



Borehole Logging Methods

Borehole Data with a Purpose

MERC 2023

Overview

- Session 1 – Introduction to Borehole Logging
 - Design, Logistics, Methods, Hole Design, Direction
- Session 2 – Physical Properties and Applications
 - Gamma, Density, Neutron, Magnetics, Sonic, Resistivity
- Session 3 – Survey Design and Data Management
 - Data calibration and sampling, file storage and exchange formats.
- Session 4 – Televiewers and Physical Property Analysis.
 - Review of televiewers and their applications.
 - Techniques to analyze physical property data.

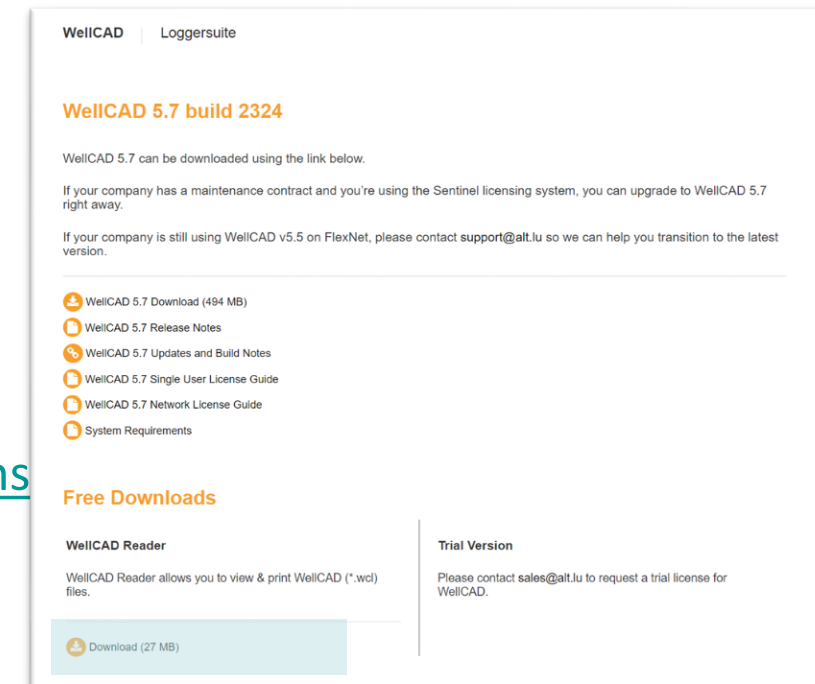
DGI Geoscience – Who are we?

- Founded in 1997
- HQ in Toronto and Field Base in Barrie and Salt Lake City
 - Established permanent base of operations also in US, Brazil, Kazakhstan and Australia
- Specializing in in-situ structural, geotechnical, geophysical and hydrogeological information
- Expertise in Televiewer, Physical Properties, Geotech and Exploration



Course Material

- All material can be found here:
 - <https://github.com/DGI-Geoscience/merc2023>
 - [Exercise 1](#)
 - [Exercise 2](#)
- Presentations
 - <https://github.com/DGI-Geoscience/merc2023/presentations>
- Software
 - [WellCAD Reader](#)



MERC 2023 - Session 1

INTRODUCTION TO BOREHOLE LOGGING



Overview

- How do we add value by using already existing resources (ie. a drillhole)?
- **Directional Data**
 - Where is the borehole in space and time. Trajectory, planning, exploration.
- **Physical Rock Properties**
 - Continuous record of the formation rock properties. Rapid, quantitative, unbiased, suited for statistical analysis.
- **Borehole Imaging**
 - Acoustic and Optical Televiewer
- Use downhole data sets to complement already existing data and provide QC.

Drilling is expensive; leverage the most amount of data from every hole drilled.

What Can We Actually Measure?

Physical Rock Properties

- Natural Gamma
- Neutron (Porosity)
- Magnetic Susceptibility
- Conductivity
- Acoustic Velocity (P and S Wave)
- Electrical Resistivity
- Spontaneous Potential
- Induced Polarization
- Density

Borehole Imaging

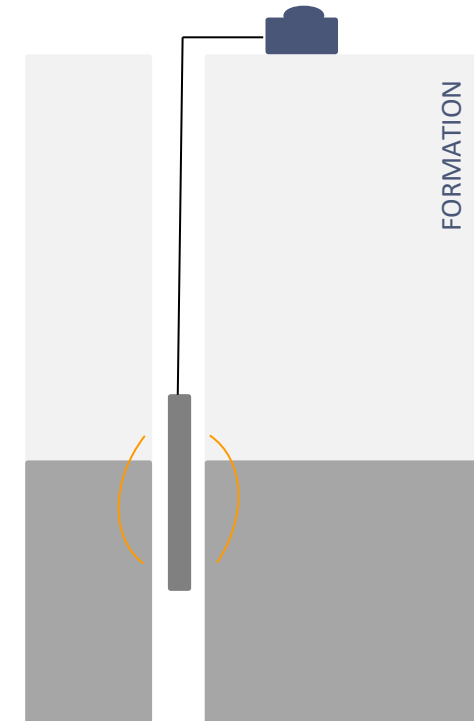
- Acoustic Televiwer
- Optical Televiwer
- Dipmeter
- Downhole Camera

Directional and Hydrogeology

- Gyro
- Caliper
- Fluid Flow
- Borehole Magnetic Resonance (Porosity, Permeability and Hydraulic Conductivity)

Other

- Sonar and laser void scanning.
- Borehole Radar



VERTICAL, INCLINED, HORIZONTAL, UPHOLE.
NEW OR PREVIOUSLY DRILLED.

Why Survey Boreholes?

