Autonomous Mapping of Abandoned Underground Mines with UAVs

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PEM
Moving Kentucky Forward

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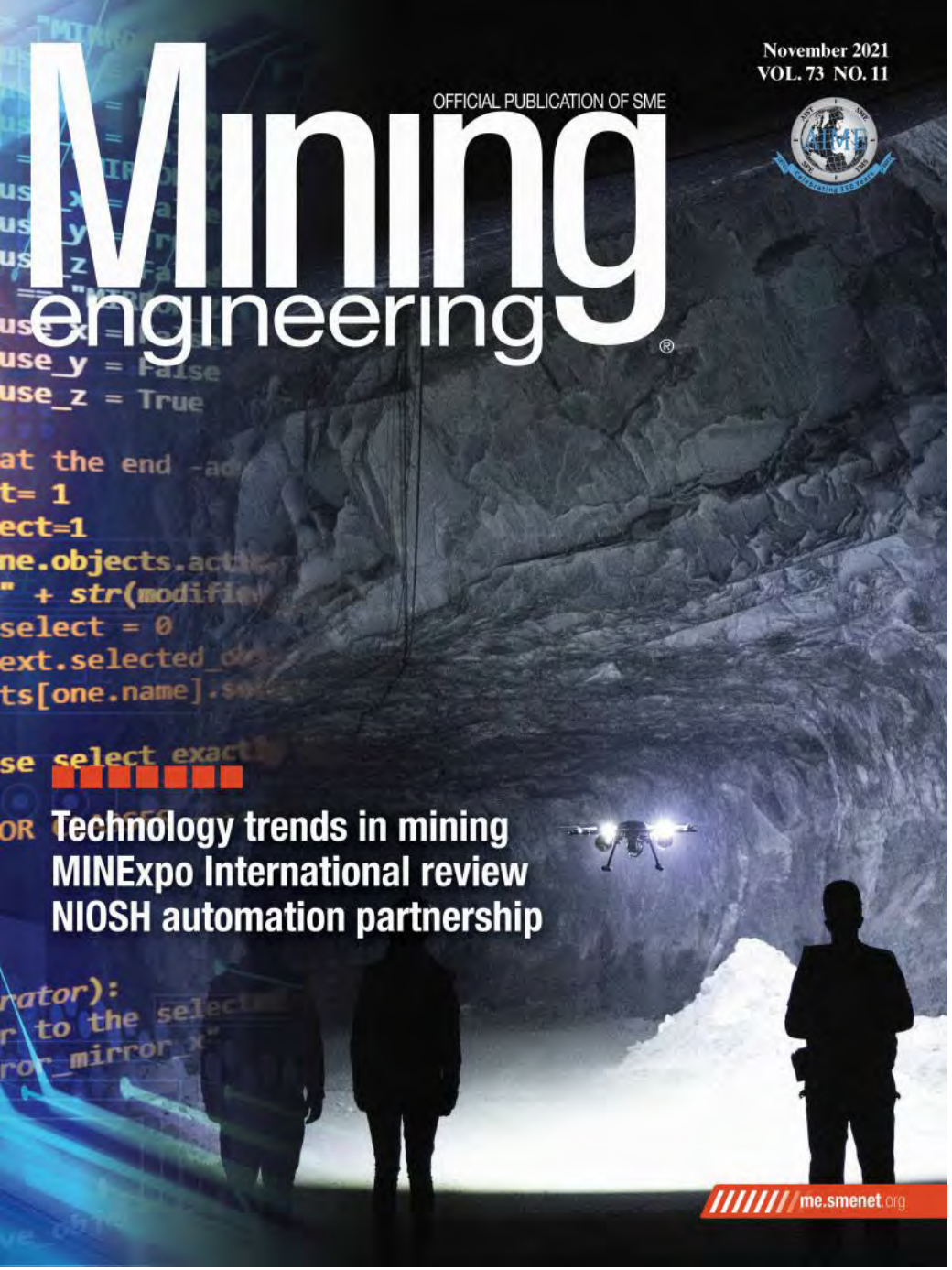
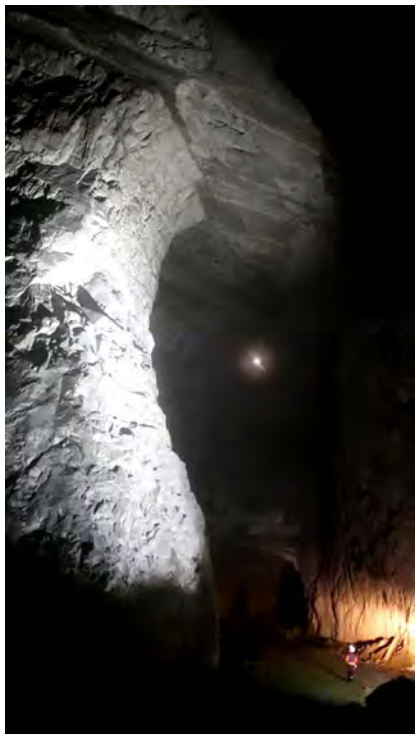
exyn
MAPTEK™



Outline

1) Background & Motivation
2) Project Goals
3) UAV Development
4) Case Studies
5) Conclusions



Motivation

Background – Stone Pillar Collapses

- Low width-to-height ratios, irregular shapes & geologic features can be problematic
- Difficult to monitor pillars in old works due to limited access
- As-mined assessment of pillars is needed
- 5 significant pillar collapses in stone mines between 2015 – 2021
- Is there a safe method to remotely map and monitor underground pillars?

