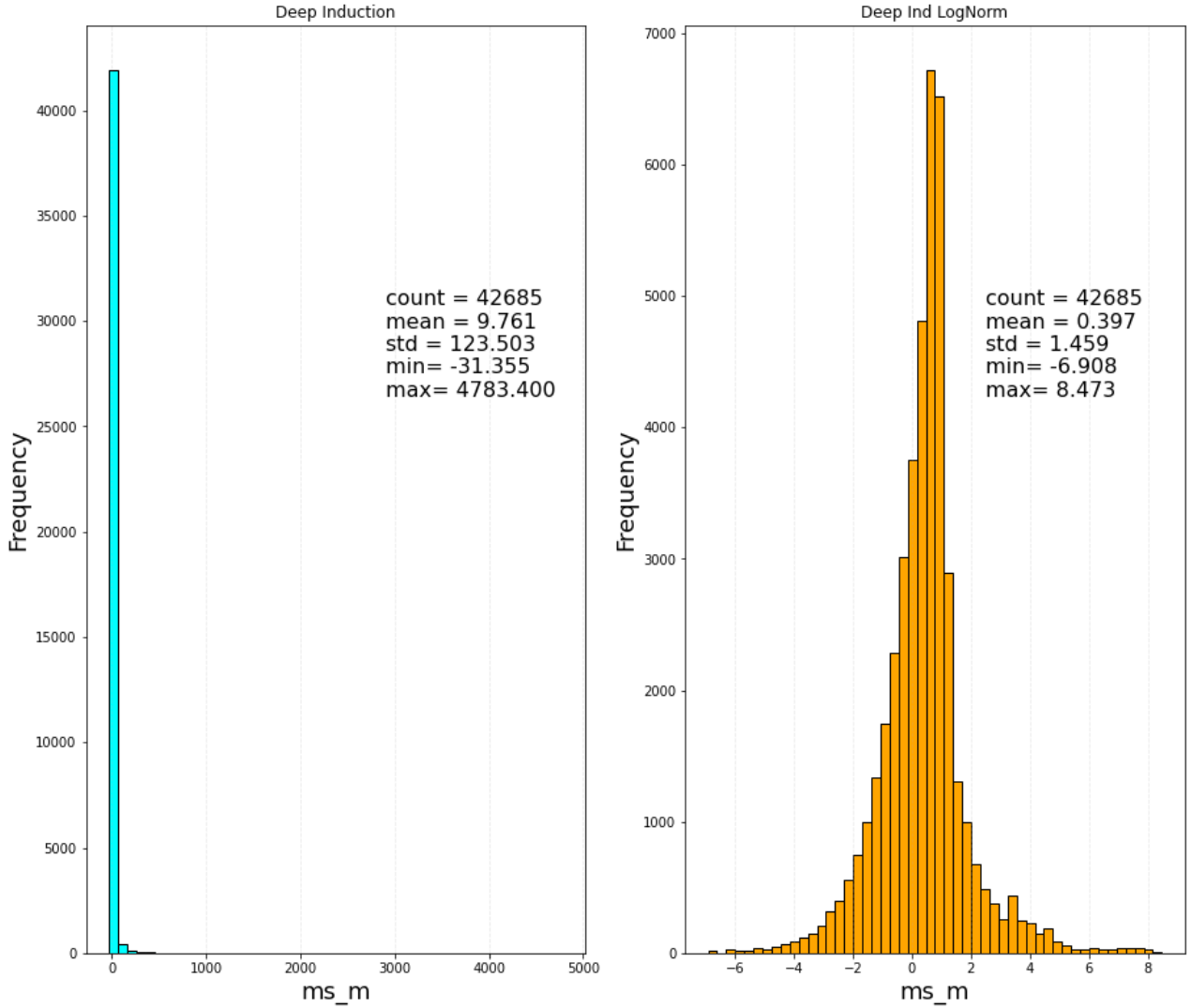
- Chargeability Capped at 20.
- P Wave Velocity Capped at (3000 & 7300)
- Natural Gamma capped at 450.



