Case Study of a Borehole Deployable Robot for Limestone Mine Profiling and Mapping

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The General Problem

Caves

Mines

Sewers

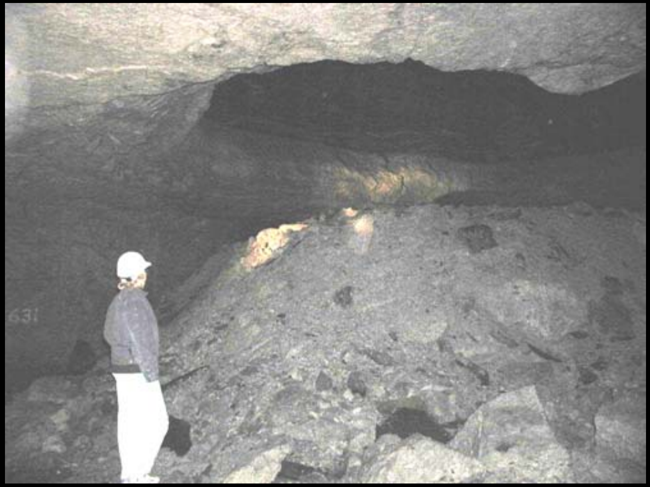
The General Problem

- Structural Instability
  - Collapses
  - Subsidence

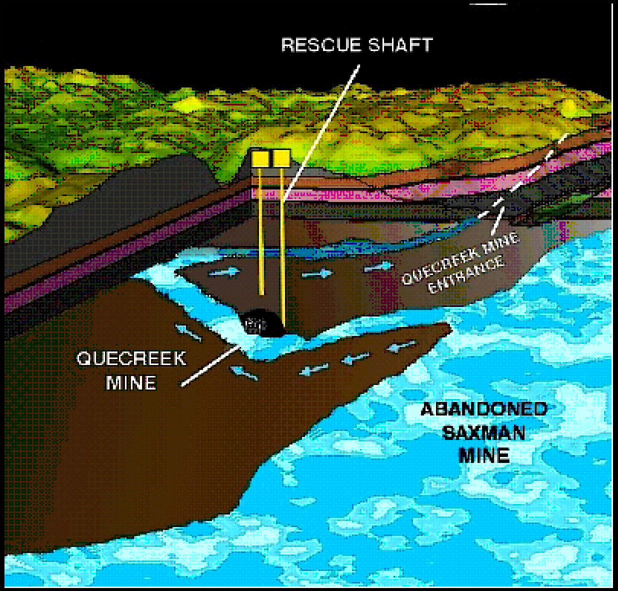
Morning temblor makes appearance in KCK

Mild quake strong enough to cause damage

Rare event leads to dozens of phone calls



- Endanger encroaching mining operations



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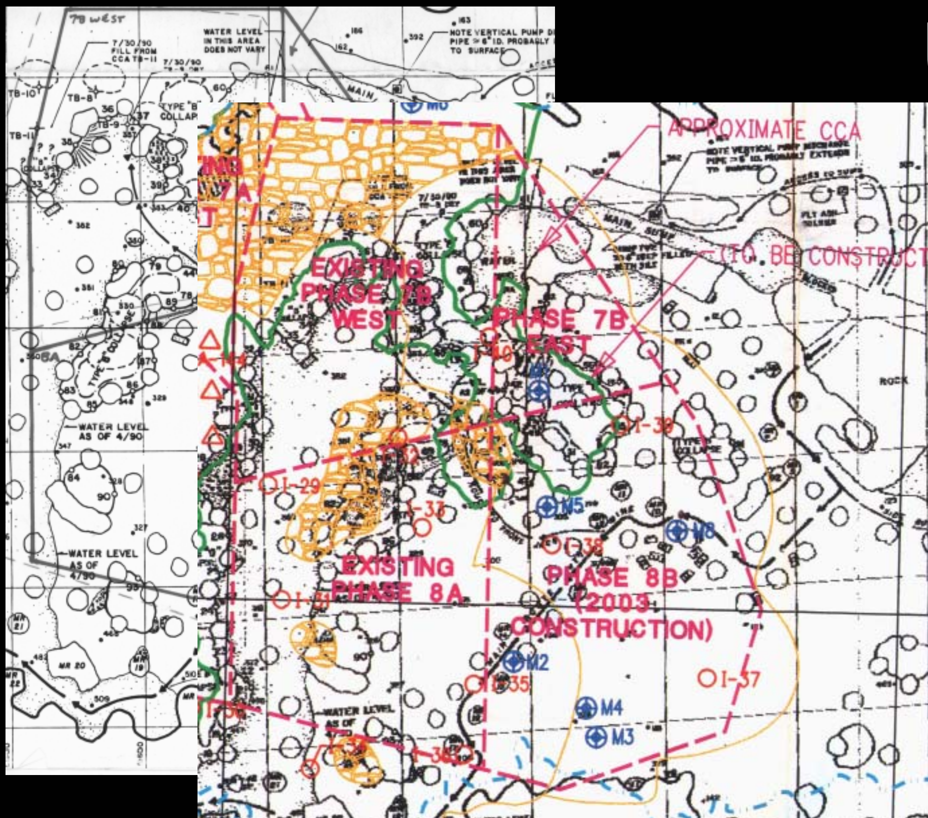
Counteraction and Prevention



Subterranean maps are the primary source of information on cavity extent.

