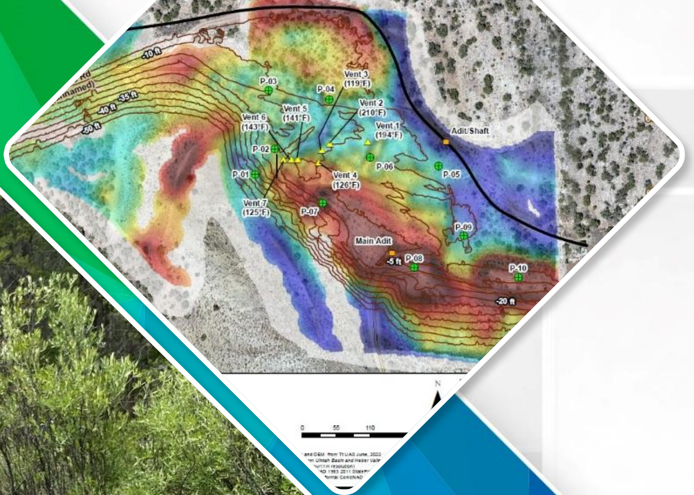

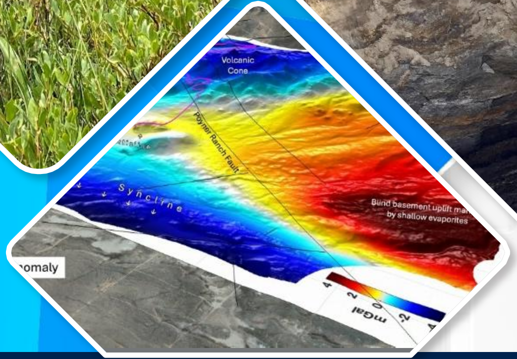

TETRA TECH

Microgravity for Abandoned Mine Voids

A Rapid, Non-Intrusive Tool for Optimized Subsidence Risk Assessment

American Society of Reclamation Sciences Annual Meeting – Laramie, WY

June 8, 2026

Presented by: Lincoln Steele

Senior Geophysicist – Tetra Tech

Problem: AML Sites Create Hazardous Ground Conditions

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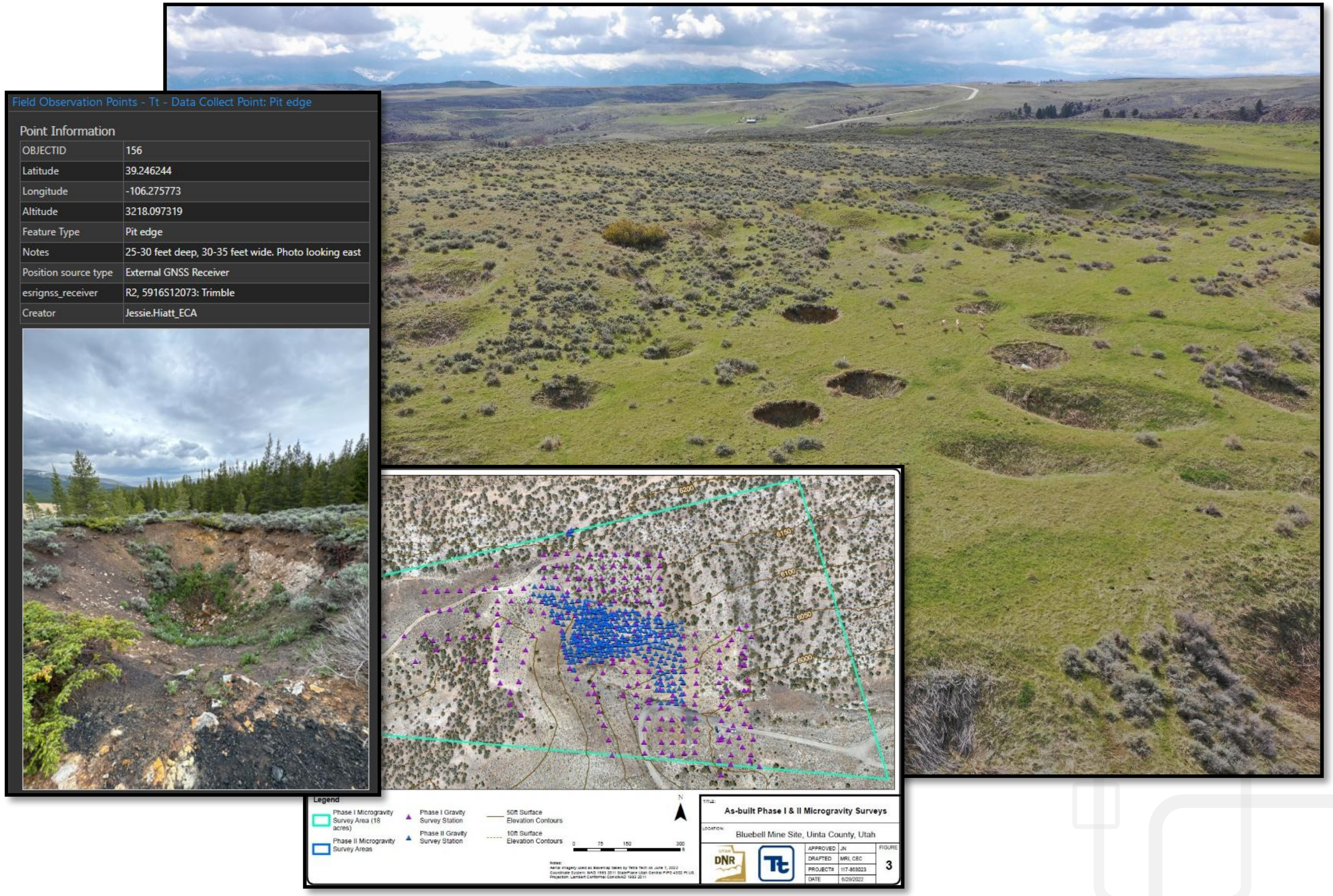
- Public safety
- Environmental impact
- Non-existent or-
- Non-georeferenced data
- Large mine-impacted areas
- Land access (ownership)
- Impact on the land
- Reclamation design challenges
- Prioritization



