Borehole Logging Methods

MERC 2025

Course 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 – Televiewers, Calibration and Data Management**
  - Televiewers.
  - Data calibration
  - File Formats and Software.
- **Session 4 – Exploratory Data Analysis**
  - Introduction to Exploratory Data Analysis (EDA).
  - EDA Case Study.

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, Chile, Kazakhstan and Australia
- Specializing in in-situ structural, geotechnical, geophysical and hydrogeological information
- Expertise in Televiewer, Physical Properties, Geotech and Exploration

Course Material

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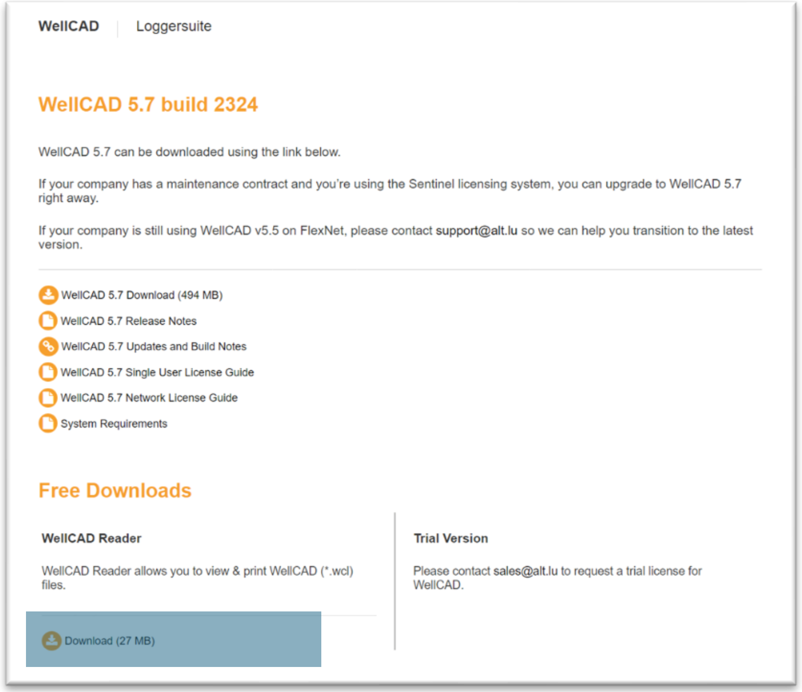
- All material can be found here:
  - 2025 - Git Hub Repository
  - Exercise 1
  - Exercise 2
- Presentations

- Software
  - WellCAD Reader



MERC 2025 - Session 1

INTRODUCTION TO BOREHOLE LOGGING

Overview

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- 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

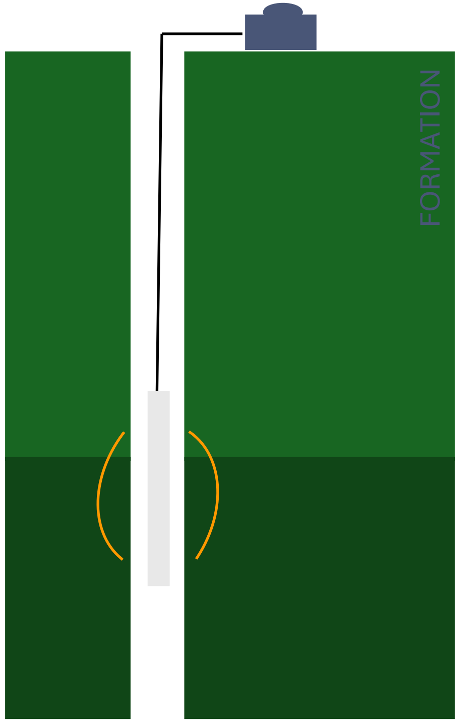
- Acoustic Televiewer
- Optical Televiewer
- Dipmeter
- Downhole Camera

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?

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- To determine the X, Y and Z spatial coordinates of a drill hole and everything it intercepts
- Exploration surveying increases the potential identification of geological anomalies and the existence of a potential economic ore body
- Knowing the specific location of a potential ore body with the intent of 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