- To determine the X, Y and Z spatial coordinates of a drill hole
- Exploration surveying increases the potential identification of geological anomalies and the existence of a potential economic ore body
- Knowing the coordinates of a potential ore body that will require future extraction is obvious; however there are many other reasons:
 - Planning holes to avoid known faults or difficult ground conditions
 - Collision avoidance of man-made obstacles
 - Intersect known targets (e.g. relief holes, breakthrough holes)
 - Geotech considerations

Survey Design

- What is the goal?
 - Select the right technology
 - Resolution
 - Borehole conditions
 - Fluid conditions
 - Time available
 - Economics
- What are the QA/QC procedures?
 - Calibration
 - Documentation
 - Processing/Interpretation
- Data Management plan



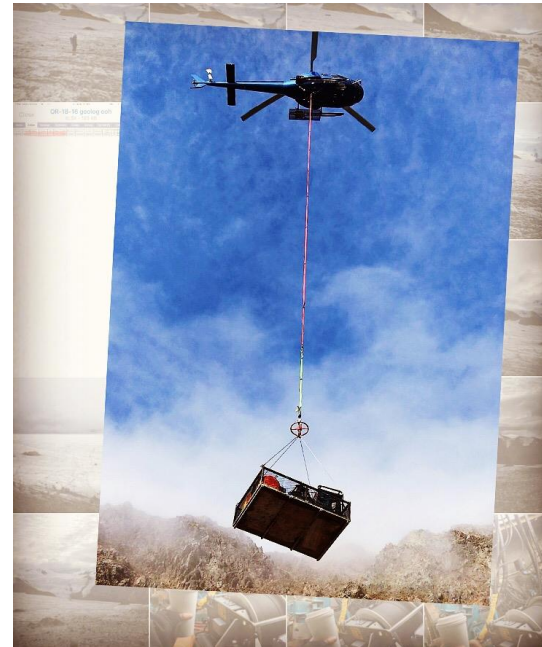
Logistical Constraints

- Truck Access (4X4 vehicles)
 - Ideal access, easily transport equipment including winch with deepest capability (+2km)
 - Trucks are not very flexible
- ATV/Snowmobile Access
 - Equipment must be manageable size, Winches considerations
 - Higher daily mob time (multiple trips)
 - Increased Health and Safety risks



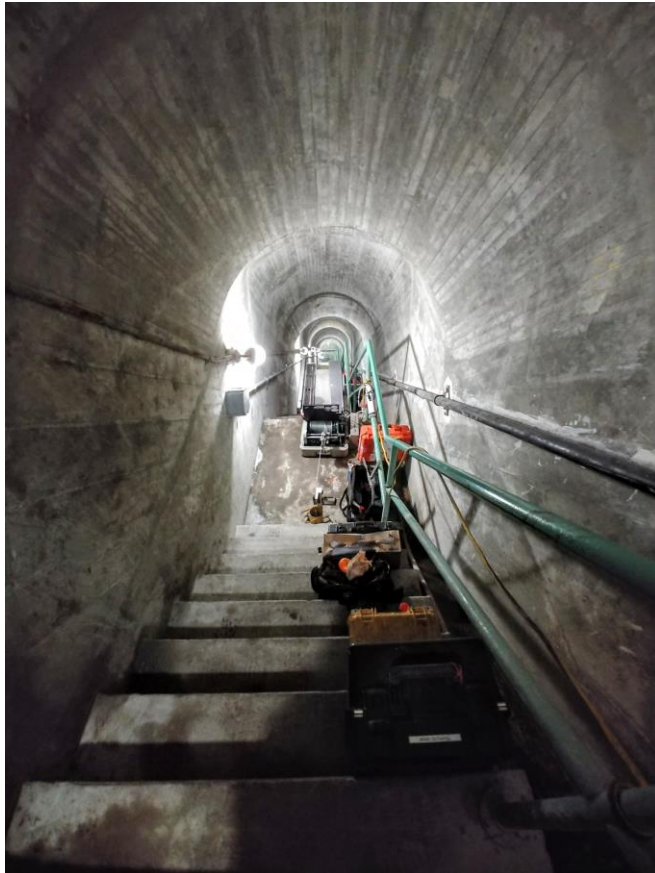
Logistical Constraints

- Helicopter Access
 - Greater work day limits (daylight hours, visibility, scheduling)
 - Equipment must be transportable
 - Cost
- Underground
 - Portable system, less time at the hole
- Driller/Road Crew supported (Muskeg/Skidder etc.)
 - Reliance on 3rd Party



Logistical Constraints

- Location and Weather!



Adapting to New Processes

- Challenging limitations on the directions the borehole probes can be logged in.
- New technologies/processes allow for probes to be run in:
 - Vertical boreholes
 - Horizontal boreholes
 - Incline or up-hole boreholes
- Logging in tough environments
 - Permafrost
 - Weathered rocks (Saprolite)
- Drilling
 - Core vs. non-core
- Blastholes, open holes, old etc.



