Utilizing LiDAR to Improve Mine Safety

Nicole Evanek

National Institute for Occupational Safety and Health

Pittsburgh Mining Research Division

NIOSH Research Project Where LiDAR is Utilized

Methods to Reduce the Potential for Massive Ground Collapses in Underground Stone Mines

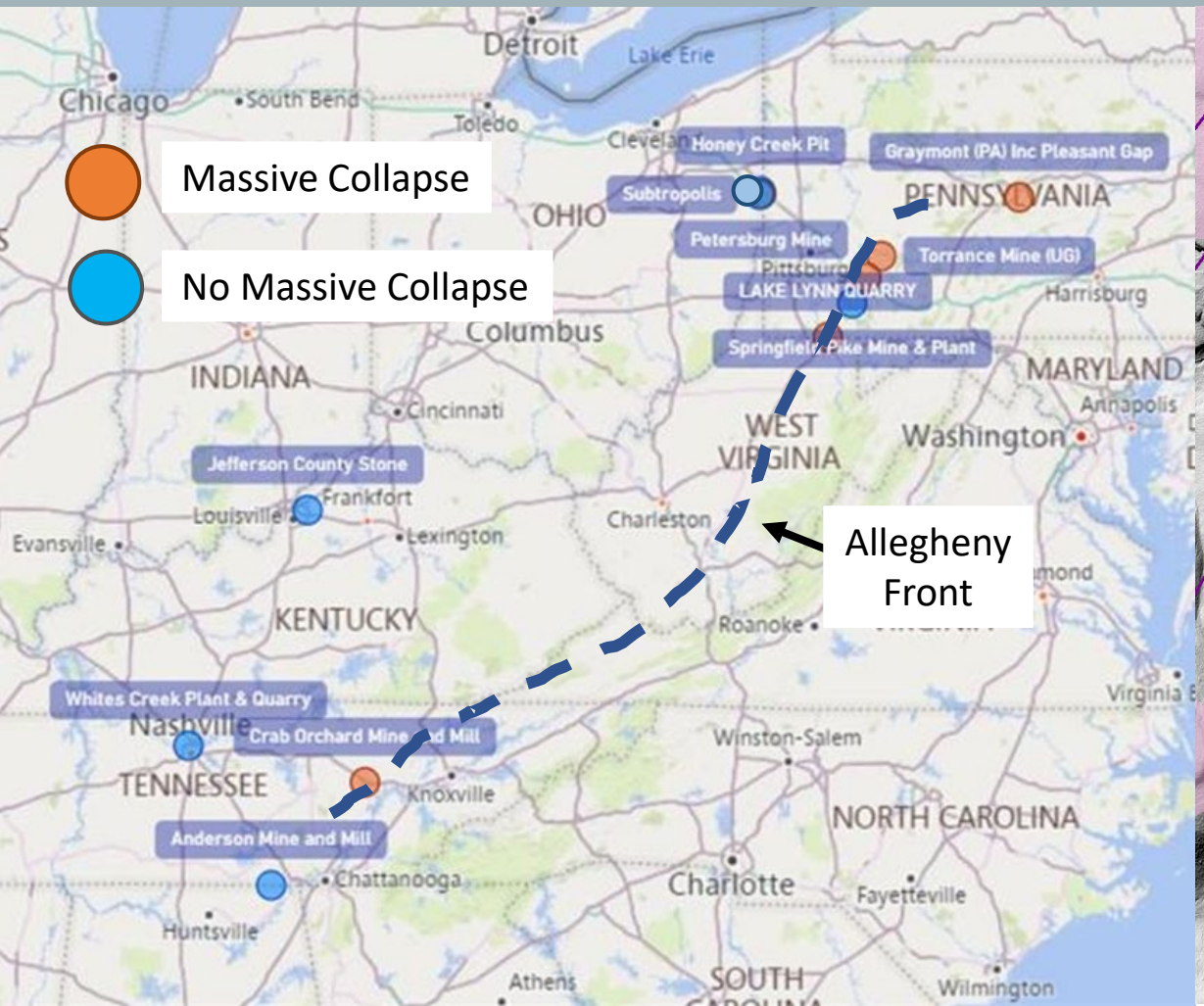
Several massive ground collapses in underground stone mines have occurred in the past decade, with four occurring in rapid succession from 2020 to 2021. These massive ground collapses represent a major hazard, that can result in traumatic injuries and fatalities with the potential for multiple-fatality events.

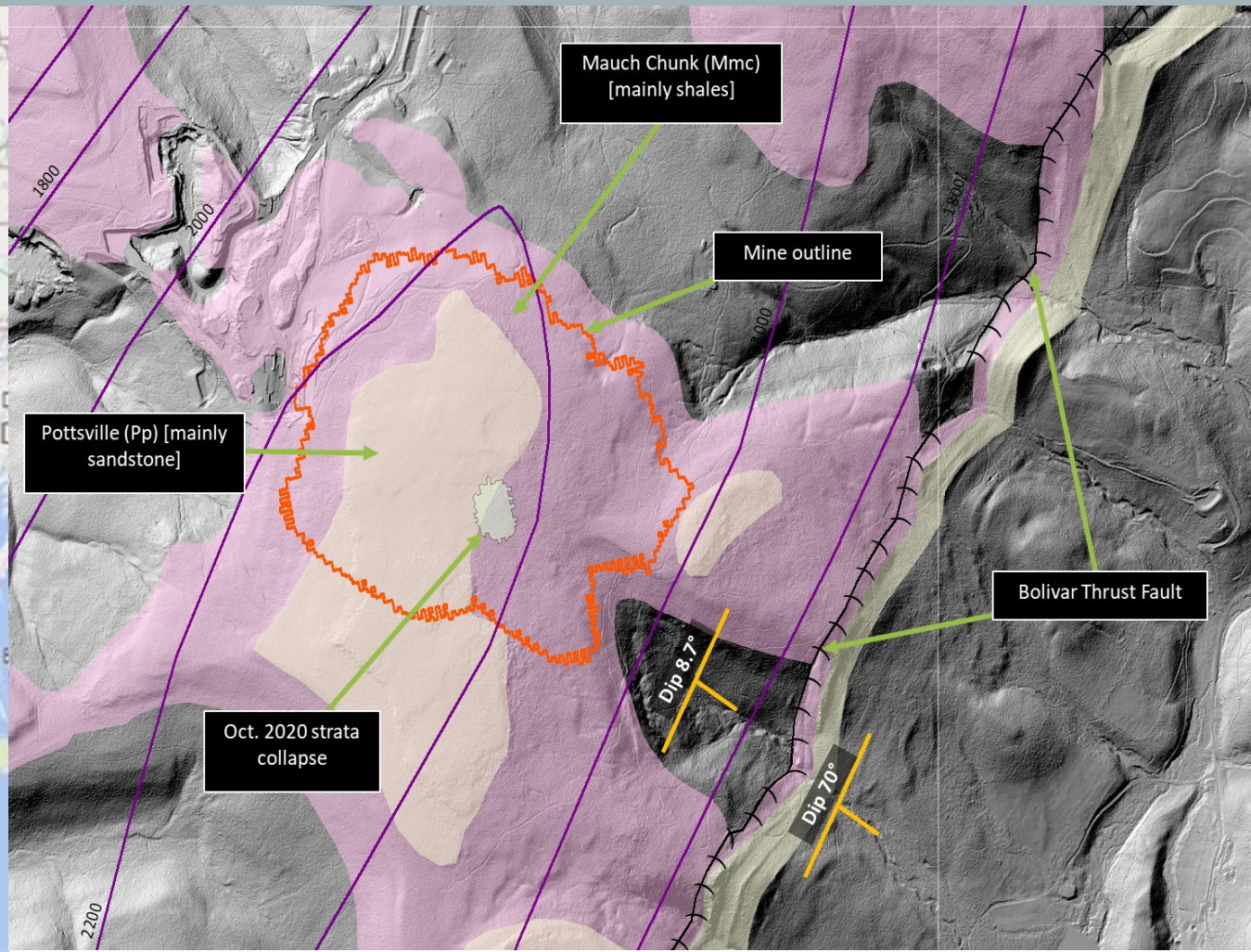
- Improved engineering interventions are needed to lessen the potential for unexpected massive ground collapses
- Progress and conclusions communicated to stakeholders through meetings, briefing reports, technical papers, peer-reviewed articles

MASSIVE COLLAPSES

Each site we visit has unique layouts, geologic characteristics and anomalies. However, the more we study, the more patterns are emerging.

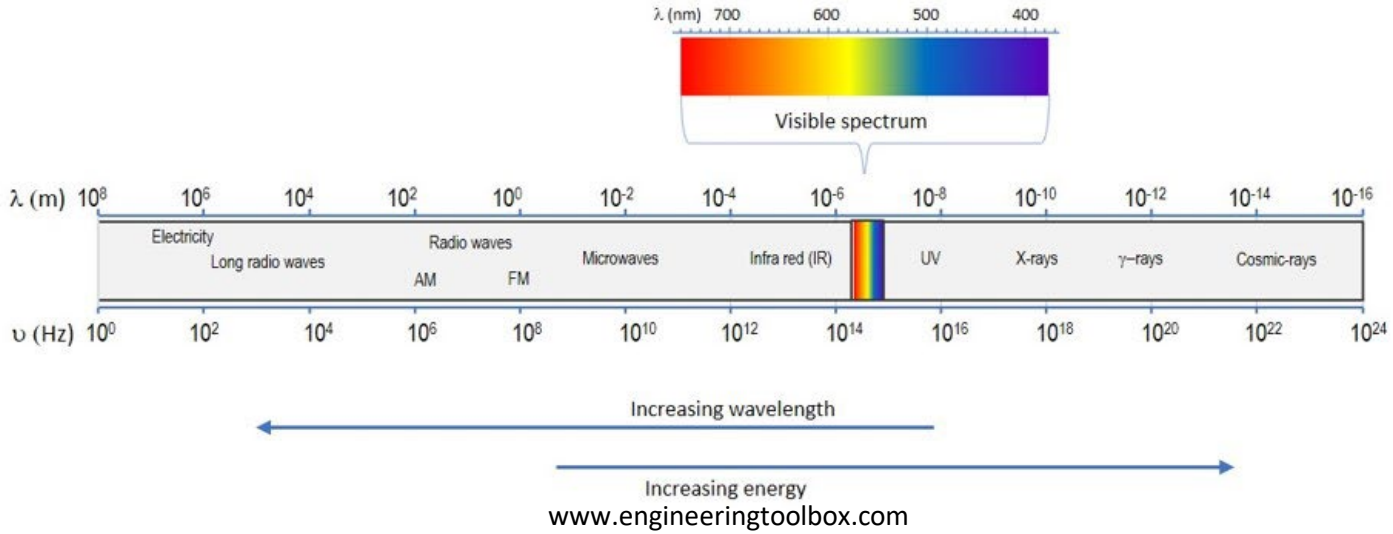
The end goal is to provide a comprehensive journal article that provides the industry with the leading factors that lead to these collapses, lessons learned from these events and possible engineering controls that may help prevent these events from occurring in the future.

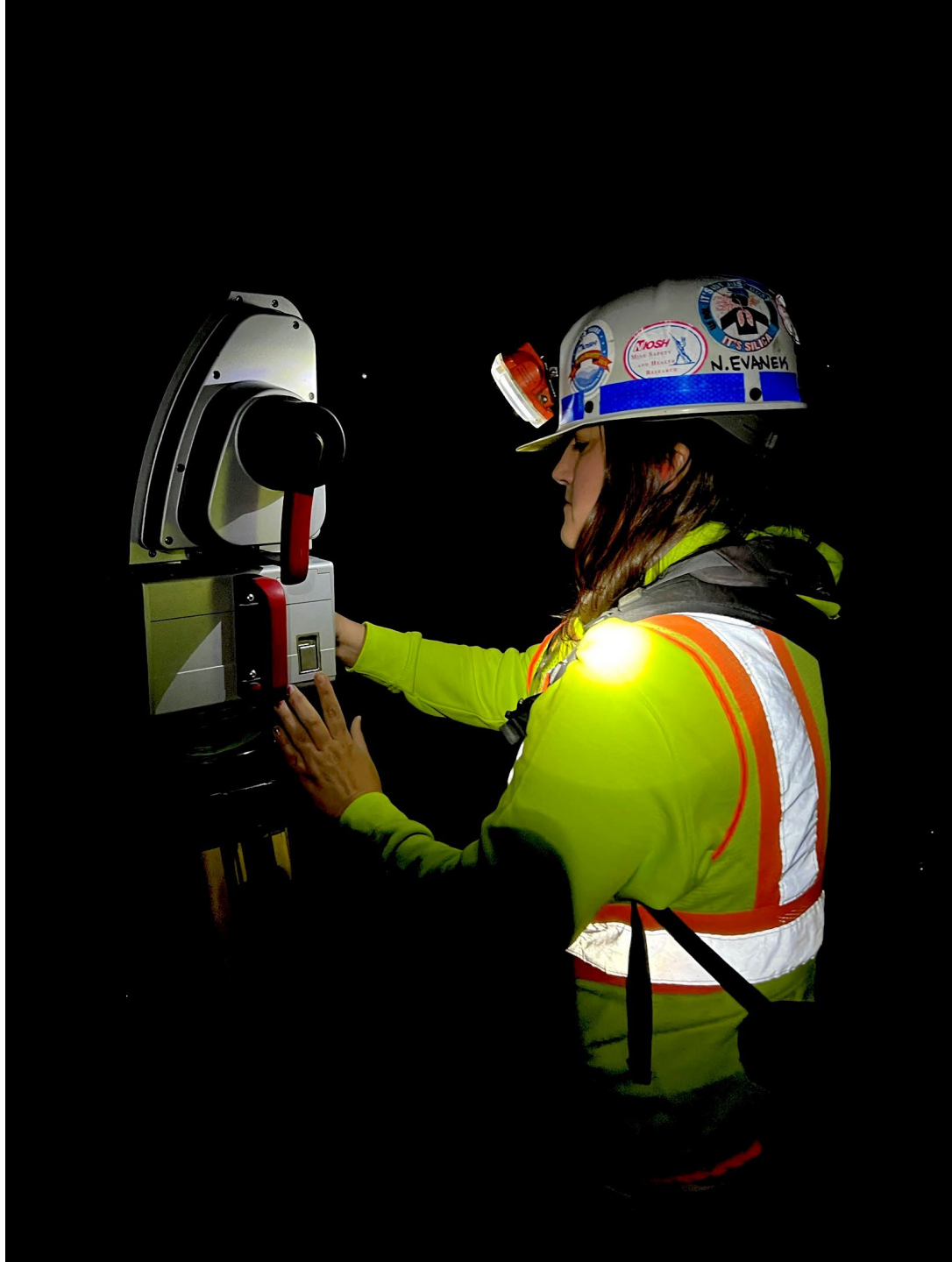




Quick background

- LiDAR = Light Detection and Ranging
- Electromagnetic Radiation
  - EM Spectrum encompasses visible light (380nm – 760nm), x-rays (0.01nm - 10nm, radio waves (1 mm – 100+ km), etc.
  - If we think about radar (Radio Detection and Ranging), it is based on bouncing radio wave signals off of objects
  - LiDAR similarly bounces a different wavelength of electromagnetic radiation off objects
    - Typically in the visible light spectrum, but don't hold me to it





MAPTEK I-SITE 8200 AND GEOSLAM ZEB HORIZON

The scanners rotate 360 degrees horizontally, and a mirror inside that can rotate 360 degrees vertically.

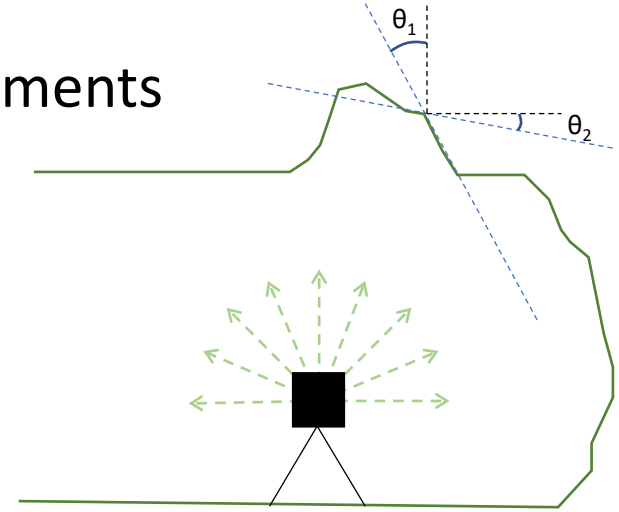
A laser shoots into the rotating mirror, which measures the time it takes to hit the target and bounce back.
Considering the speed of light, and time it takes to receive the signal, we now have the distance to the object.

