Material Characterization while drilling on Moon: Review of the Preliminary Atmospheric Test Results

Deep Joshi*, Alfred Eustes, Jamal Rostami, Christopher Dreyer

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*deepjoshi@mymail.mines.edu

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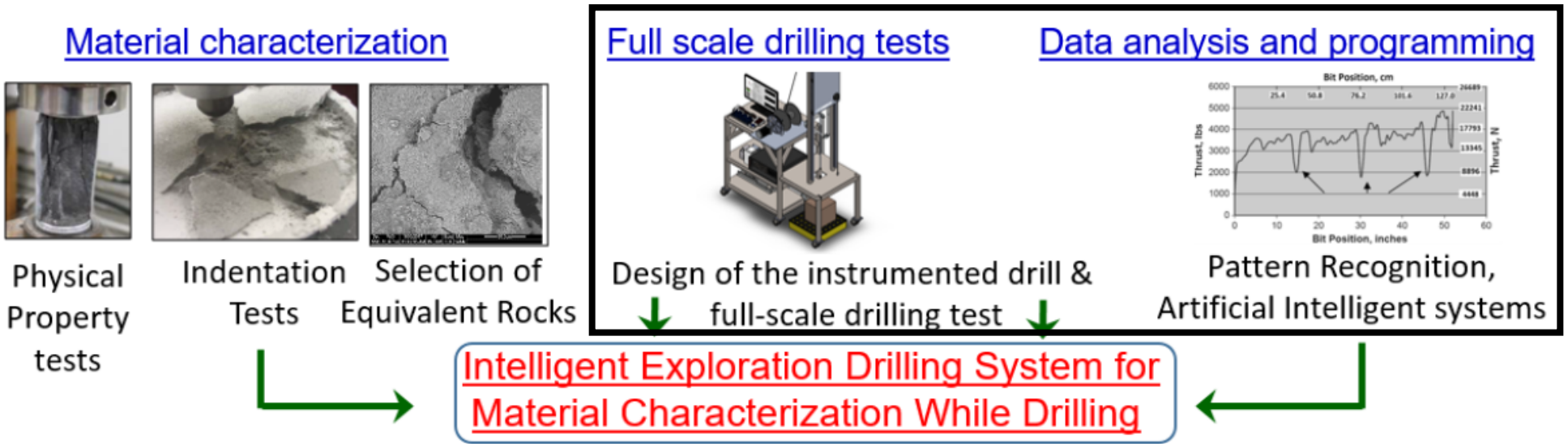
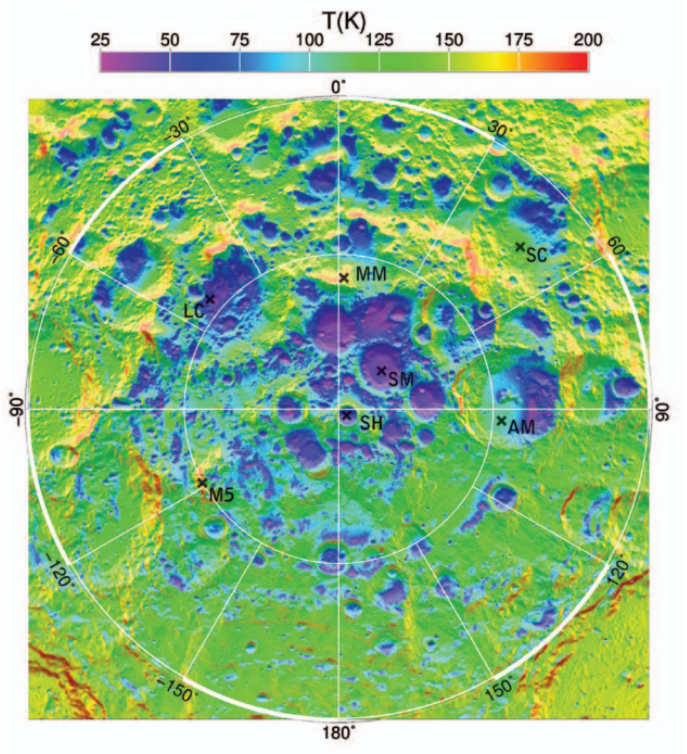
Objectives

- Characterize the water-ice formations based on real-time high frequency drilling data
- Identify the thickness and distribution of water-ice and estimate the geotechnical information from the drilling data

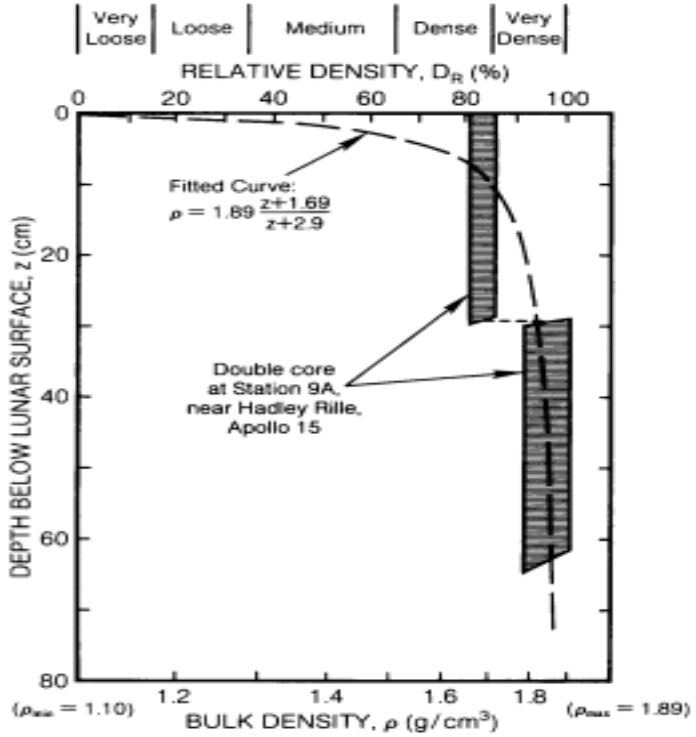


Challenges of Drilling on the Moon

- Low gravity resulting in low weight on bit (WOB)
- Mass and power limitations
- High rock density
- Geological uncertainty
- Low temperatures
- Cutting transport
  - Can't use a drilling fluid to circulate the cuttings out
- Corrosion issues