← Source: MSHA →

Source: 1057 News

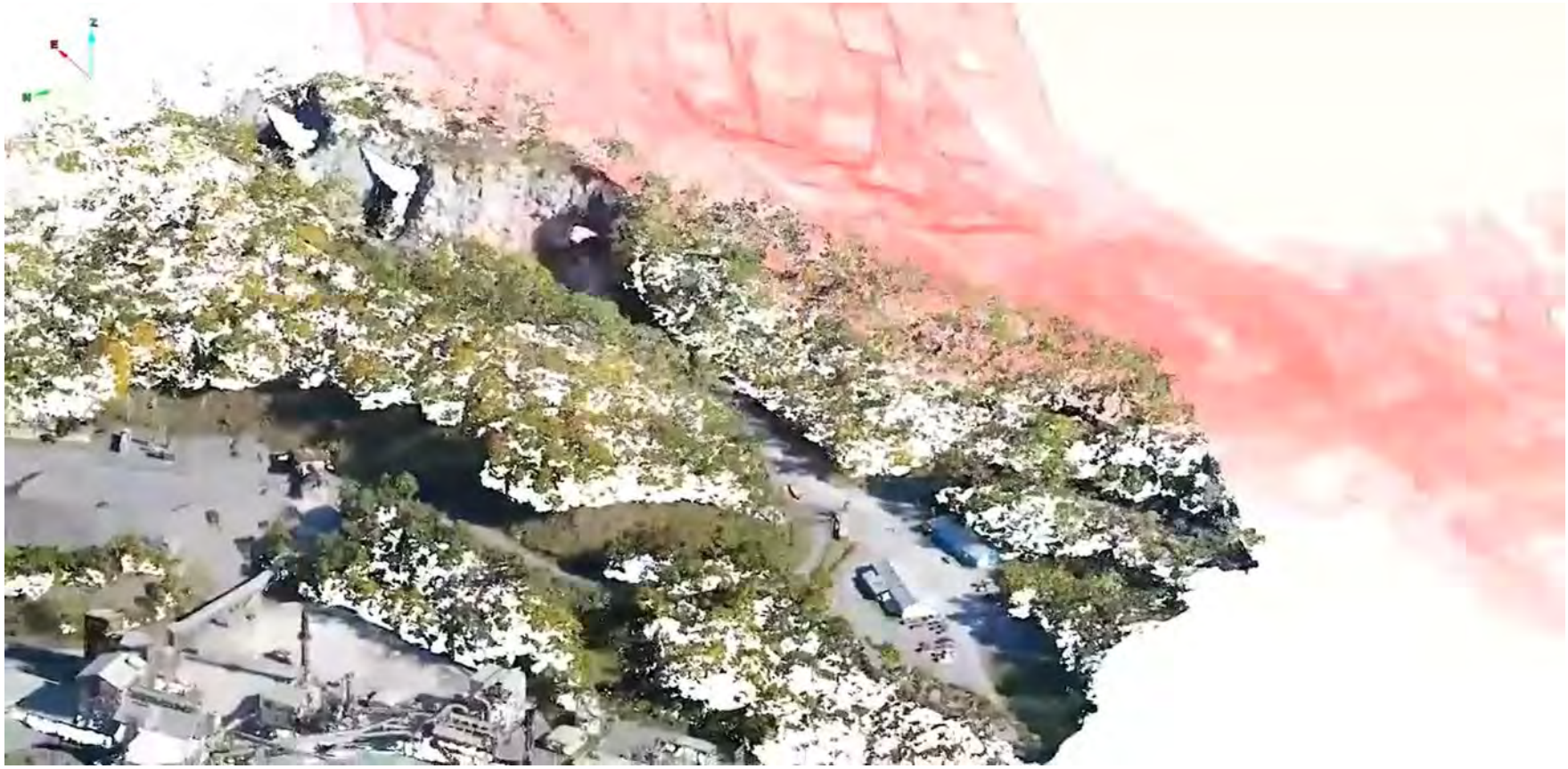
Traditional Surveying

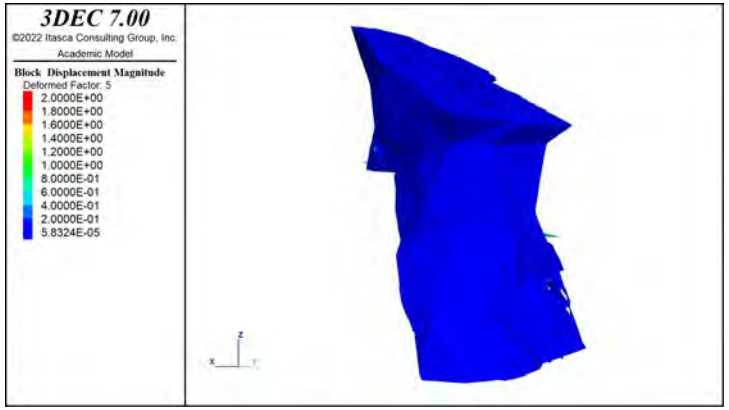
- Proven, Precise

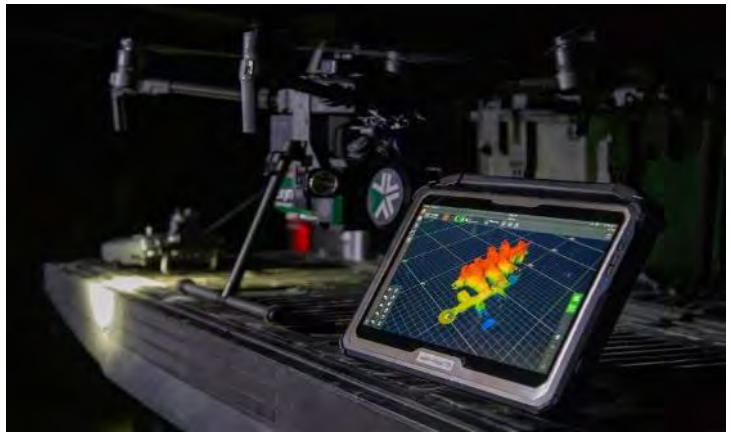
  ..but time consuming, few points
- Places surveyor at risk to potential ground falls, slip/trip hazards
- Limitations due to accessibility

Project Goals

- #1: Drone-based mapping beyond visual line of sight (BVLOS) in GPS-denied u/g mines
- #2: Capture quality data to use for geotechnical & numerical analysis