Point Clouds

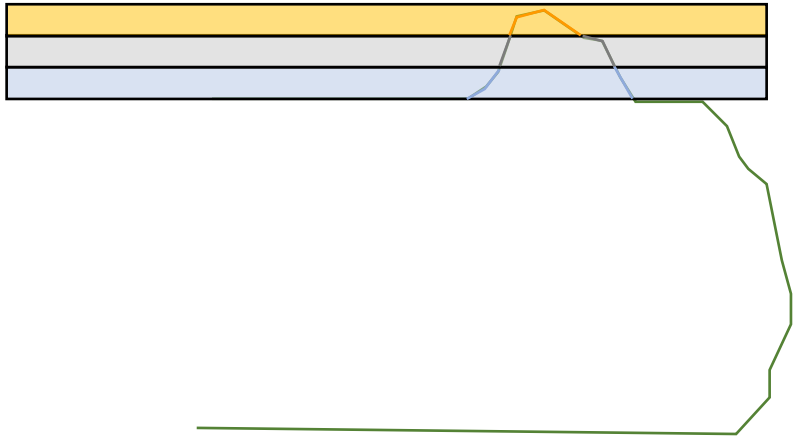
Techniques for using LiDAR as a measurement tool fall into two broad categories of time-independent and time-dependent

Time-Independent

Geotechnical Assessments

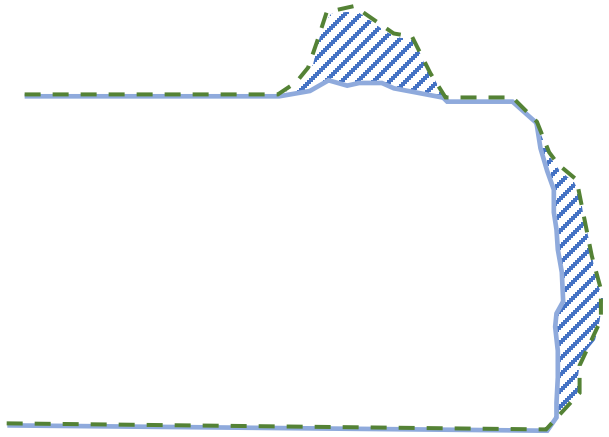


Elevation Contours

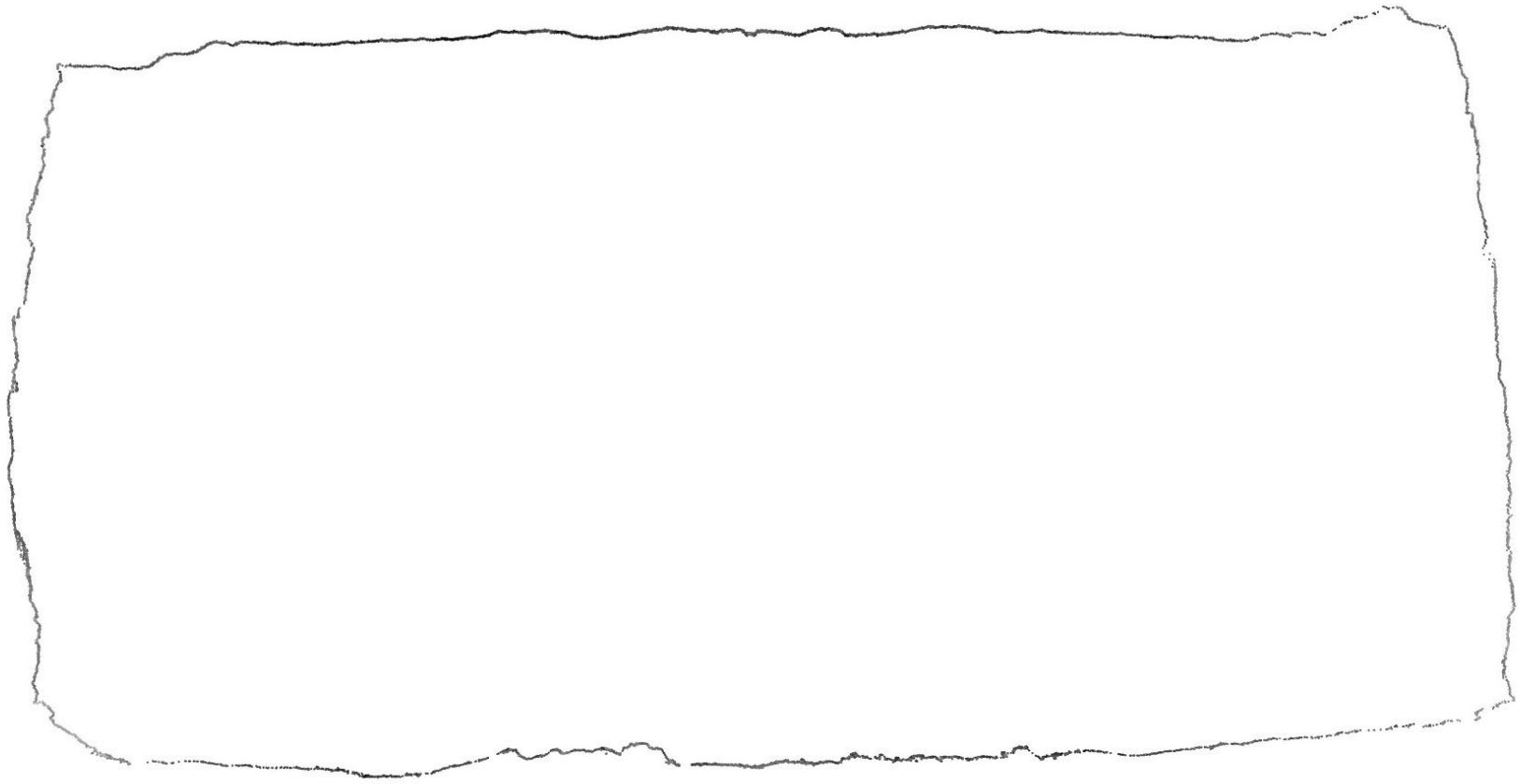


Time-Dependent

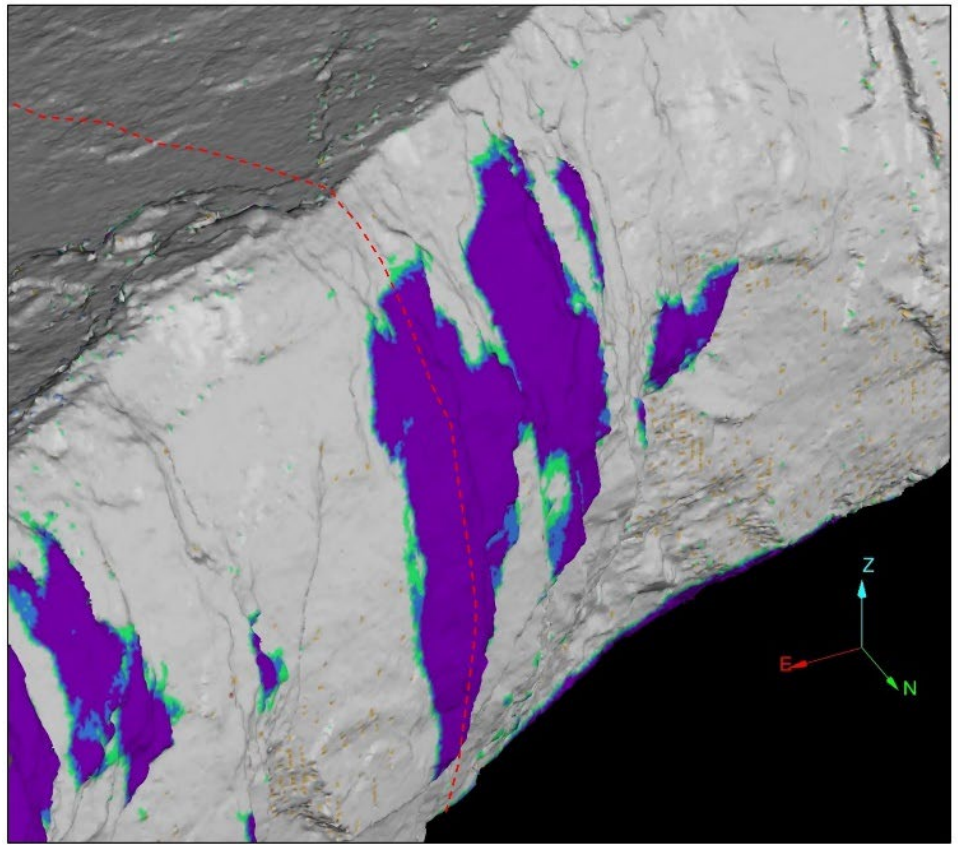
Change Detection

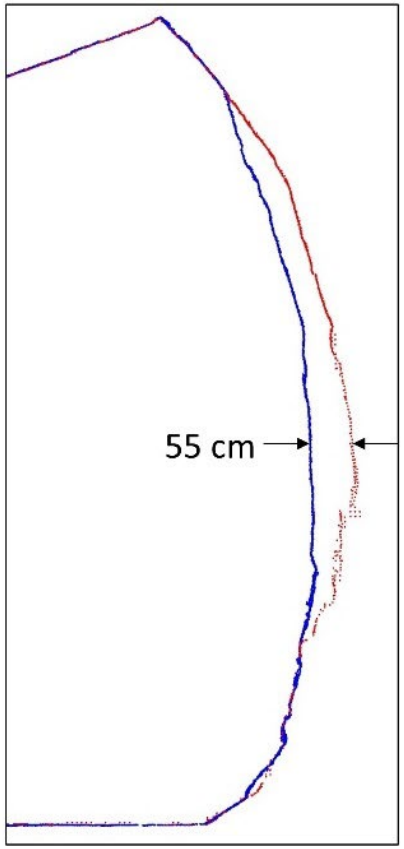


Tracking ground movements is important, but difficult with single point measurement devices



Change detection requires time to have elapsed and something to have changed, but it can easily highlight areas of concern



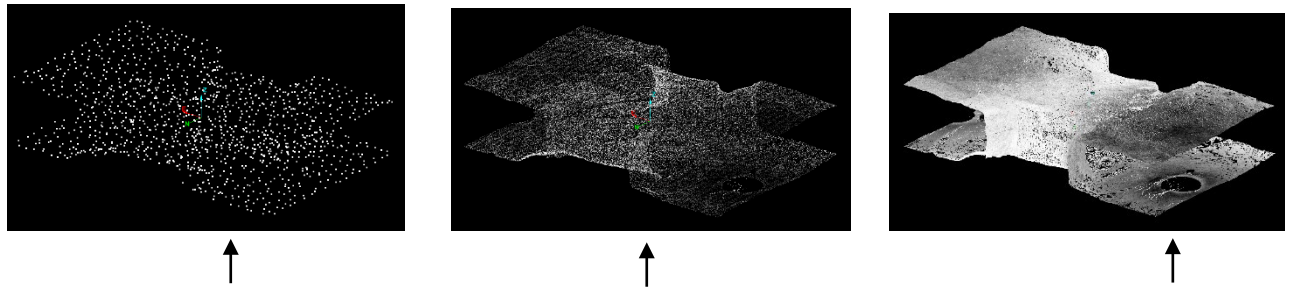


Spalling is the easiest displacement to detect, as it tends to far exceed the precision of any close-range terrestrial LiDAR scan

Accuracy, point cloud density, registration error, and other commonly conflated and problematic concepts…

- Accuracy
  - Unless you are a salesman, this rarely matters for stationary systems
- Point cloud density
  - Matters in a lot of ways, but not the ways you expect
- Registration error
  - The silent killer…where compounding error will destroy your project

Every distance measurement has its own precision and point density requirements



Roof Convergence

Fracture Mapping

Surveying

Floor Heave

Surface Contouring

Object or Feature Measurement

Fall of Ground Detection

Mine Geometry

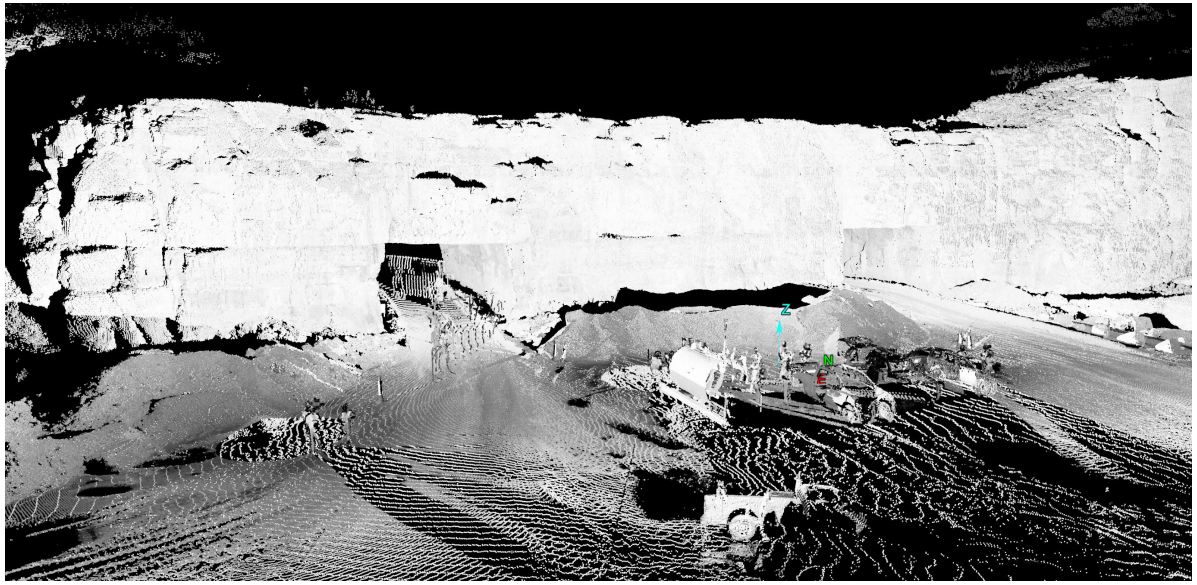
Minimum accuracy typically required (cm)

1
2
3
4
5
6
7
8
9
10

1
10
100
1,000
10,000
100,000
1,000,000
10,000,000

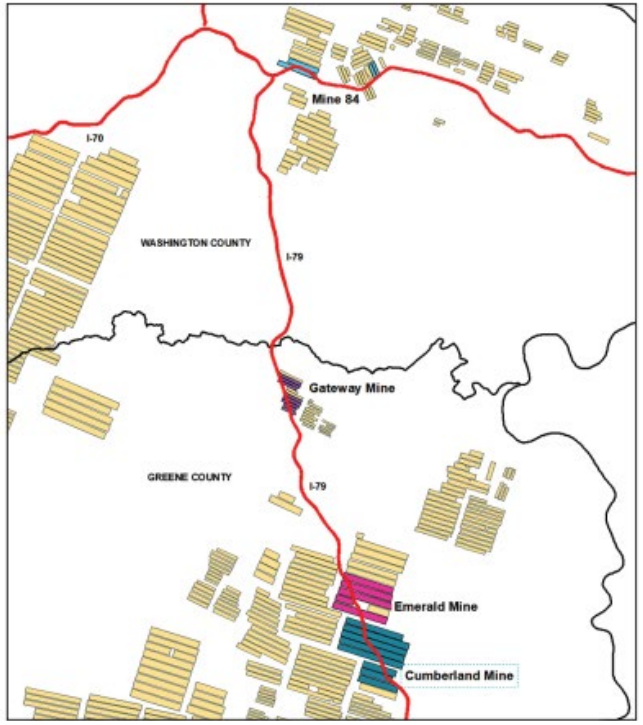
Number of points desired in a typical opening (~30 linear meters)

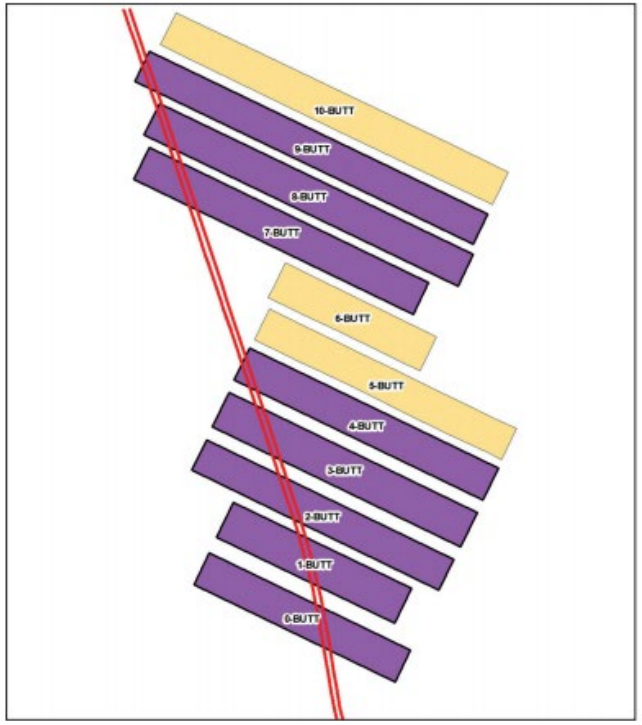
Surveying



Surveying

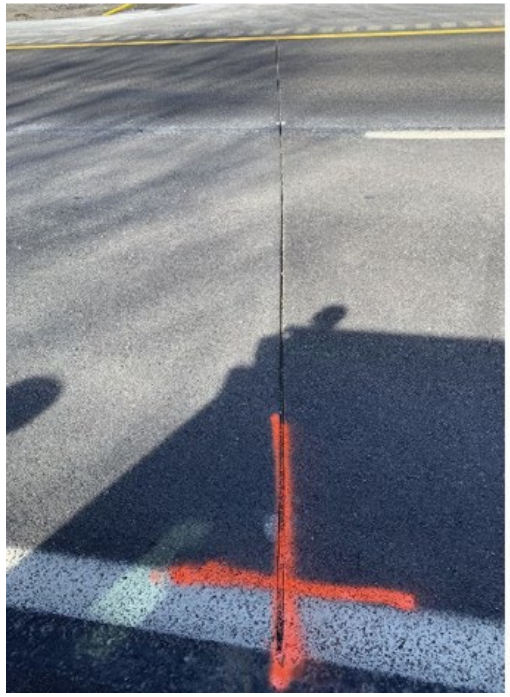
Laser Scanning to Track Subsidence on Pennsylvania Highways