http://lunarnetworks.blogspot.com/2010/10/lro-diviner-lunar-radiometer.html



'Lunar Sourcebook', Heiken et al., 1991

Experimental setup

- Robust frame to provide stability while drilling
- Rotary auger drill (no percussion)
- Rotary actuator: Three-phase AC induction motor operated through a VFD
- Z-displacement: precision ball screw operated through a NEMA - 34 stepper motor
- Guide rails to reduce the vibrations
- Tests use a commercially available masonry bit

Drilling Data Acquisition system

- Drilling data recorded at 1000Hz frequency

Sensor	Purpose	Rating
Draw String Potentiometer	Drilling depth	1m
Hall-effect Sensor	RPM	-
2 x Load cell	Axial Load	75 kgf each
Torque sensor	Drilling and auger torque	50 N.m
Accelerometer	Drilling vibrations and formation properties	
DAQ		
NI-cDAQ 9174		

Drilling data acquisition system

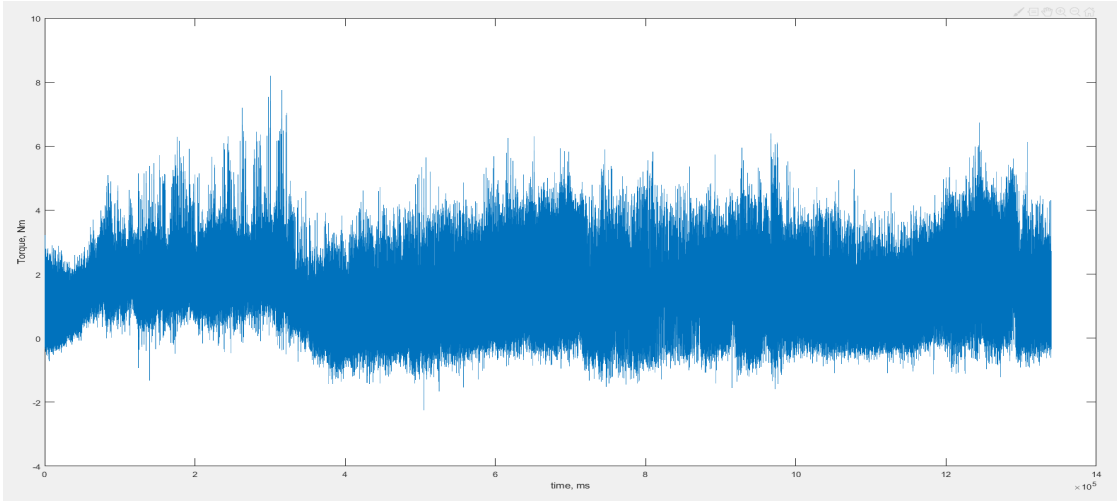
- The raw data divided in to drilling and non-drilling data
- Mechanical Specific Energy calculated in real-time

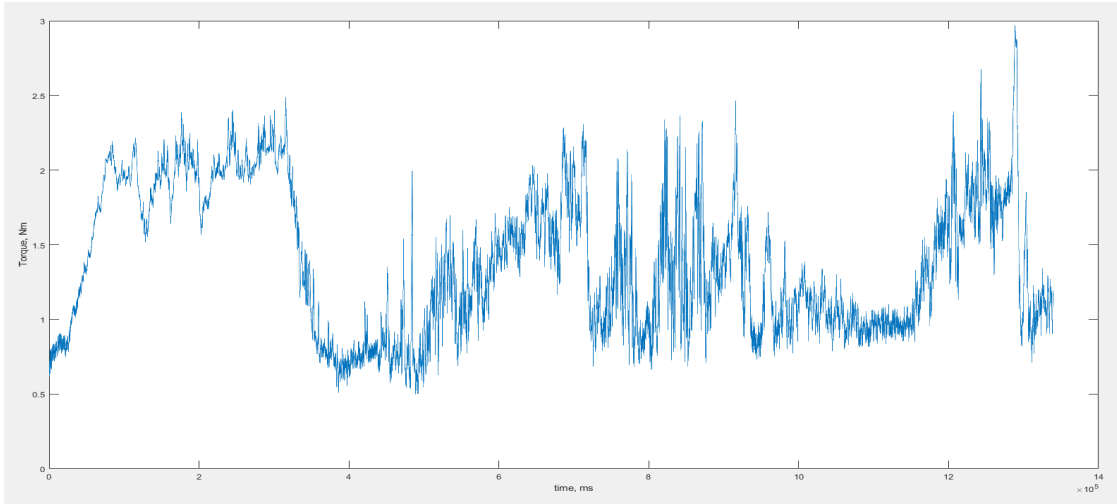
$$MSE_{bit} = \frac{WOB}{A} + \frac{(2\pi \times RPM \times Torque)}{ROP * A}$$

Measured Data	Derived data
Axial force	Weight on Bit
RPM	Drilling depth
Torque	Mechanical Specific Energy
Block height	Rate of Penetration
Time	