DGI Reformulating the Typical System at the Face

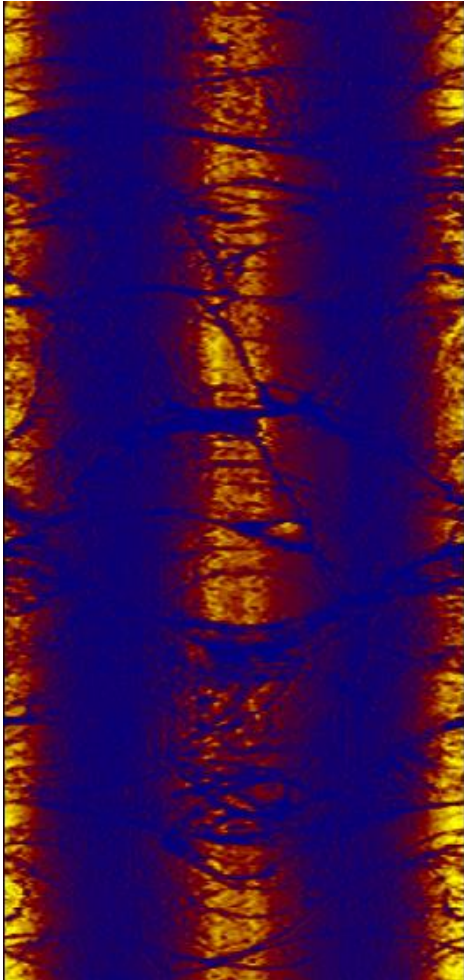
Centralisation

- Prevents tool moving about in the hole
- PVC, Brass, Steel
 - Variable sizes

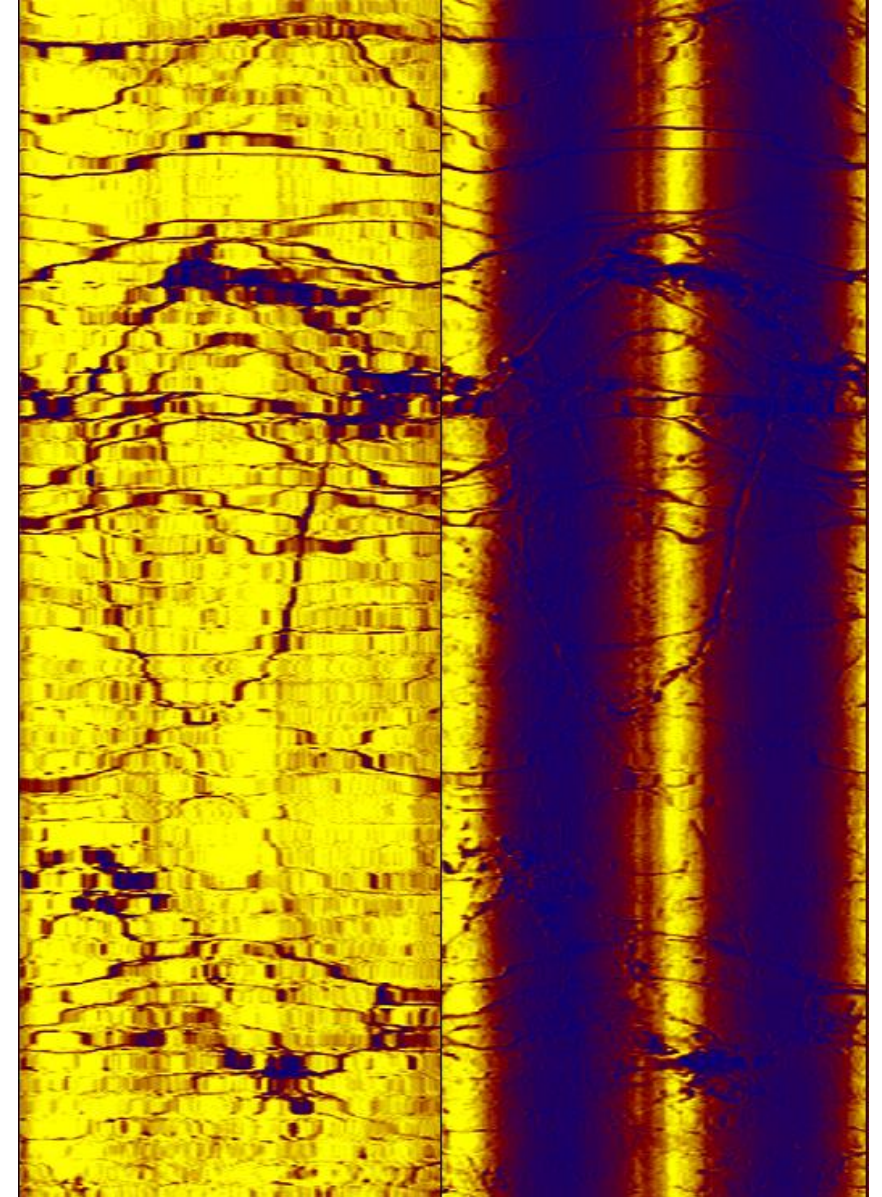


Picture: Mount Sopris

Bad Centralisation - Example



- Tool moving about in the hole during collection
- Creates decentralized image on televiewer data
- Can be caused by poor hole conditions and/or inadequate set up
- Pixelization can occur also occur due to poor borehole conditions



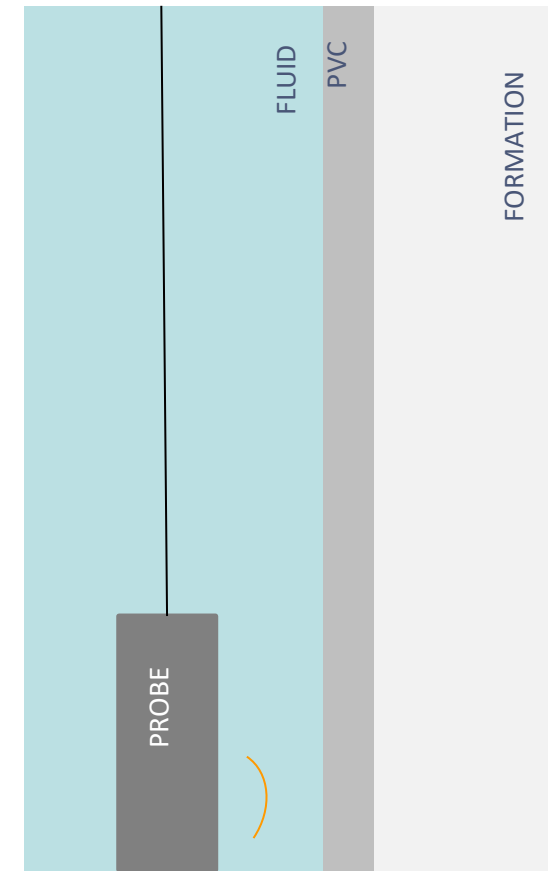
Hole Type

- Various Sizes and conditions
- “Standard” sizes;
 - NQ – 76mm
 - HQ – 96 mm
 - PQ – 123 mm
 - BQ – 60 mm
- Other sizes possible
- Open hole, in rods, steel casing, in PVC casing
- Blastholes
- Any orientation; Uphole, downhole, inclined, horizontal.....