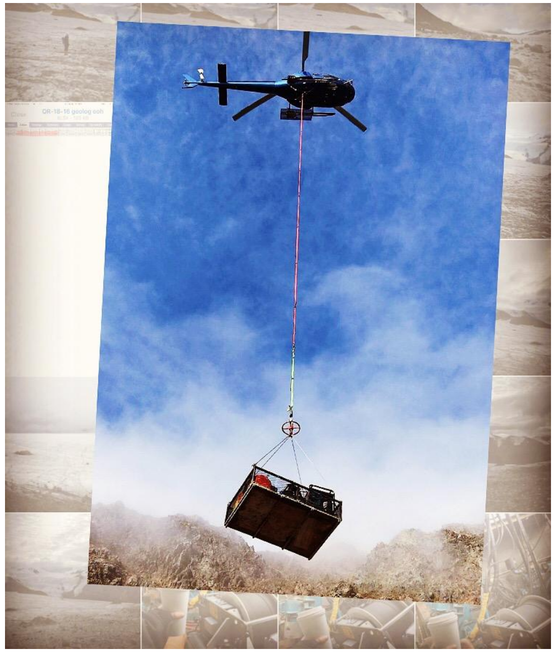
- What is the goal?
  - Select the right technology
  - Resolution
  - Borehole conditions
  - Fluid conditions
  - Time available
  - Economics
- What are the QA/QC procedures?
  - Calibration
  - Documentation
  - Processing/Interpretation
- Data Management plan

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

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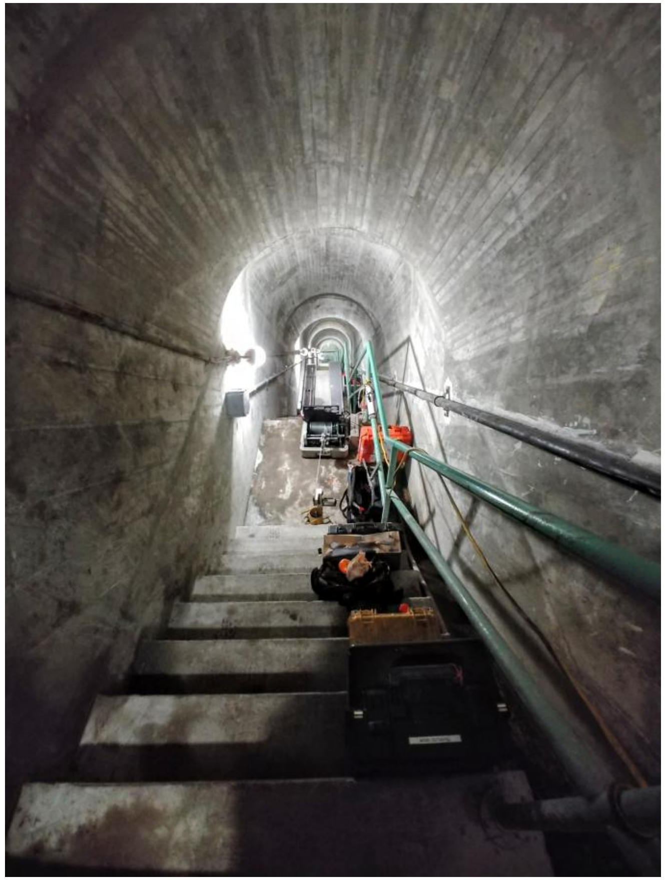
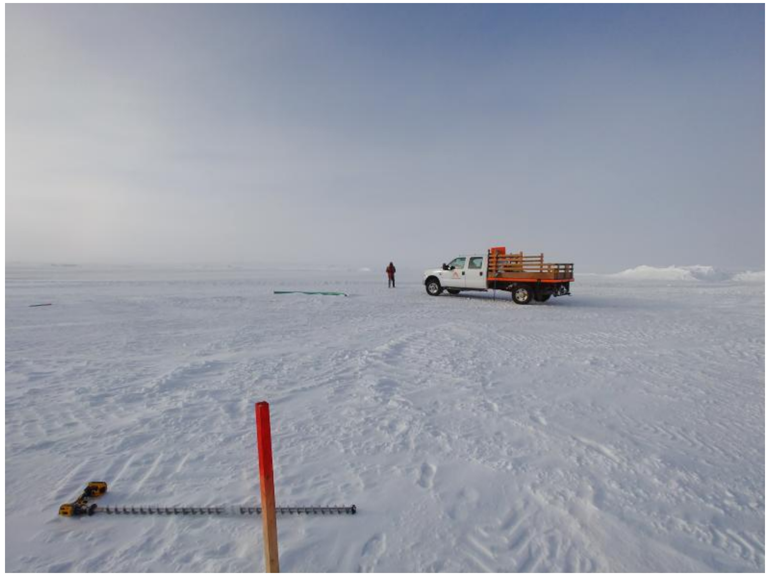
- Location and Weather!