Motivation: Optimize Risk Site-Specific Evaluations

Desktop Subsidence Hazard Assessments

Finding the mine using historical data can be beneficial, but it can also add uncertainty

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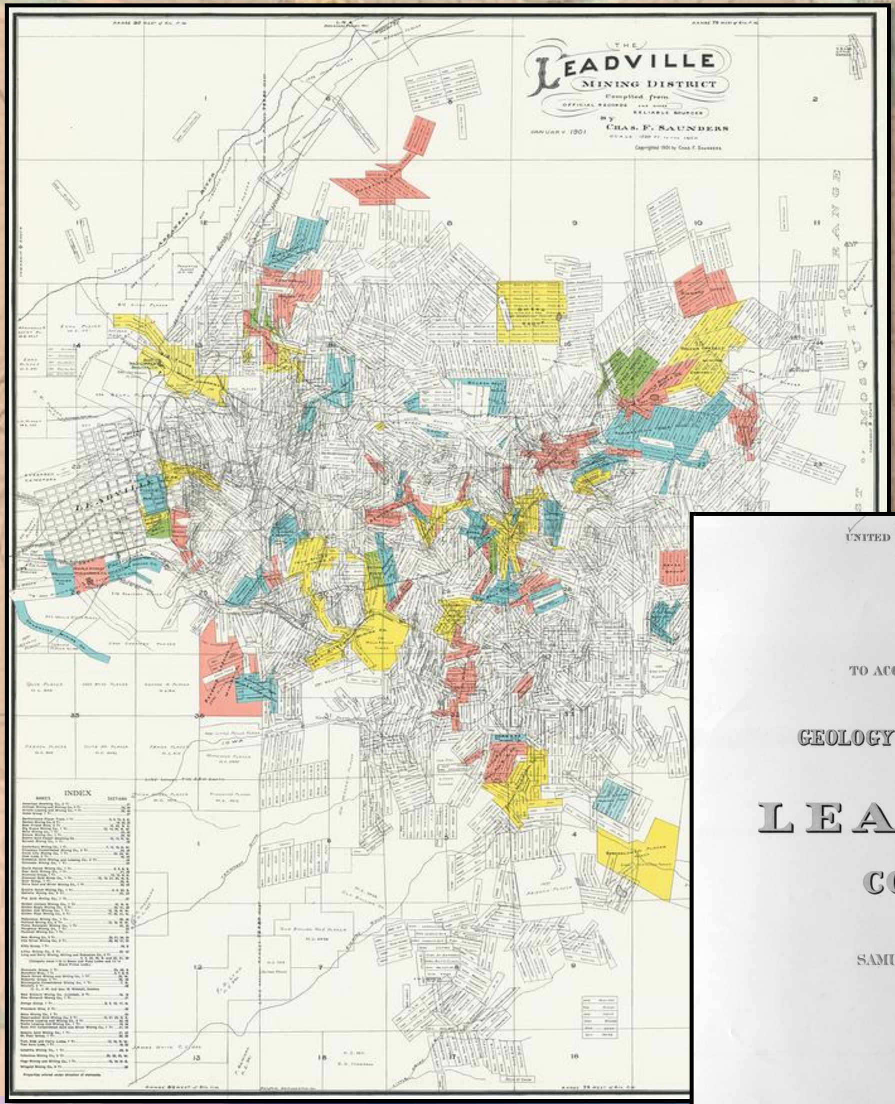
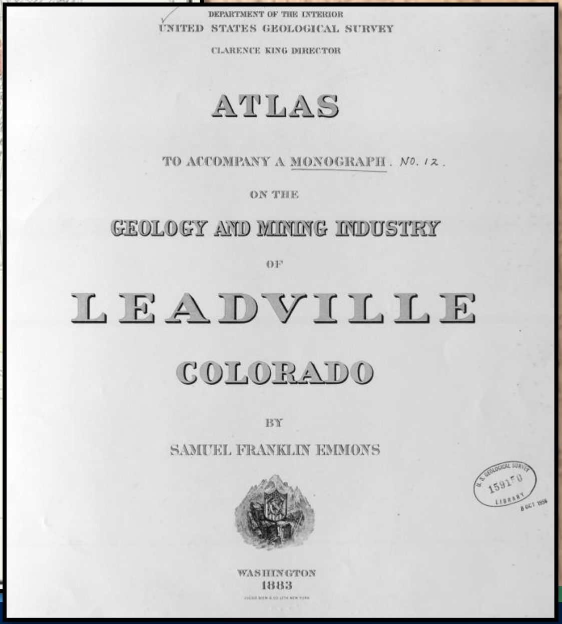