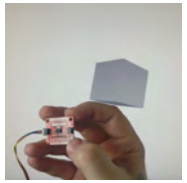






UAV Multi Sensor Fusion

Sensors

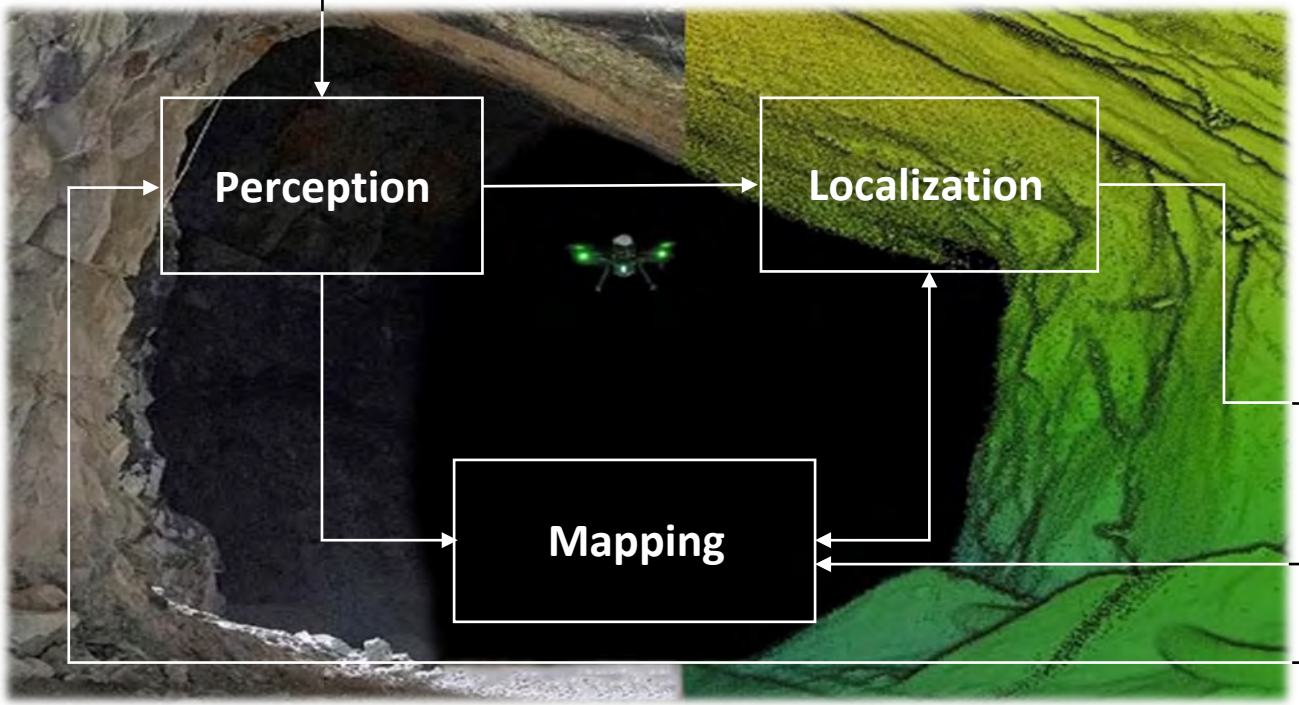

IMU

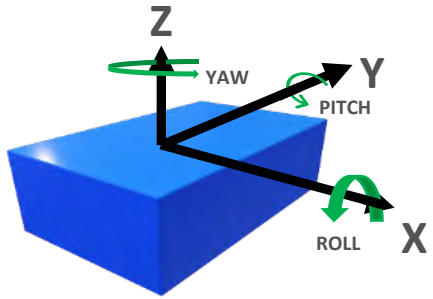

Optical Flow

Lidar


Laser Rangefinder

Stereoscopic Computer Vision



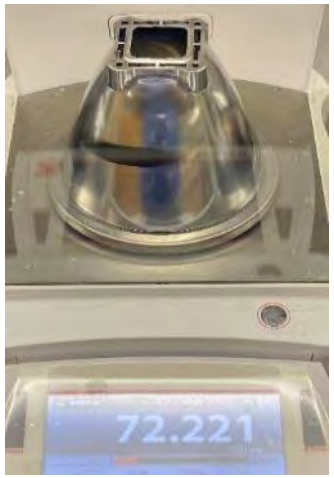


Path / Motion Planning