Adapting to New Processes

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- 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

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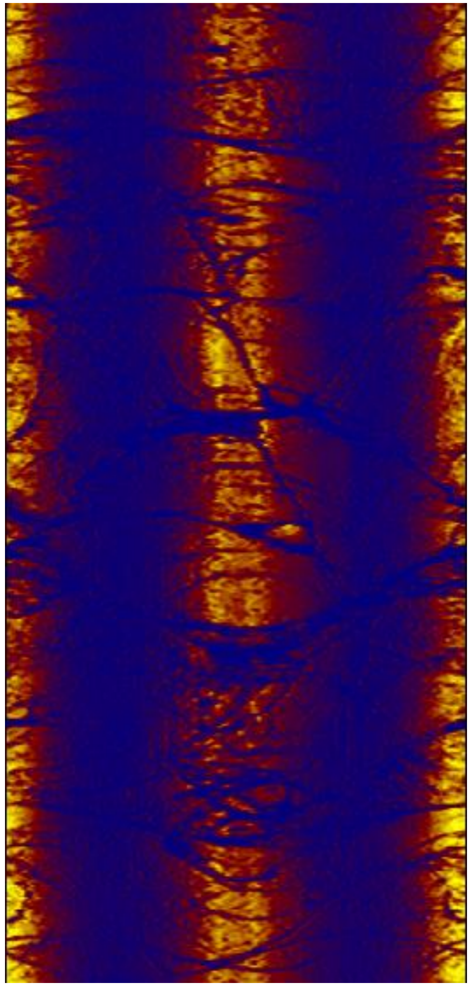
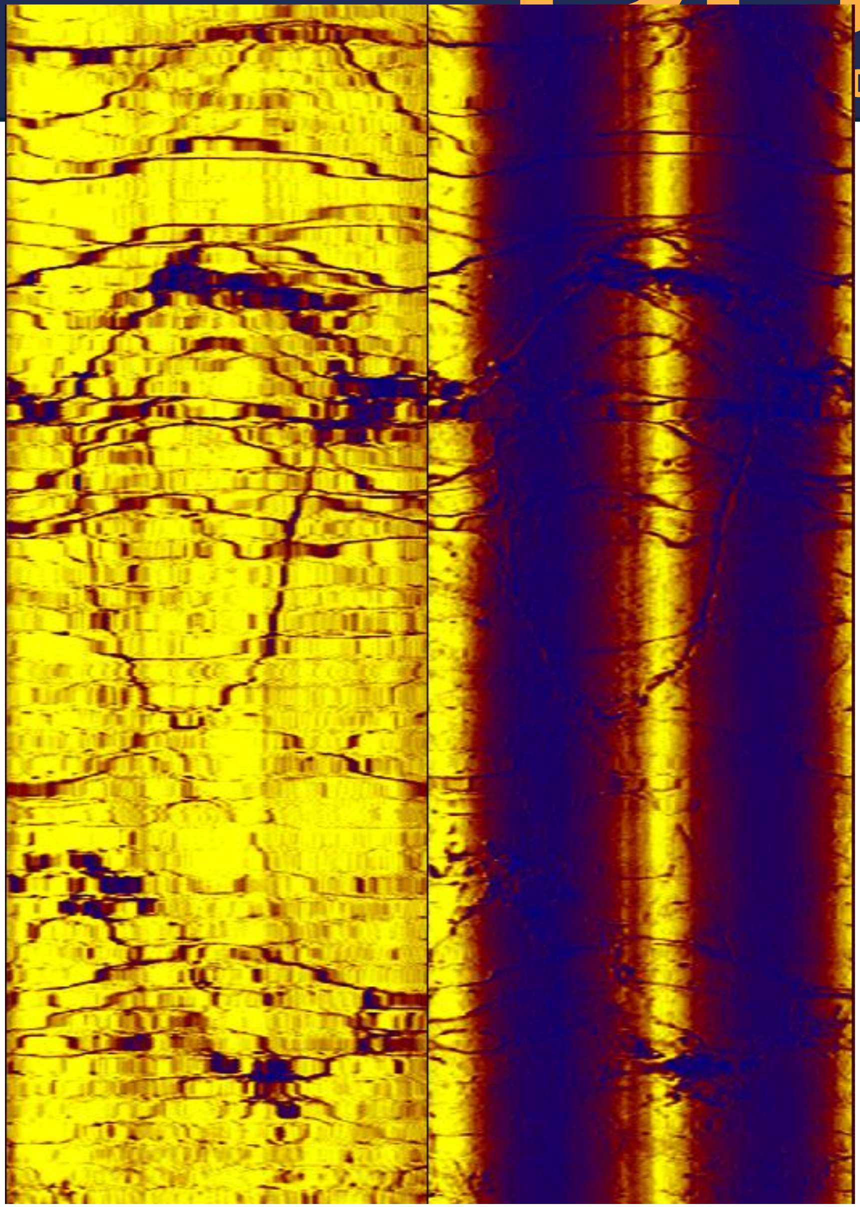
- Prevents tool moving about in the hole
- PVC, Brass, Steel
  - Variable sizes

Picture: Mount Sopris

Bad Centralisation - Example



- Allows tool to move around in the hole during data 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