Data Processing

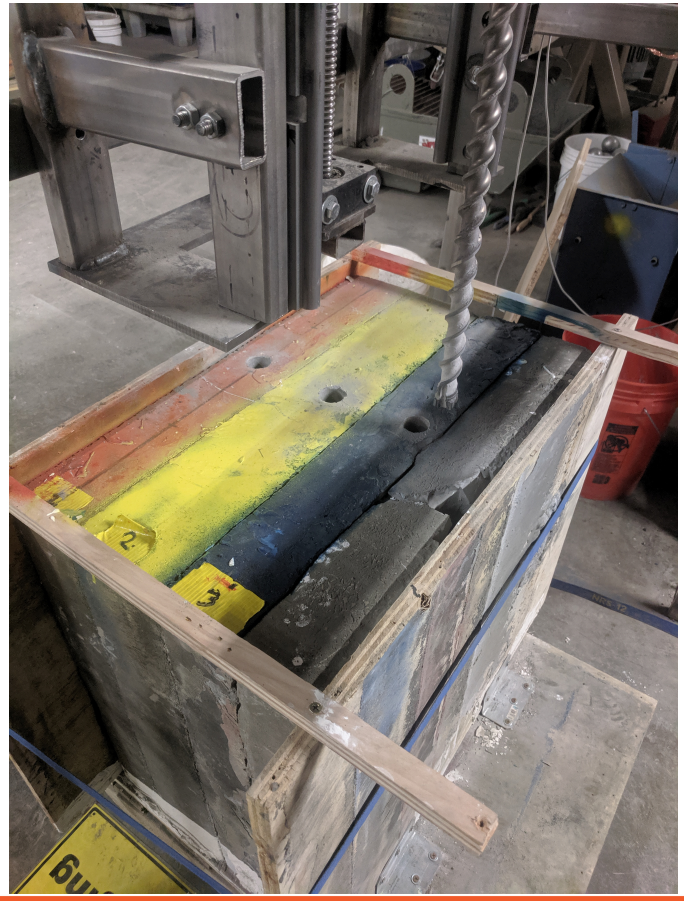
- The drilling data is *extremely* noisy
  - Electromagnetic interference
  - Electrical noise
  - Mechanical noise
- Minimizing the electrical noise and electromagnetic interference:
  - Use a high pass filter under 2 Hz.
  - Removed outliers
  - Used moving average over a window to smoothen the data