Unfortunately…

- Poor condition
- Idealized
- Misaligned
- Not surface registered
- Partially complete
- Unavailable

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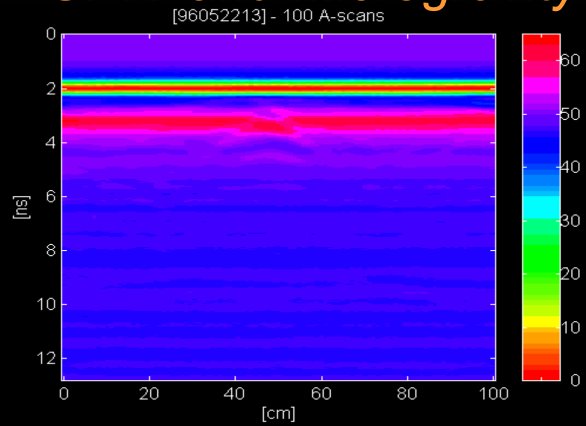
Obtaining Data On Void Extent

Human Presence

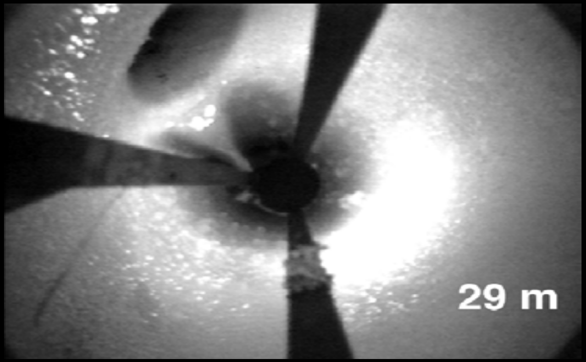
- Places inspector into harms way
- $$$$ expensive
- Not always an available option

GPR and Microgravity*



- Limited range
- Time consuming
- Void must be inferred
- Accuracy?

Borehole and Camera



- Requires many holes
  - Expensive
  - Time consuming
- Little quantitative information

*Ground Penetrating Radar

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Robotic Mapping Methods: Ferret

- Obtain a presence in the subterranean space
- Removes human from hazardous exposure
- Sensing technology provide quantitative data
- Improved precision
- Savings in time and cost

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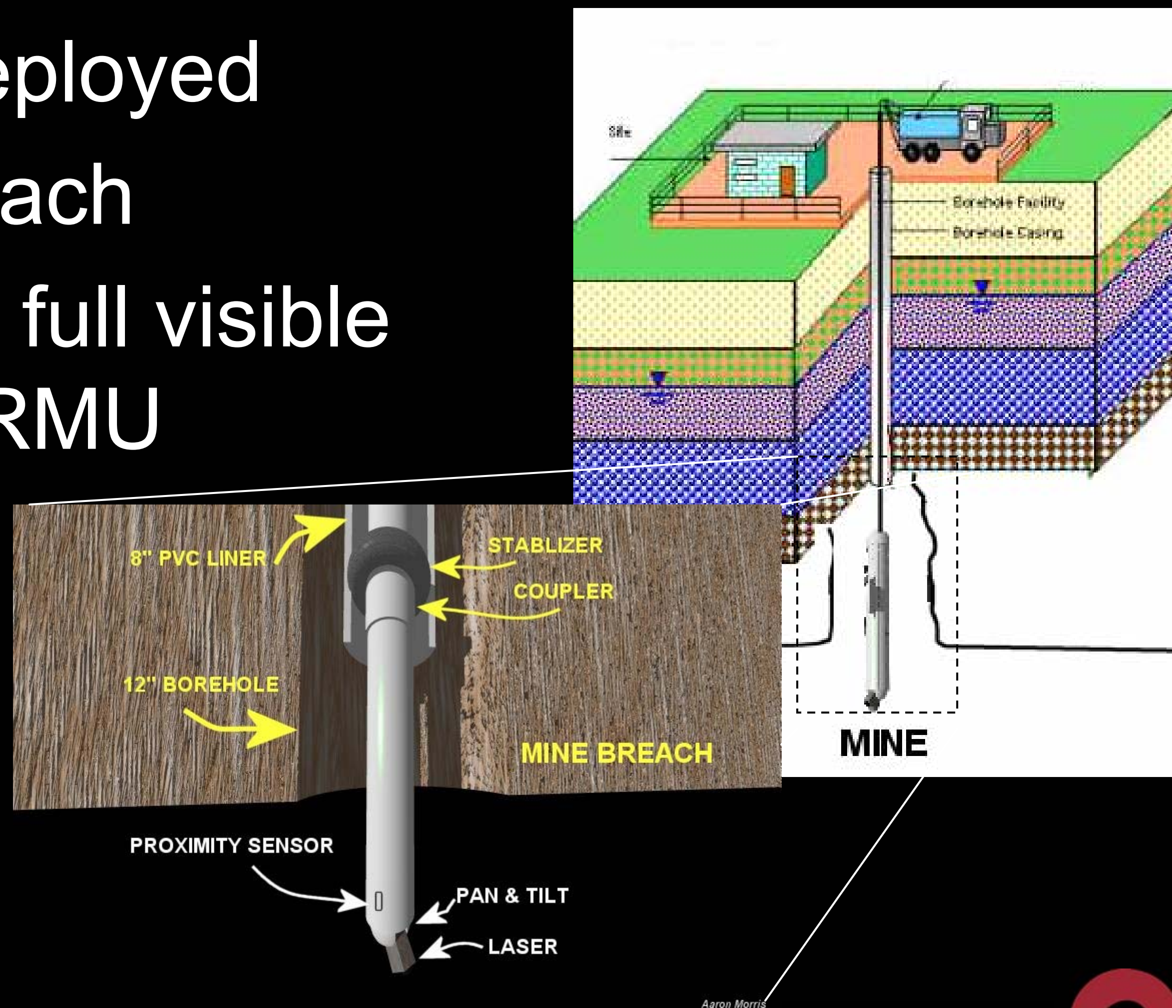
Ferret: How It Works