Hole Type: Example - Logging Through PVC

- Obtain fracture orientations through PVC casing in situations where the borehole would not remain open long enough to survey
- Multi-echo acoustic televiewer records multiple arrivals, allowing the tool to record an image through PVC

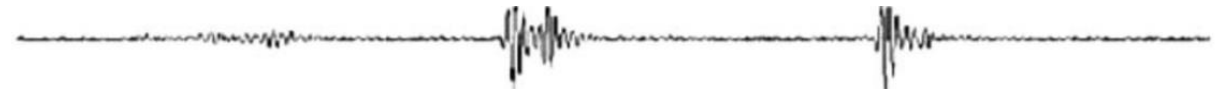


First Reflector: Edge of tool

Second Reflector: PVC

Third Reflector: Borehole wall

RECORDED
WAVEFORM



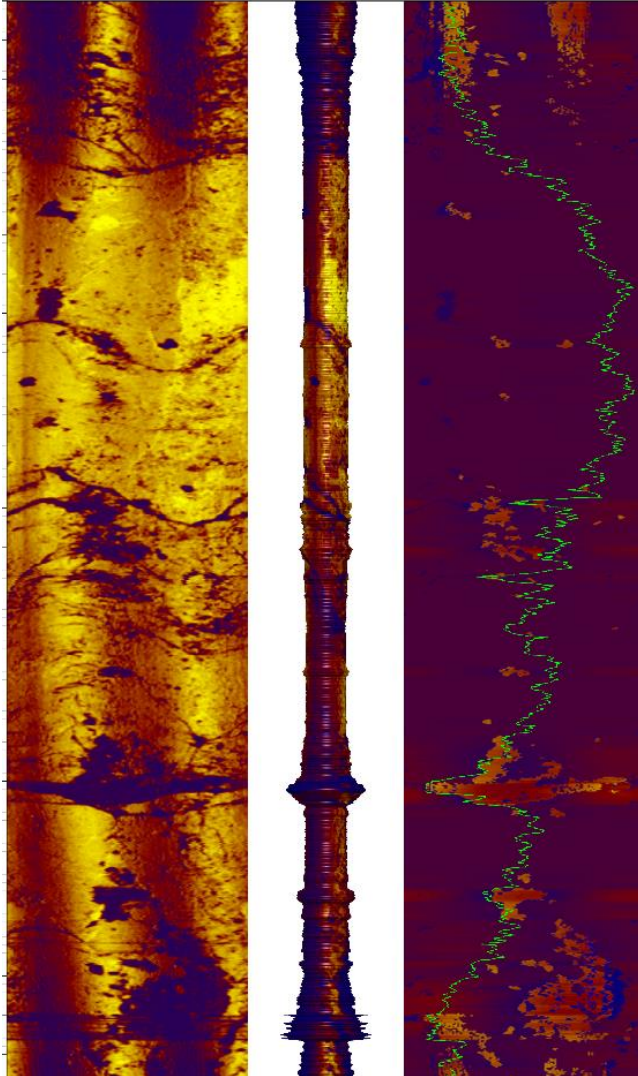
TOOL EDGE

CASING

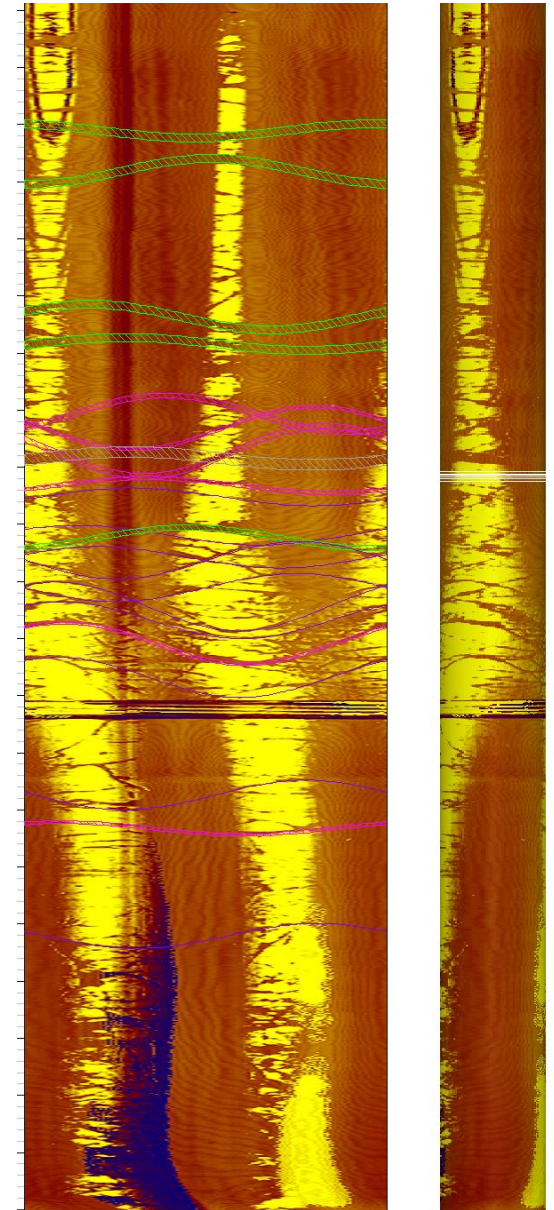
BOREHOLE WALL



Hole Type: Example - Logging Through PVC



- Obtain fracture orientations through PVC casing in situations where the borehole would not remain open long enough to survey.
- Multi-echo acoustic televiewer records multiple arrivals, allowing the tool to record an image through PVC.
- Key: centralization of both the acoustic televiewer and PVC in the borehole.



Direction – Where are we?

- Drilling straight holes is virtually impossible and borehole deviation is the **norm** and not the exception
- Drill holes can be, and often are, any orientation; Vertical (up and down), horizontal, inclined
- Direction and trajectory of drill hole can change during drilling
- Several factors influence the (unplanned) trajectory of the borehole.
 - Geological factors, such as rock hardness, bedding planes and fractures
 - Technical factors, such as drilling parameters, hole location and equipment condition