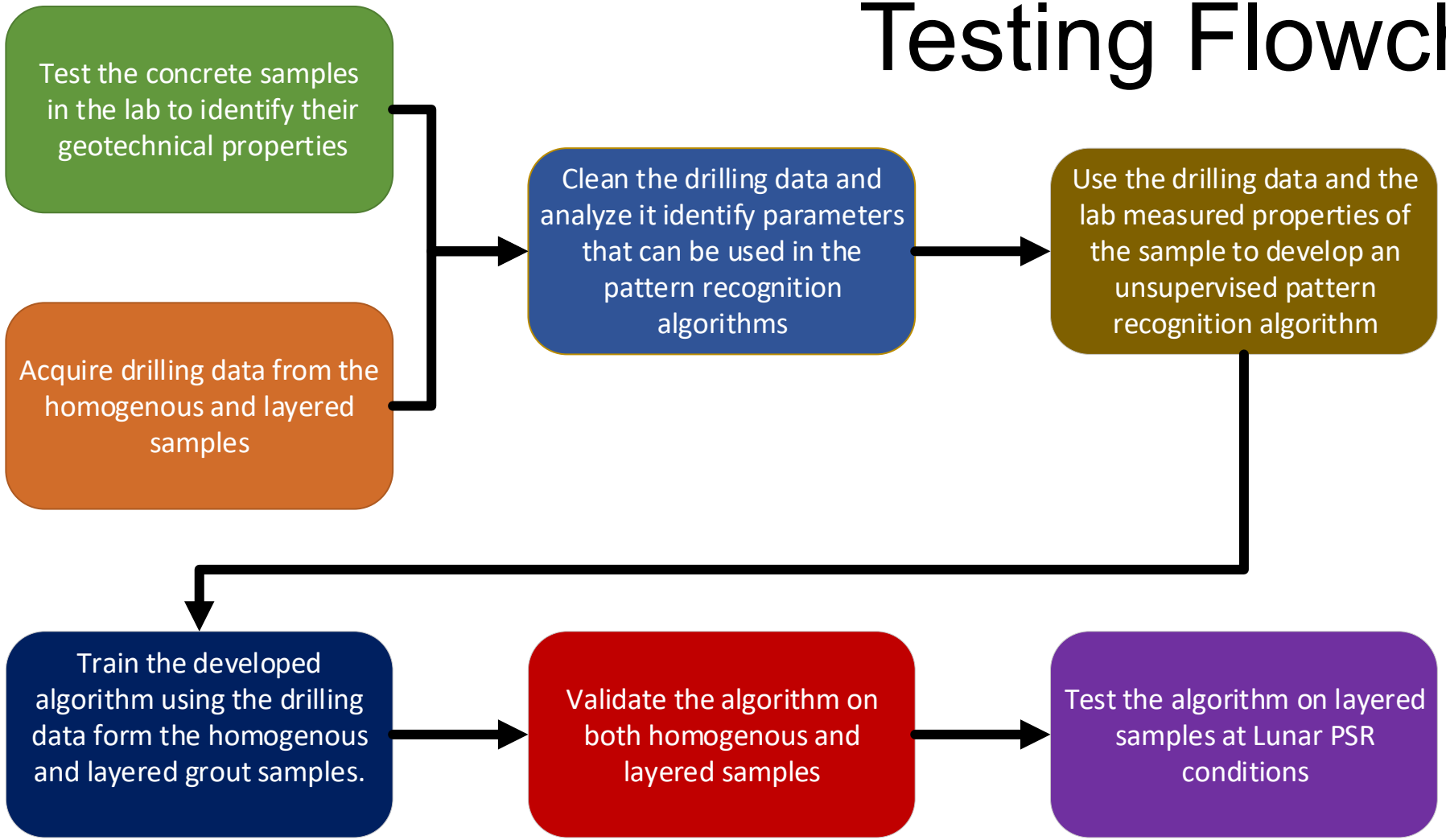


Preparation of the grout blocks

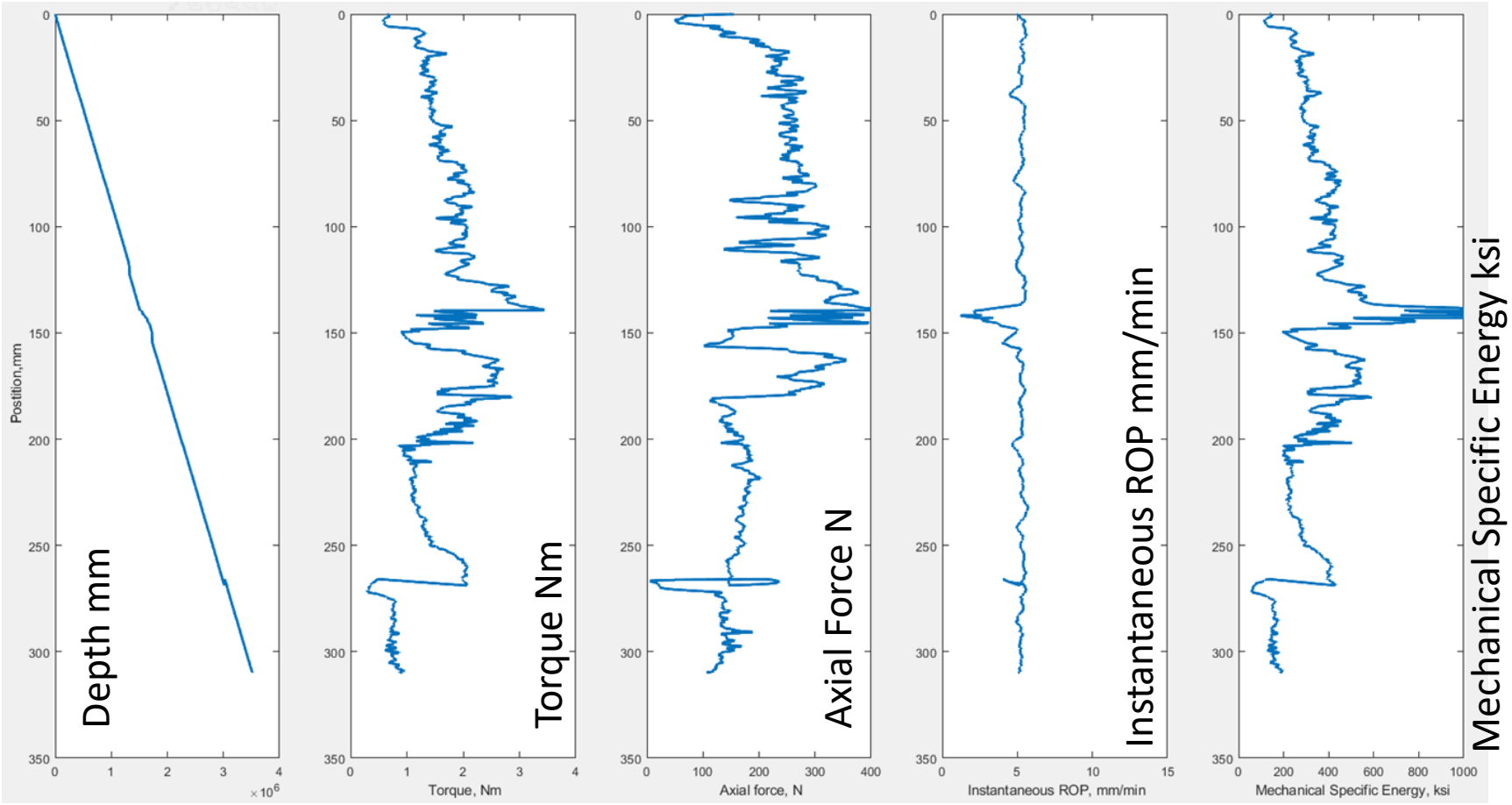
- Lab lunar simulant tests determined block strength
- Simulant particle size distributions used as concrete aggregate
- Compressive strengths varied by water ratio
- Blocks cast for minimum four weeks
- Block Strength
  - 1: Homogenous
    - 40 Mpa (5800 psi)
  - 2: Layered
    - Layer 1: 20 Mpa (2900 psi)
    - Layer 2: 10 Mpa (1450 psi)
    - Layer 3: 5 Mpa (725 psi)