- Borehole deployed
- Detects Breach
- Sweeps the full visible range with RMU
- Reconstruct geometric environment
- Correct map



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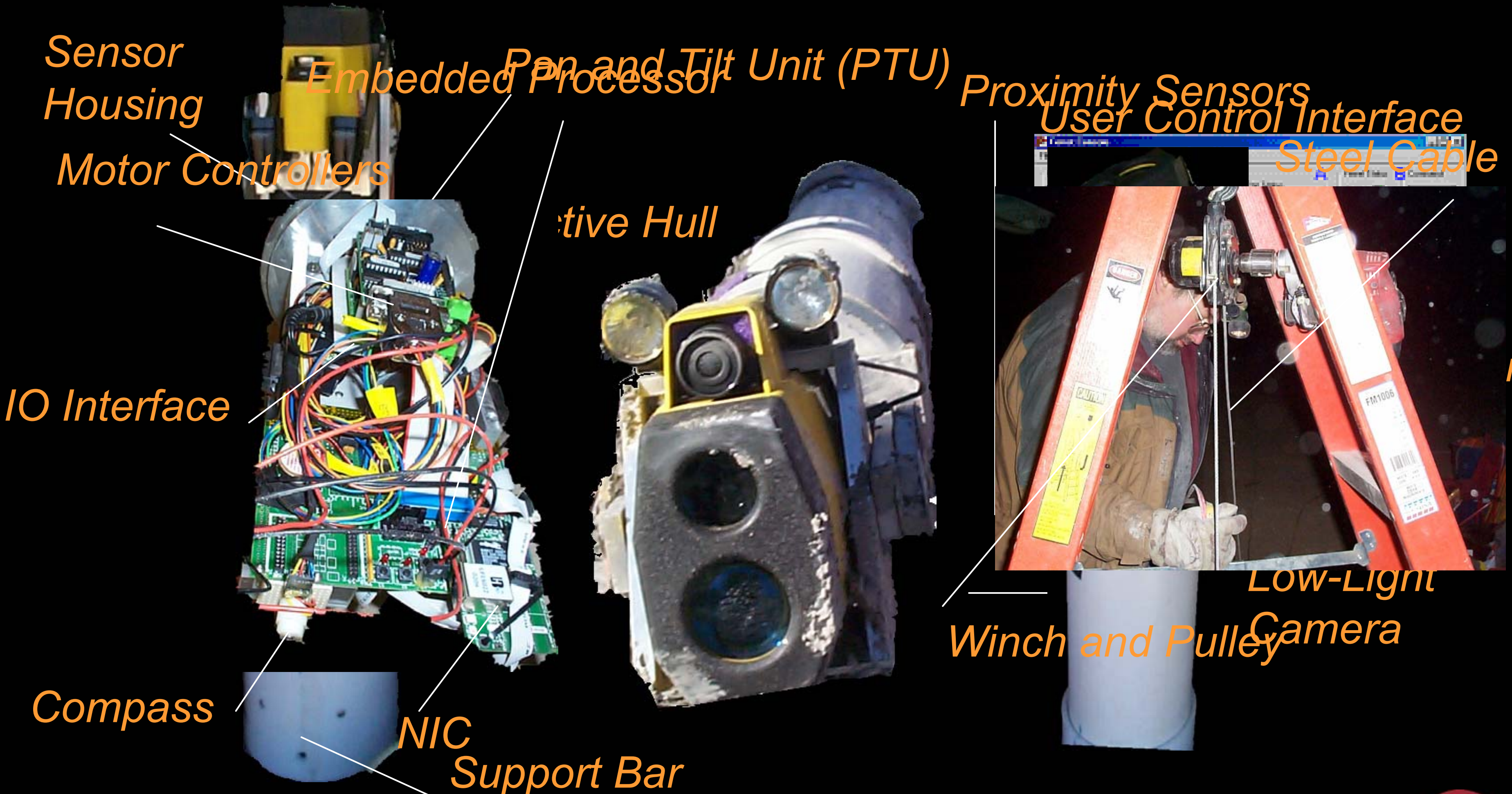
Ferret: A Brief System Description