Geological Factors

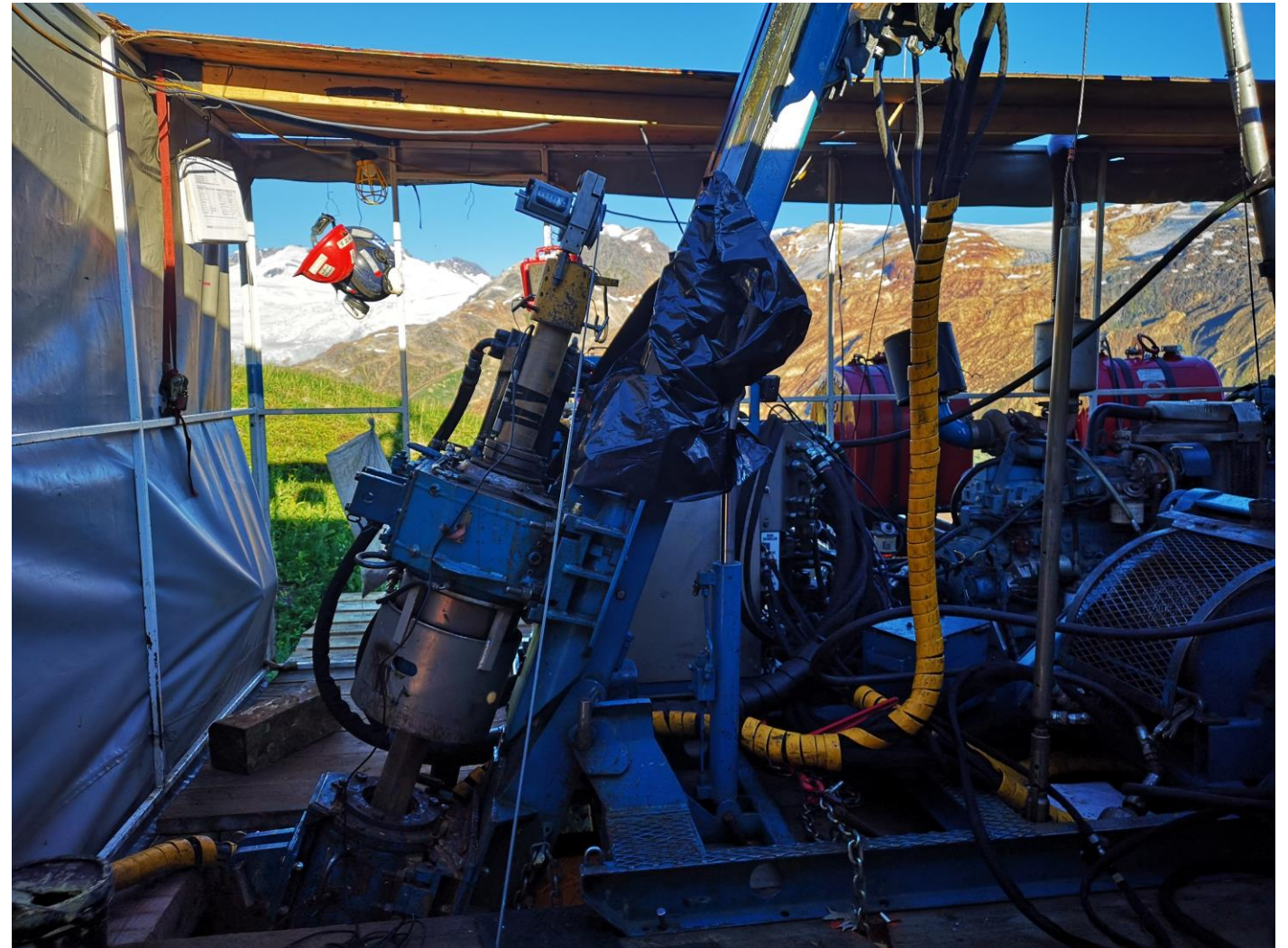
- Theoretically uncontrollable; however an experienced driller and hole planner can draw upon skills and accumulated knowledge to minimize these influences
- Geological factors that are relevant to borehole deviation include:
 - Rock characteristics – hardness, homogeneity
 - Bedding planes – direction, thickness, alternating hardness
 - Fractures – dip, surrounding structure (hardness, thickness)
 - Abrupt changes in the geological conditions may trigger sudden dog legs in the trajectory of the borehole if left uncompensated by the Driller

Technical Influences

- Technical influences are usually controllable, meaning that borehole deviation – at least to a certain extent – can be avoided or minimized by an experienced and competent drilling crew.
- Operating parameters which will influence borehole deviation include;
 - Starting procedure; Collaring accuracy, angular accuracy
 - Drilling parameters; Thrust, rotation speed
 - Hole specifications; Depth, diameter, inclination, azimuth heading