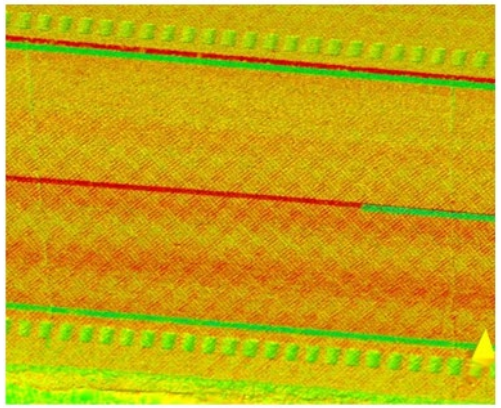


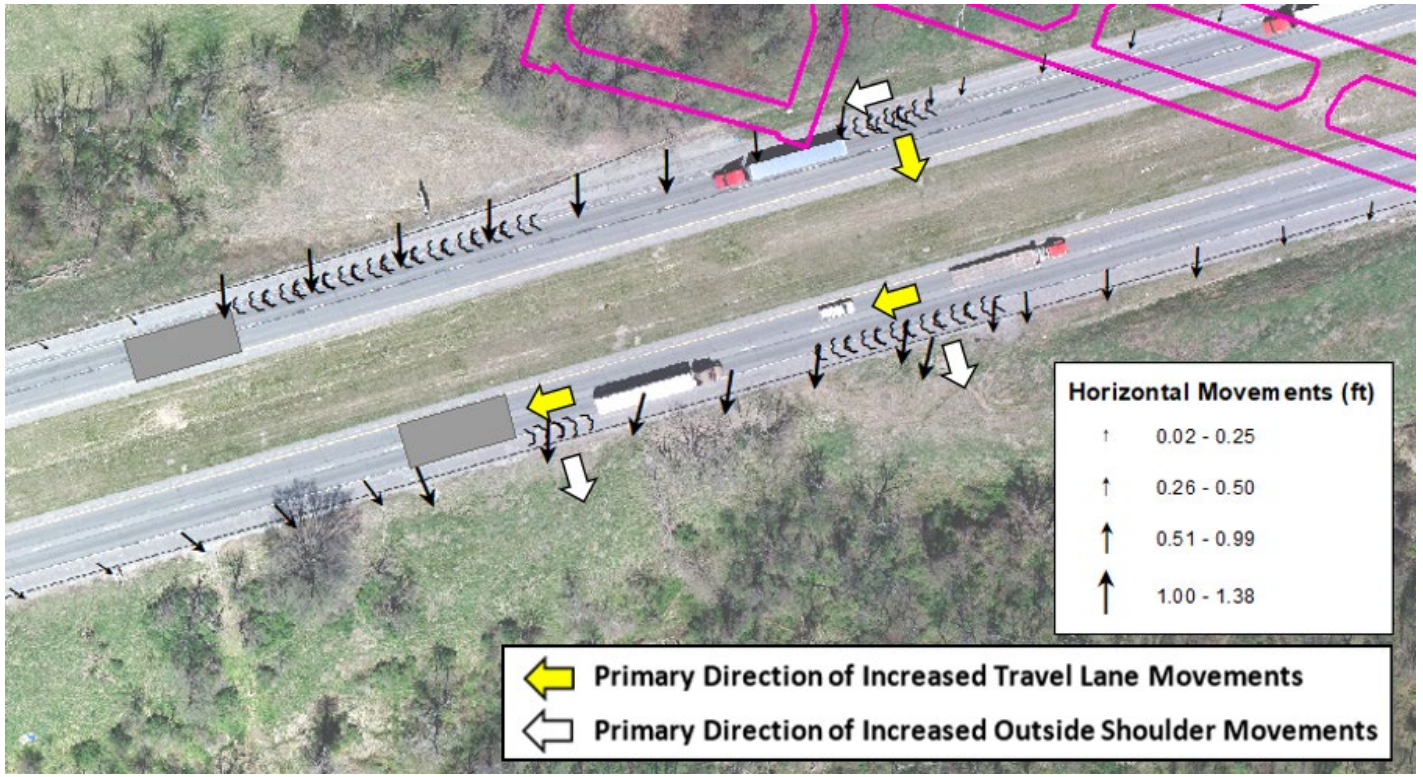


Surveying

Laser Scanning to Track Subsidence on Pennsylvania Highways

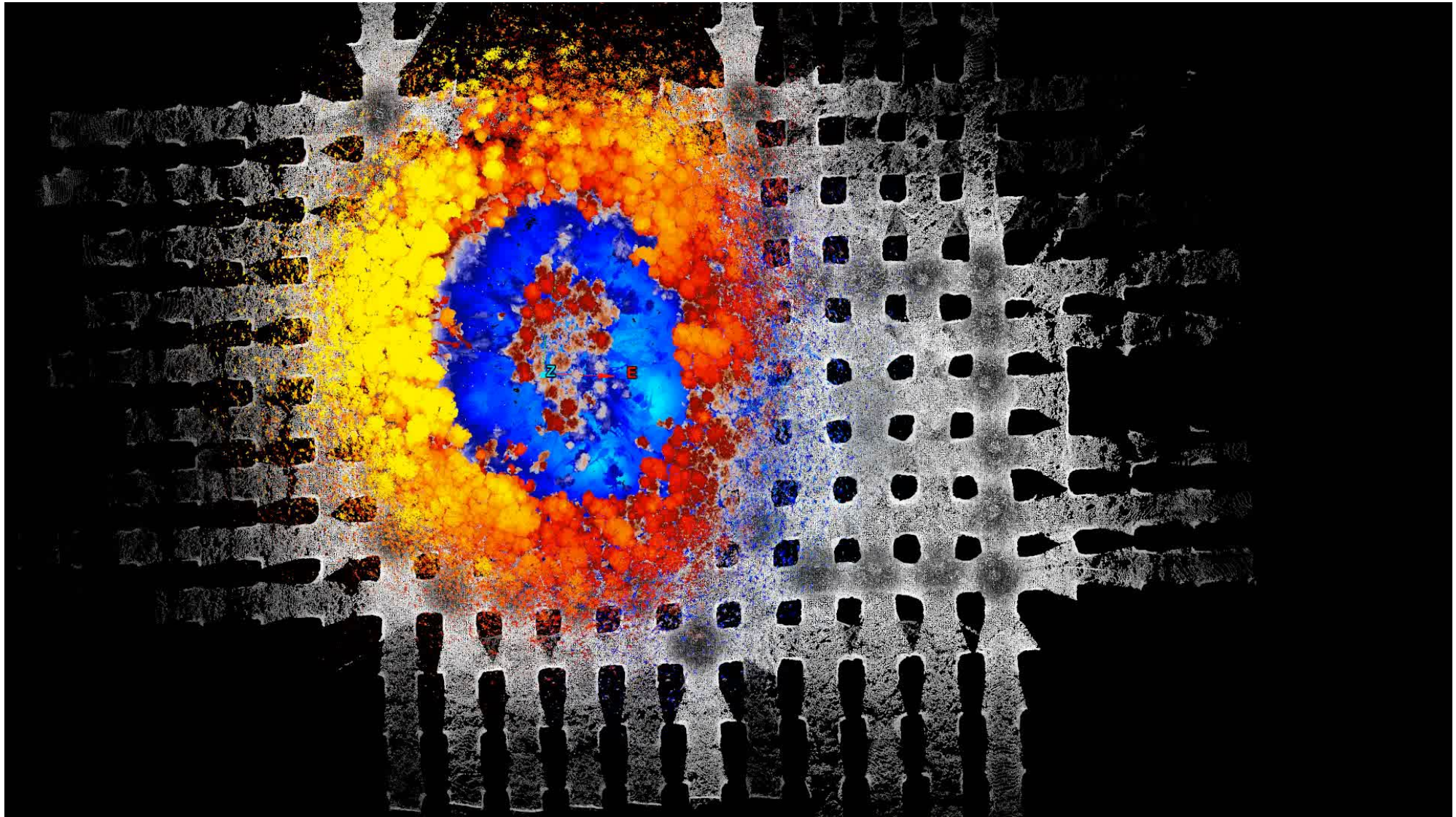




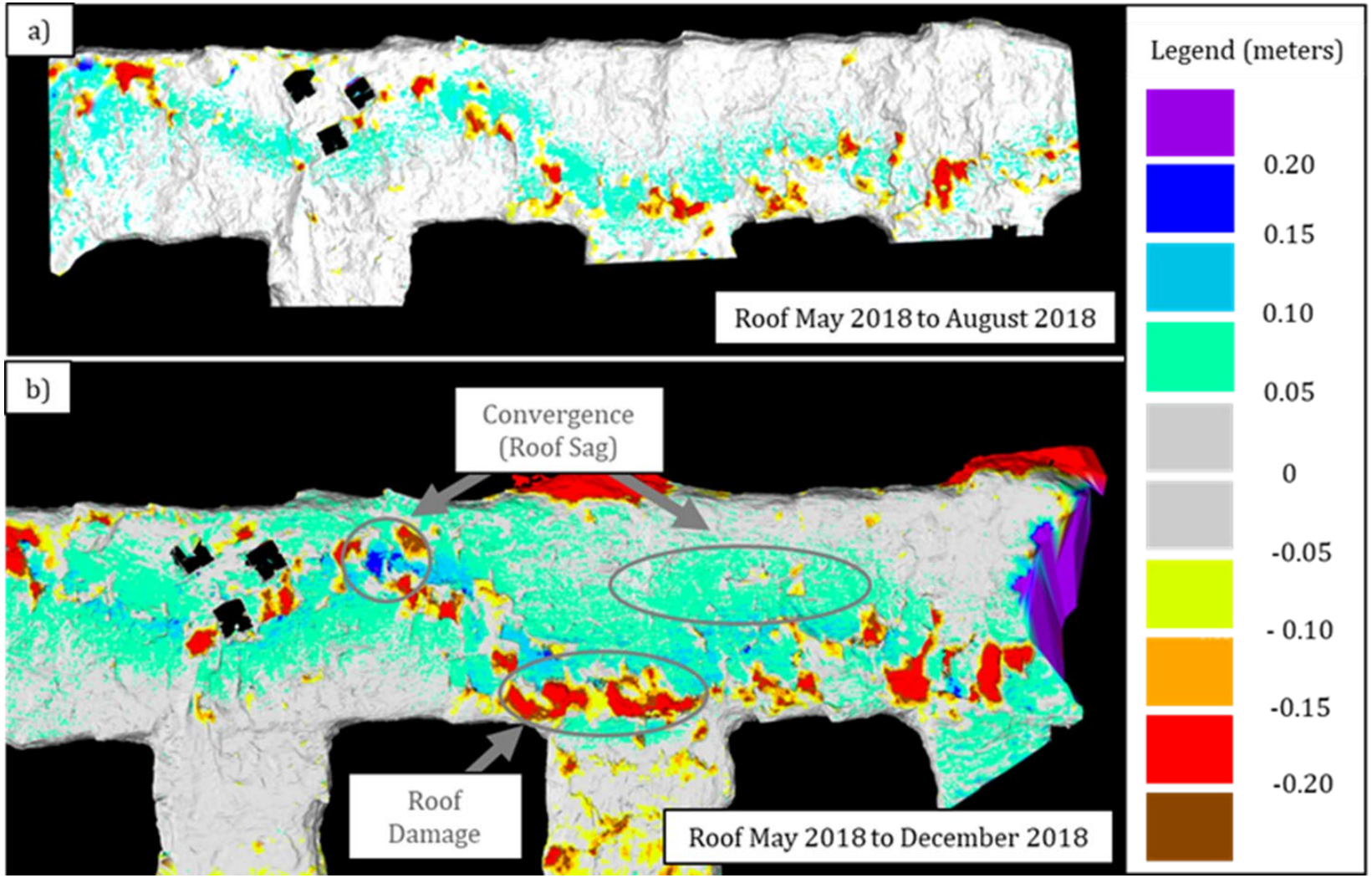


Surveying

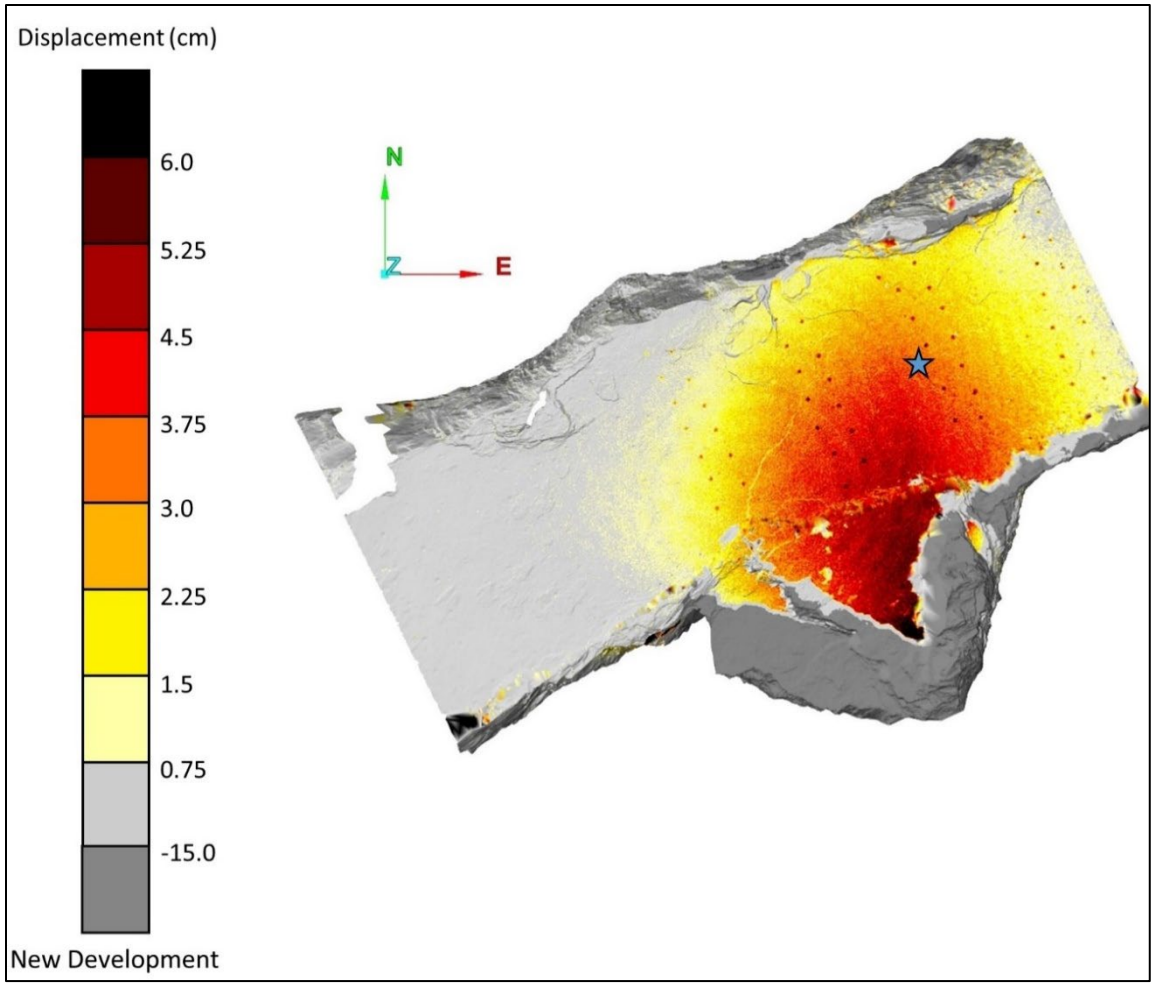
Laser scanning the underground and surface around a collapse area



Roof Convergence



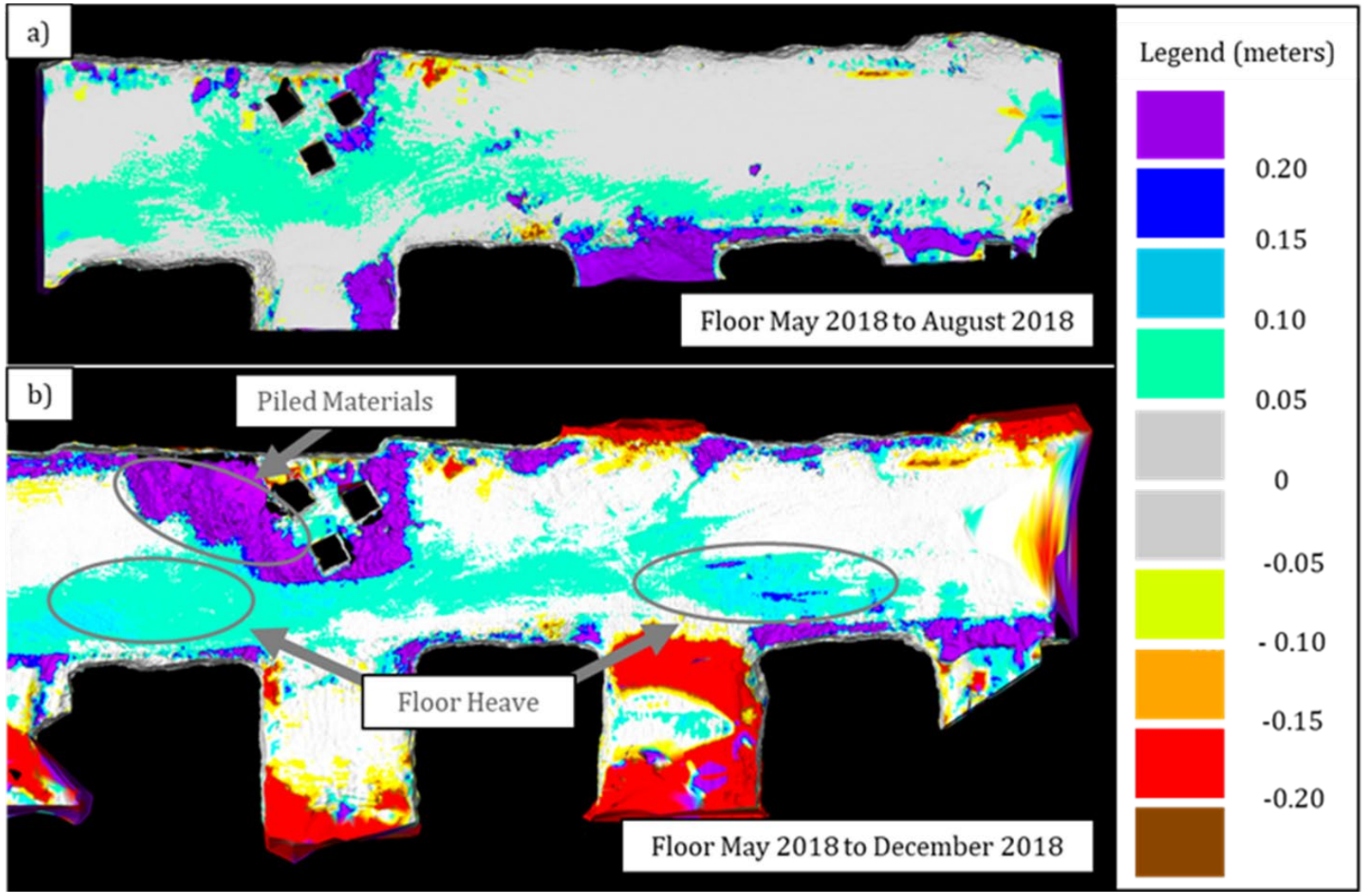
Roof Convergence



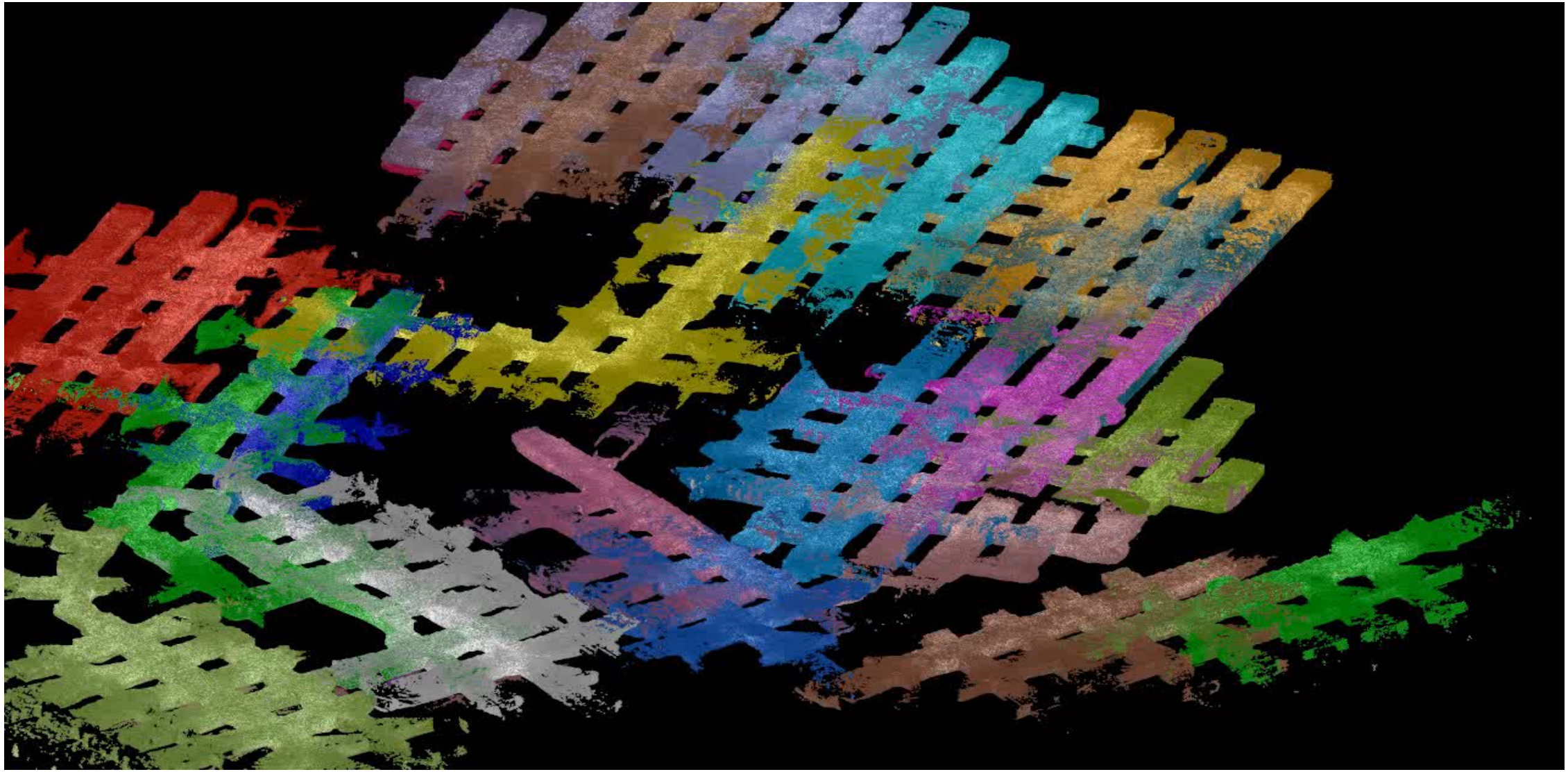
- Roof conditions were observed to be poor and a Miner's Helper (MH) was installed (star on figure).
- LiDAR scanning was performed around the time the MH was installed and continued indefinitely.
- The movement seen in the MH was 2.3 cm and the movement shown in the scans is in the range of 2.25-3.75 cm.