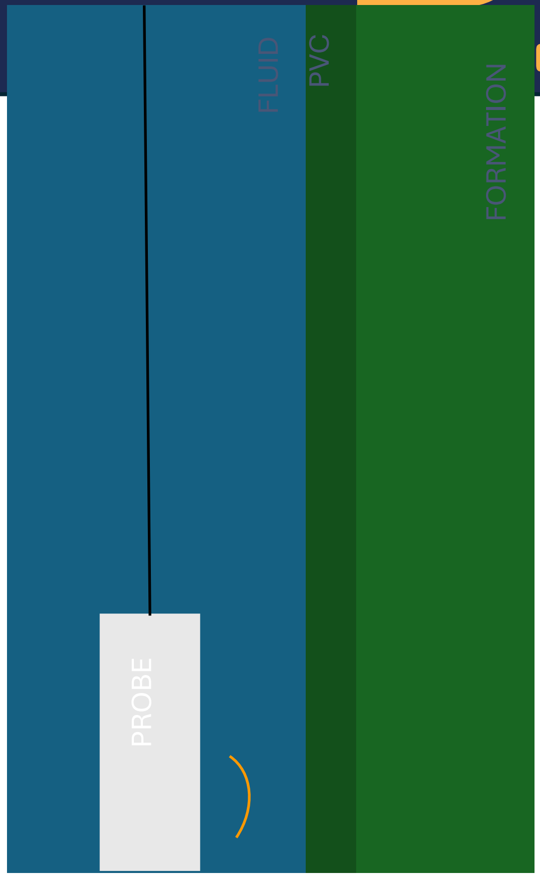


Hole Type

- 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

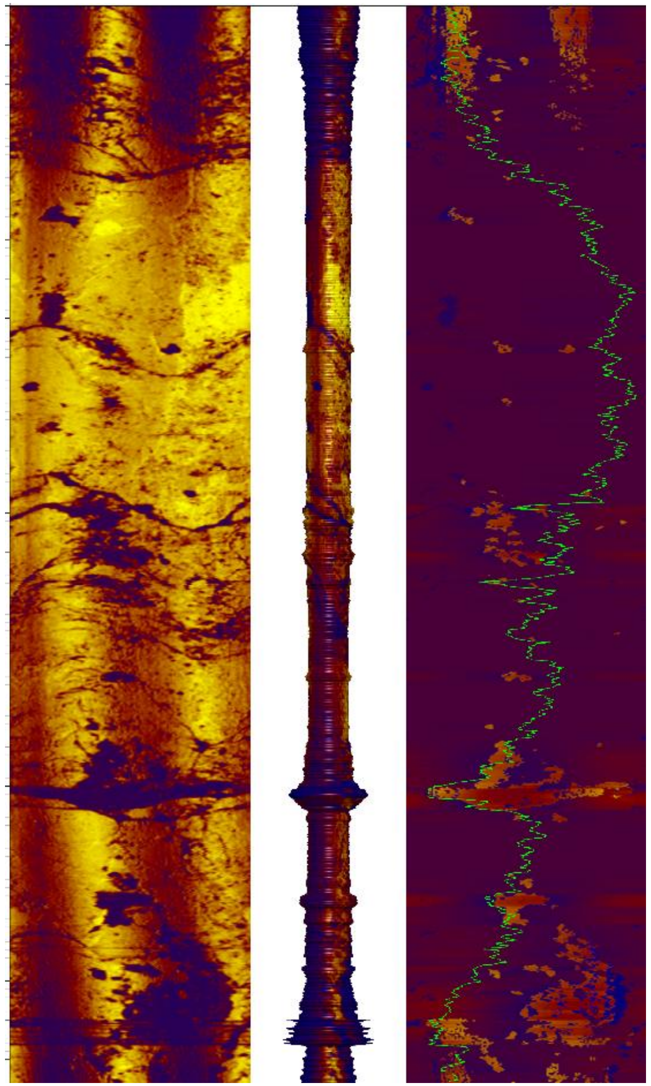


First Reflection: Edge of tool

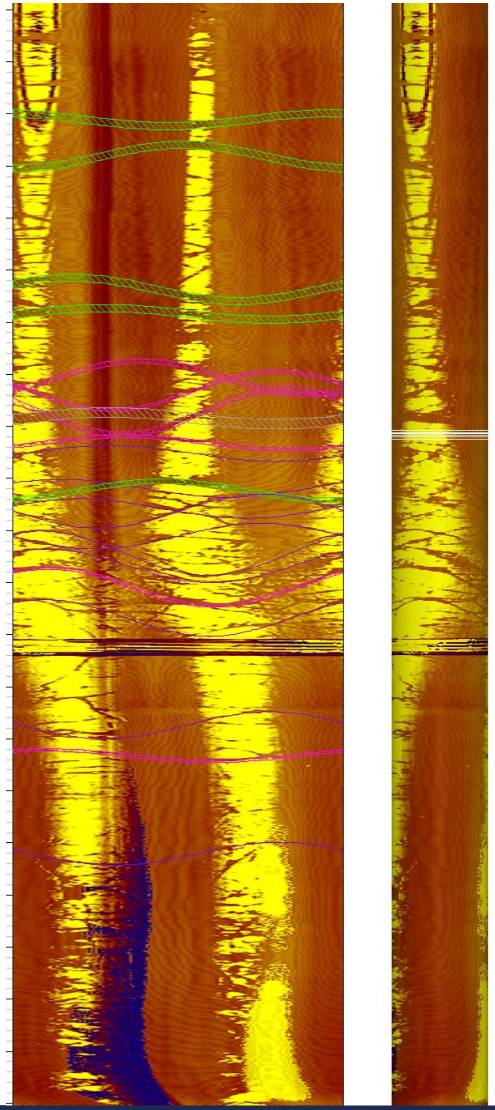
Second Reflection: PVC

Third Reflection: 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.



Directional

Direction – Where are we?

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- 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