Testing Flowchart

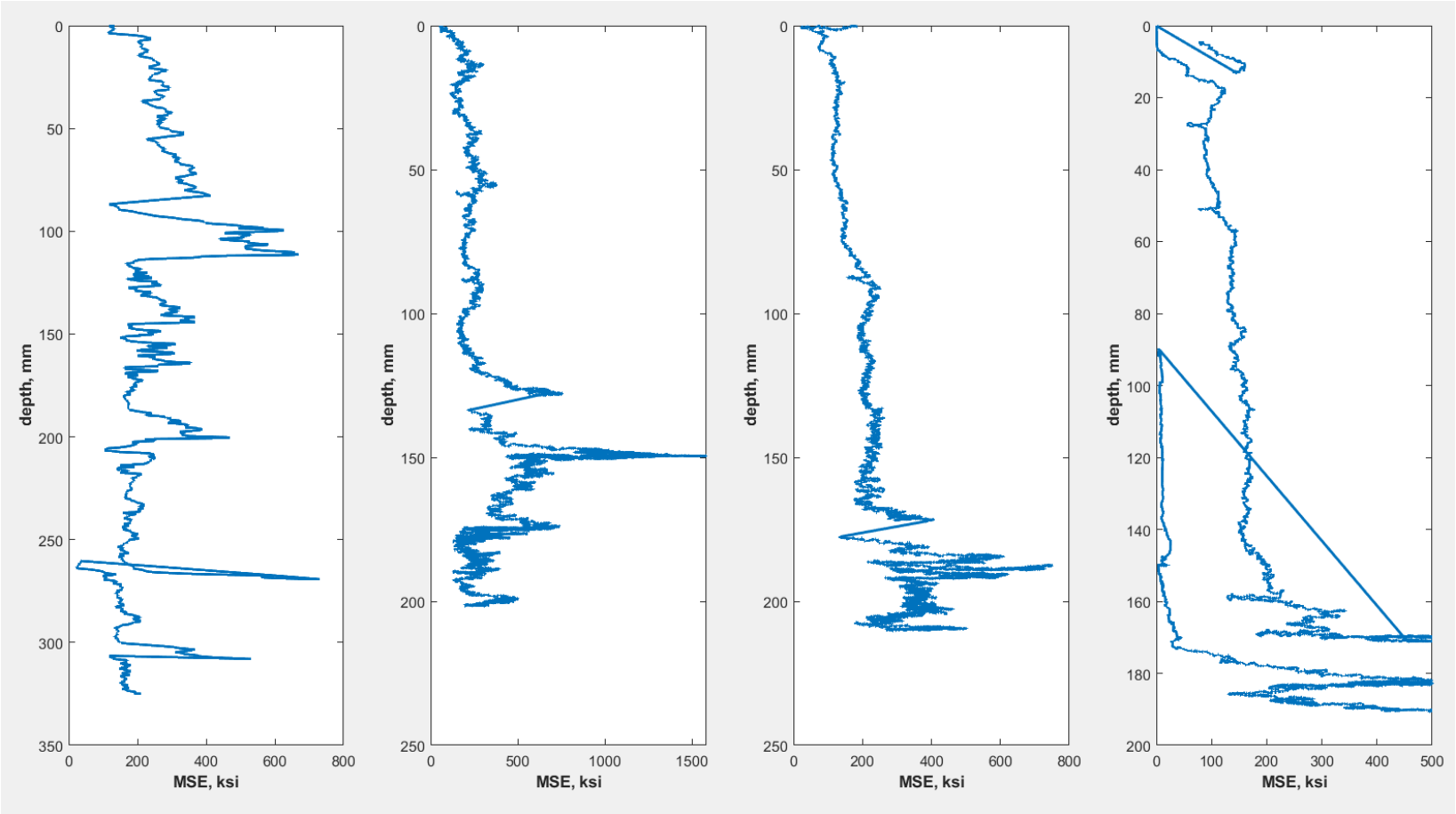


Results: Drilling Parameters vs Depth



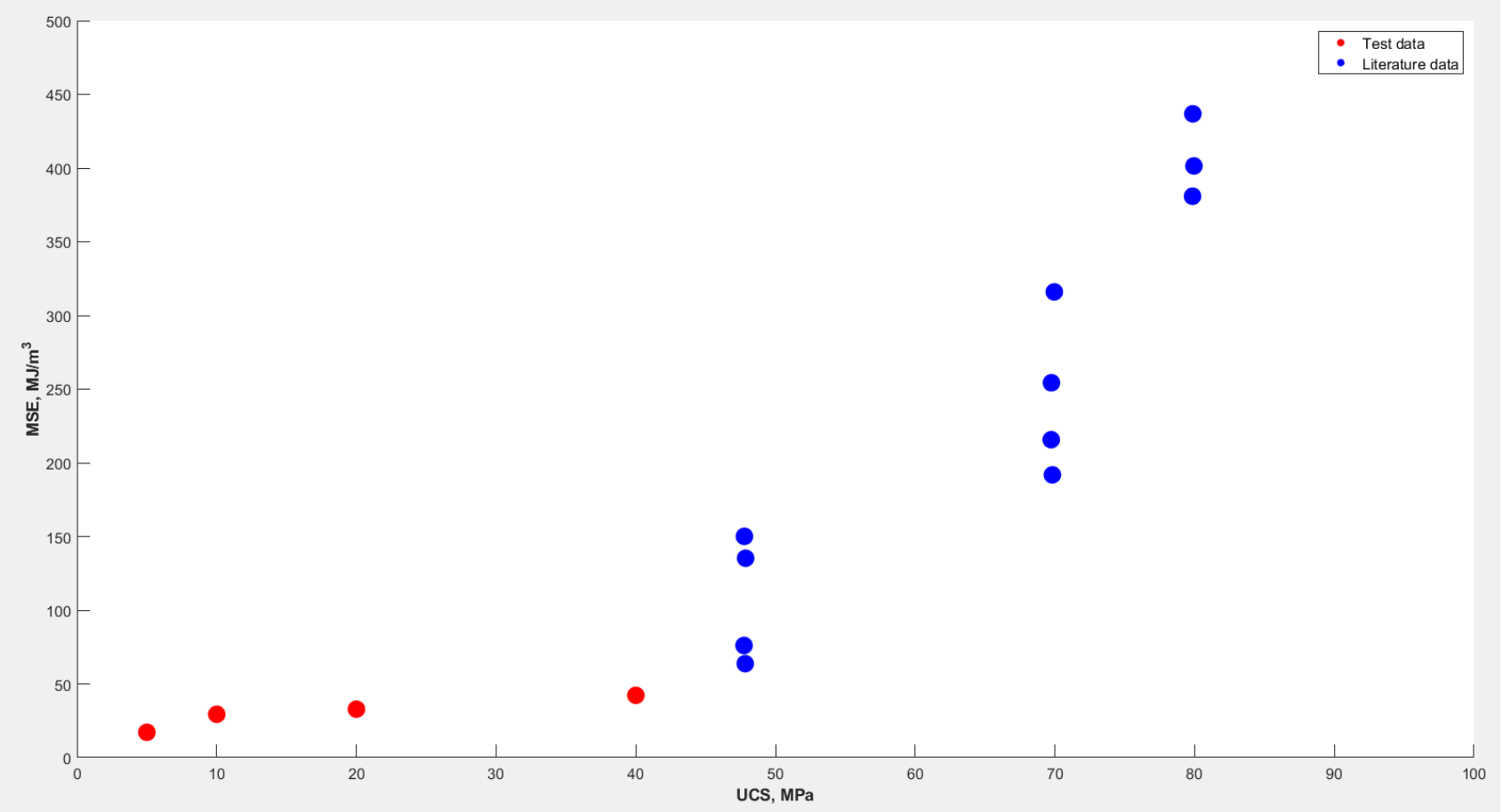
Drilling data for Block 1 borehole 12

Results: MSE vs Depth