Floor Heave

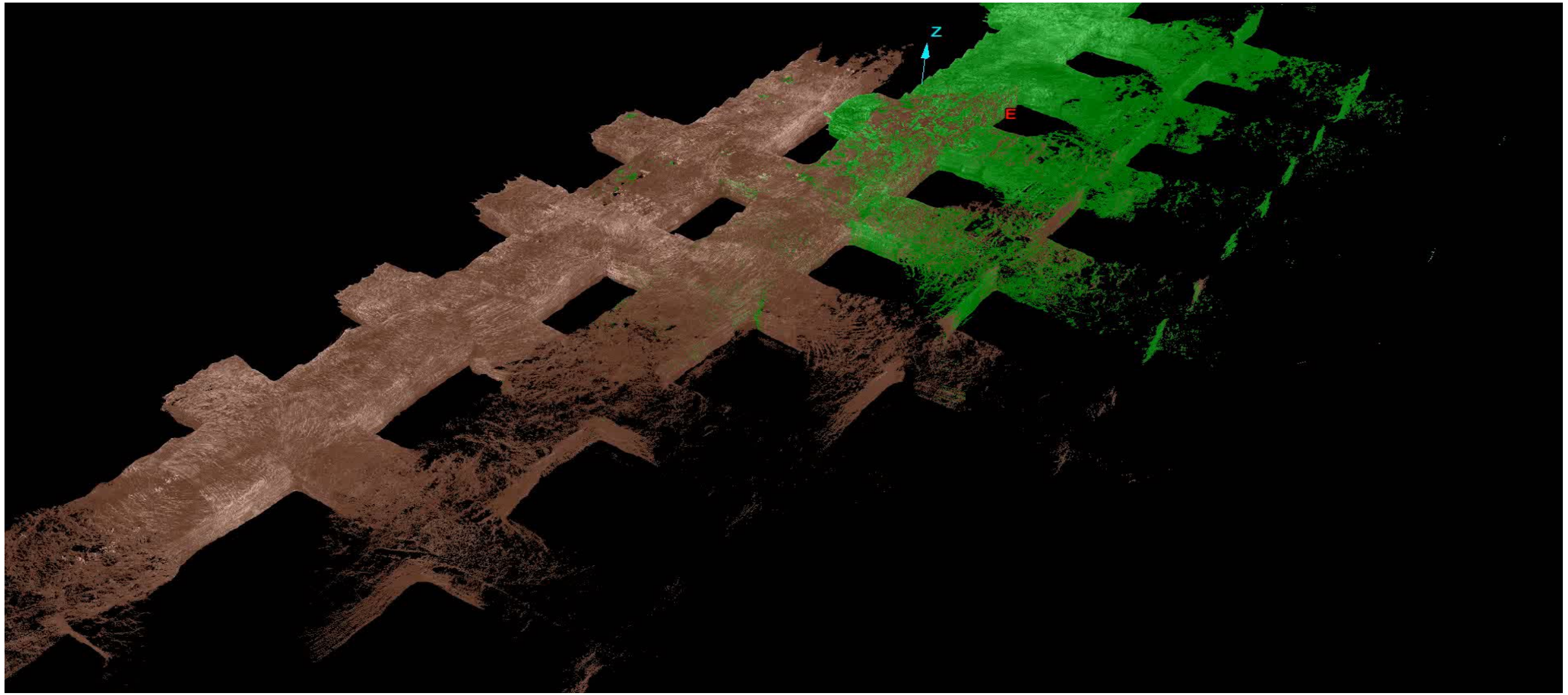
Caused by Changes in Stress Conditions



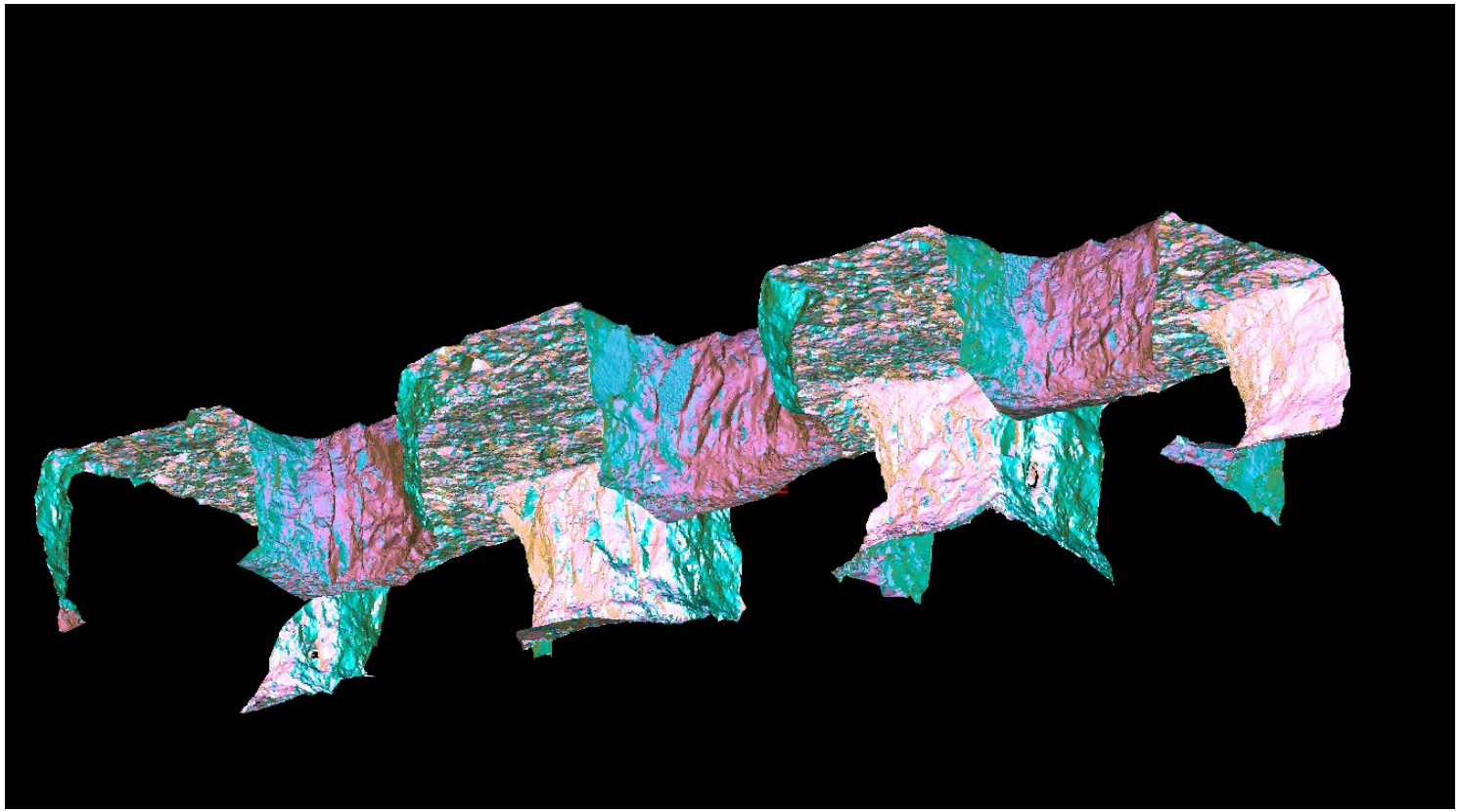
Mine Geometry



Mine Geometry



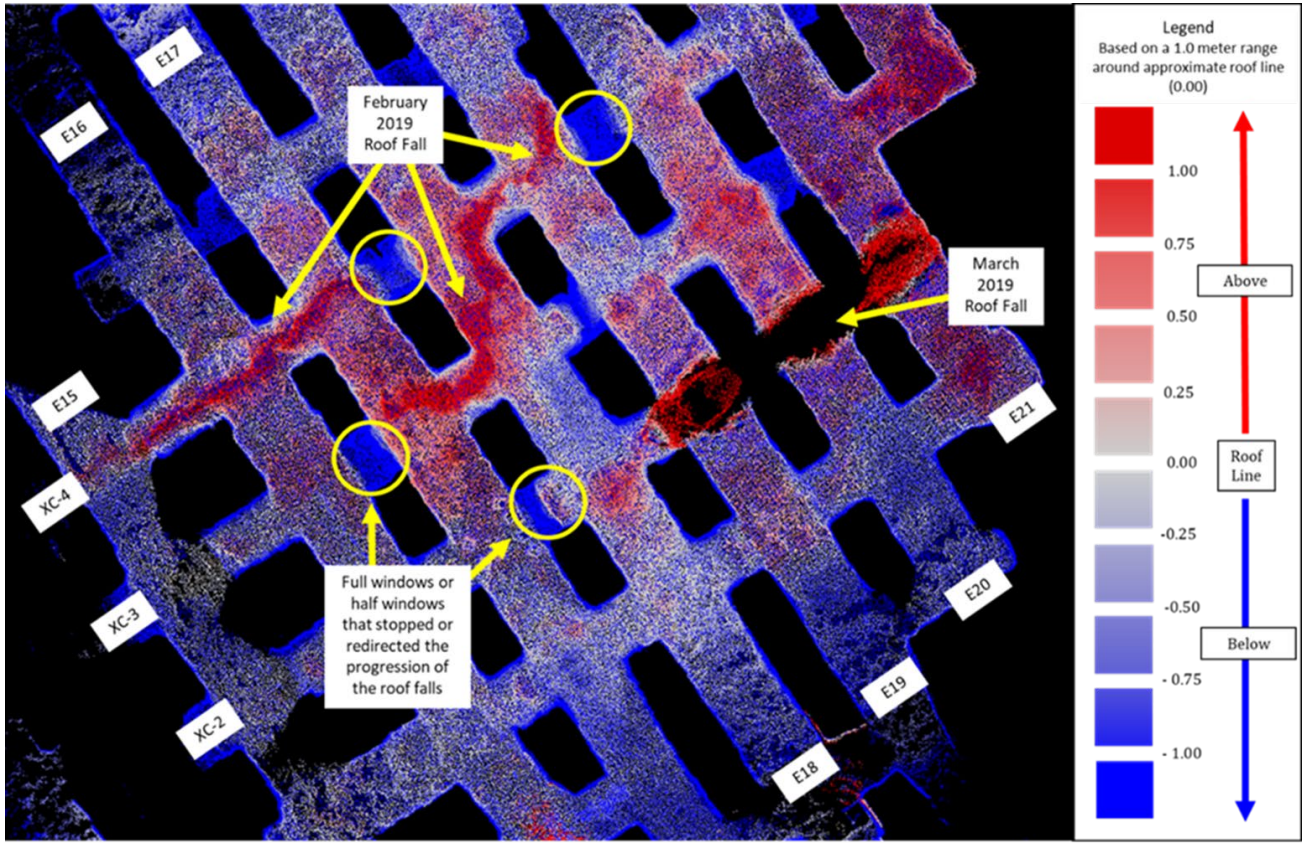
Surface Contouring



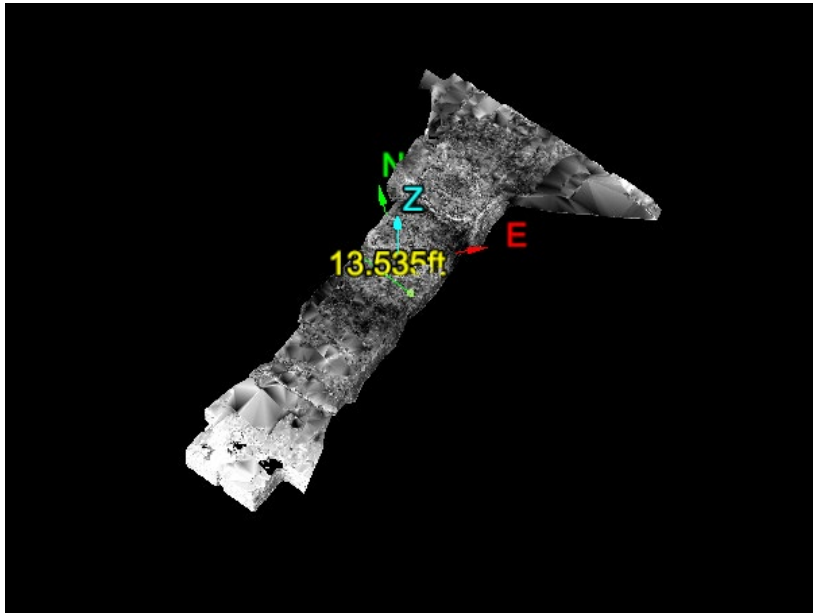
Analyze for...

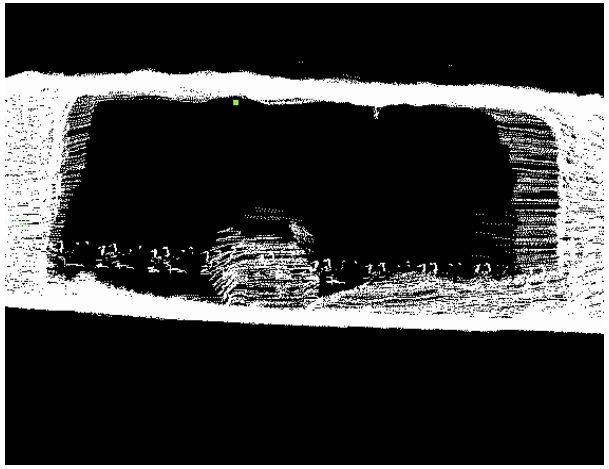
- Volumes
  - Roof falls
  - Blasting
  - Ventilation
- Joint patterns