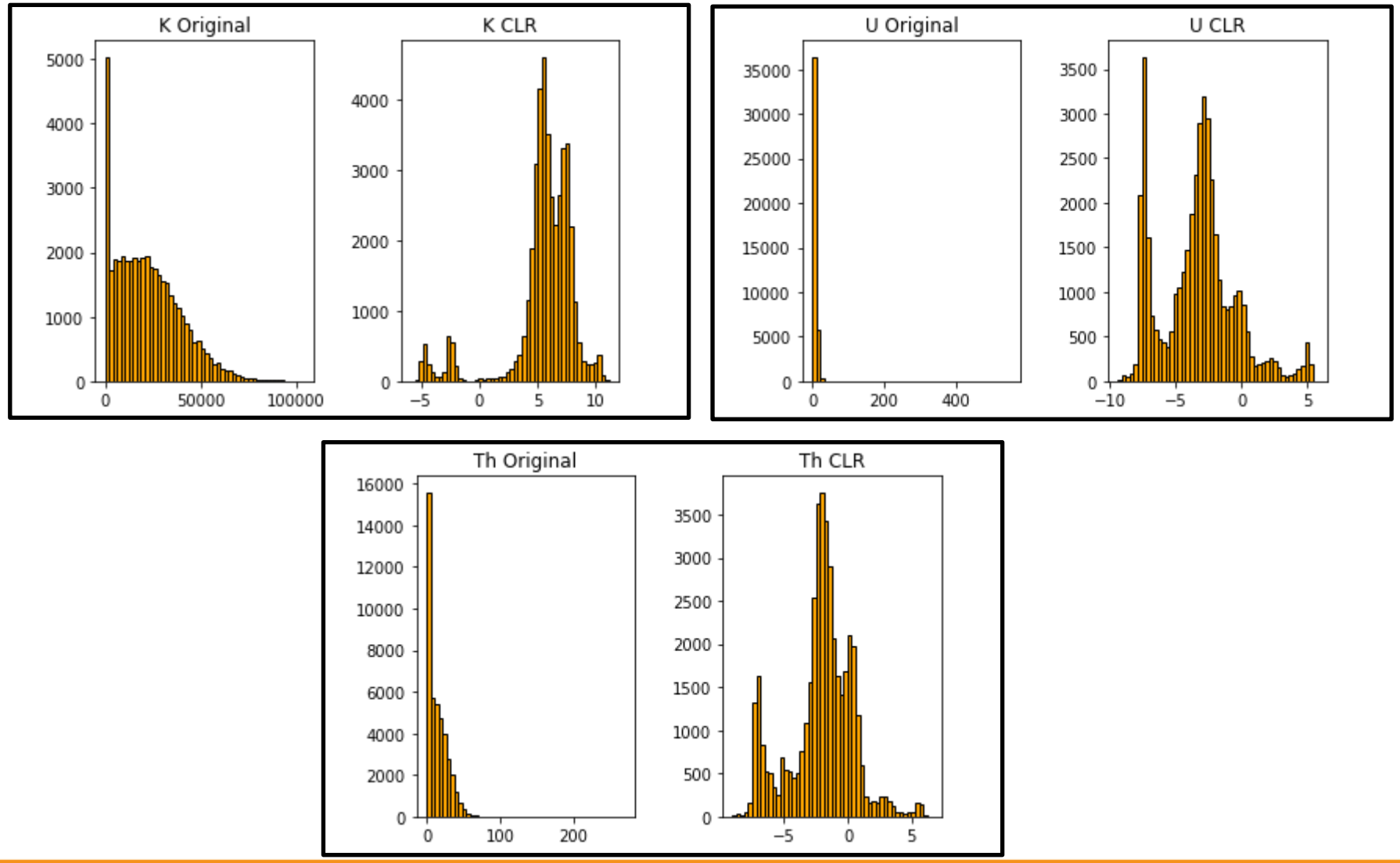




Data Preparation: Log Transform Induction



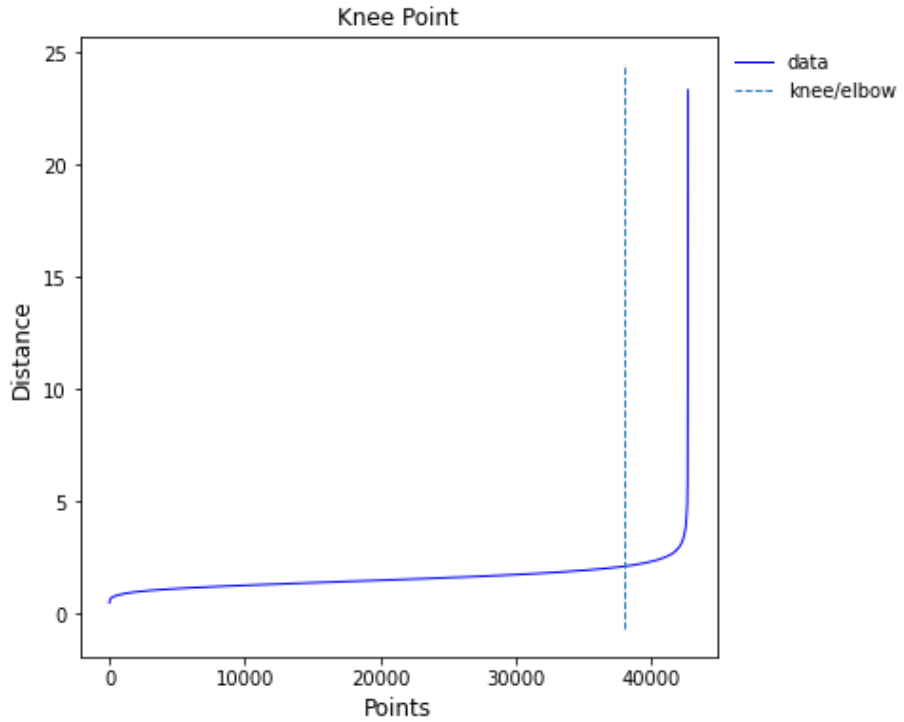
Data Preparation: Compositional Scaling of Spectral Gamma