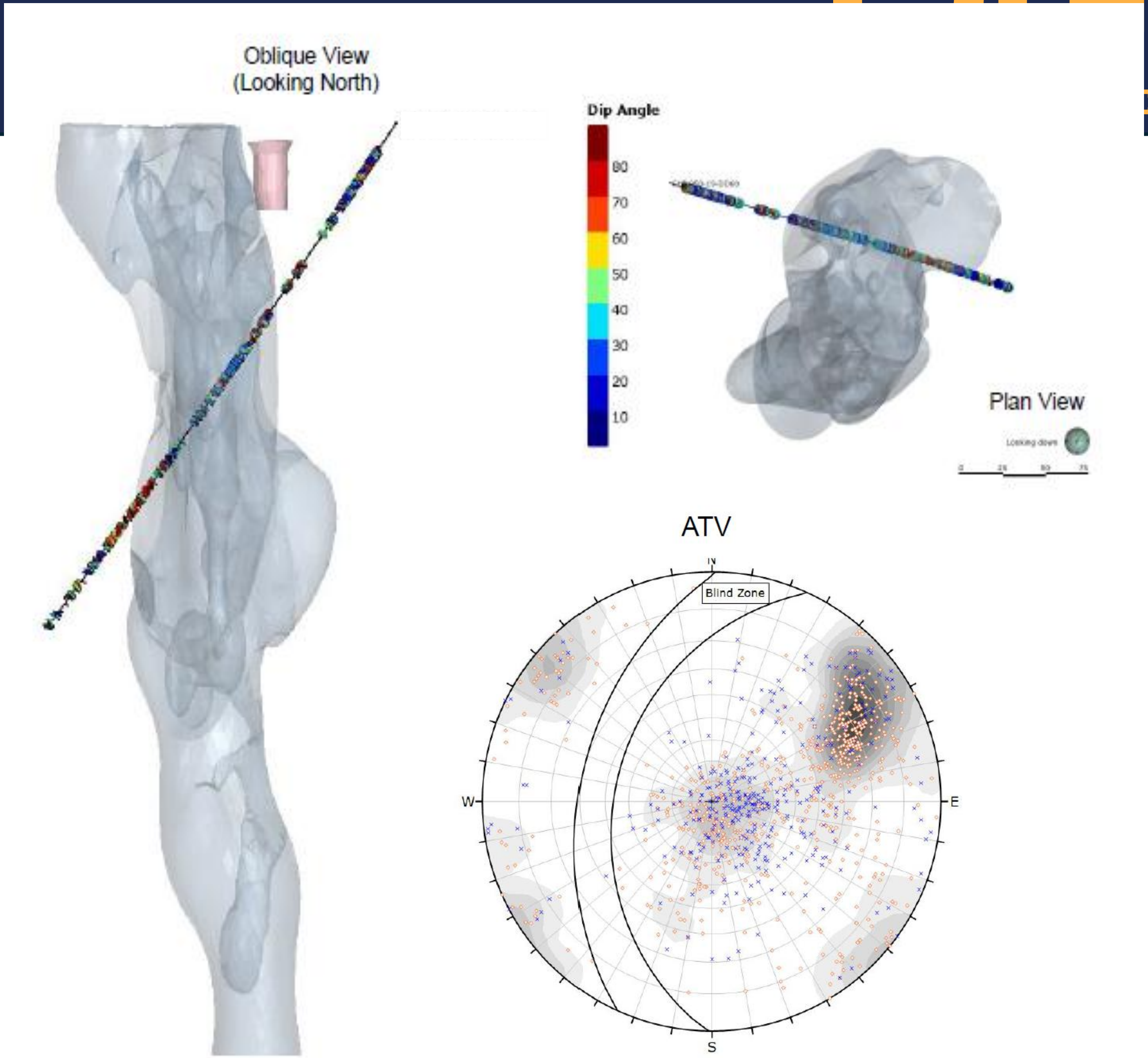
- Theoretically uncontrollable; however an experienced driller and hole planner can draw upon skills and accumulated knowledge to minimize these influences
- Geological factors that are relevant to borehole deviation include:
  - Rock characteristics – hardness, homogeneity
  - Bedding planes – direction, 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 for by the Driller