Comparing the MSE responses for one borehole on block 1 and boreholes on each layer of block 2

Results: Average MSE vs UCS



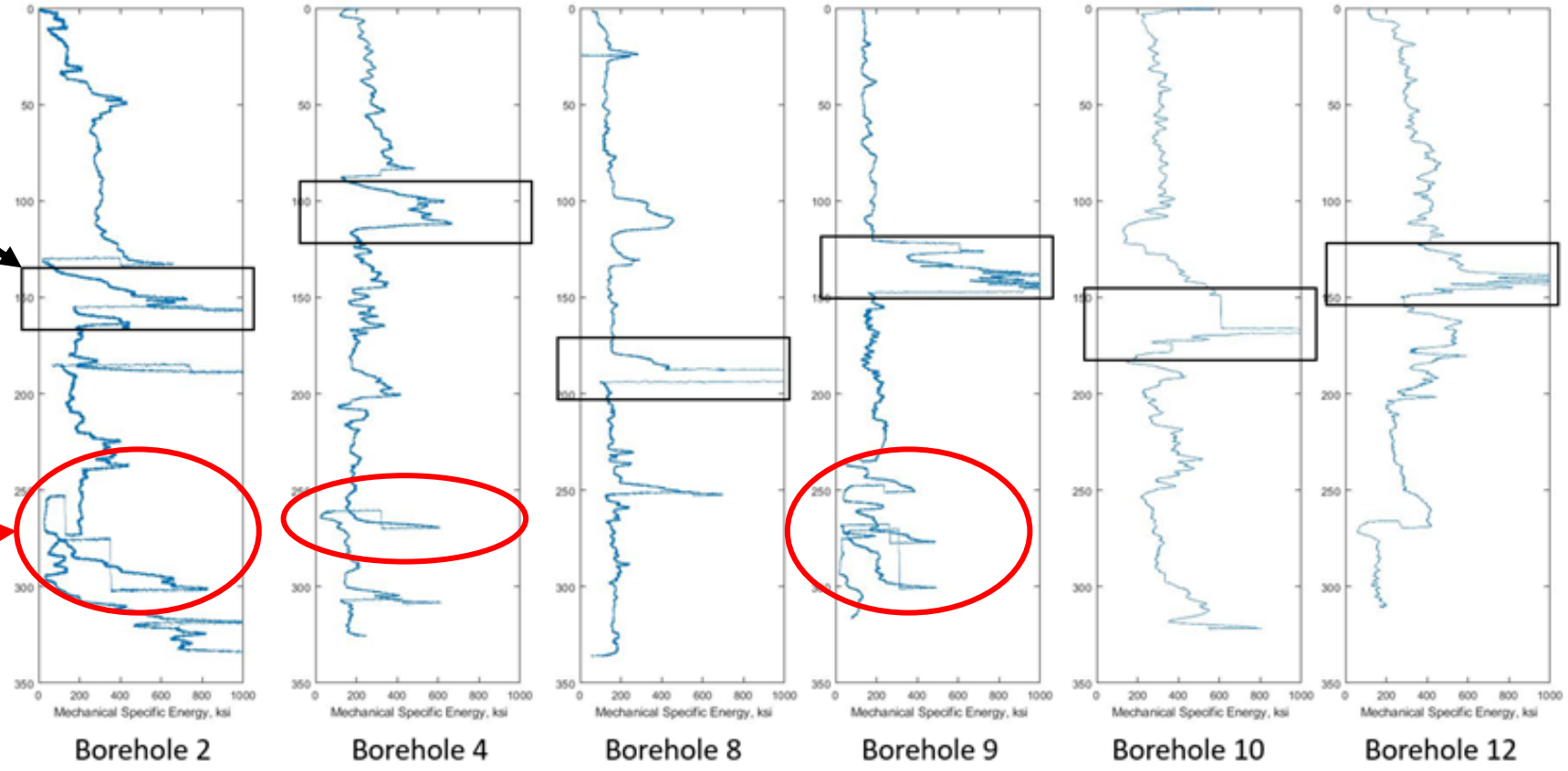
Average MSE recorded from first two blocks consistent with MSE data available in the literature