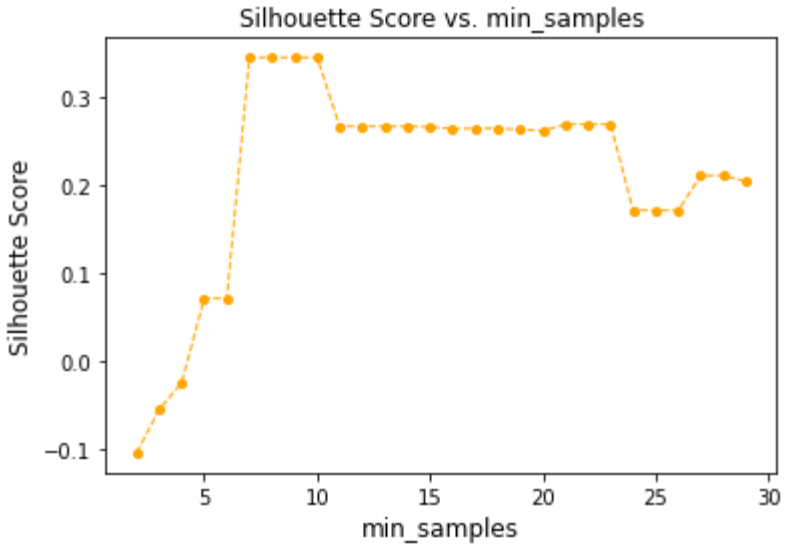
Dimensional Reduction using TSNE

Clustering Tuning Parameters