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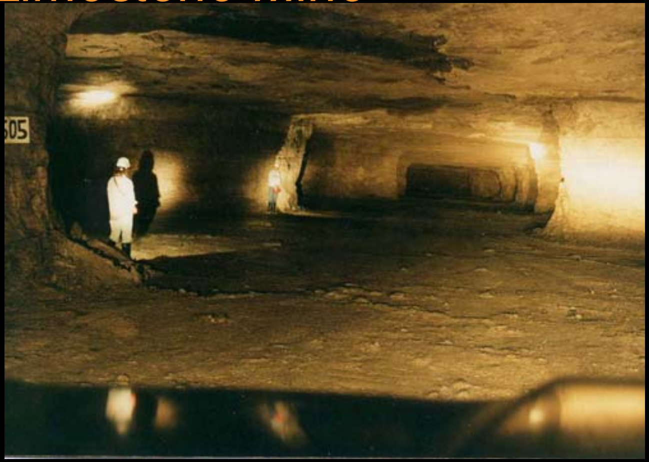
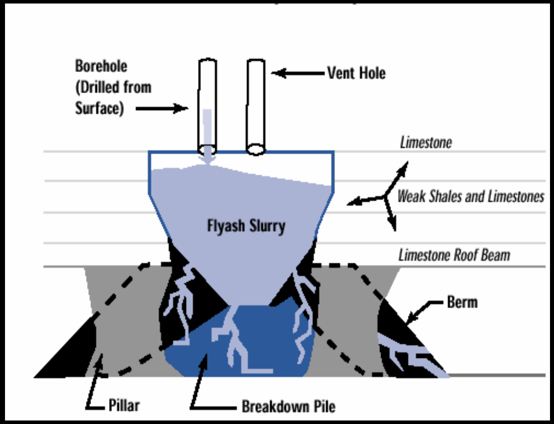
Kansas City

- Kansas City Limestone Mines
- Weak Ceiling Integrity results in Domeouts
- Prohibit Land Development
- Mitigation through backfilling

Limestone Mine



Domeout

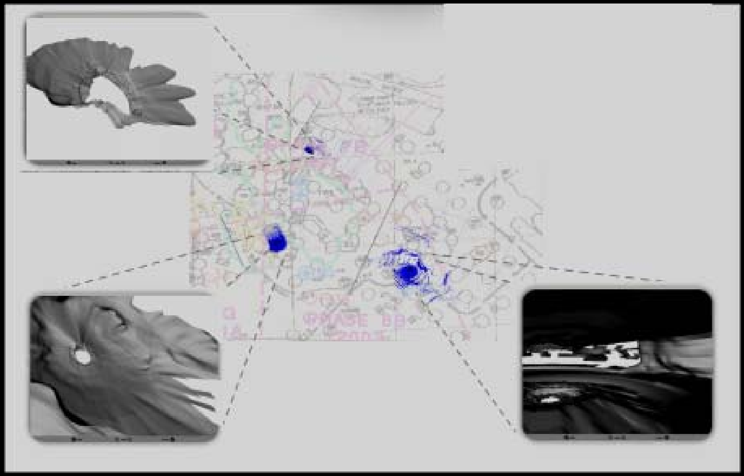


Backfilling

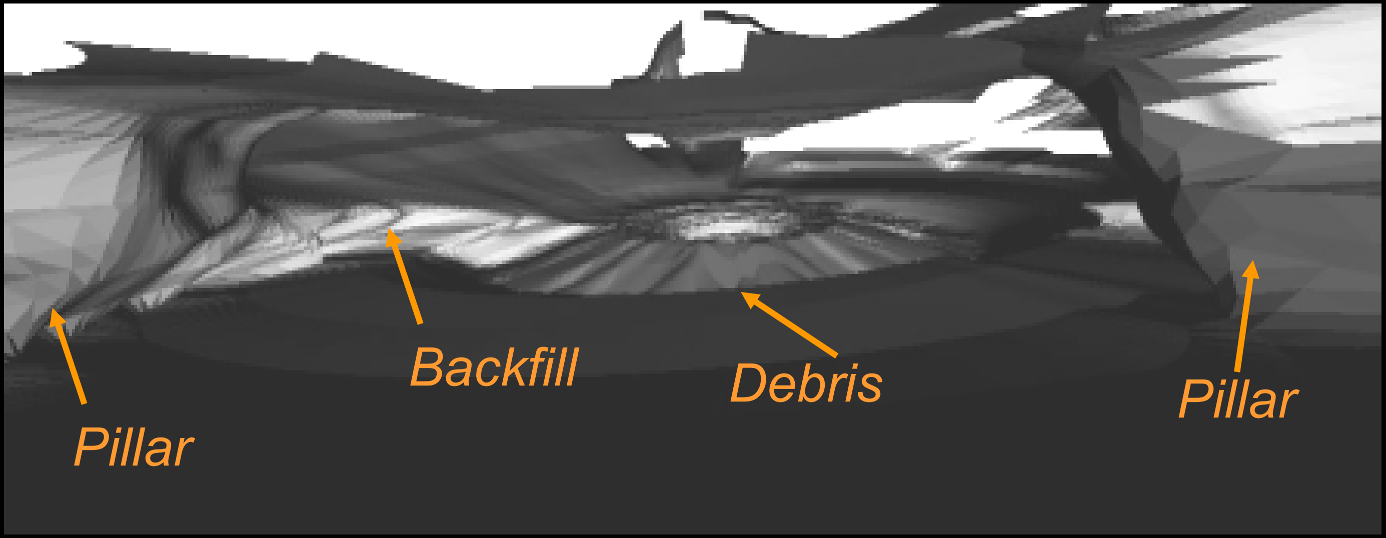
Fly-ash

Ferret: Kansas City Case Study

- Deployed in 3 boreholes over 3 days
- Average borehole depth of 150 ft
- Performed 6 to 9 hours of operation per day
- Rugged environmental conditions
  - Water and mud
  - Temperature