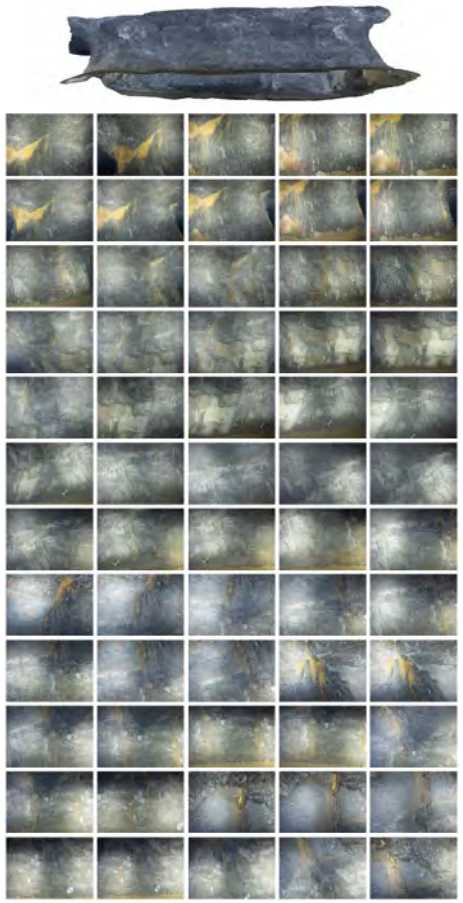
$p(x_{0:T}, m \mid z_{1:T}, u_{1:T})$

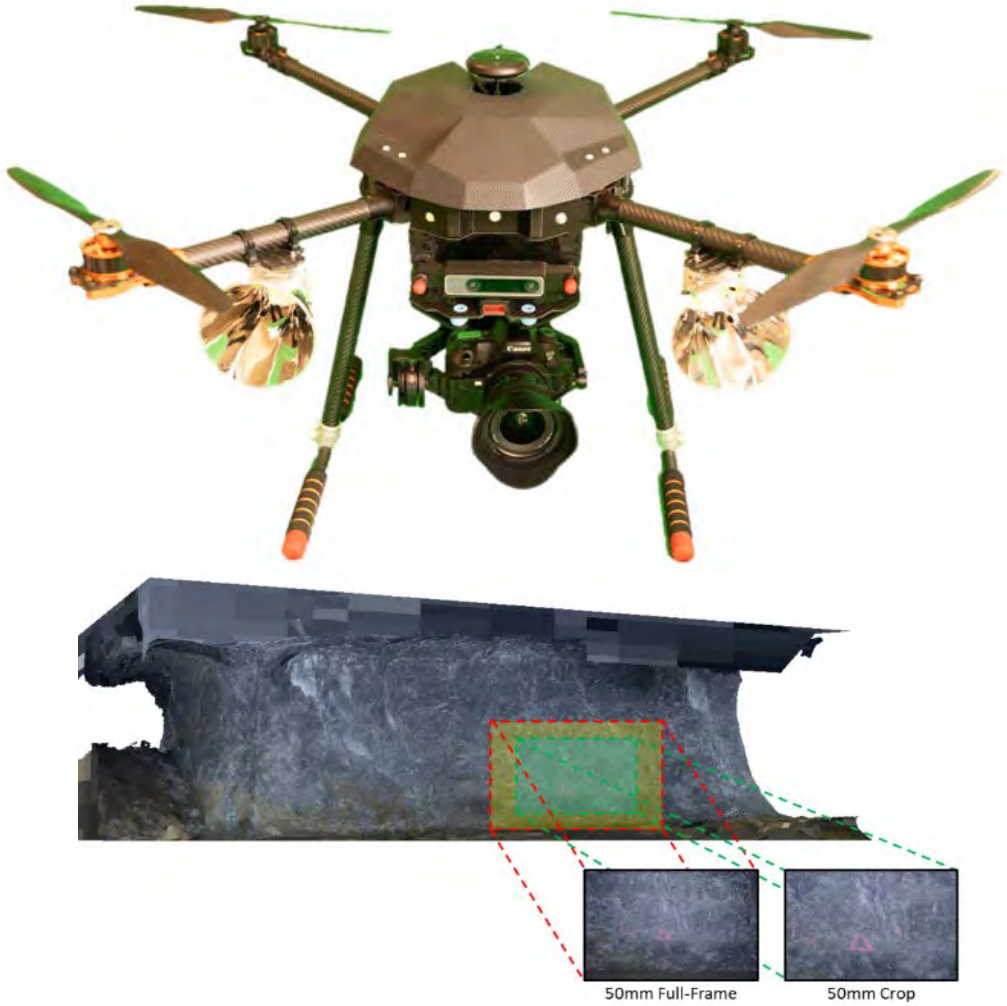
Control

Onboard Lighting Development



Camera Design





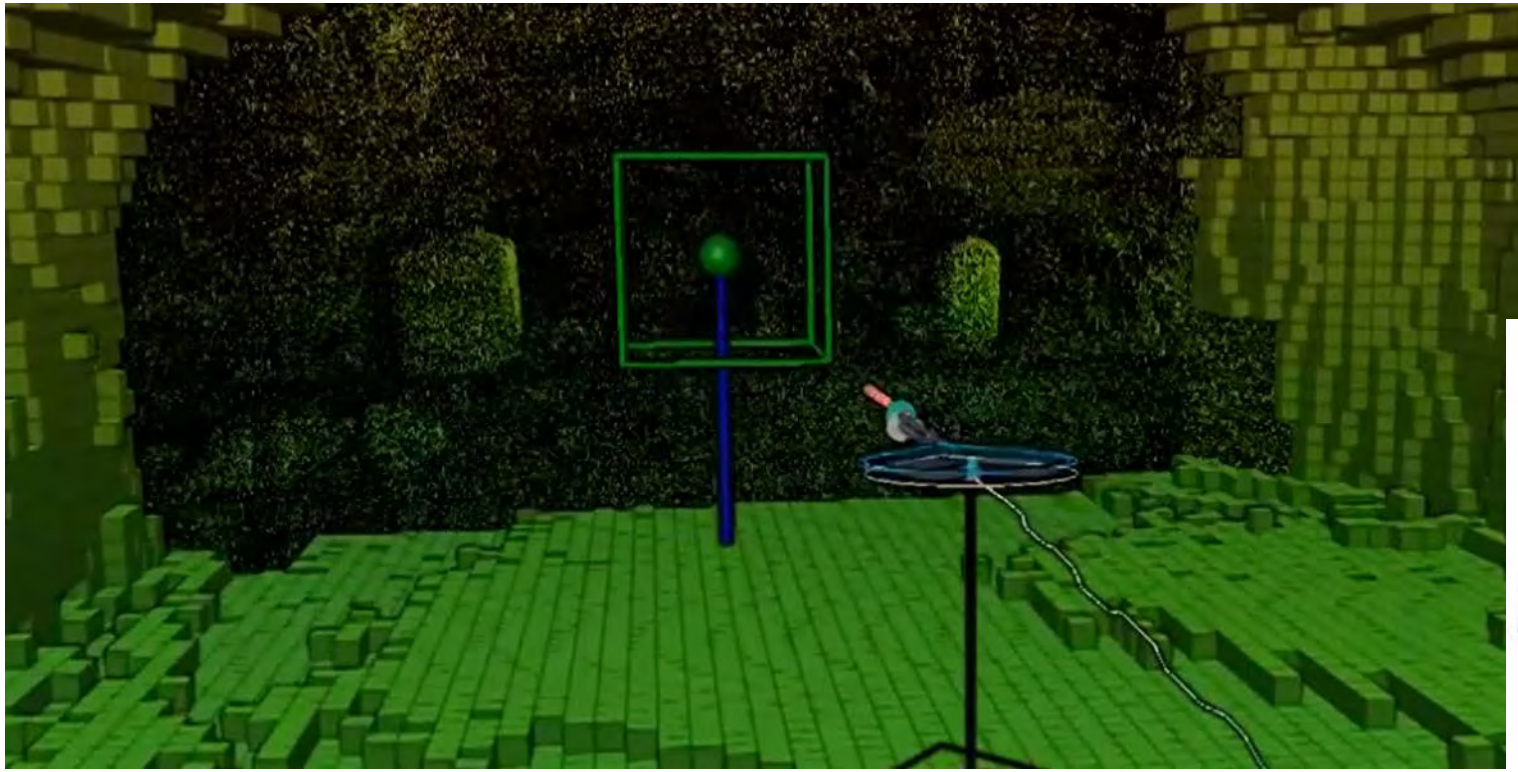
AUTONOMOUS UAV’s

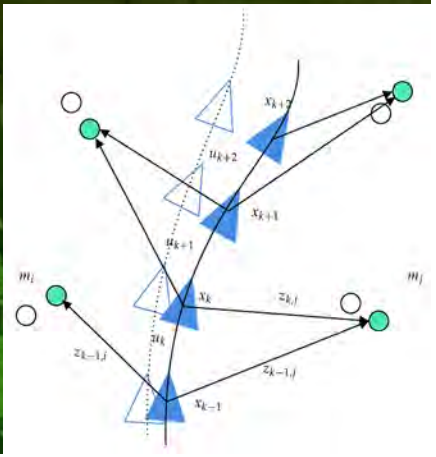
FILM: PROMETHEUS (2012 FILM DIRECTED BY RIDLEY SCOTT)