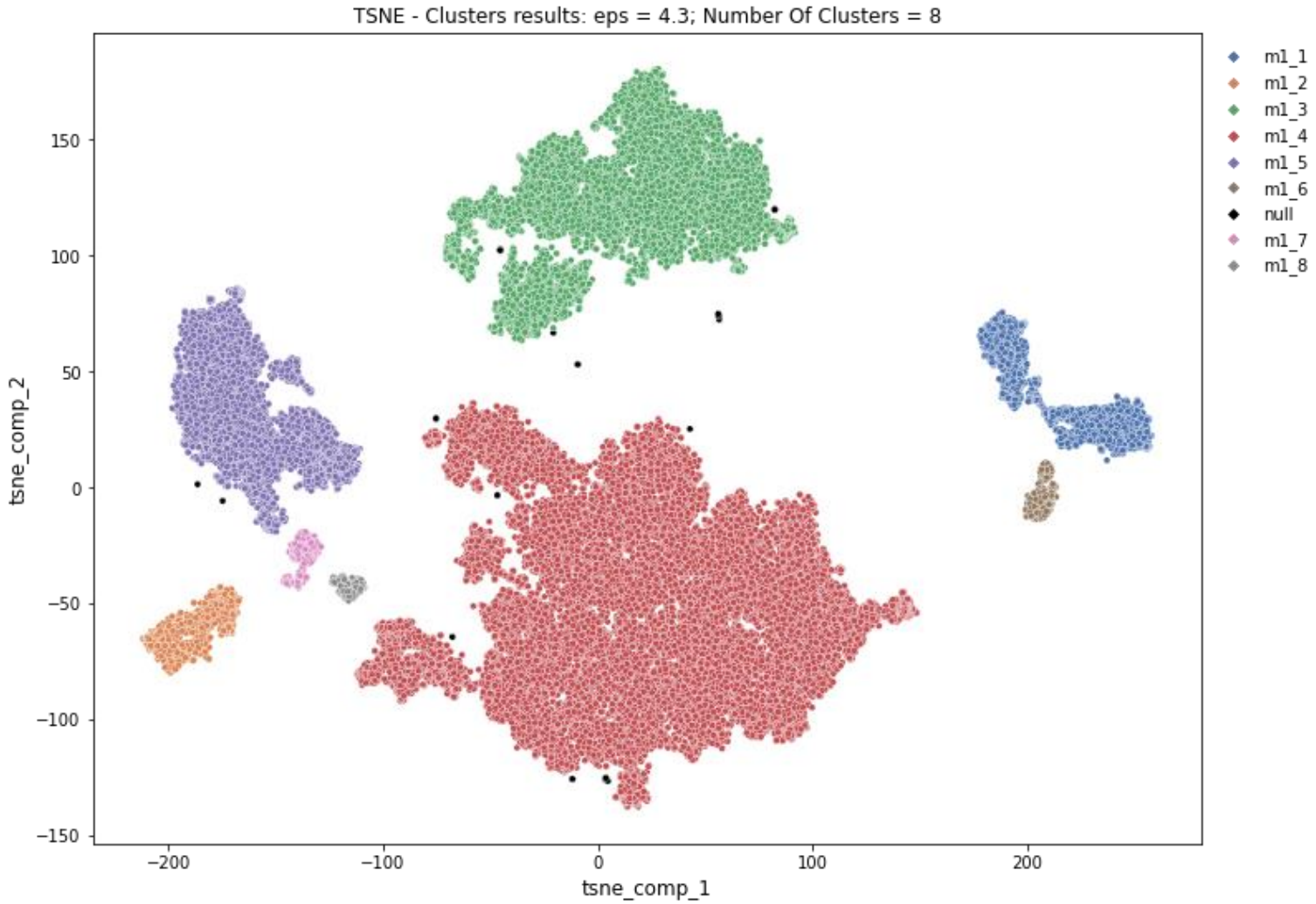
Epsilon Value



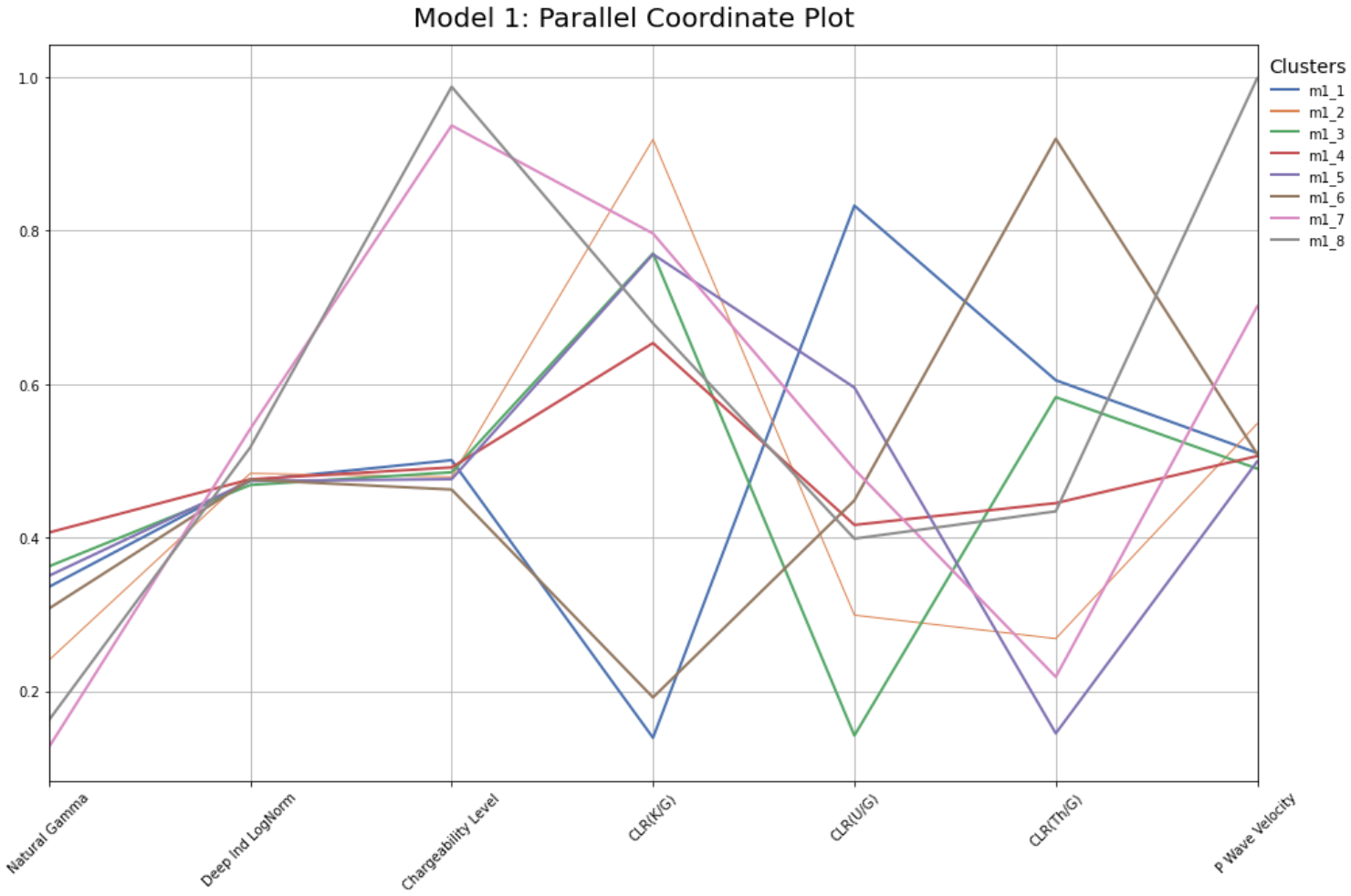
Minimum Samples

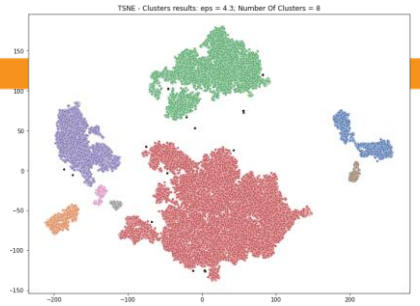