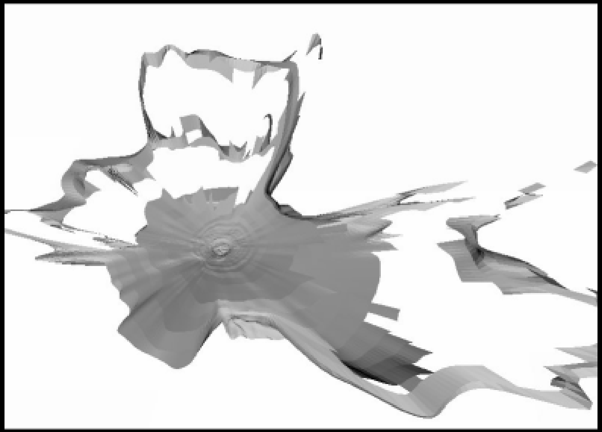


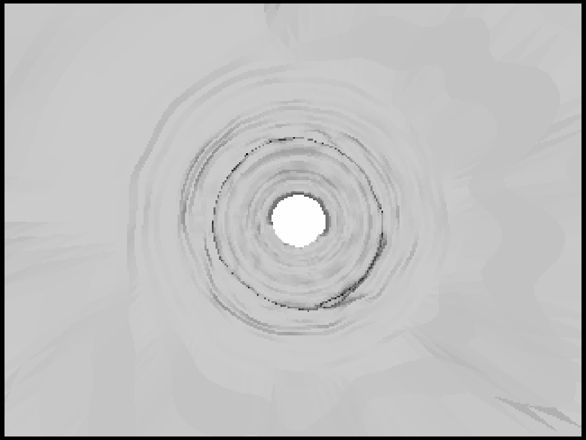
Results: Meshes of M8



Internal View

External View

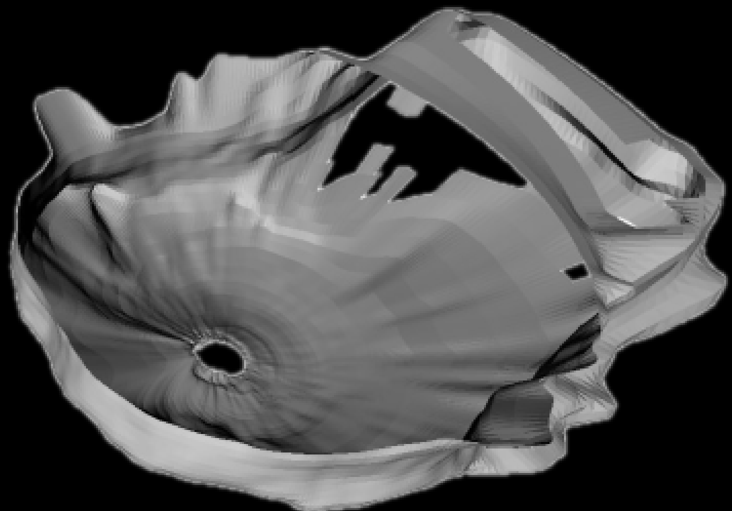




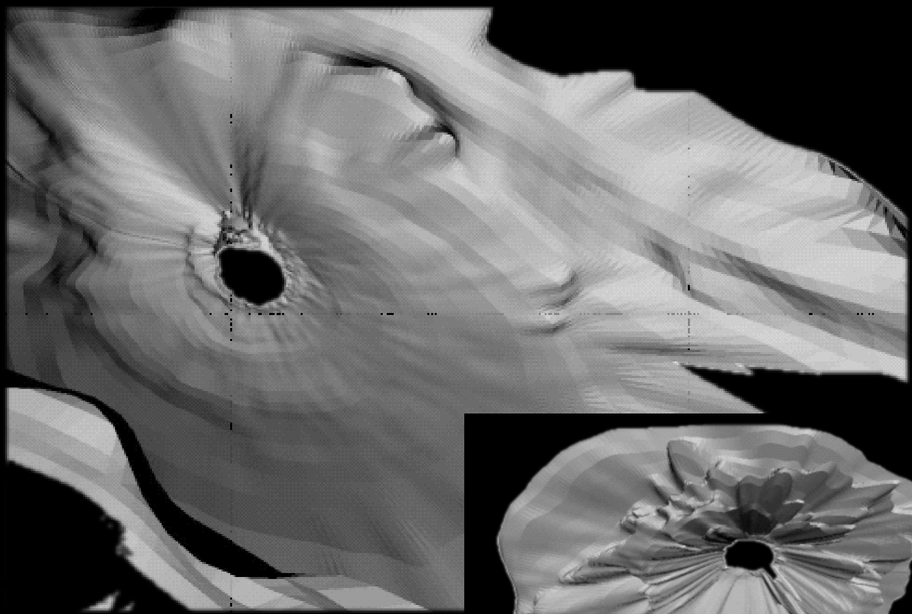
The Model

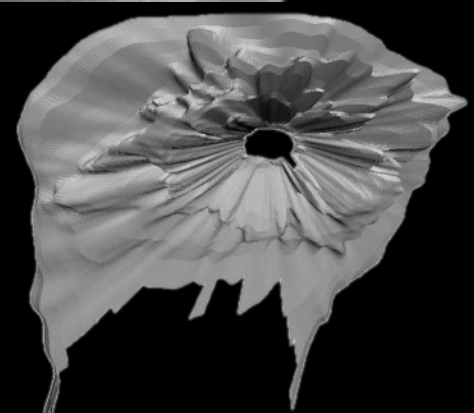
Results: Meshes of M5

Domeout View 1

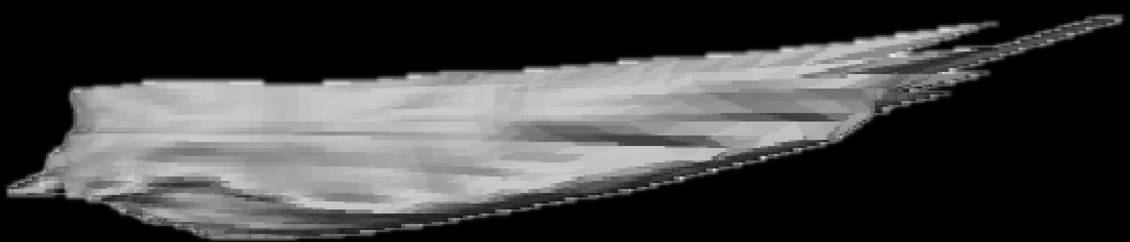


Domeout View 2





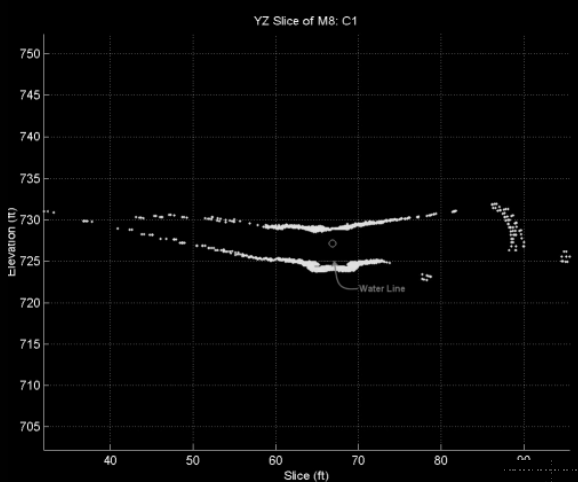