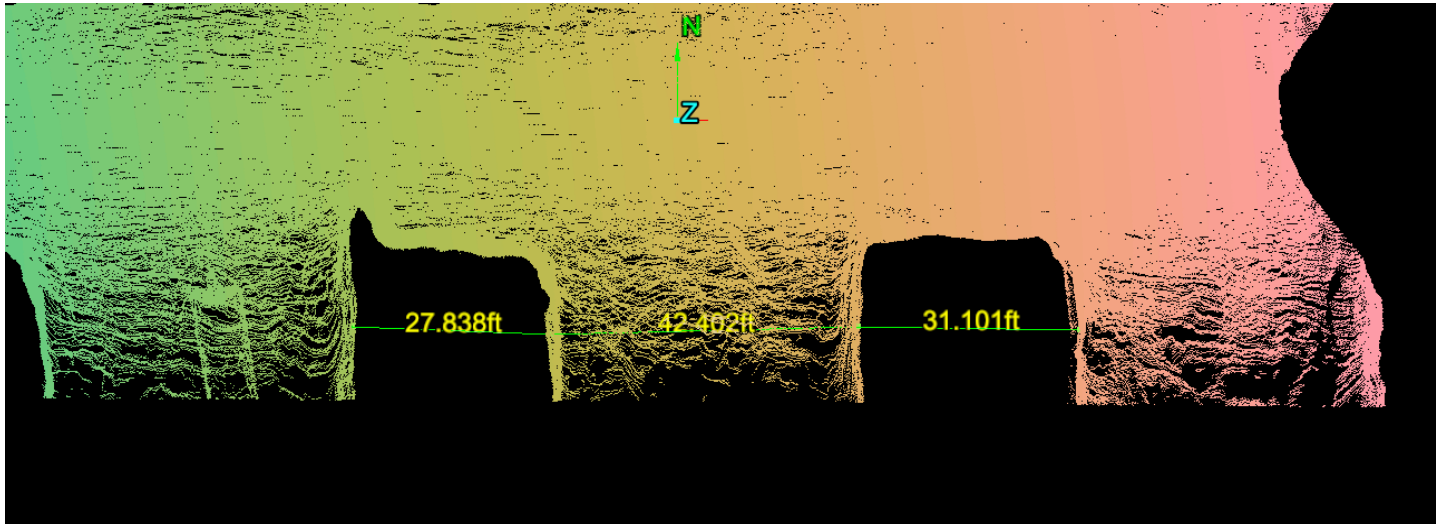
Fall of Ground Detection



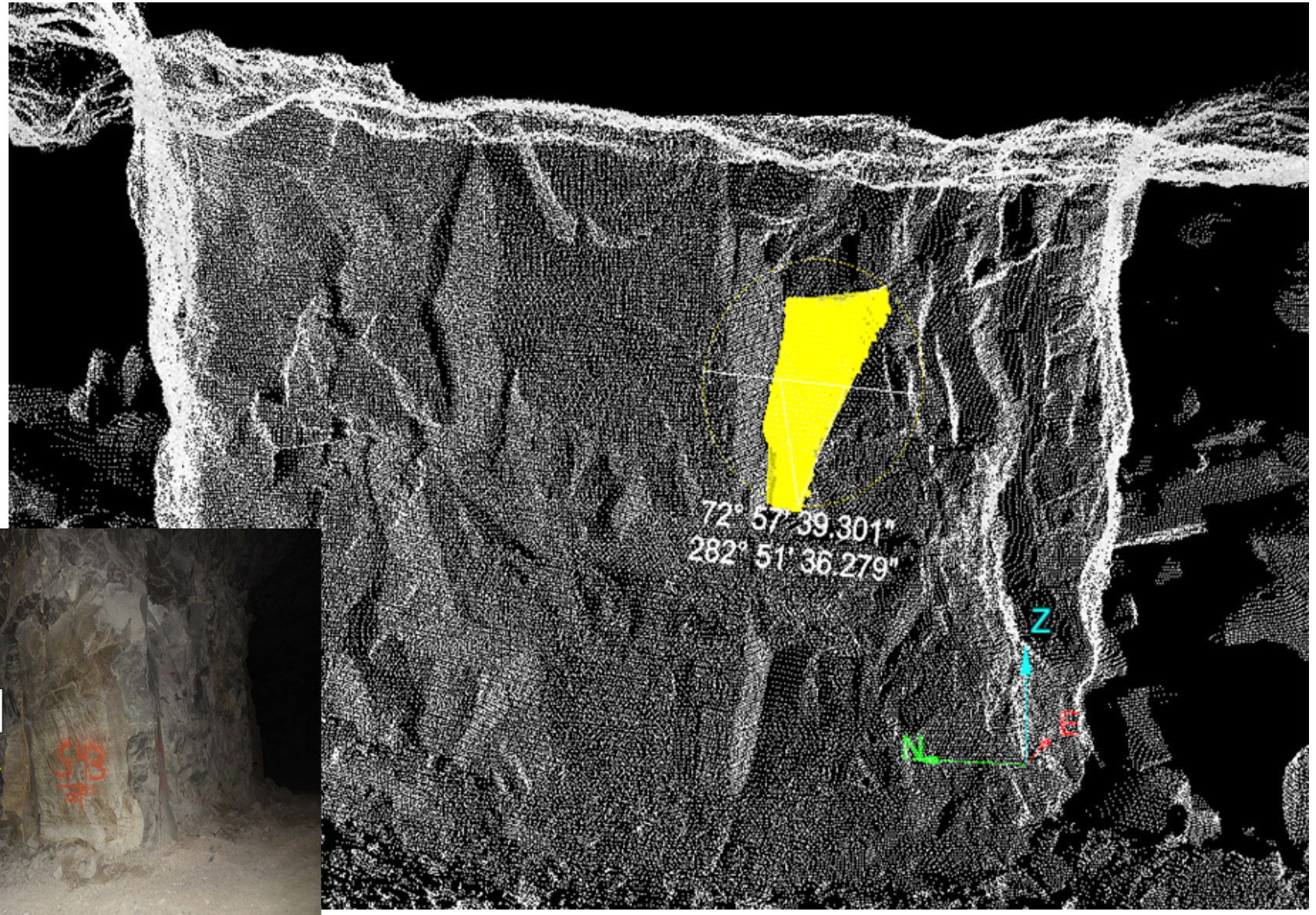
Object of Feature Measurement

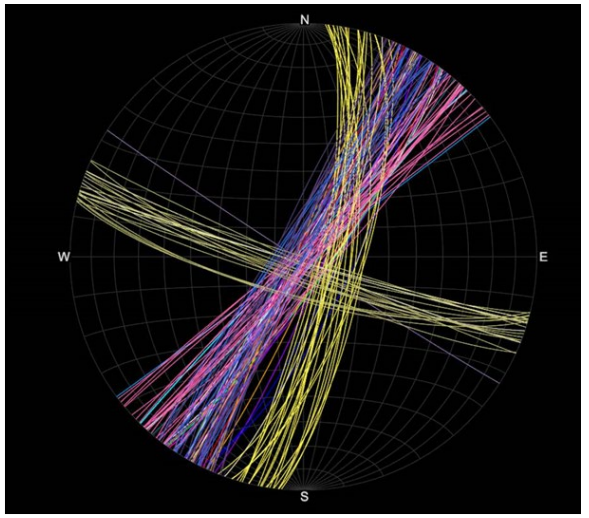


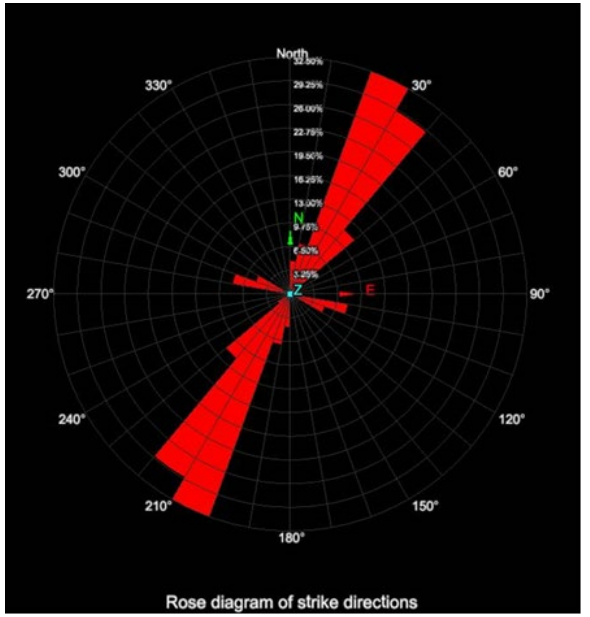




Fracture/Joint Mapping





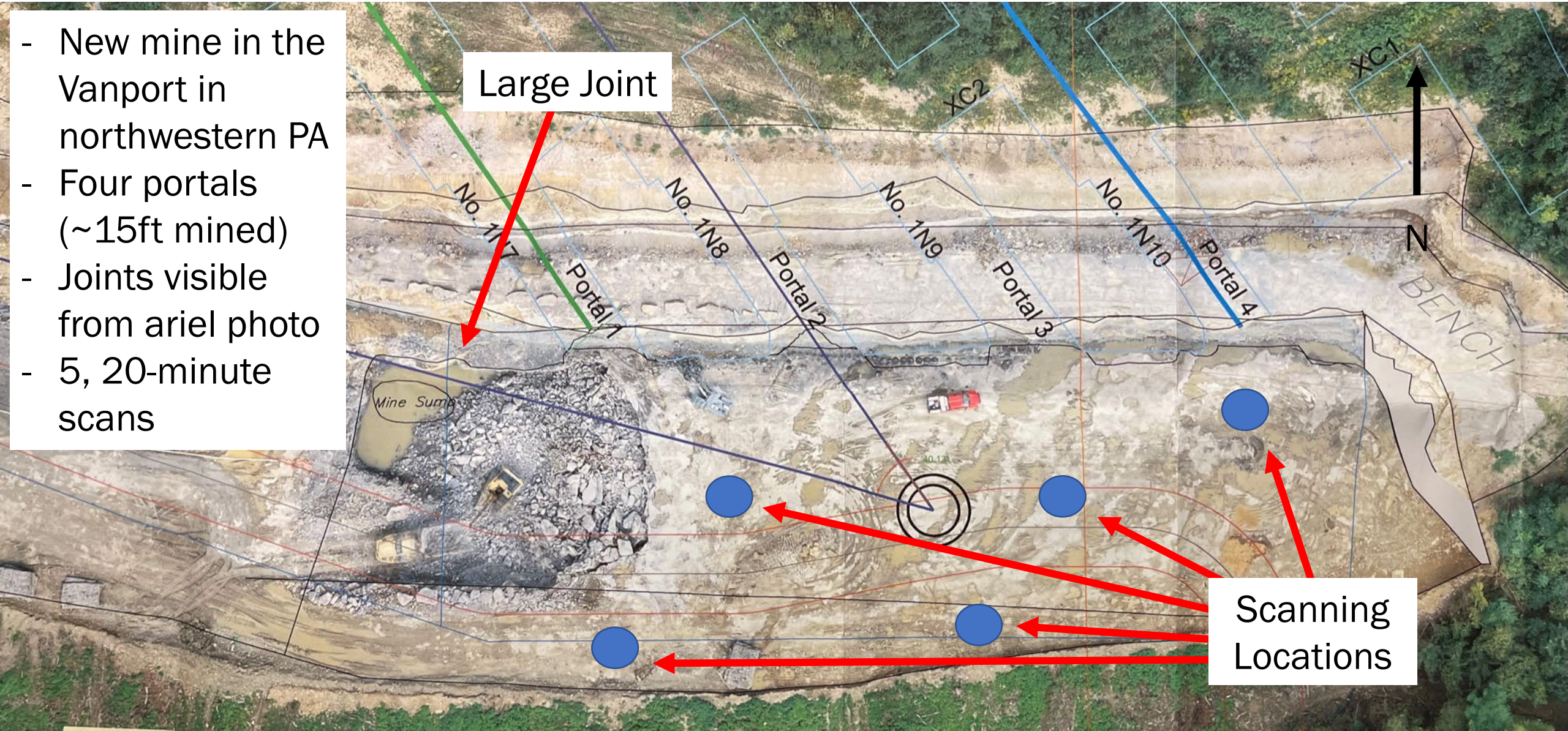


Highwall Geotechnical Assessment

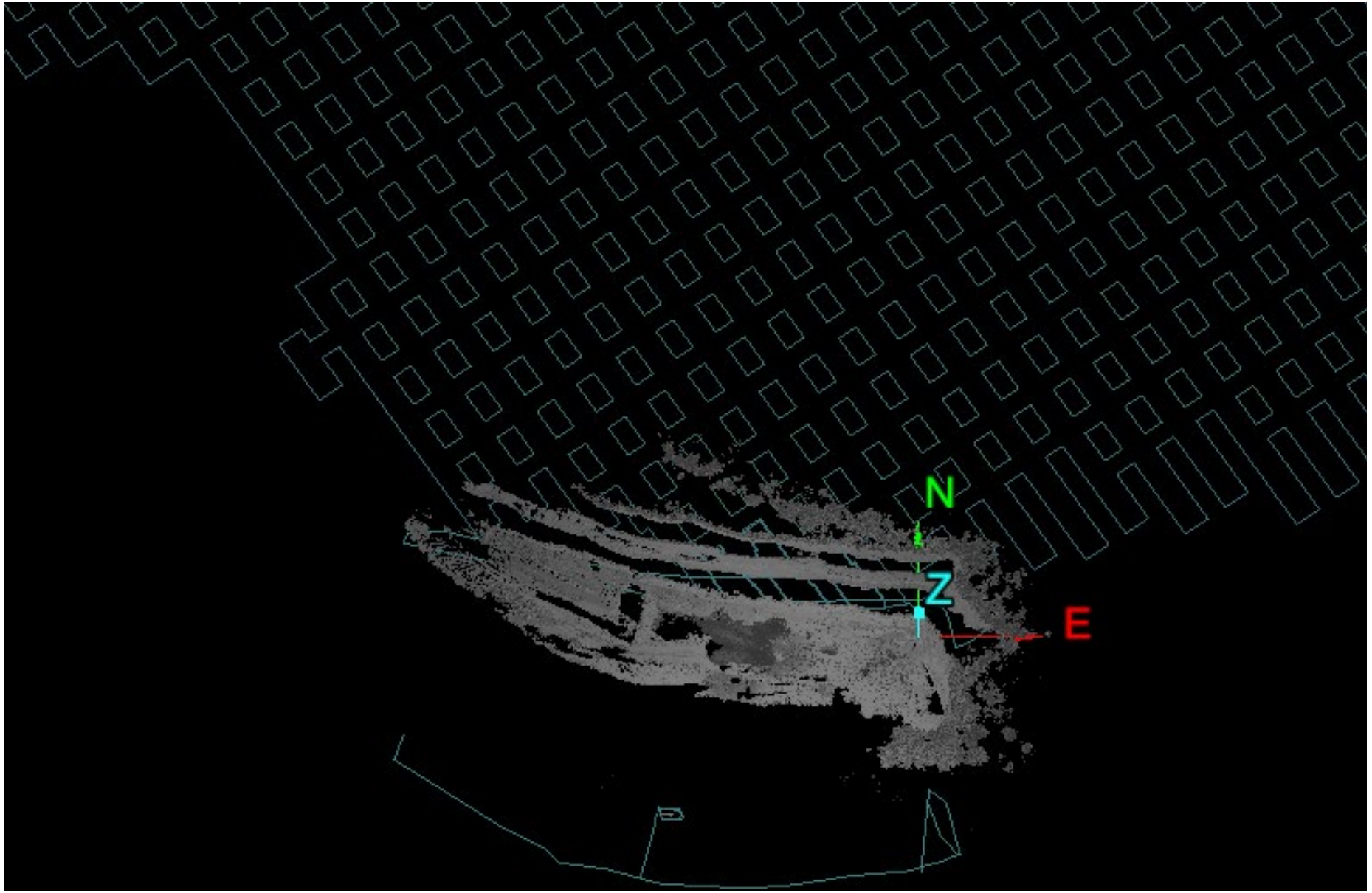
- Highwall Assessment Goals:
  - Map joint sets in LiDAR data
  - Reproduce joint orientations
  - Check accuracy of orientations against field measurements
  - Monitor changes after blasting

Study Site

- New mine in the Vanport in northwestern PA
- Four portals (~15ft mined)
- Joints visible from ariel photo
- 5, 20-minute scans