Cluster Analysis: 8 Clusters in the model

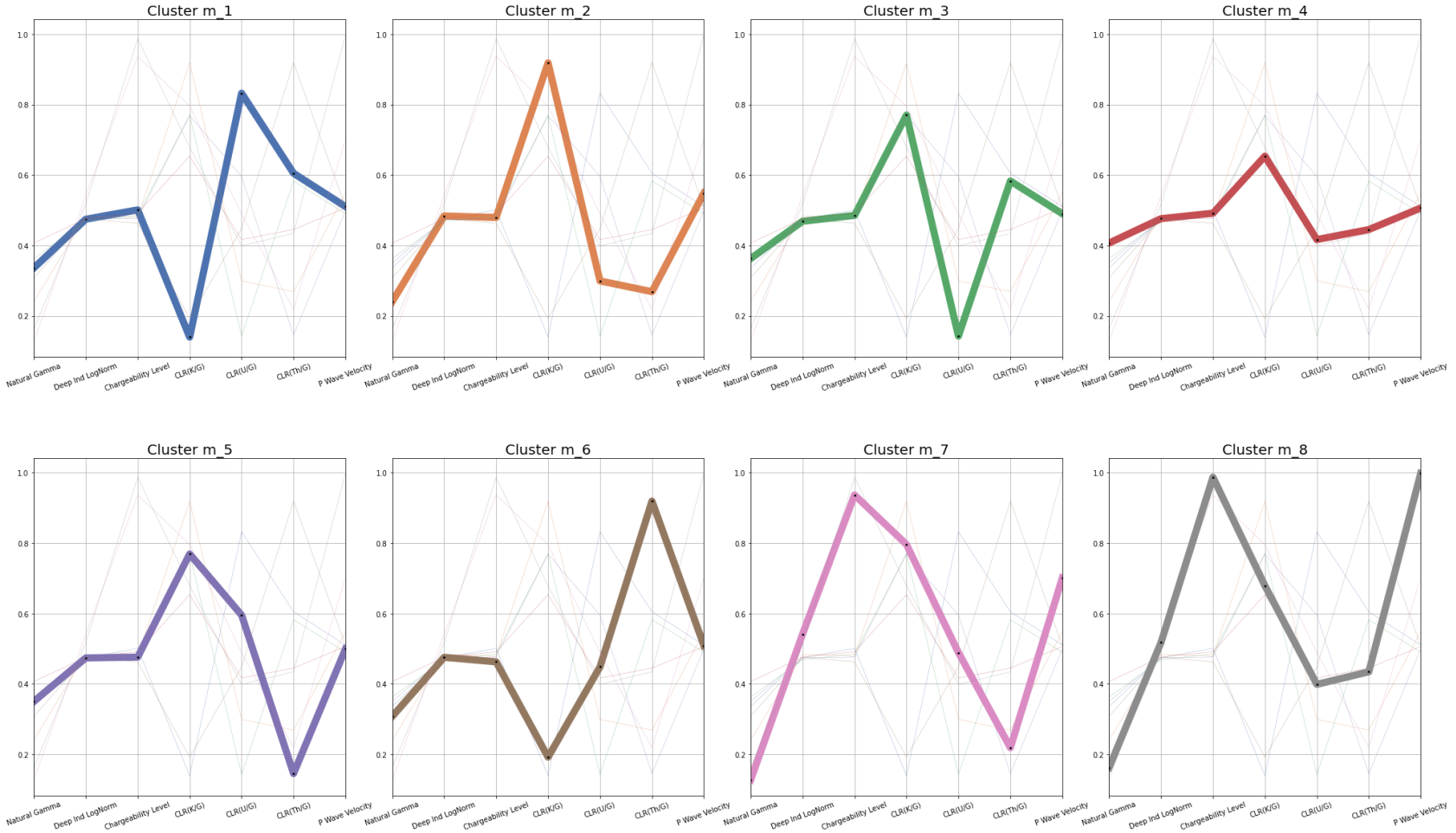


Parallel Coordinate Plot