Domeout Ceiling



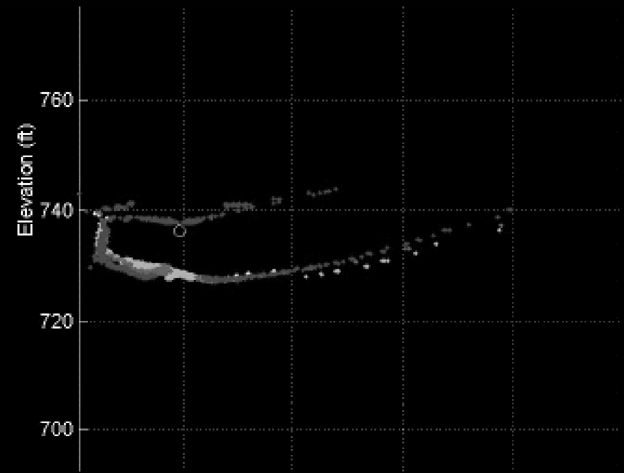
Domeout Profile

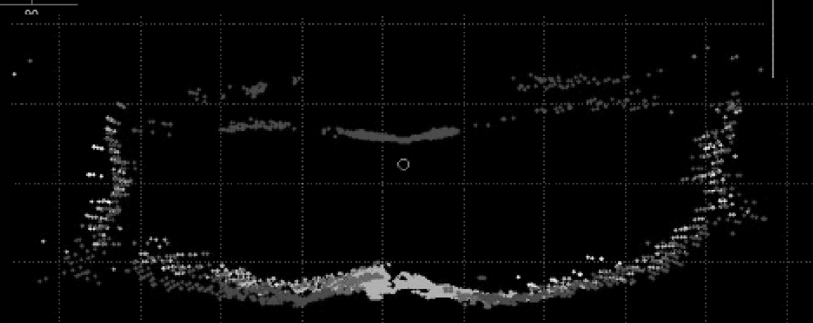
Data Profiling

Hole M8

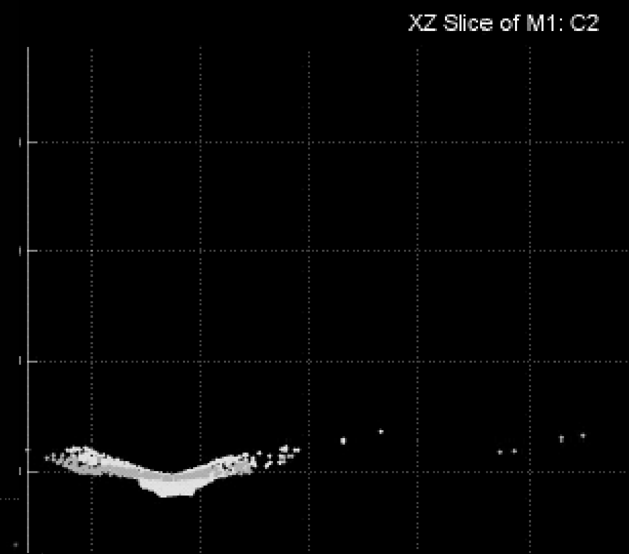


Hole M5

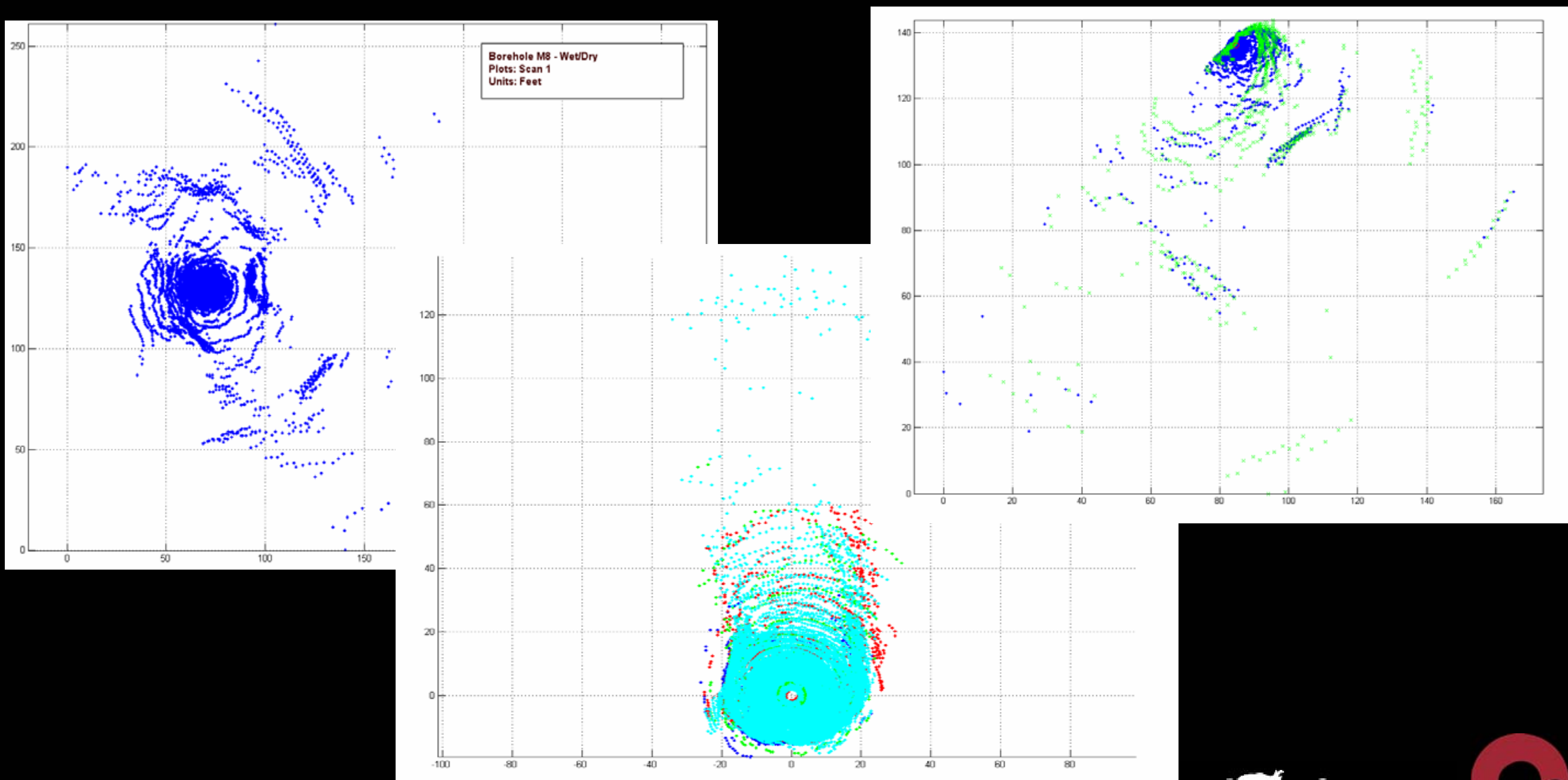




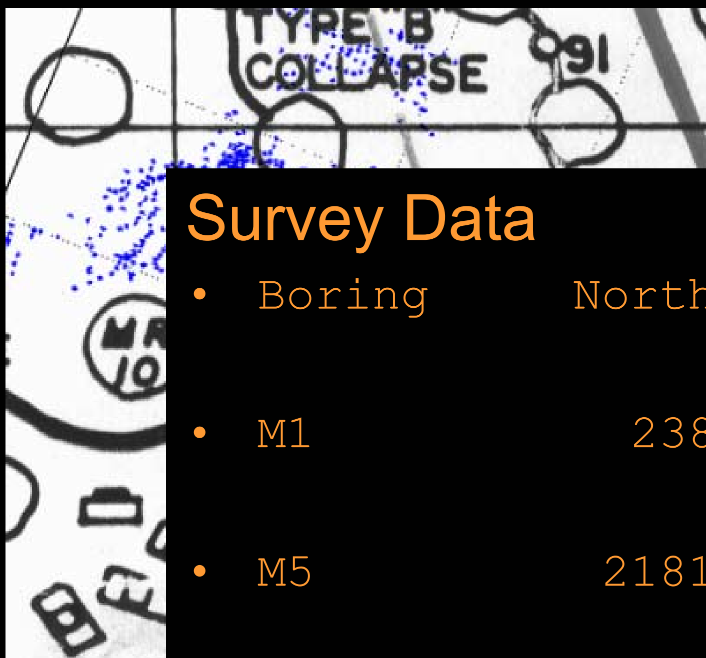
Hole M1

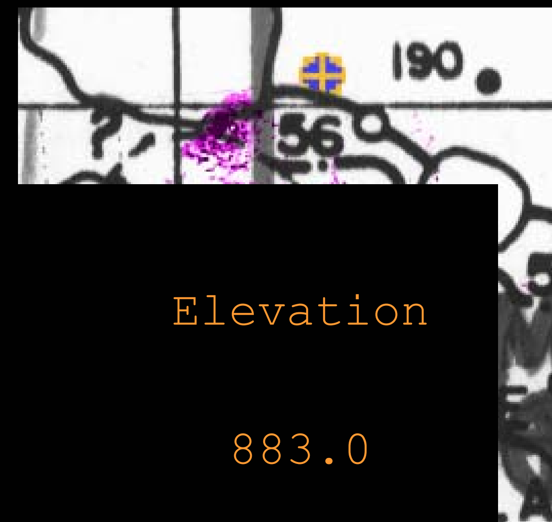


Projection Plots



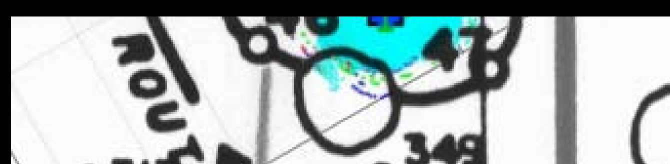