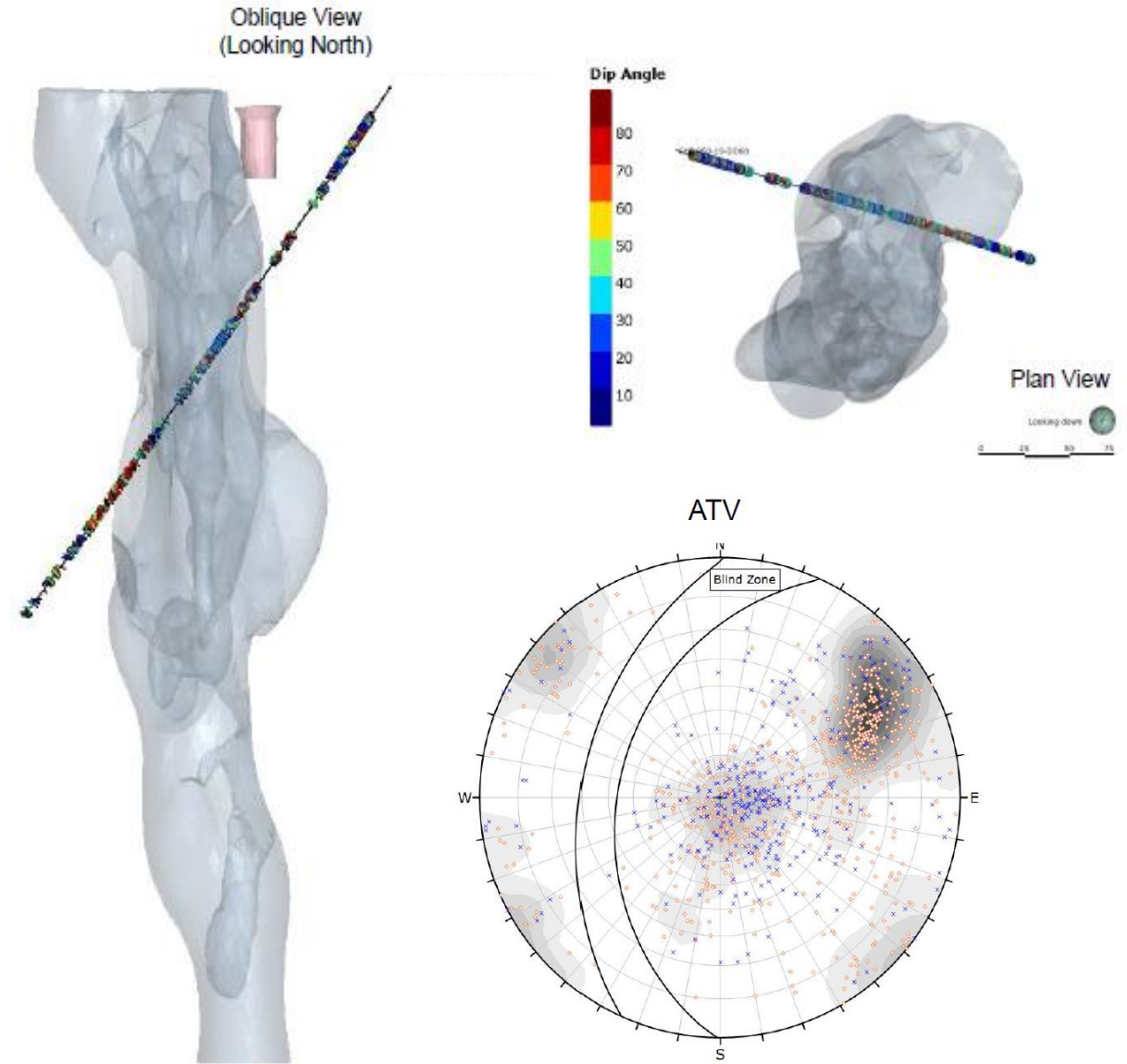
Drilling Parameters

- The primary constituents of drilling inputs that can impact borehole deviation are:
 - Weight on Bit (WOB)
 - RPM of the drill string
 - Hole size (e.g. RC, NQ, HQ, PQ)