Drone-based Lidar Scanning

Simultaneous Localization and Mapping

- **SLAM** - algorithm to map an environment while keeping track of the object's location within
- **Occupancy grid -** generated to simplify localization & reduce onboard processing req'd



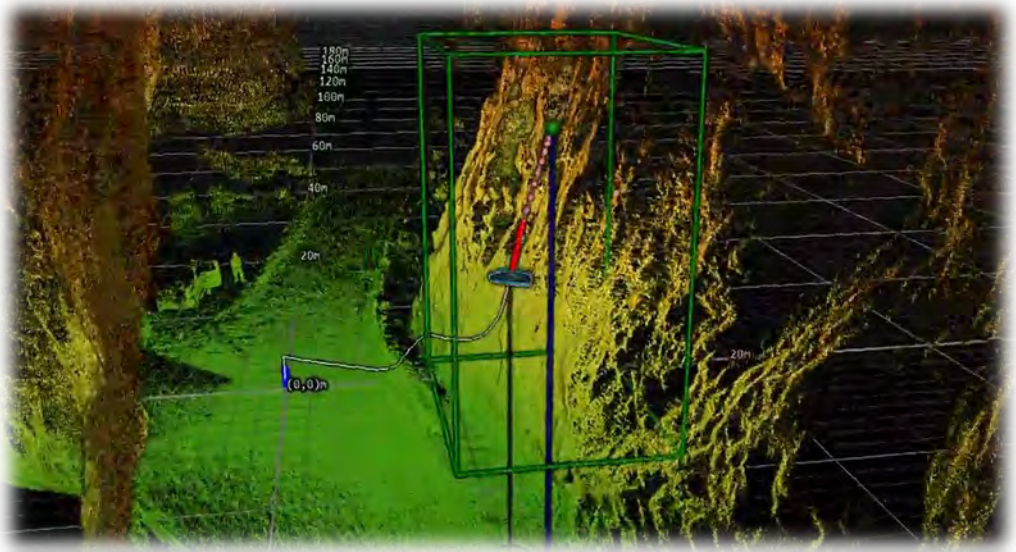


Playback @ 4X

Case Study #1: Benched Mine Pillar (30m height)

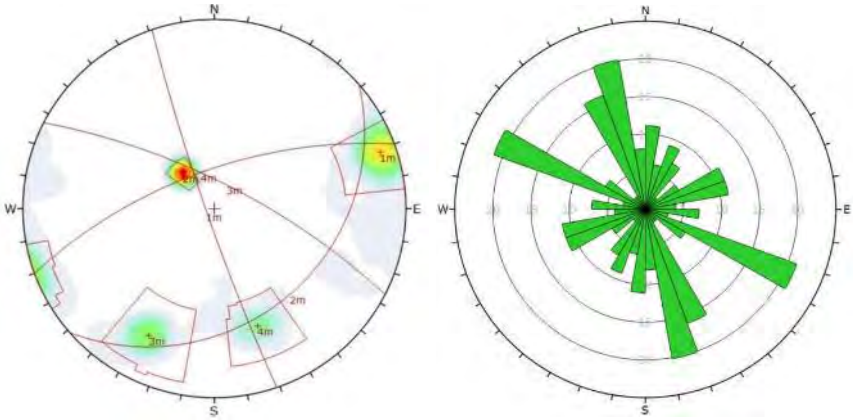
Drone-based Mapping of a 30m Benched Pillar

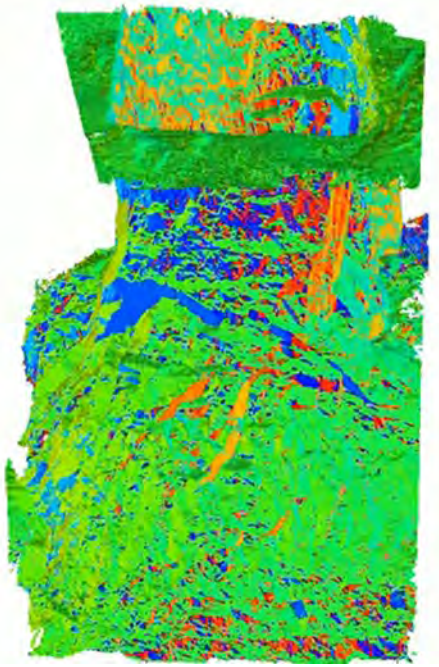
Drone-based Mapping of a 30m Benched Pillar