Map Overlay



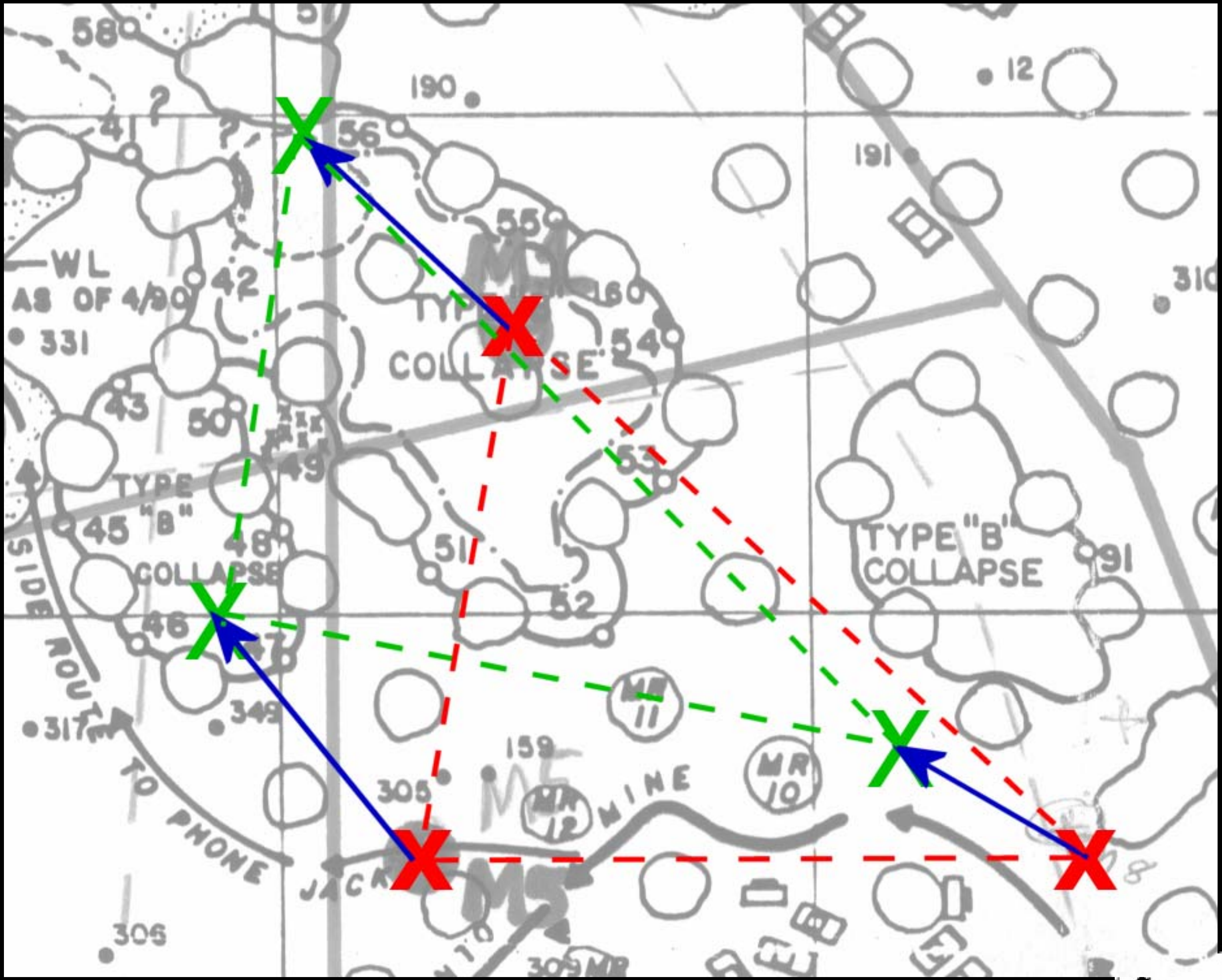


Survey Data

Boring	Northing	Easting	Elevation
M1	2384.90	3468.36	883.0
M5	2181.51	3412.69	869.6
M8	2134.97	3674.52	879.7



Surface Coordinate Registration



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Conclusions

Accomplished

- Scanned ~28,800 ft^3 (816 m^3) of void space
- Rectified mine map from 33,810 ft^2 (3141 m^2) of mine site
- 40% reduction of drilled boreholes

Discovered

- Fragility of borehole placement
- Need for smaller and submersible devices

Future of Ferret

- Smaller, faster laser scanning technology
- Modular sensing and utilization of sonar
- Deeper deployment
- Qualified to explosive environments
- Cooperation of Ferret with mobile platform

Questions?

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