Technical Influences

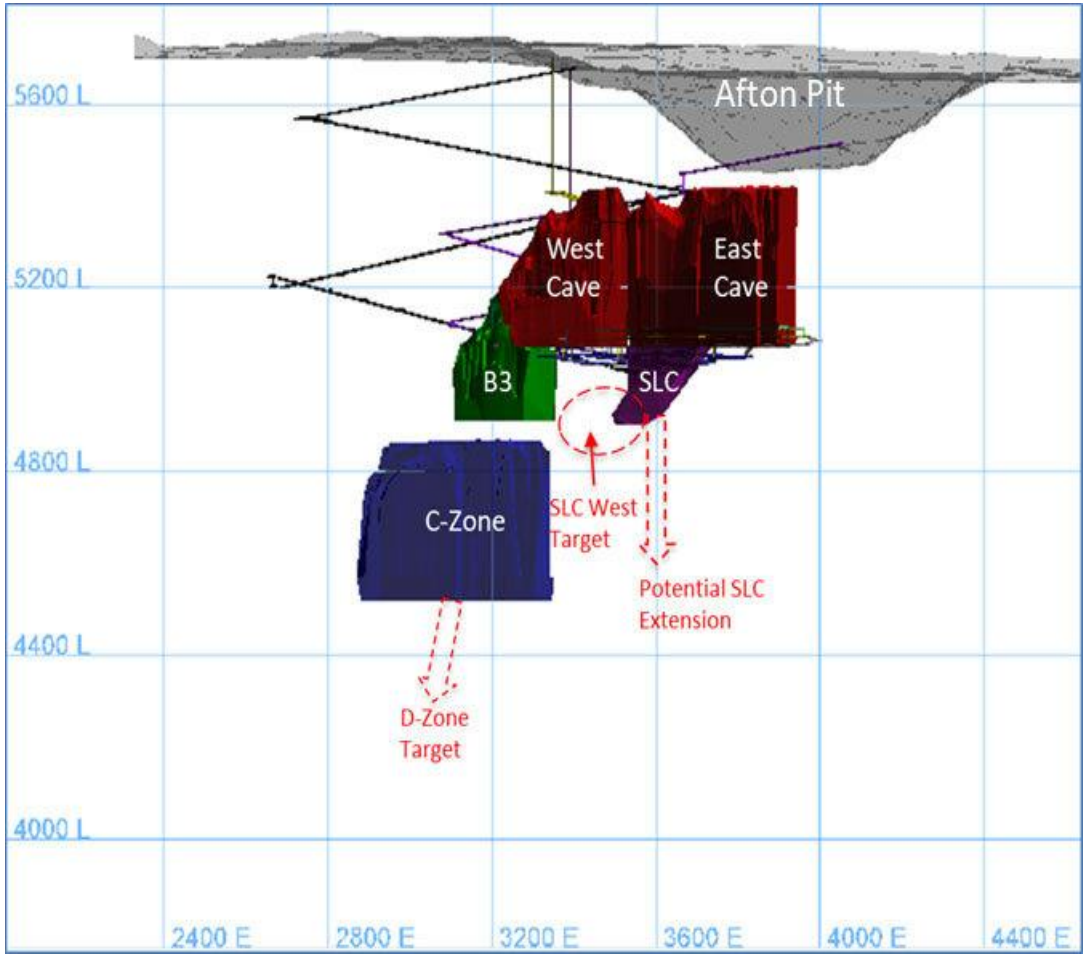
- Technical influences are usually controllable, meaning that borehole deviation – at least to a certain extent – can be avoided or minimized by an experienced and competent drilling crew.
- Operating parameters which will influence borehole deviation include;
    - Starting procedure; Collaring accuracy,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