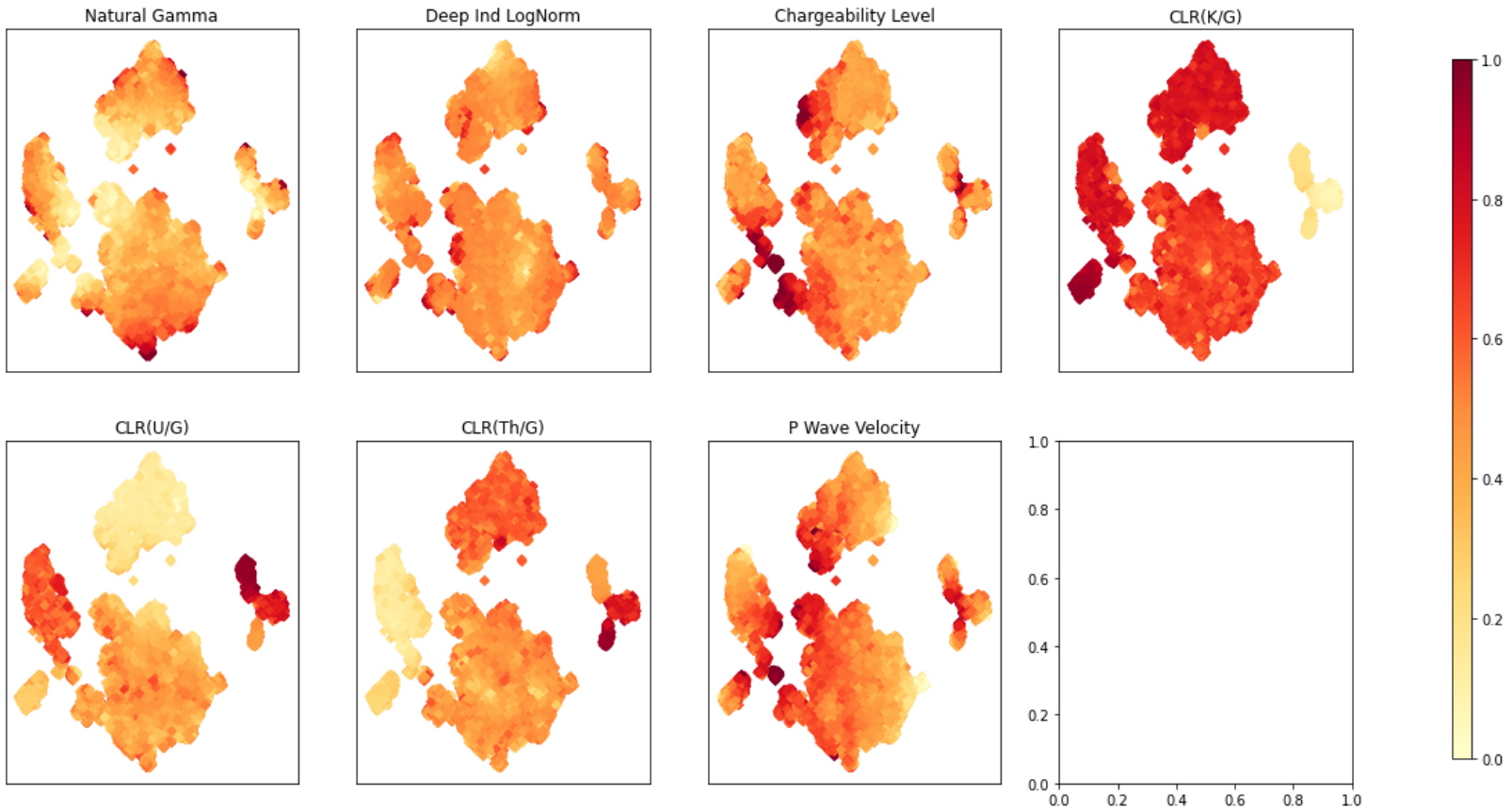




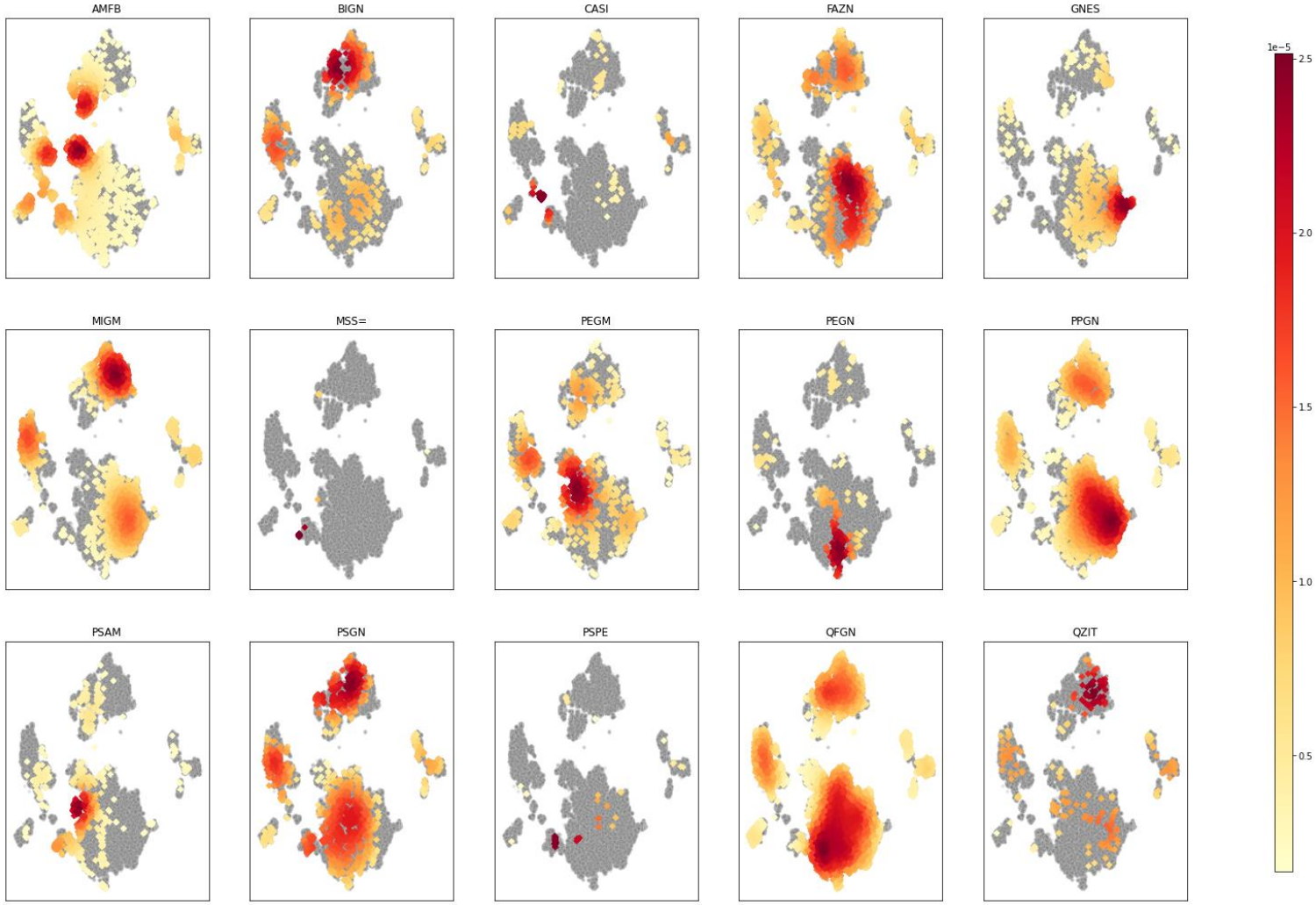
Parallel Coordinate Plots of 8 Clusters