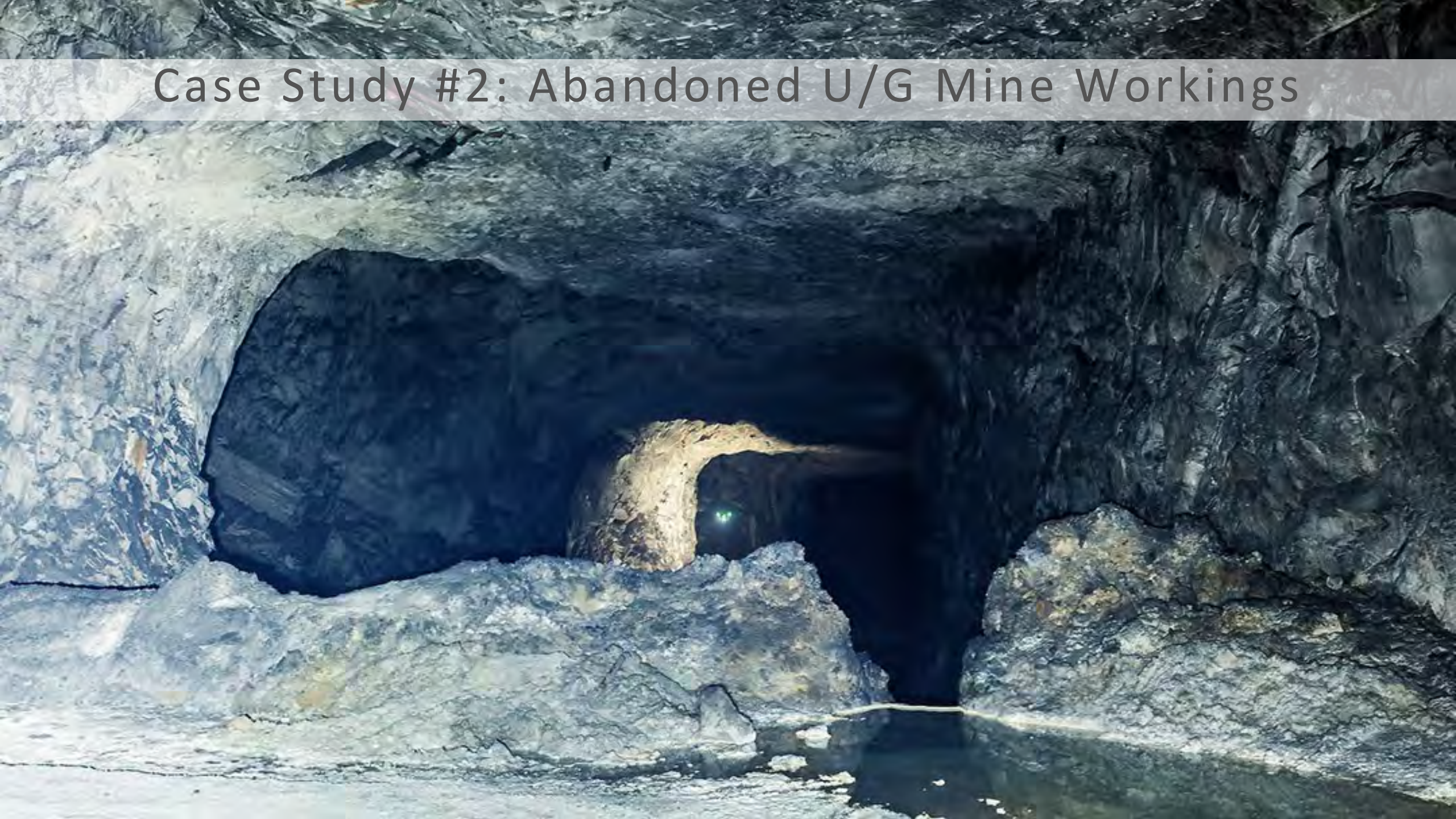
Geotechnical Mapping

- Orientation & Dip + Dip Direction
- Color by dip & strike
- Map Discontinuities
- Stereonets & Rosette Diagrams





Case Study #2: Abandoned U/G Mine Workings



Mapping Abandoned Mine Areas w/ Autonomous Drones

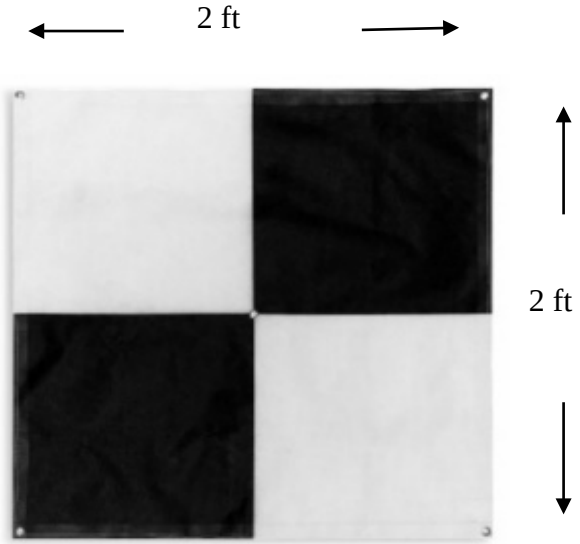
- 500-acre surface limestone cement operation
- ~23 miles of historic underground mining
- 100’ thick high calcium deposit dipping 23^{o}

Surface Model

Highwall Model

Georeferencing & Scaling

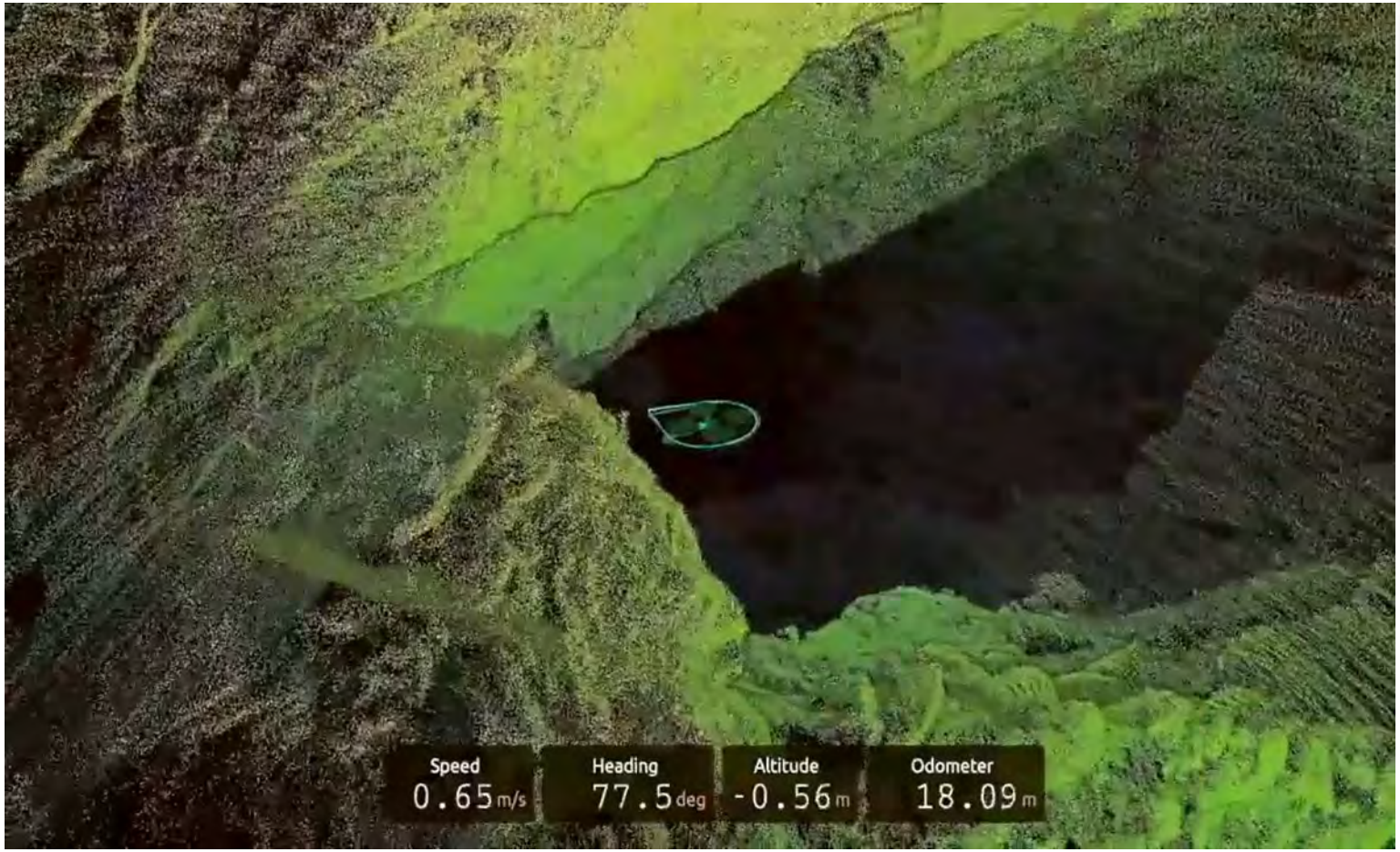
- Retroreflective survey targets for lidar
- 2’ x 2’ Aerial Ground Control Point Targets
- Survey in for best alignment & global reference