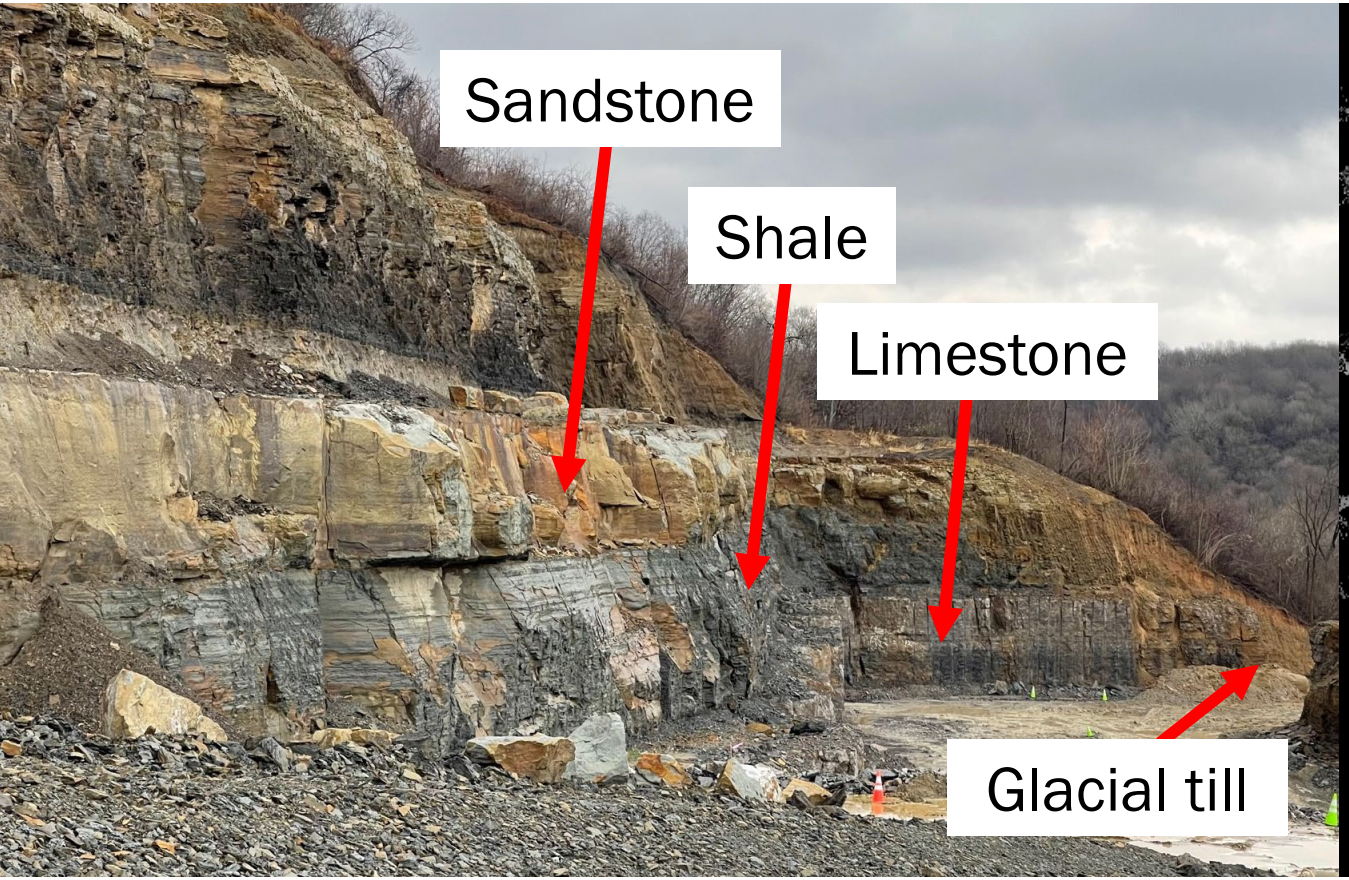


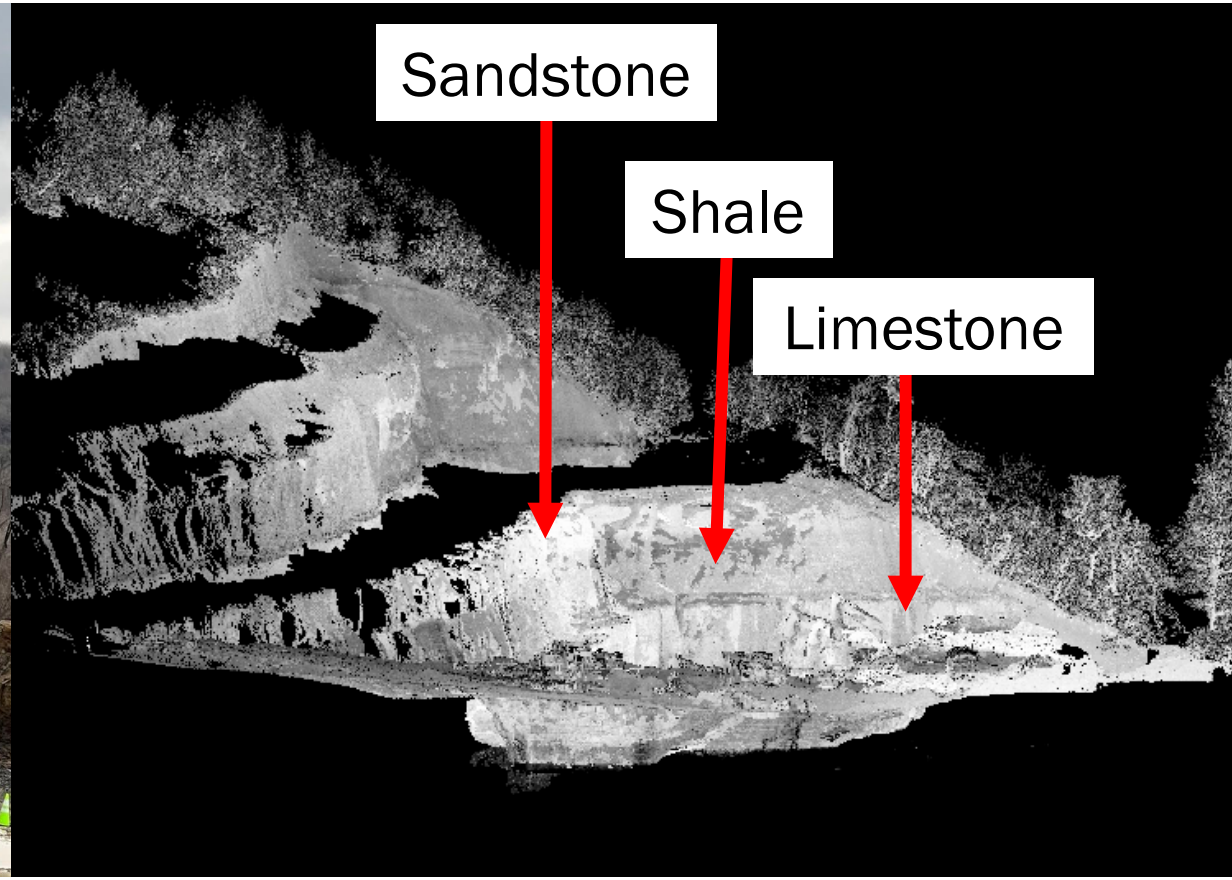
Study Site



- Adjusted scans to mine coordinates to obtain correct joint orientations

Geologic Characteristics

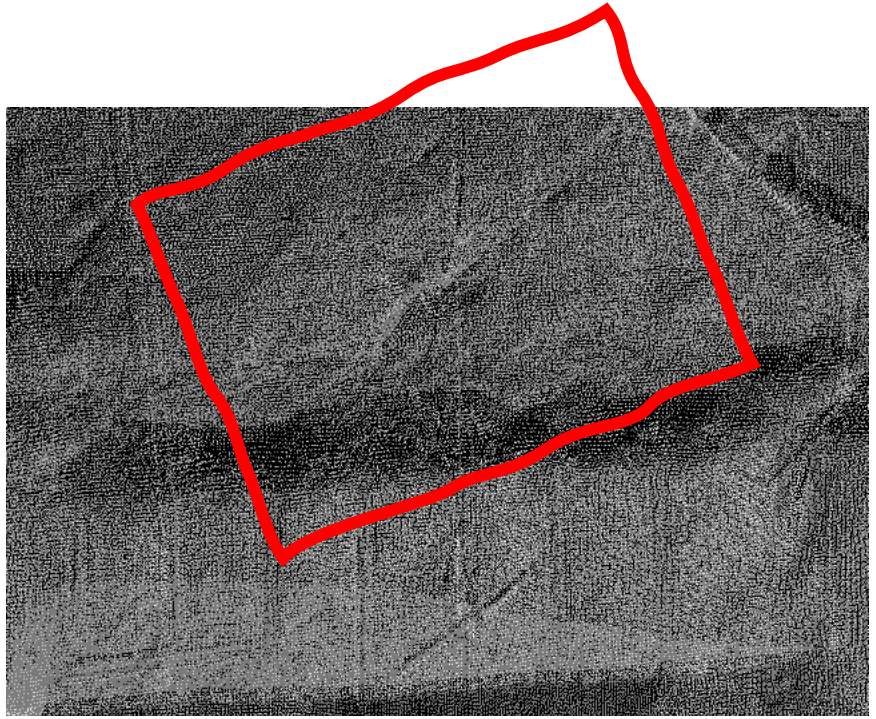




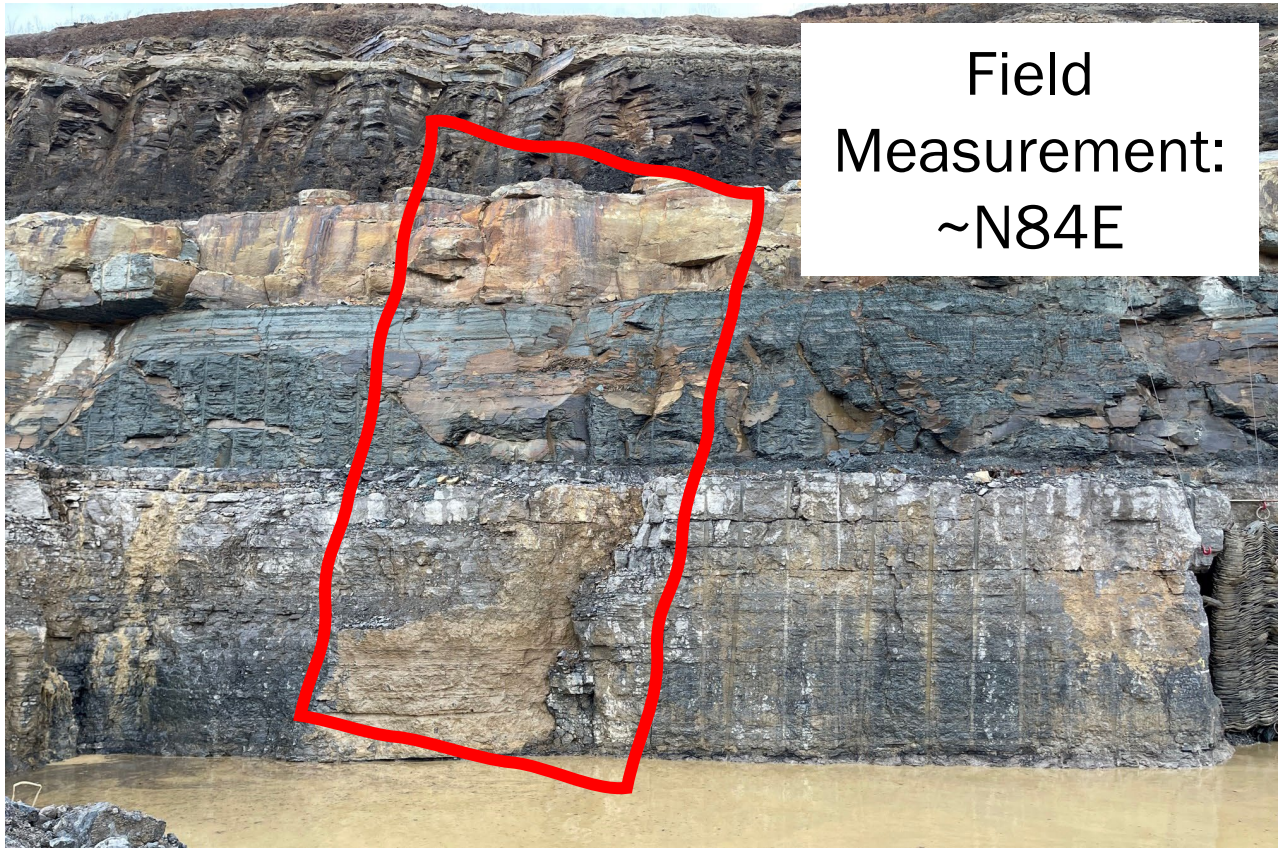
- South facing highwall, may be more prone to weathering (freeze/thaw)
- Immediate roof is shale with overlying sandstone
- Glacial till present, possible extension associated with uplift

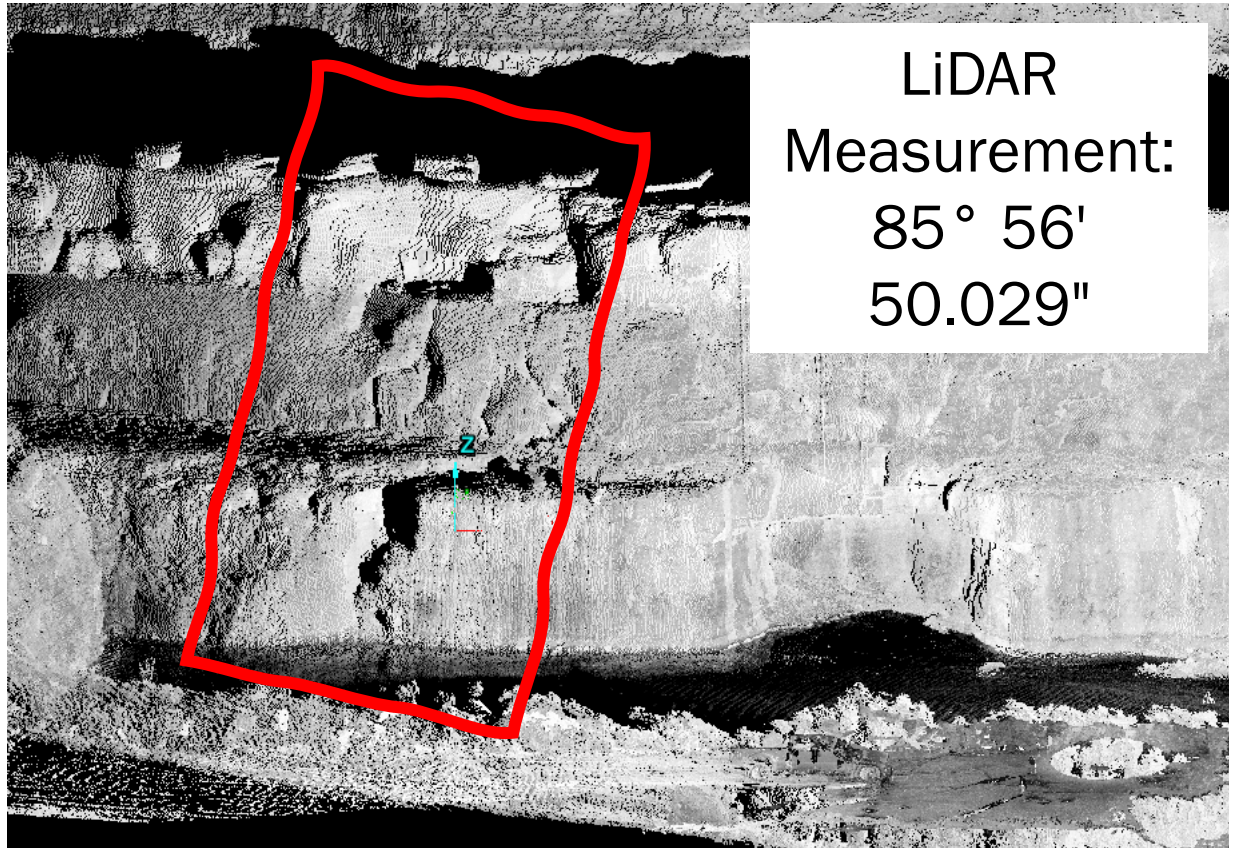
Joint Mapping

- Small joints
  - Scans pick up less prominent features
  - Intersecting joints in weak shale



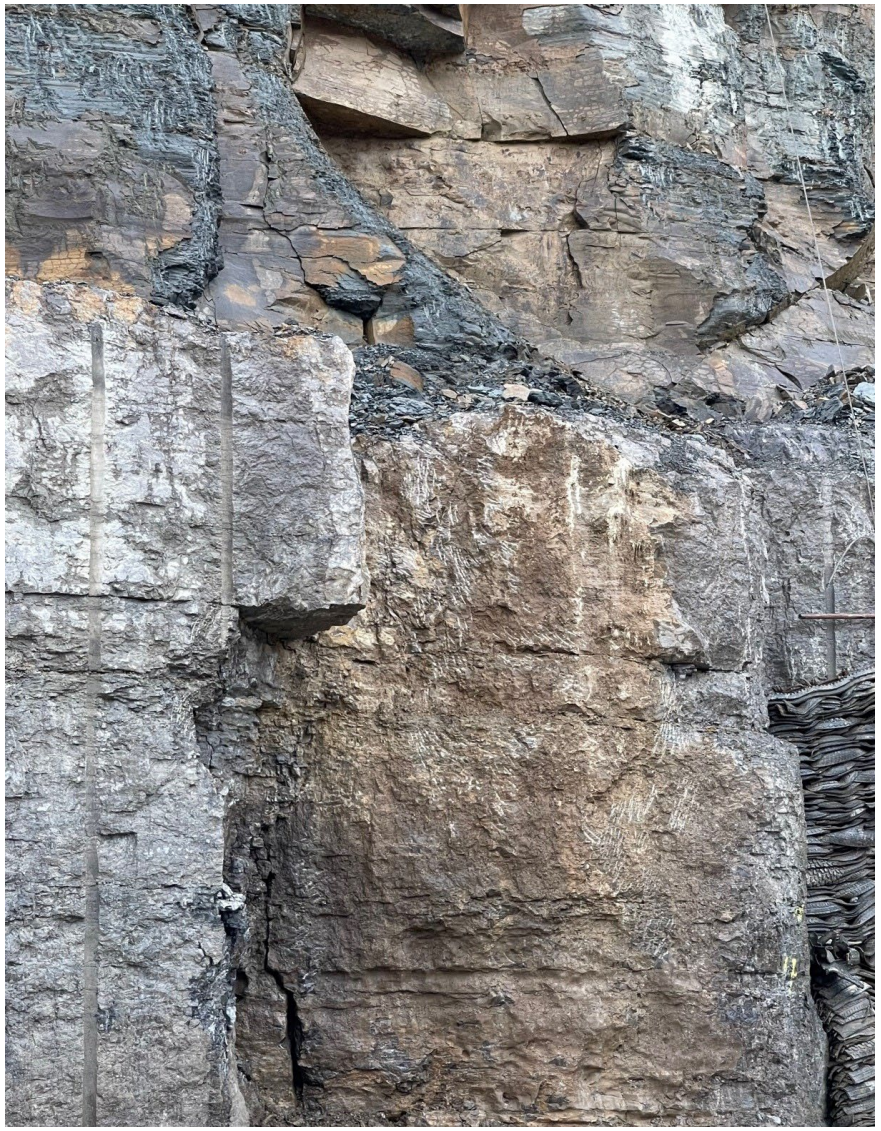
Joint Mapping



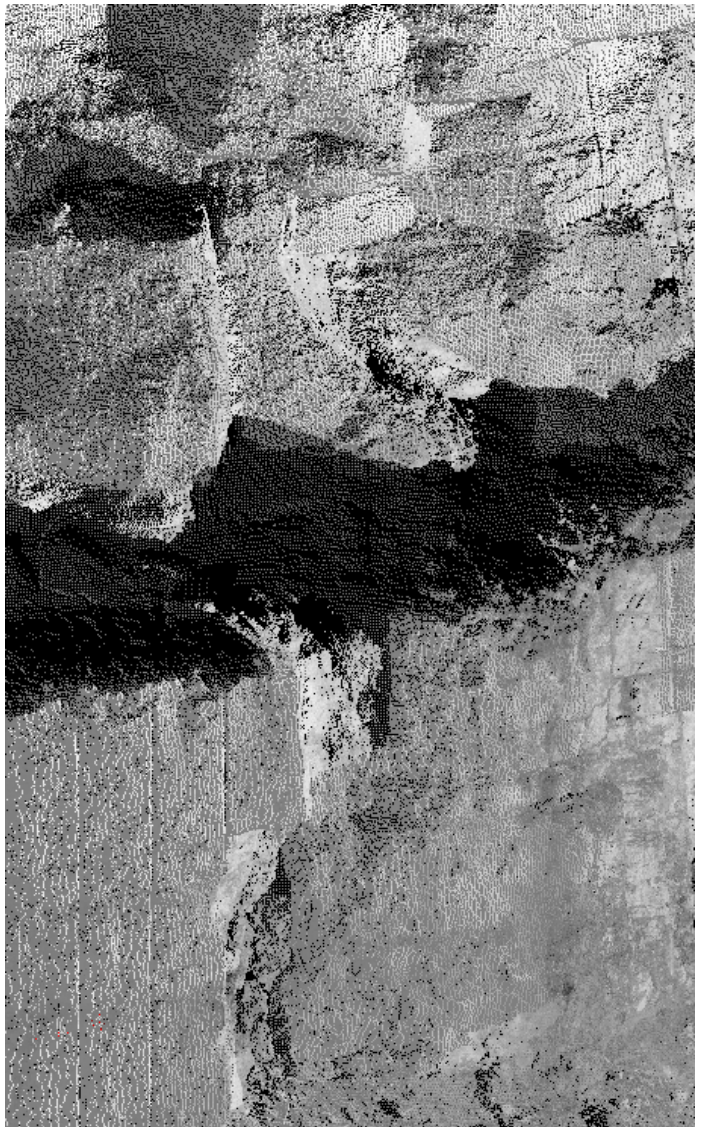


- Large joint
  - Orientation wavy
  - Extends into overlying strata (hillseam)
  - Projects across Portal 1 entry