Directional Surveys

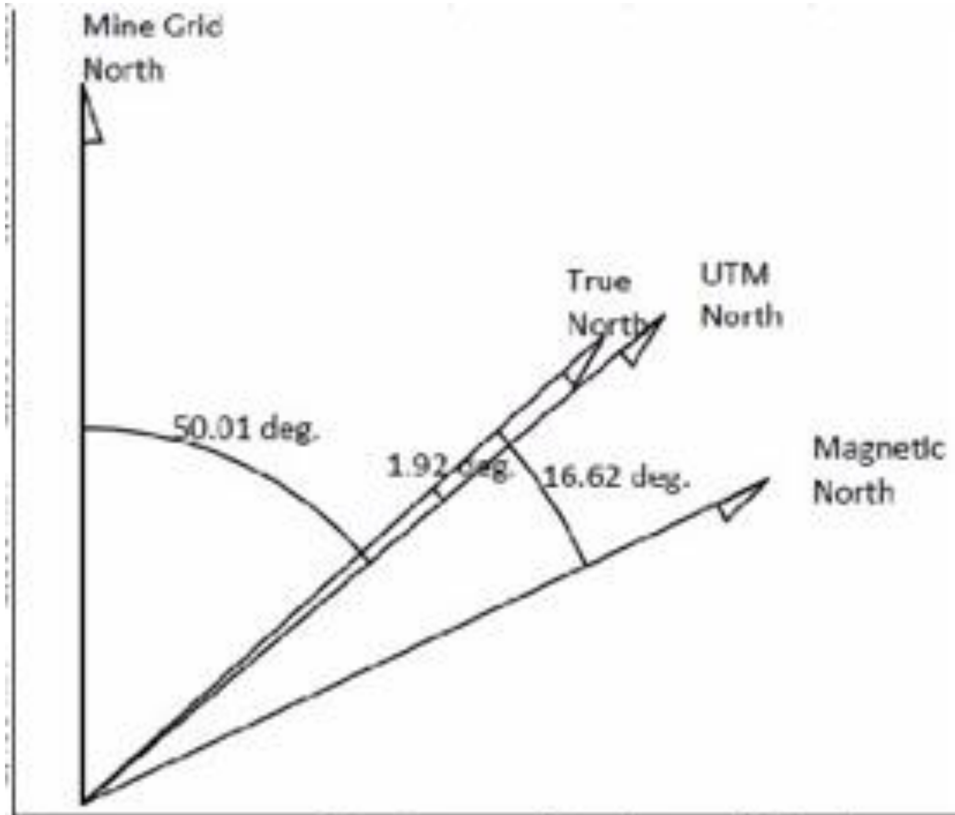
- Used to identify hole location and path
- Important all types of surveys
- Used to;
    - Determine the boundaries and geometry of an ore body
    - Aid in mapping geological features
    - Determine the trajectory of tunnel pilot holes / breakthrough holes
    - Steer directional drill holes



Local Mine Grid

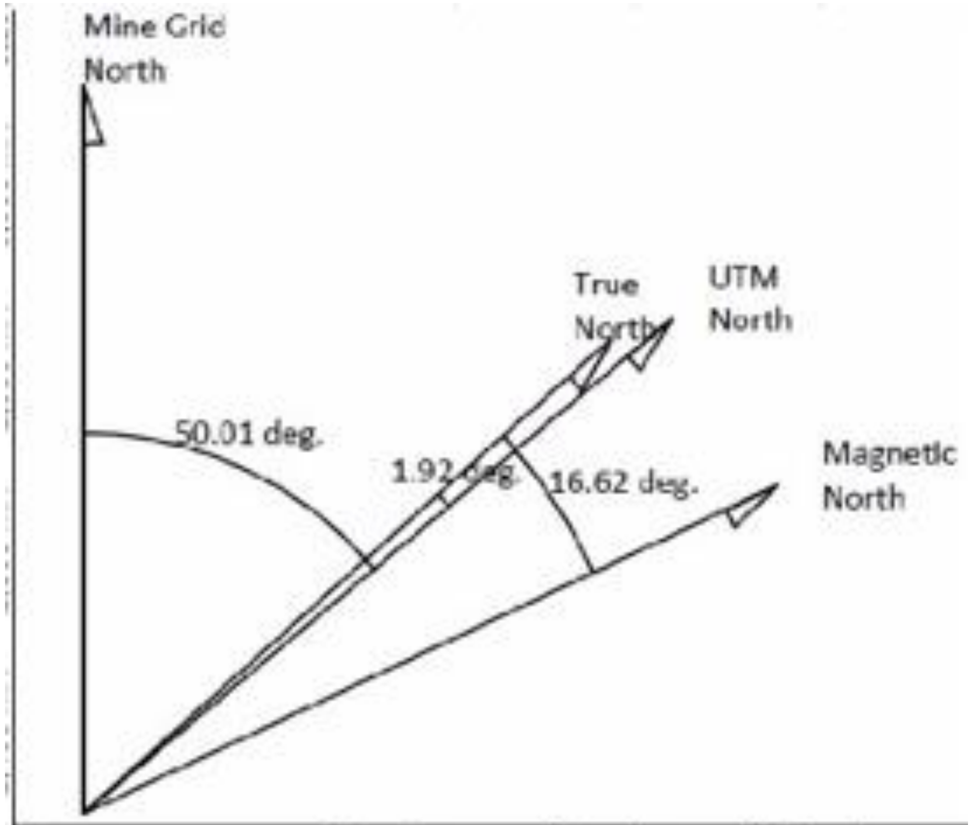


New Afton Mine footprint with target locations



Datum	Easting	Northing	Elevation
Local Mine Grid	3000E	2000N	5000RL
UTM NAD 83 Zone 10	675,070E	5,614,338N	0.15 RL

Local Mine Grid



Datum	Easting	Northing	Elevation
Local Mine Grid	3000E	2000N	5000RL
UTM NAD 83 Zone 10	675,070E	5,614,338N	0.15 RL

- 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

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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

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- 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 orient the Azimuth to True North.