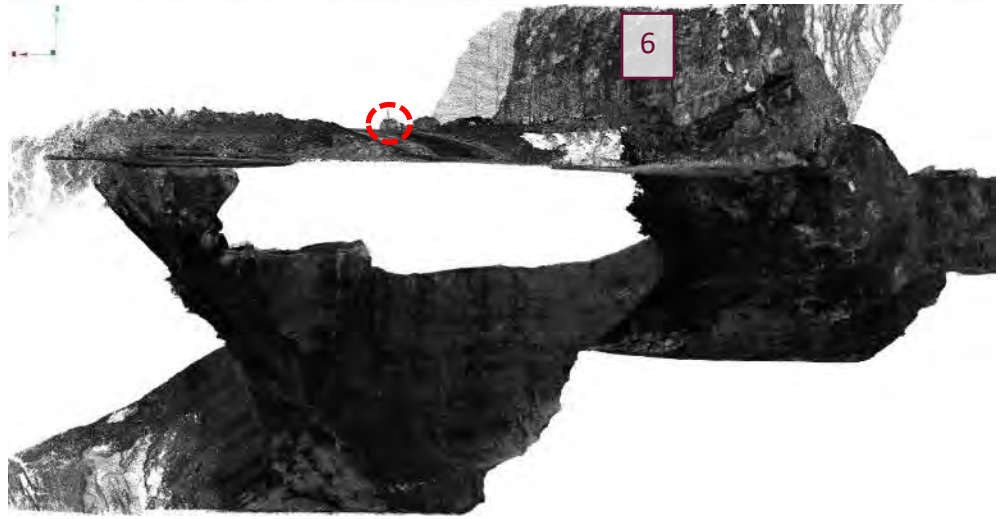


Underground Drone Survey Access Points

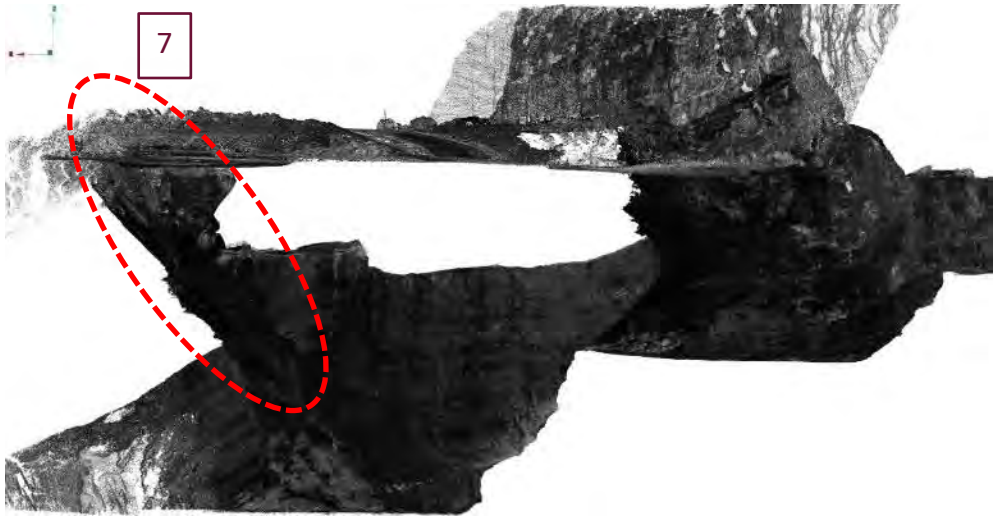
Underground Mapping from Highwall

Underground Mapping from Pit

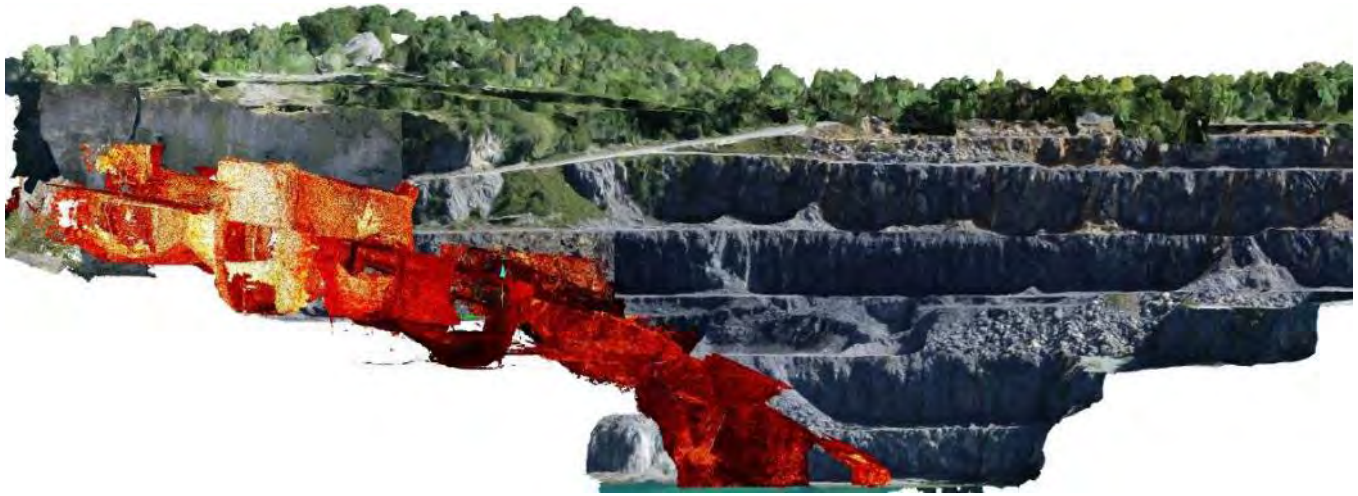


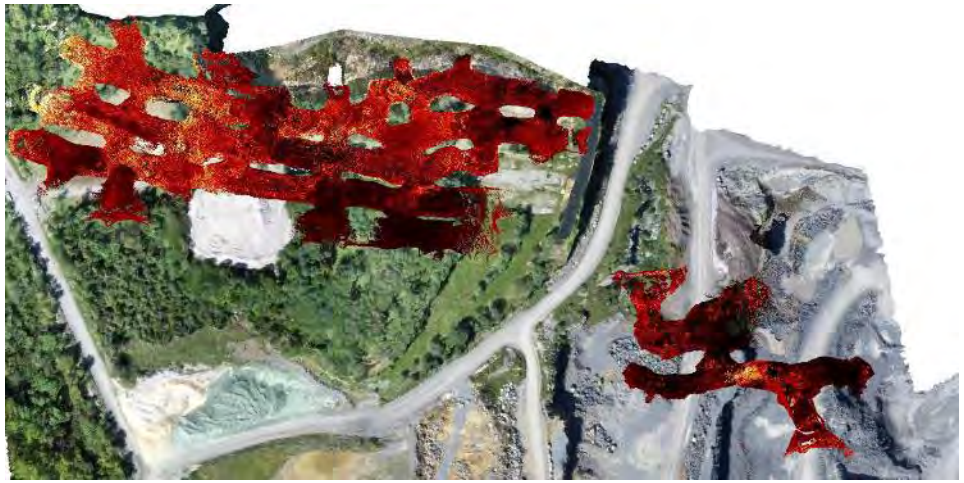


Underground Mapping from In-Pit Opening

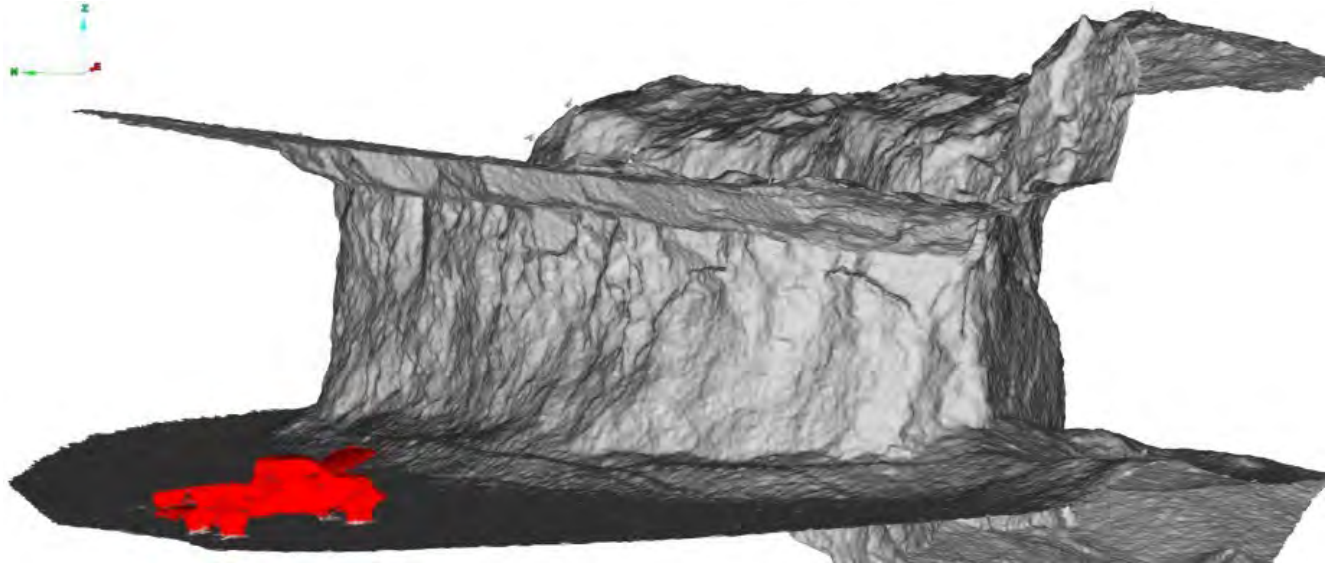