Joint Mapping



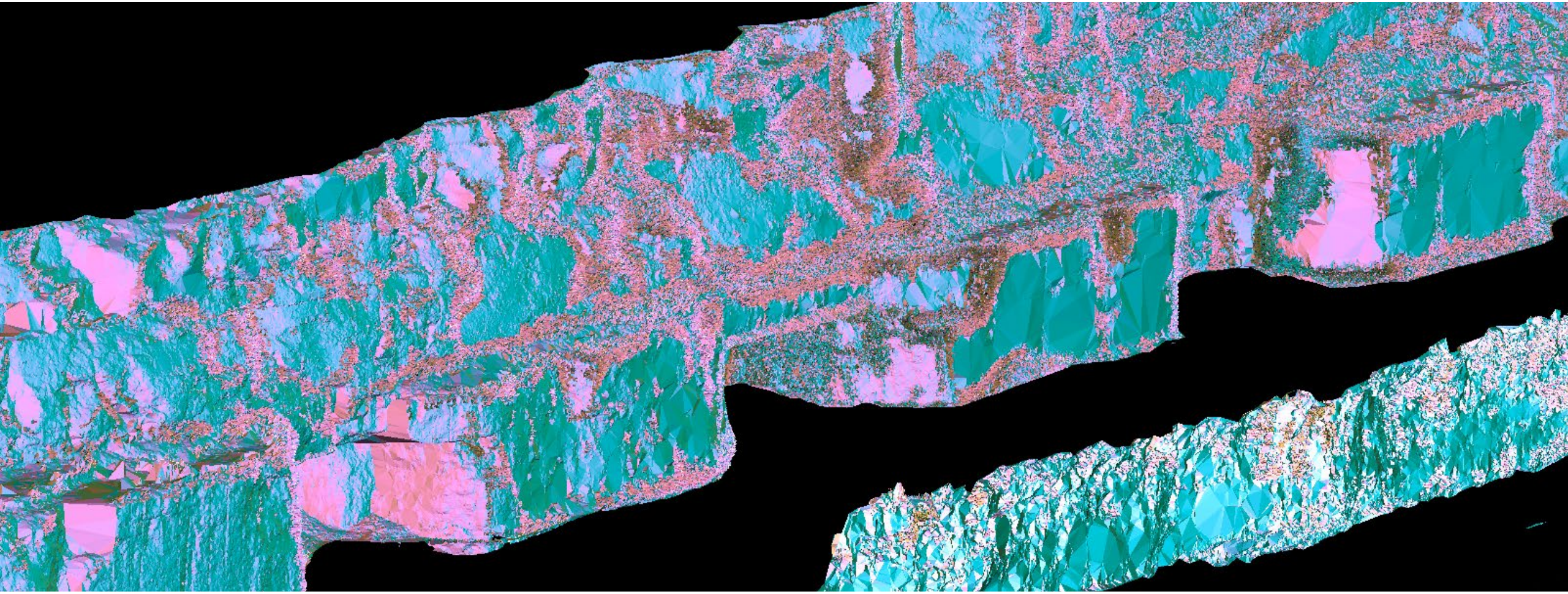
Photo



Pointcloud

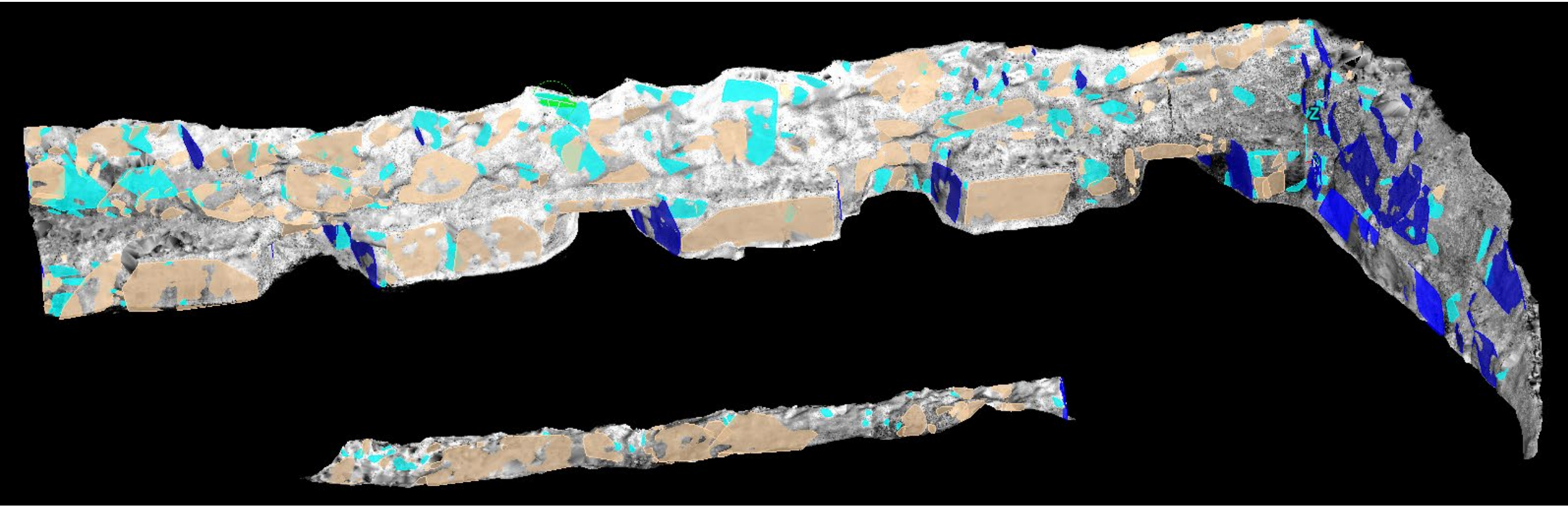
Surface with Mapped Joints

Color by Strike



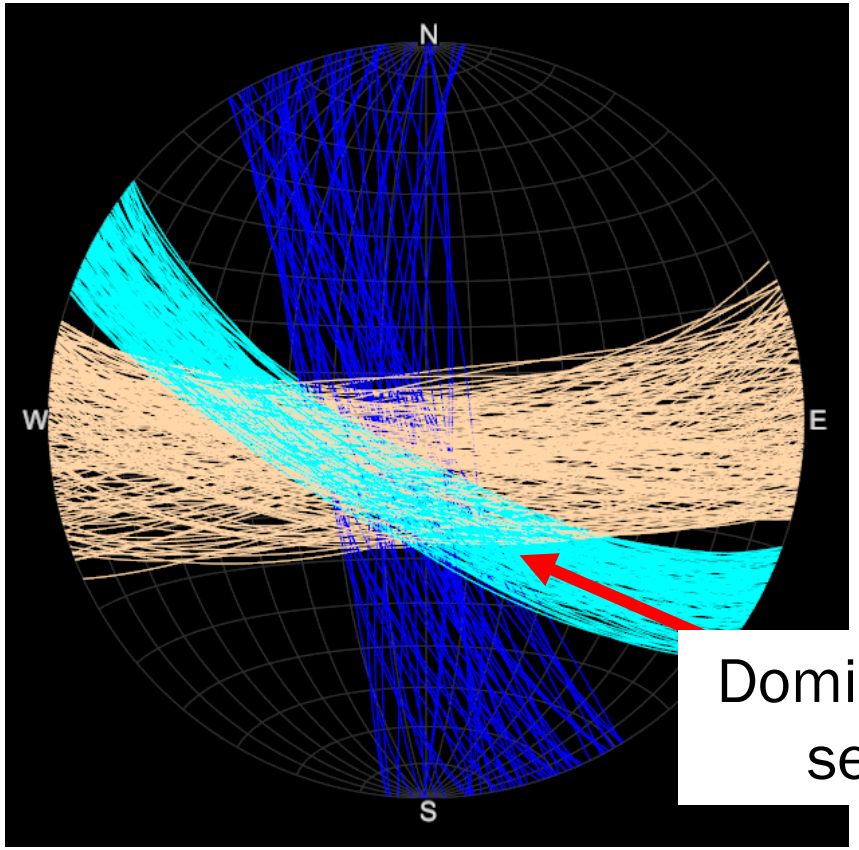
- Joints more noticeable
- Identify patterns

Extracting Joint Orientations from LiDAR

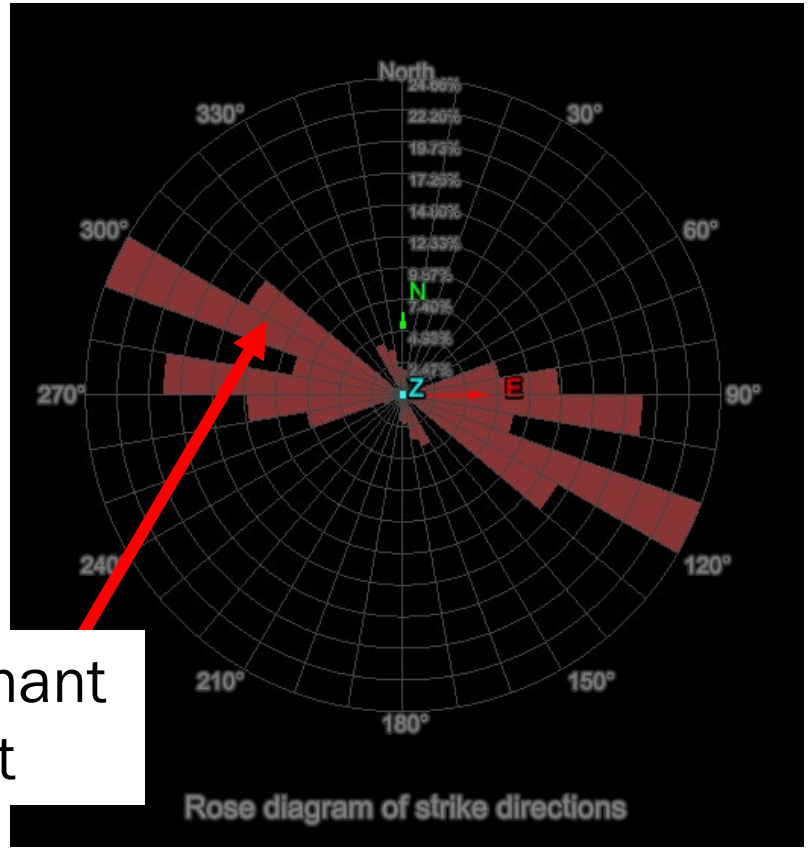


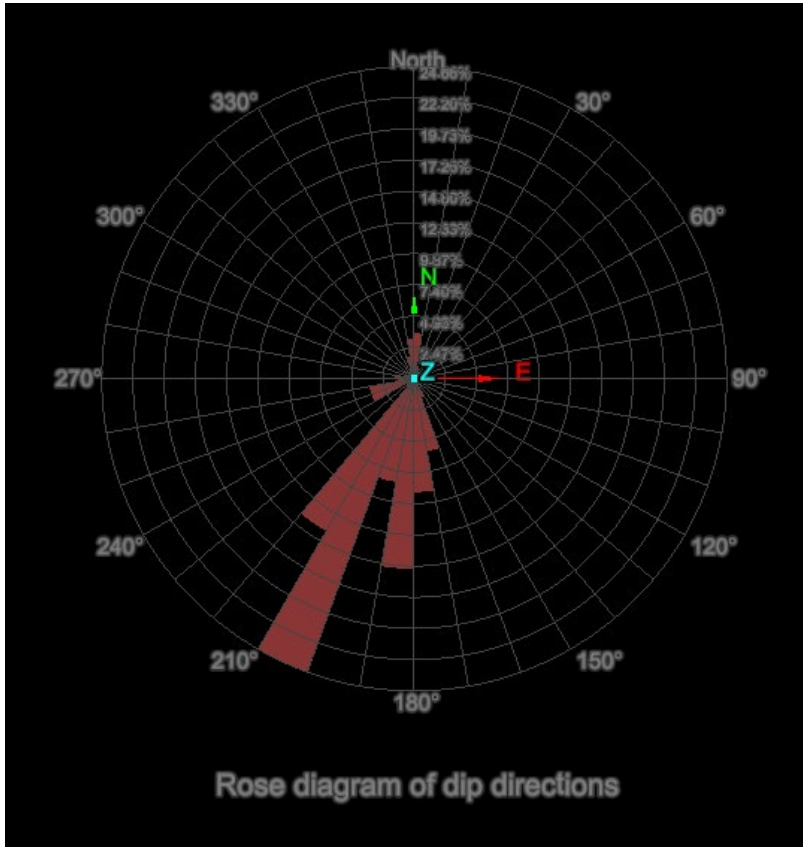
- Three joint sets
  - Tan (Field ~N84E), Wavy 20-degree variant
  - Cyan, Straight 10-degree variant
  - Dark Blue (Field ~N44W), Wavy 20-degree variant

Stereonets and Rose Diagrams



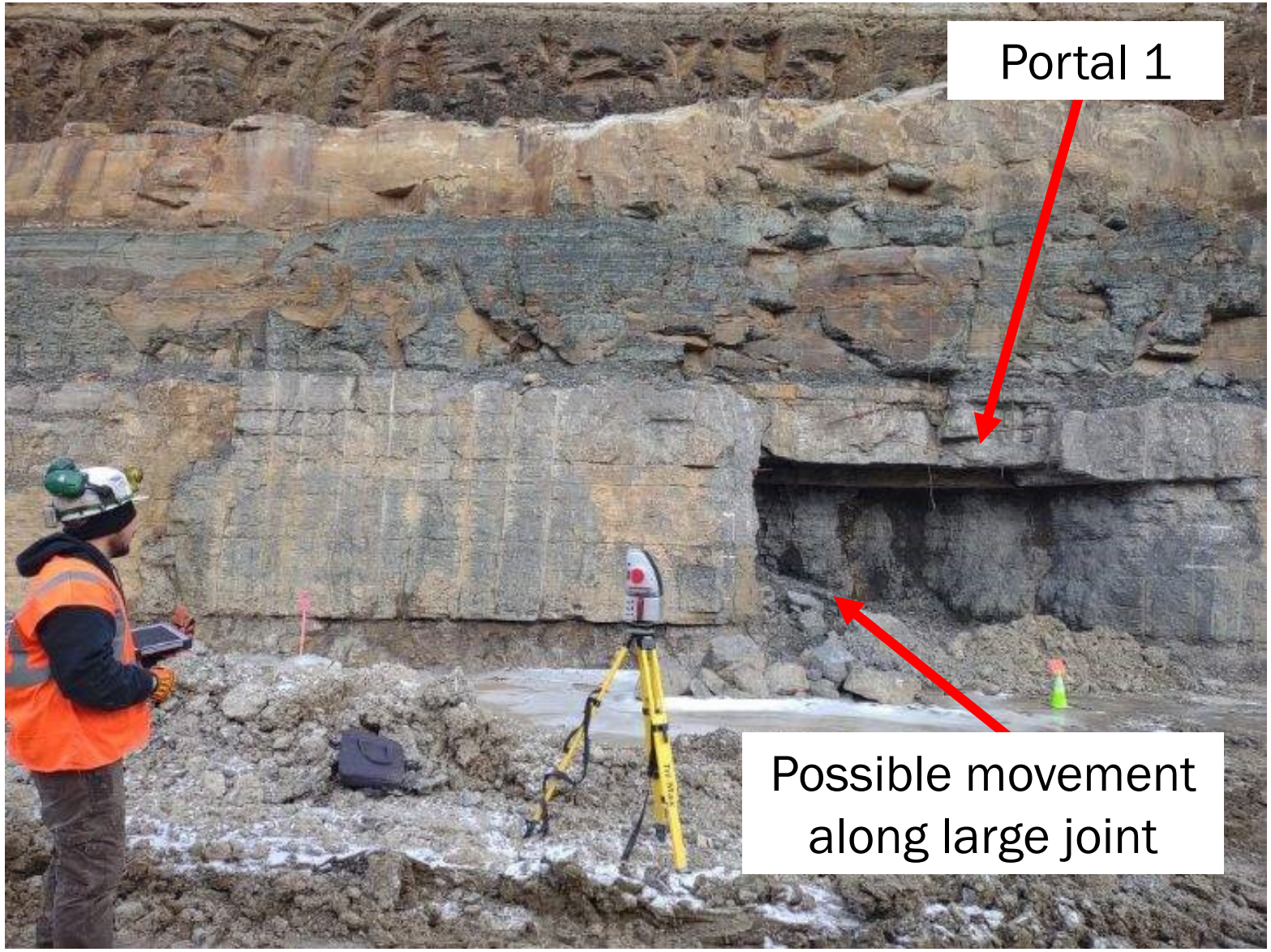
Dominant set





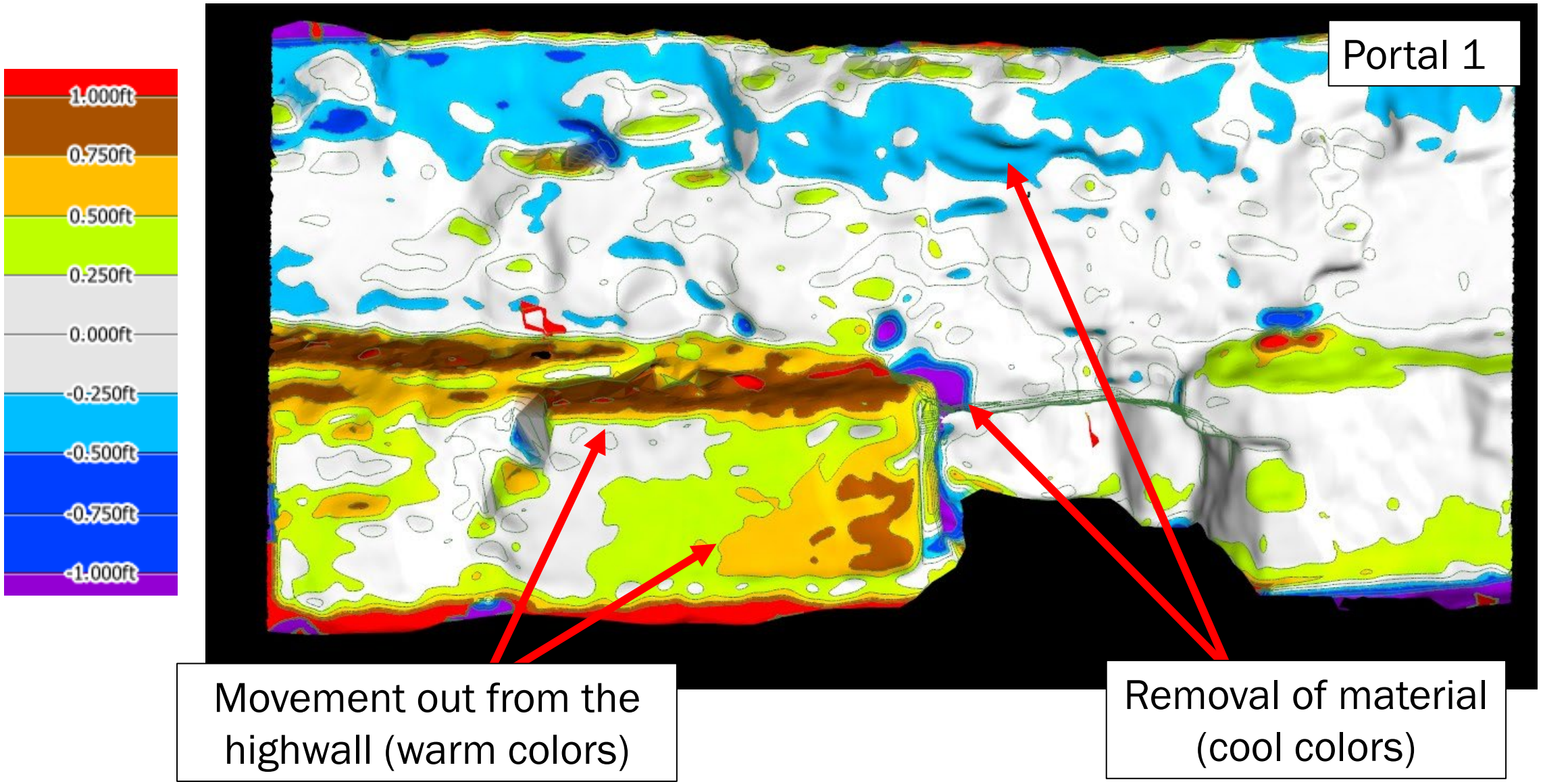
- LiDAR joint orientations correlate to field measurements

Change Detection

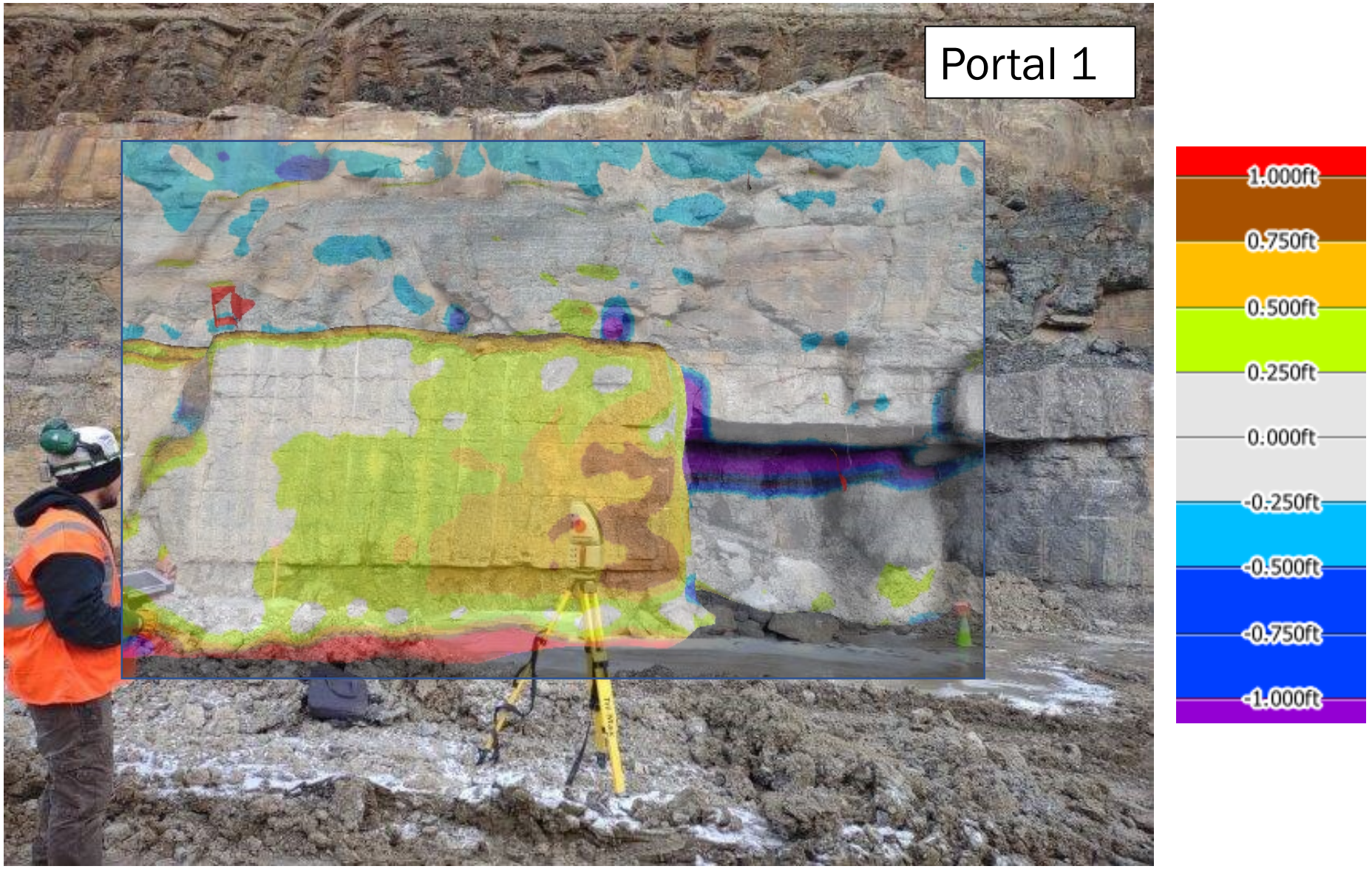


- Movement along large joint noticed after blasting in Portal 1
- November 2022: NIOSH scanned prior to movement, establishing a baseline scan
- December 2022: NIOSH returned after movement to attempt to pick up the changes in the LiDAR scans