Non-Magnetic Instruments

Examples:

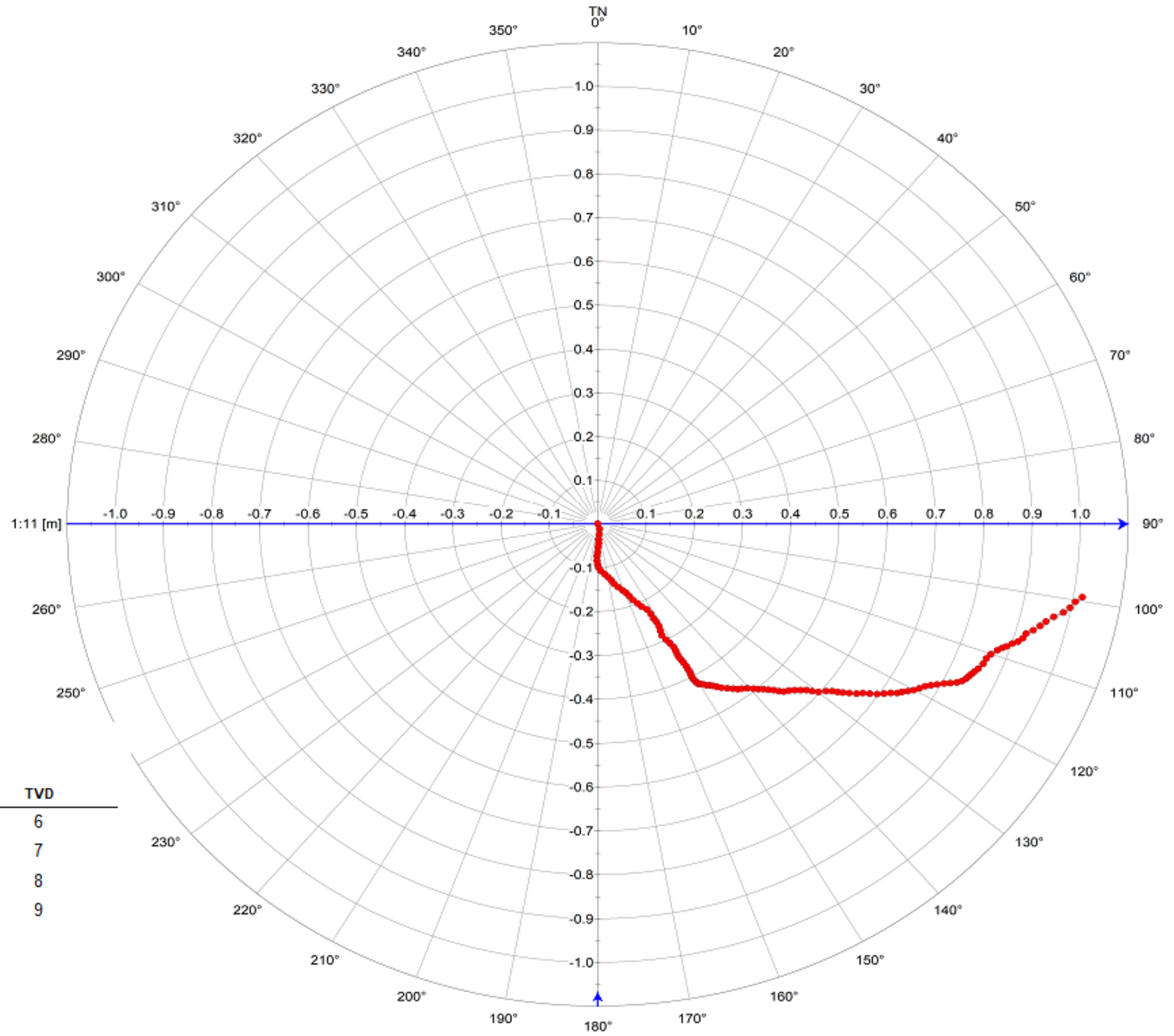
- Maxibor
  - Measures the bending of its own rods within the drill hole via use of a camera and a set of reflective rings
- Gyro

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 – From Direction to Position

- Methods such as **Minimum Curvature** to convert from direction measurement to a geographic X, Y, Z position.



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