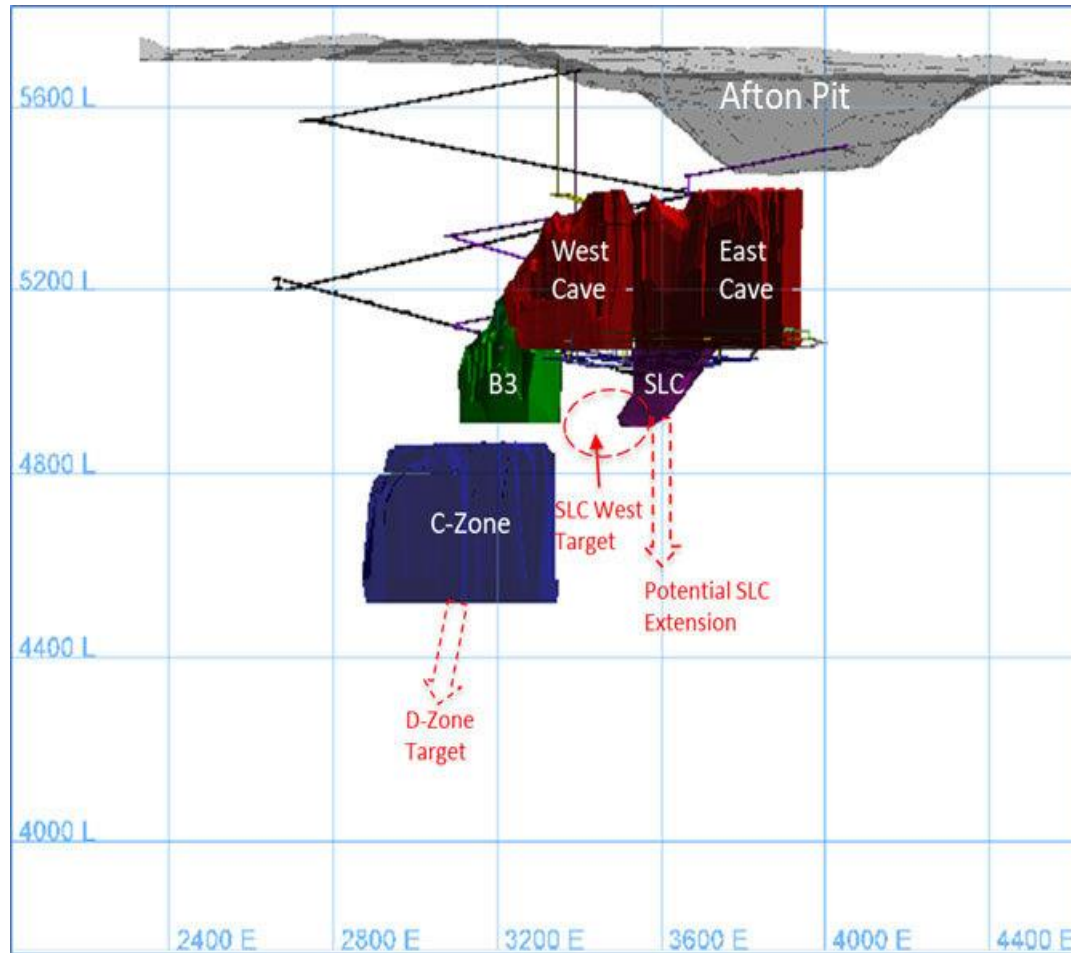


Directional Surveys

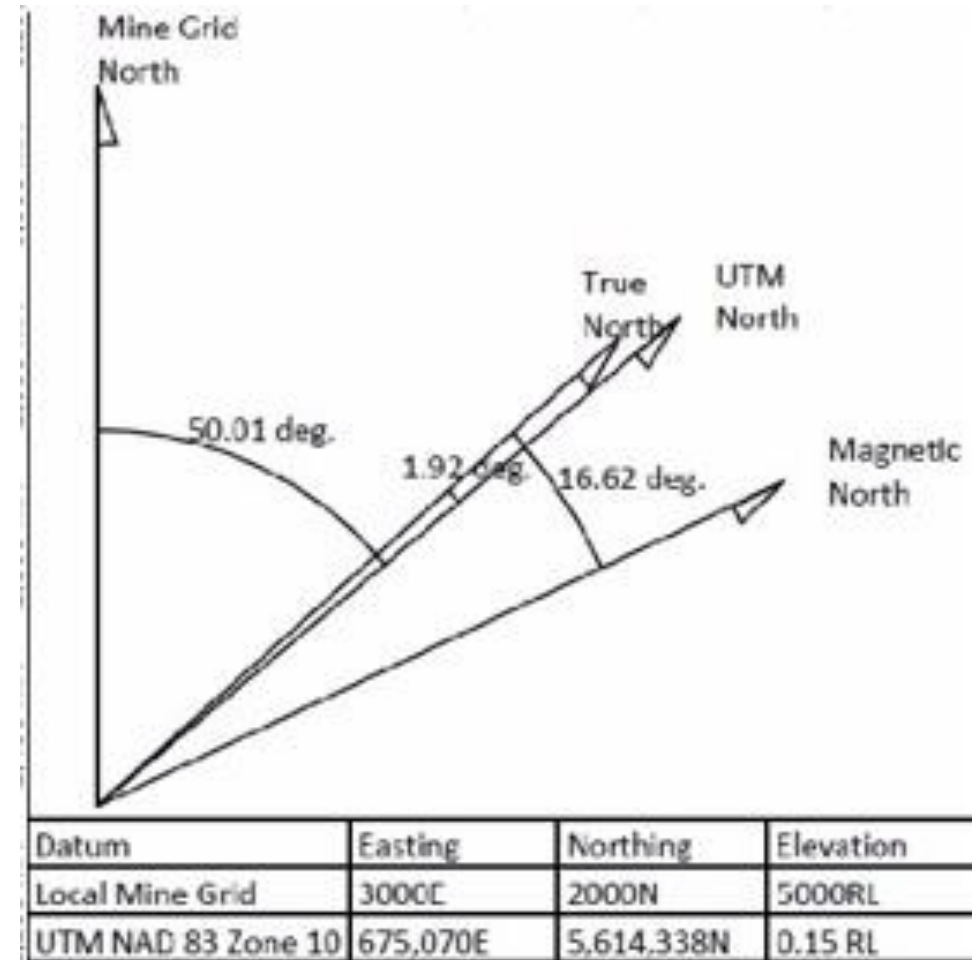
- Used to identify hole location and path
- Important all types of surveys
- Used to;
 - Determine the boundaries and geometry of an ore body
 - Aid in mapping geological features
 - Determine the trajectory of tunnel pilot holes / breakthrough holes
 - Steer directional drill holes



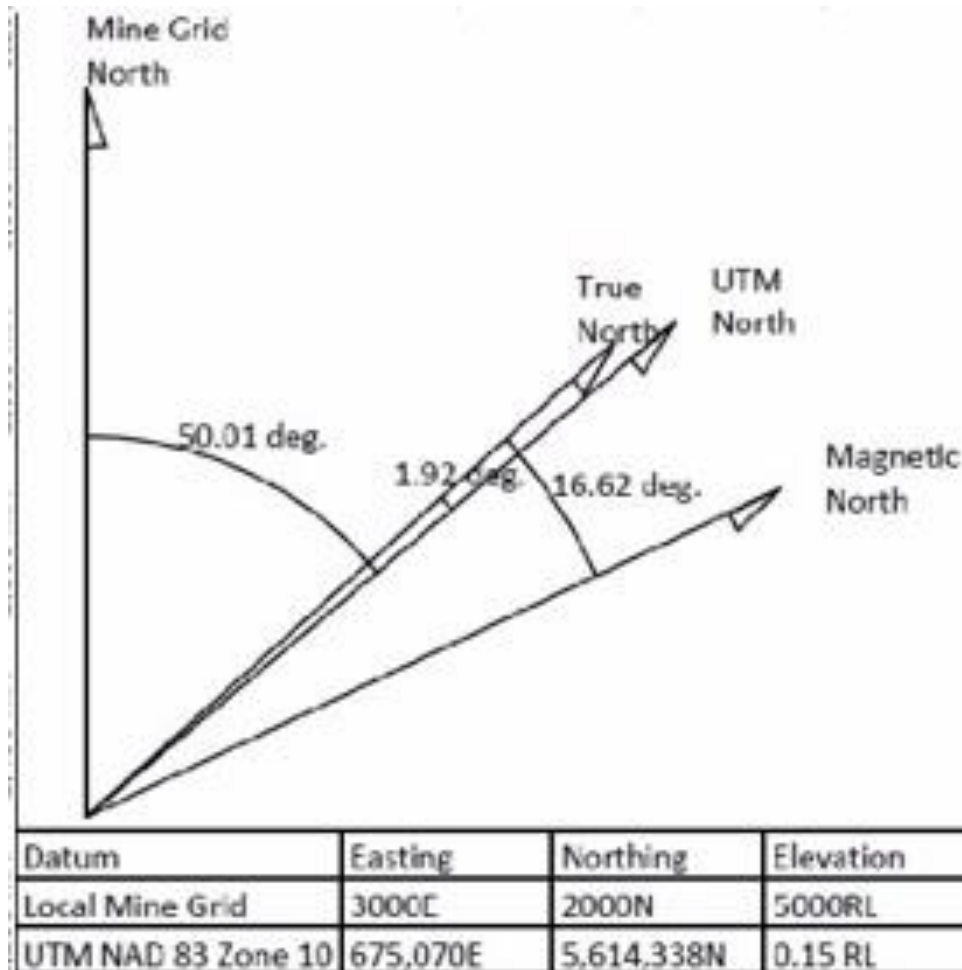
Local Mine Grid



New Afton Mine footprint with target locations



Local Mine Grid



- Measured positions relative to a point placed at site
- Reference point is unmoving
- Easier to use
 - UTM multiple numbers with many decimals
 - Grid