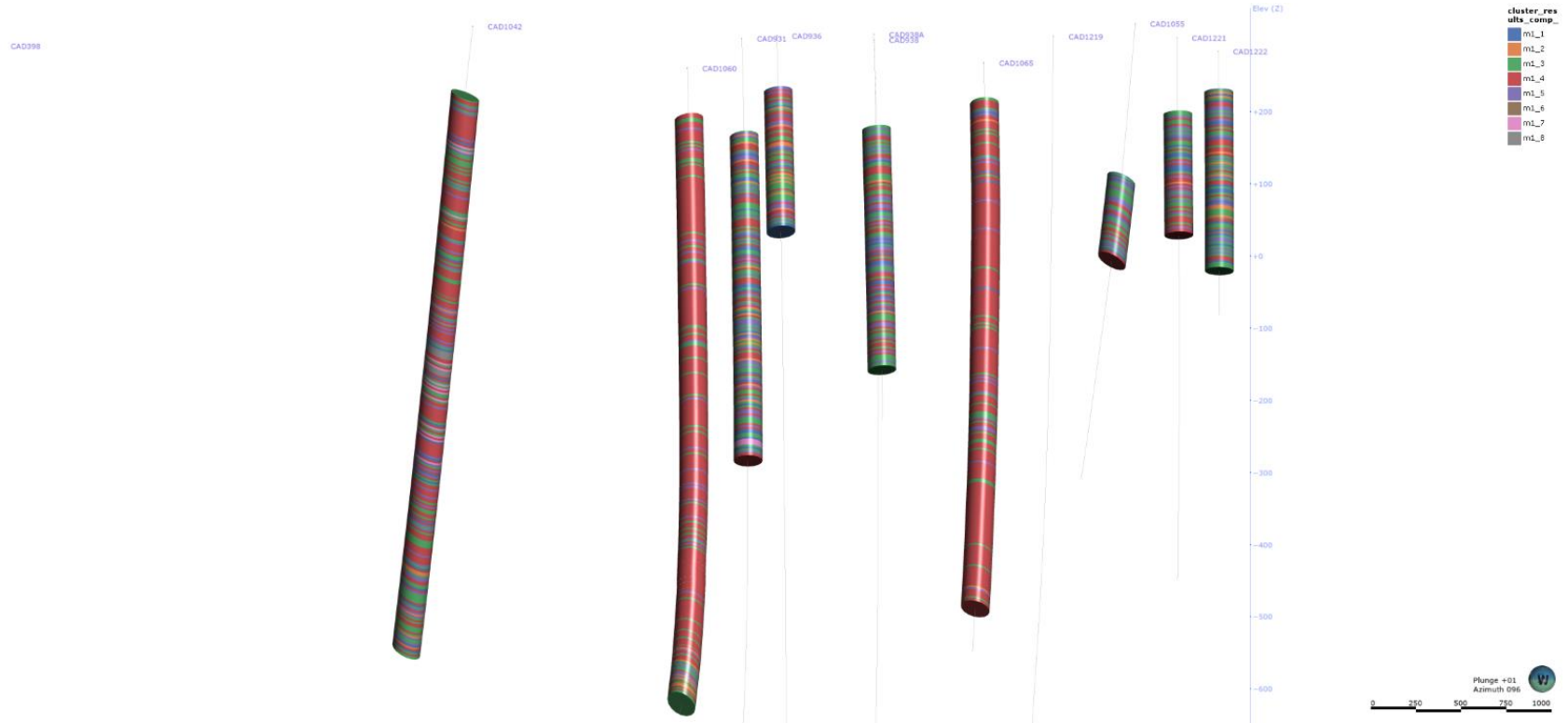
PRP Parameter Heat Map



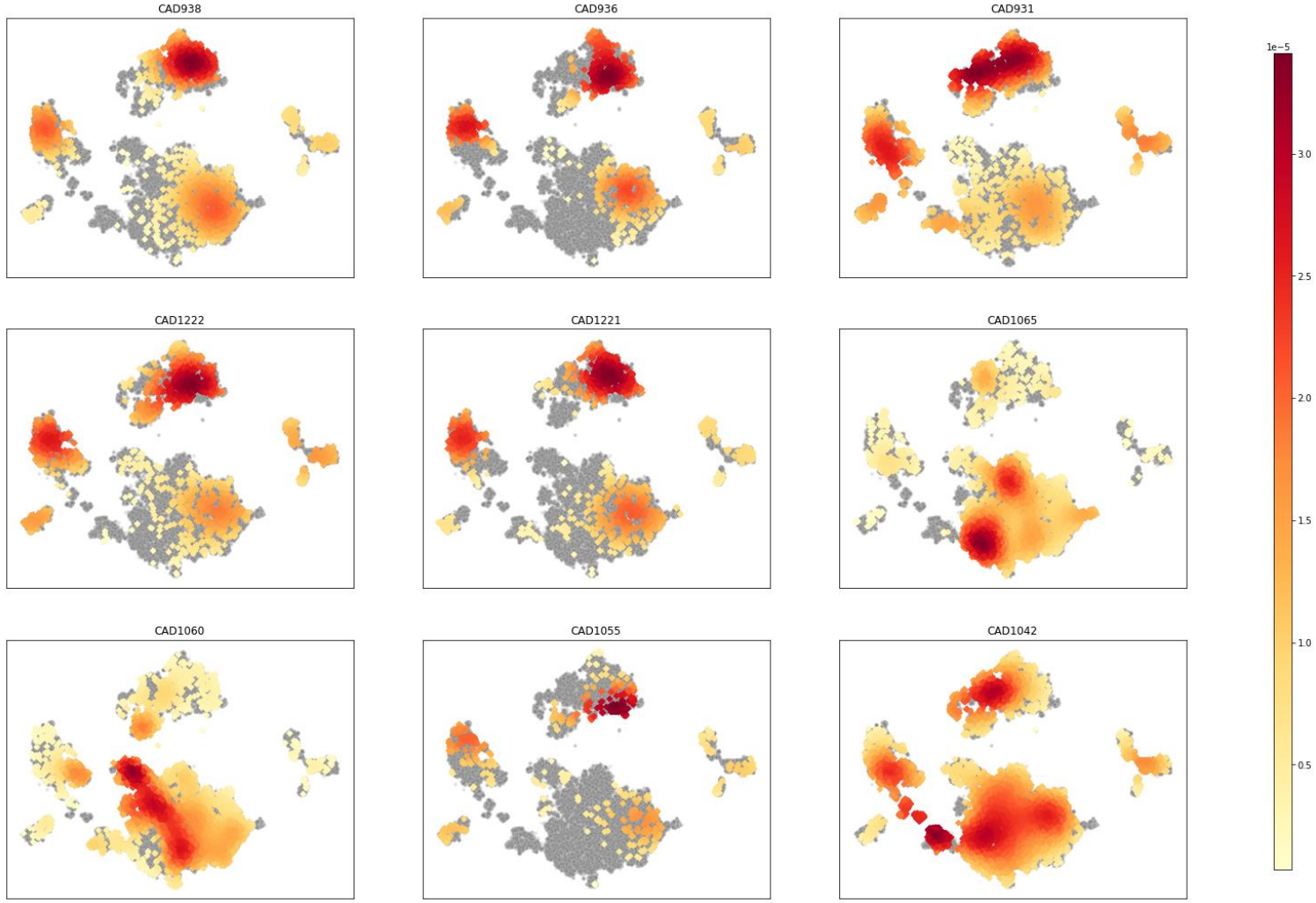
Lithology Heat Map



Spatial Distribution of Clusters



HOLEID Heat Map



Exercise
Python Analysis and Visualization

Click Here to Open