Zacny et al. , 2006

Result: Drilling dysfunctions

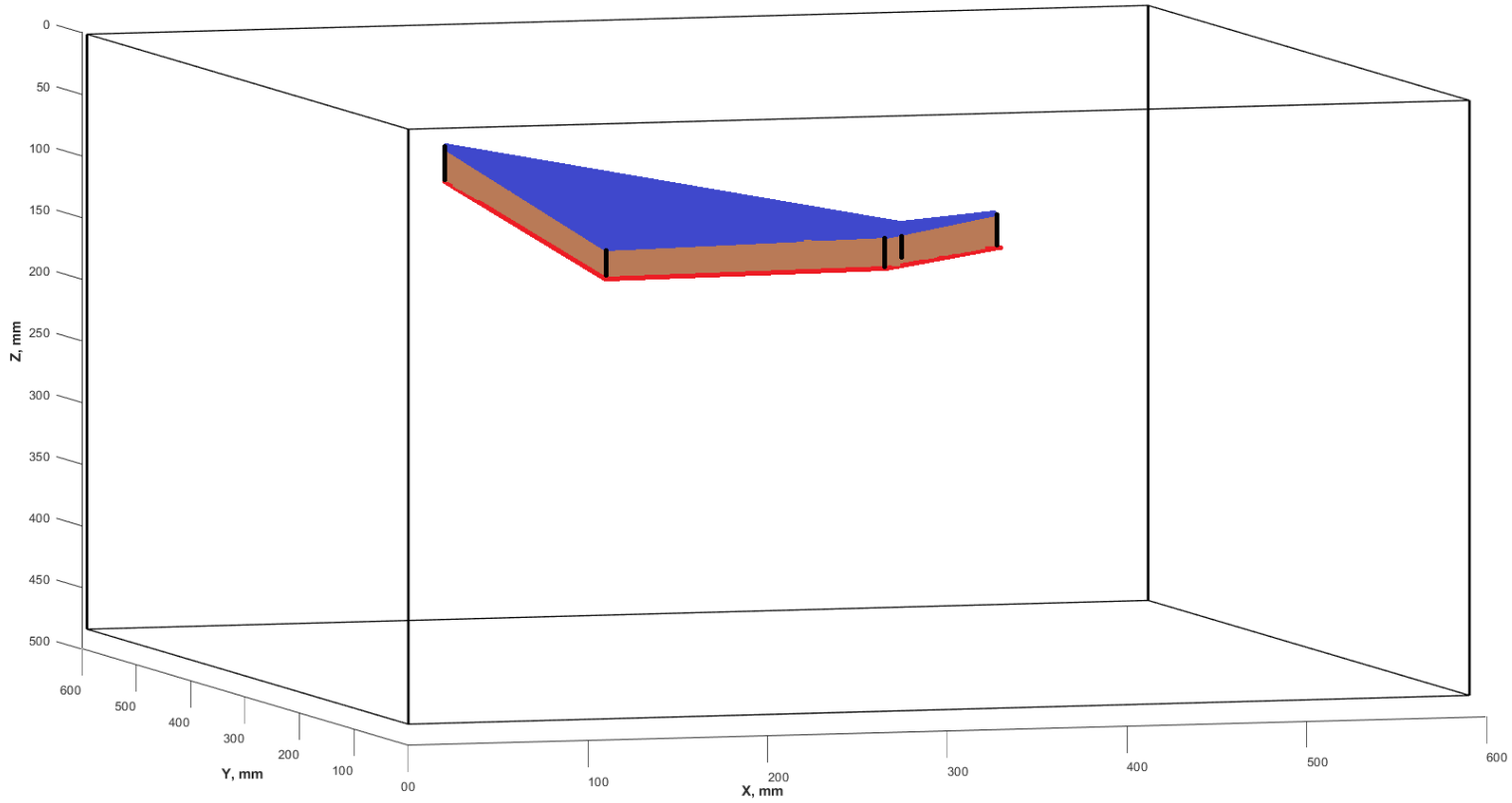
Hard formation layer

Cutting transport issue



Note the drilling dysfunctions in red

Results: Subsurface mapping

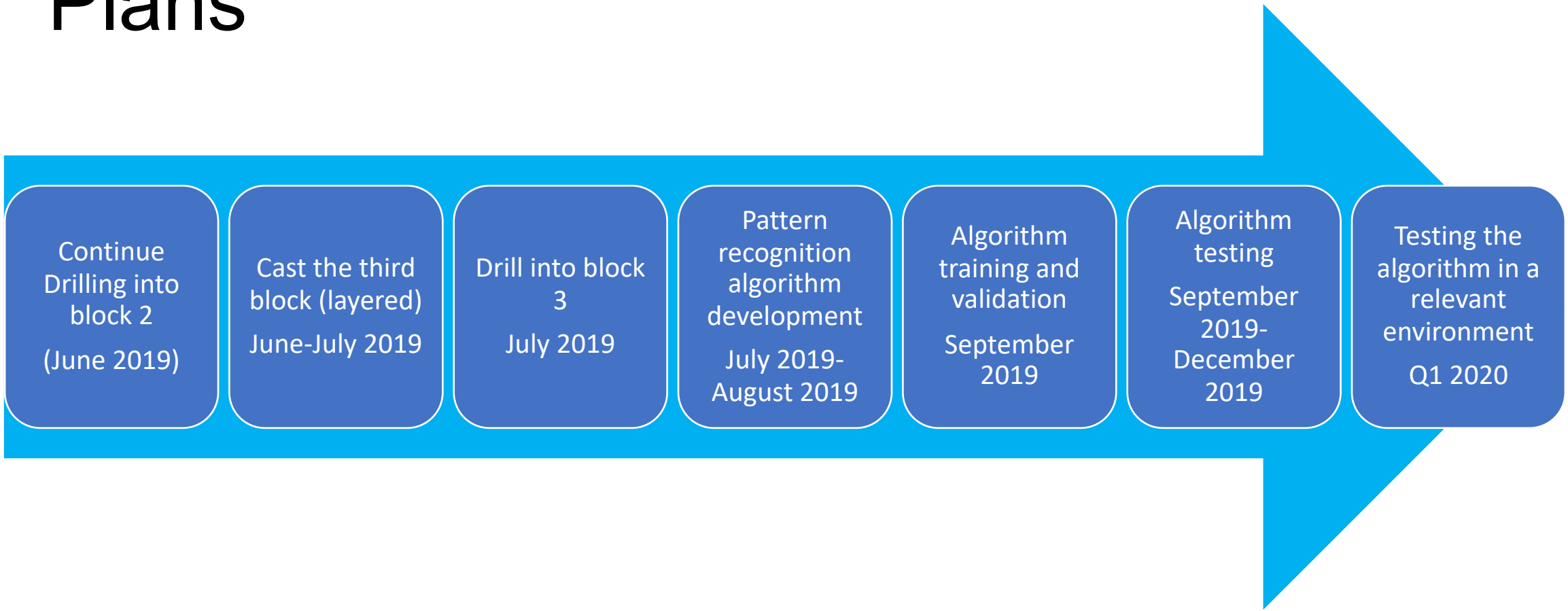


Mapping the hard formation layer in the block using drilling data

Conclusions

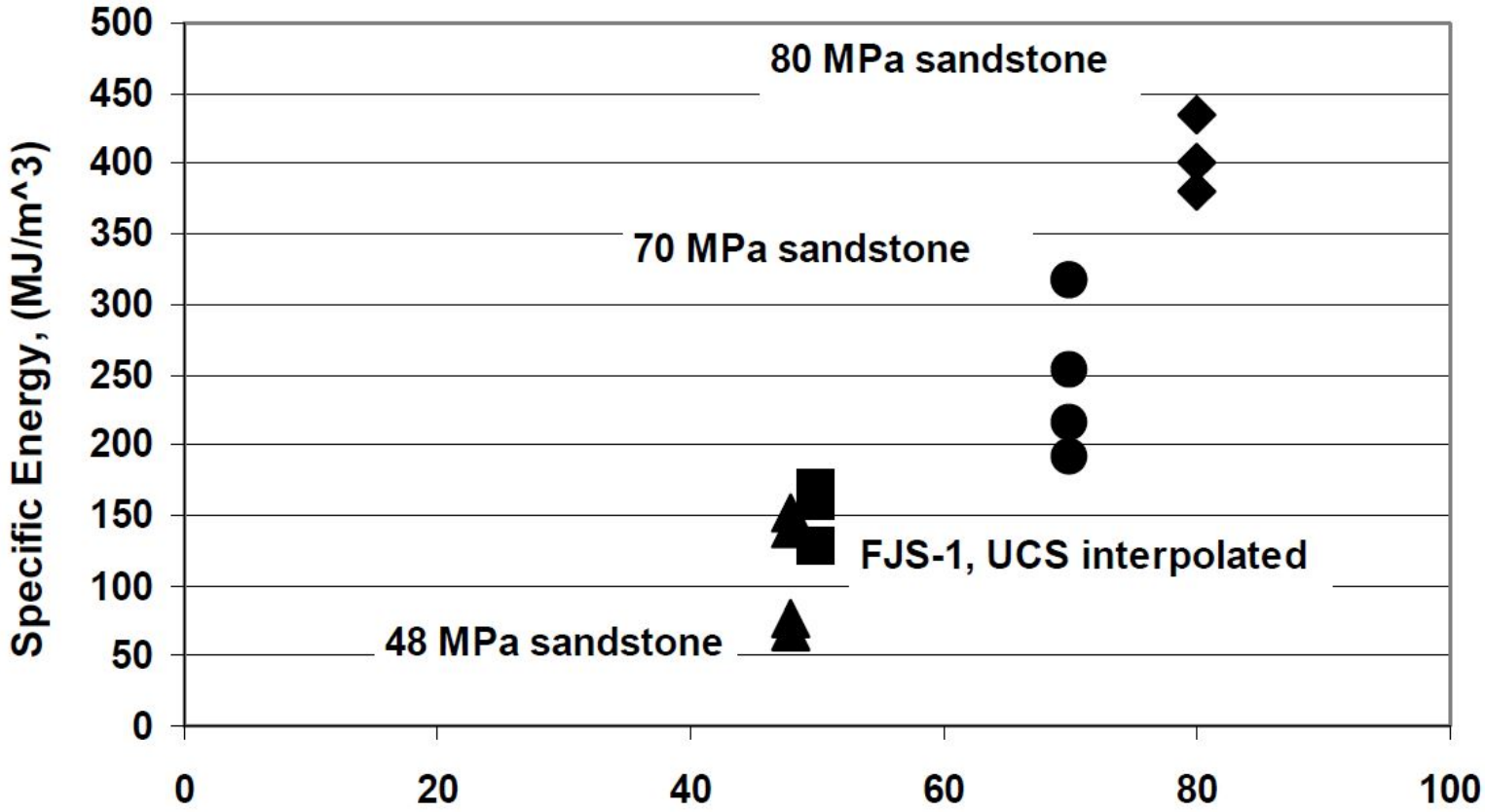
- Developed a drilling test unit to acquire high-frequency drilling data
- Drilled into two grout blocks:
  - Block 1: Homogenous
  - Block 2: Layered
- Drilling data analyzed to identify
  - Drilling dysfunctions
  - Subsurface stratigraphy
- Initial relationship between UCS and Mechanical specific energy established

Plans


Continue Drilling into block 2
(June 2019)
Cast the third block (layered)
June-July 2019
Drill into block 3
July 2019
Pattern recognition algorithm development
July 2019-August 2019
Algorithm training and validation
September 2019
Algorithm testing
September 2019-December 2019
Testing the algorithm in a relevant environment
Q1 2020

Backup Slides

Literature data for MSE vs UCS



Regolith PSD