Types of Directional Surveys

Magnetic

- Utilizes natural magnetic fields to obtain a dip and azimuth of the borehole at survey stations
- Older techniques used compass and clockwork mechanisms
- More recent instruments use accelerometers and magnetometers

Non-Magnetic

- Uses the influence non-magnetic forces to determine the position / orientation of survey stations
- Examples of non-magnetic methods are gyroscopic, optical, and chemical

Magnetic Tool Data and Errors

- All magnetic survey instruments will suffer from magnetic interference (man-made or natural) that will disturb the magnetometers
- Magnetic instruments measure their own heading relative to the direction of the Magnetic North
- If that field direction is distorted by a deposit e.g., magnetite (or a pipeline), the instrument will record a deviation of the hole. The Driller or Geologist will not know whether the deviation is real or simply a distortion
- Magnetic instruments measure Azimuth relative to Magnetic North, so must be corrected in order to correct Azimuth to True North.



Non-Magnetic Instruments

Examples:

- Maxibor
 - Measures the bending of its own rods within the drill hole via use of a camera and a set of reflective rings
- Gyro



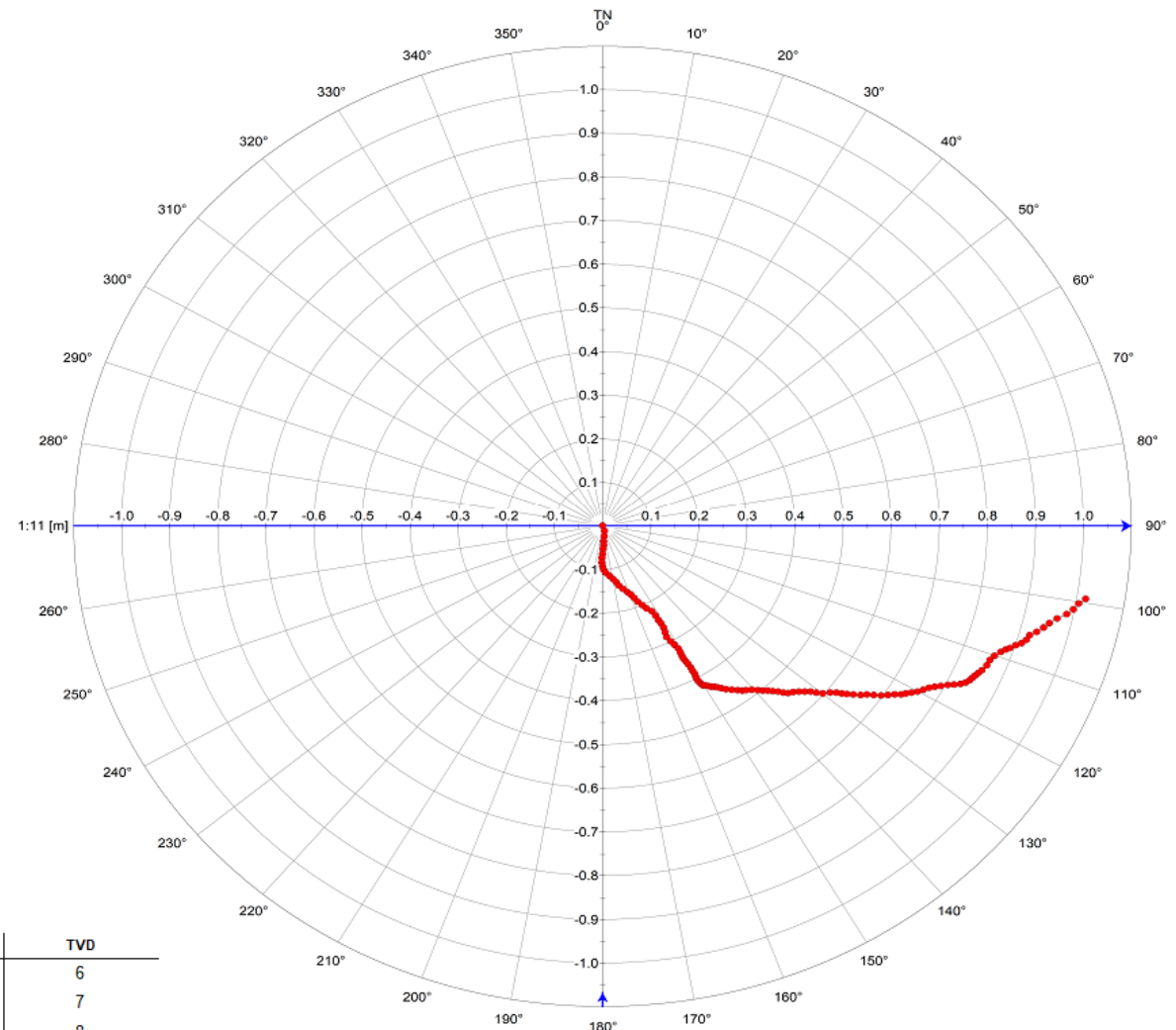
Gyro

- Deployed downhole via wireline winch and data is acquired at operator controlled survey depths
- Gyro unaffected by local magnetic fields allowing logging in rods and magnetic environments
- Delicate and expensive



Deviation

- Uses the onboard tool instruments to record direction downhole
- Orientation still possible even without gyro or other surveys



DEVIATION

Depth [m]	AZIMUTH_TN	TILT	EASTING	NORTHING	CLOSURE_ANGLE	CLOSURE_DISTANCE	TVD
6	140.32	0.93	0	0	0	0	6
7	183.22	0.7	0	-0.01	158.56	0.01	7
8	191.22	0.7	0	-0.02	172.26	0.02	8
9	178.02	0.7	0	-0.04	176.32	0.04	9



When Probes Get Stuck

- The borehole environment can be hostile, how do you mitigate risk?:
 - Dummy probe all boreholes
 - Steel casing to competent rock
 - Order of probes
 - PVC casing
- When a probe does get stuck:
 - Jigging
 - Recovery tools
 - Drill rig
 - Abandonment
- Risk is surprisingly low:
 - DGI's experience: 0.05% collapse/cave in during survey