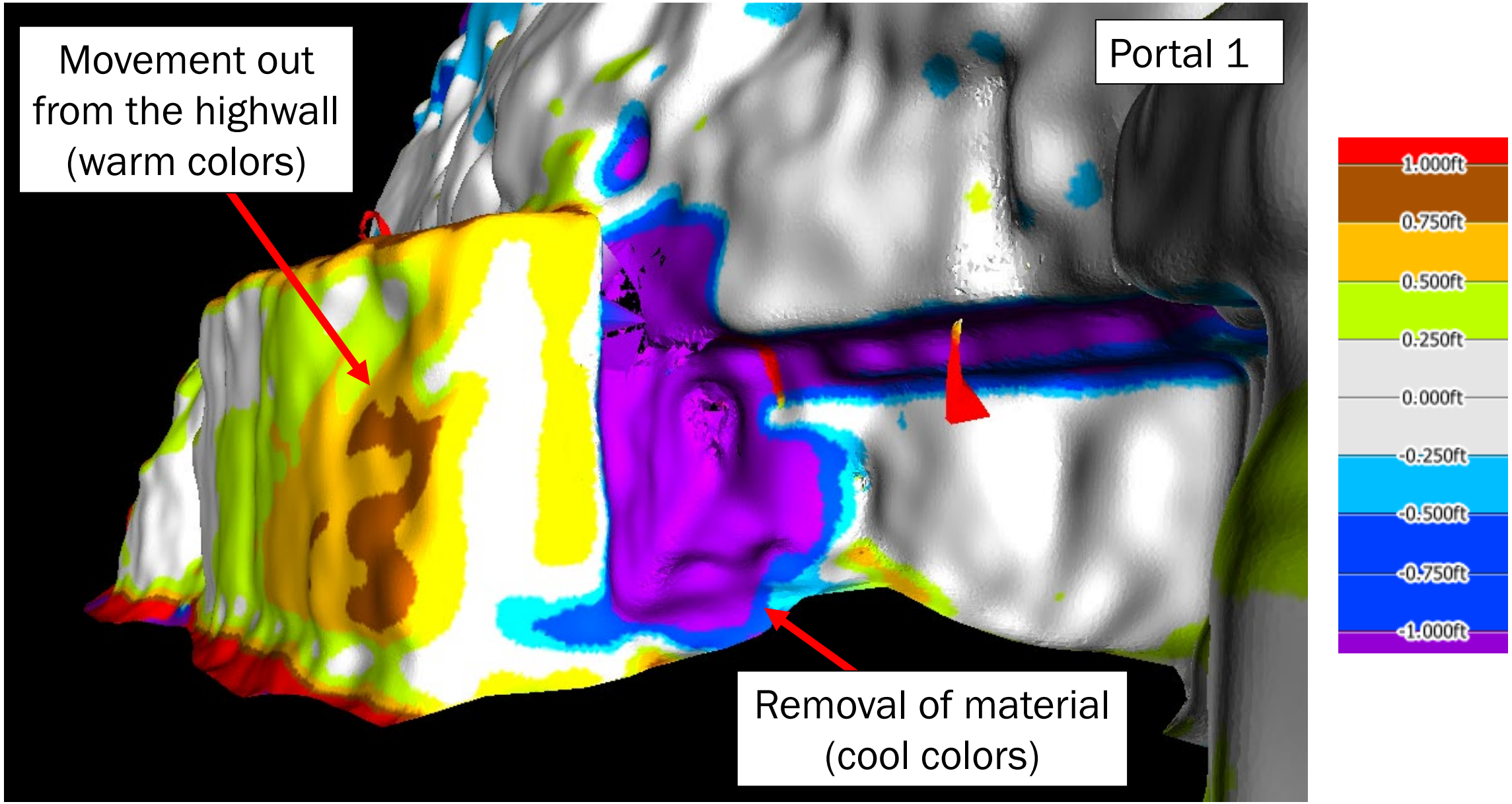
Change Detection



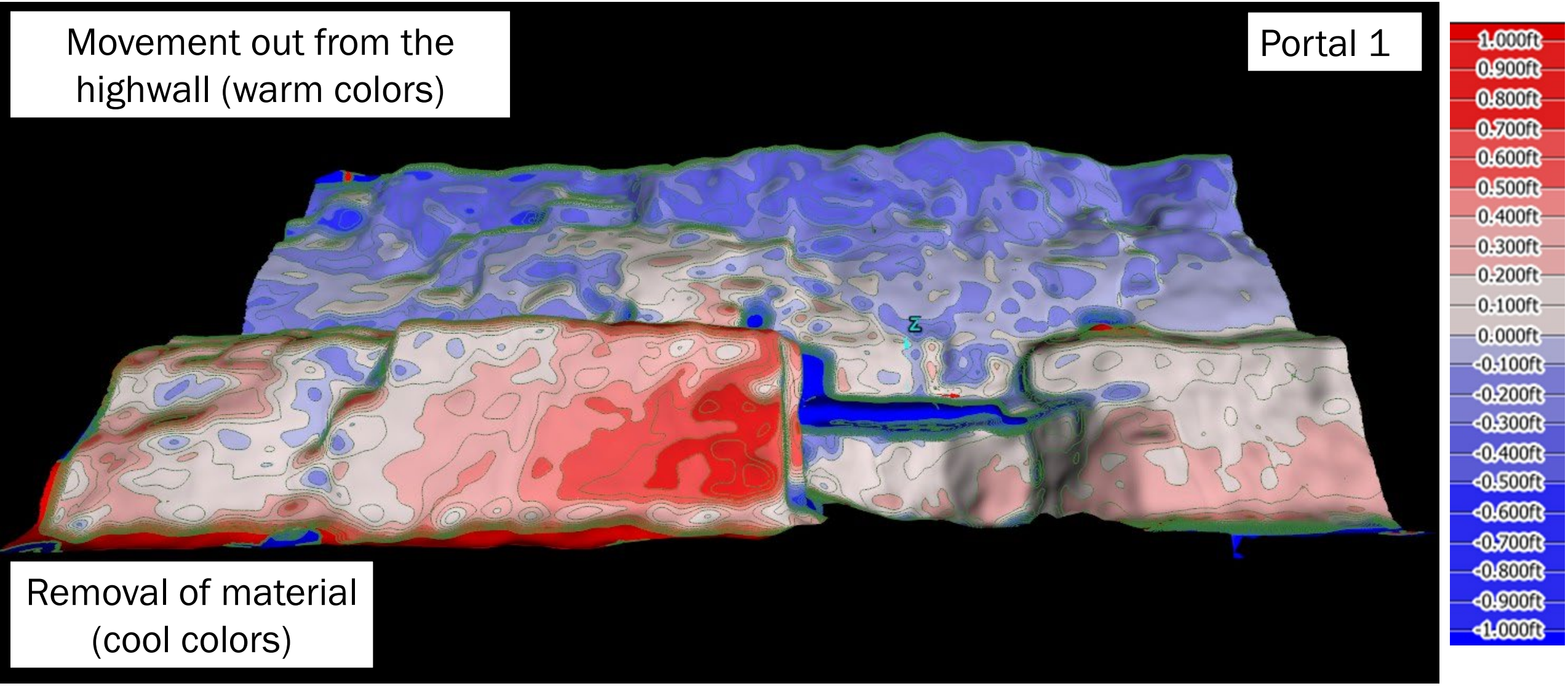
Change Detection



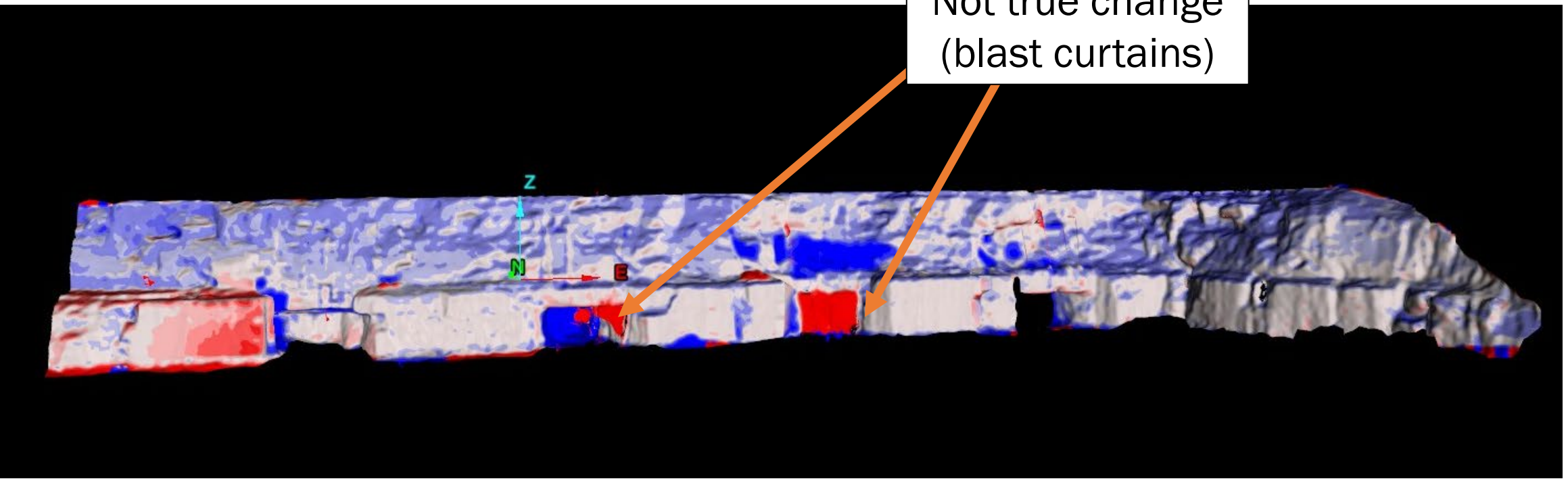
Change Detection



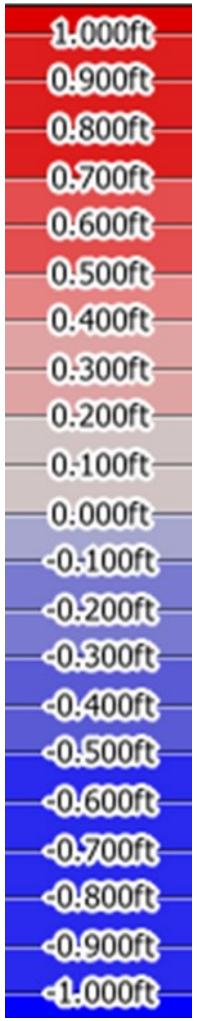
Change Detection



Change Detection



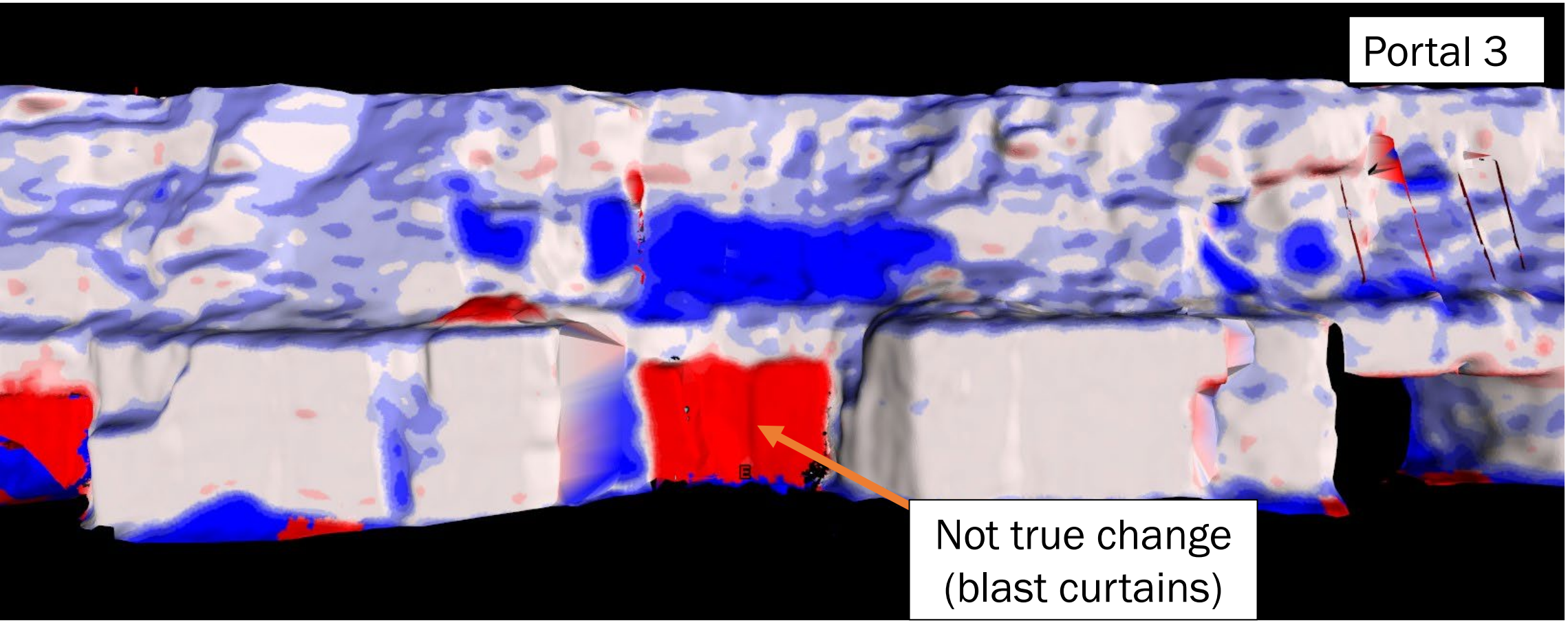
Not true change (blast curtains)

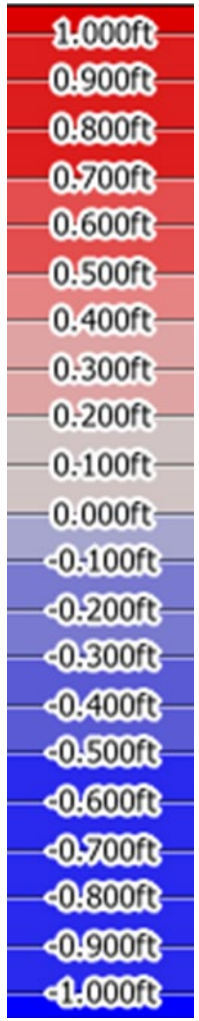


Movement out from the highwall (warm colors)

Removal of material (cool colors)

Change Detection

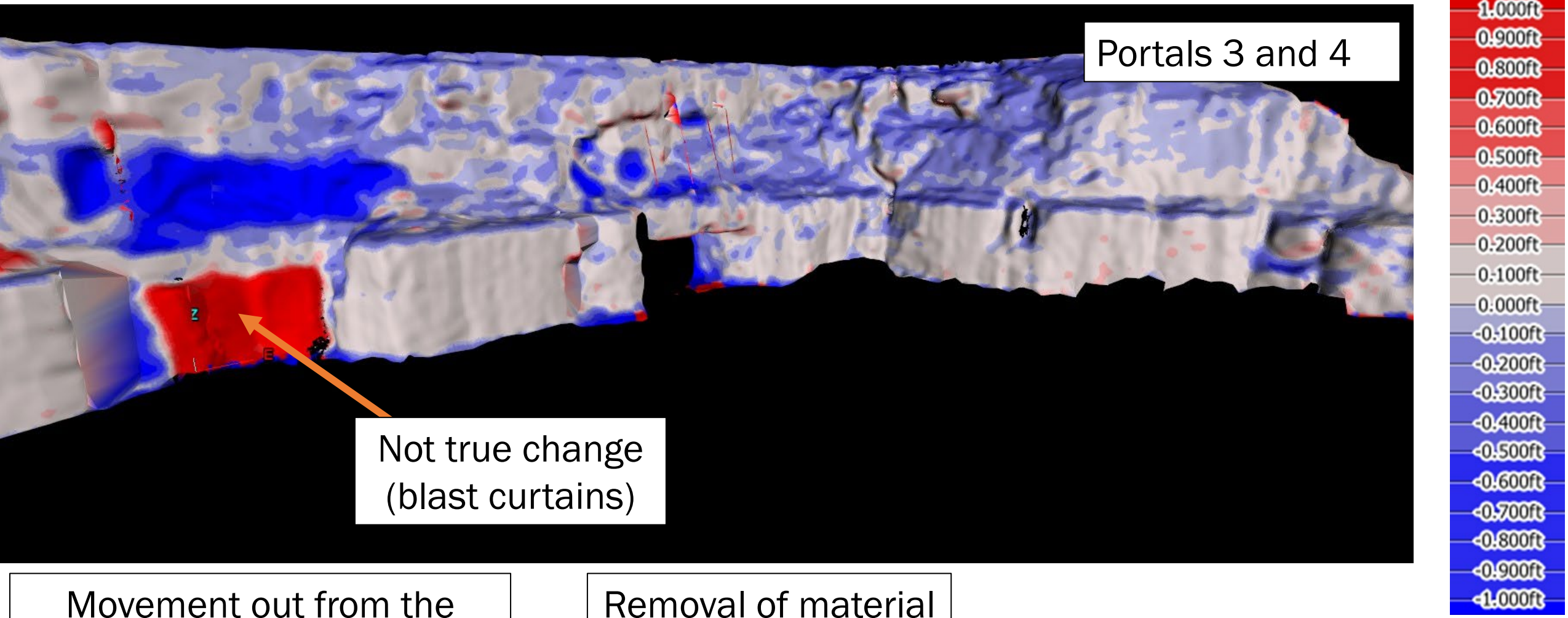




Movement out from the highwall (warm colors)

Removal of material (cool colors)

Change Detection



Movement out from the highwall (warm colors)

Removal of material (cool colors)

LiDAR has been extremely useful for not only the Methods to Reduce the Potential for Massive Ground Collapses in Underground Stone Mines Project, but also for several other projects at PMRD.

Questions?