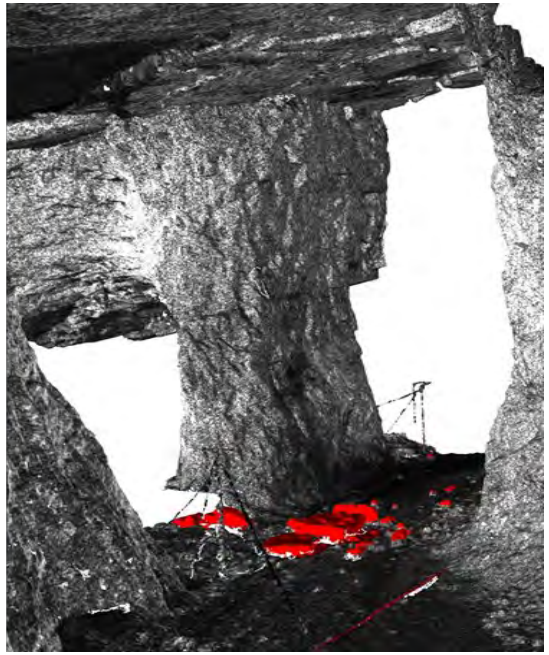
Pit Cross Sections & Top View





Hazard Identification from Scans





Conclusions

- Mitigation of risk & reduced personnel exposure
- Faster data collection
- Improved visualization & modelling
- Remote geotechnical analysis
- Facilitate inspections in difficult or previously inaccessible areas