DEPARTMENT OF THE INTERIOR
UNITED STATES GEOLOGICAL SURVEY
CLARENCE KING DIRECTOR

ATLAS

TO ACCOMPANY A MONOGRAPH. NO. 12.

ON THE

GEOLOGY AND MINING INDUSTRY

OF

LEADVILLE

COLORADO

BY

SAMUEL FRANKLIN EMMONS

WASHINGTON
1883

1. Geo-information models and databases function as both a preliminary screening tool and an additional filtering mechanism in subsidence investigations

2. Ground-truthing the historic data with field observations and precision geospatial data strengthens the database and allows for field survey planning

3. A remote-access geospatial dashboard gives team members a powerful platform for data capture, visualization, and expanded risk analysis.

Microgravity Method – Gravity Basics

How do we measure gravity and why?

Generally, a lower ***g*** indicates a higher potential for a void

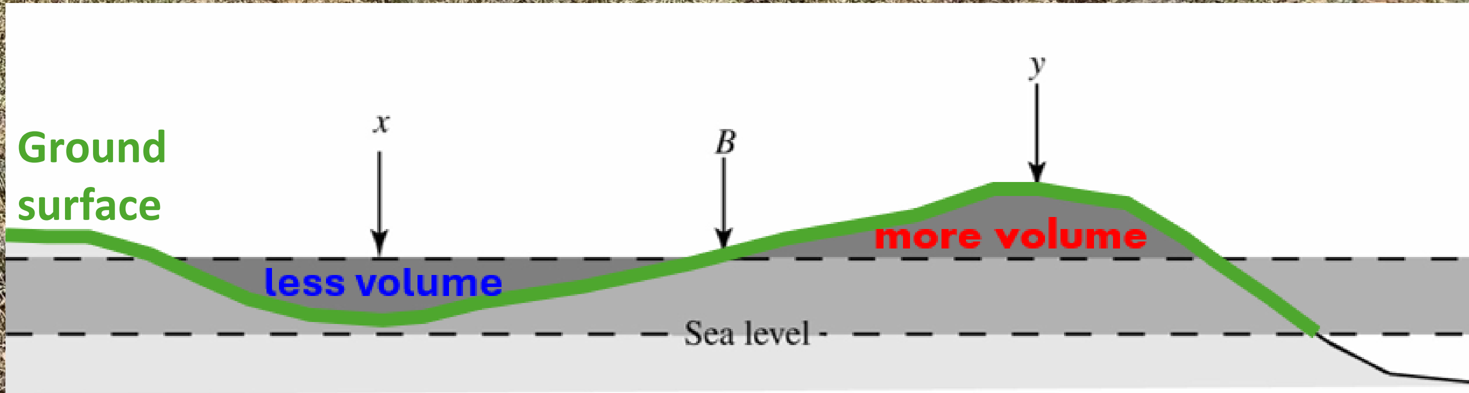
- $g = G$ mass / distance^2

- More mass, **higher g**
  - Basement
  - Welded tuffs
  - Lithified sed rocks

- Less mass, **lower g**
  - Soils
  - **Voids**
  - Ashy / Air-fall tuff
  - Unlithified sed rocks
  - Karst

Gravity readings are corrected for:

- Latitude
- Tides
- Instrumental drift
- Measurement elevation correction E
  - *free-air (FA = +0.3086 E)*
- Topographic volume
  - *Bouguer = -0.04193□E*
  - *& terrain corrections*

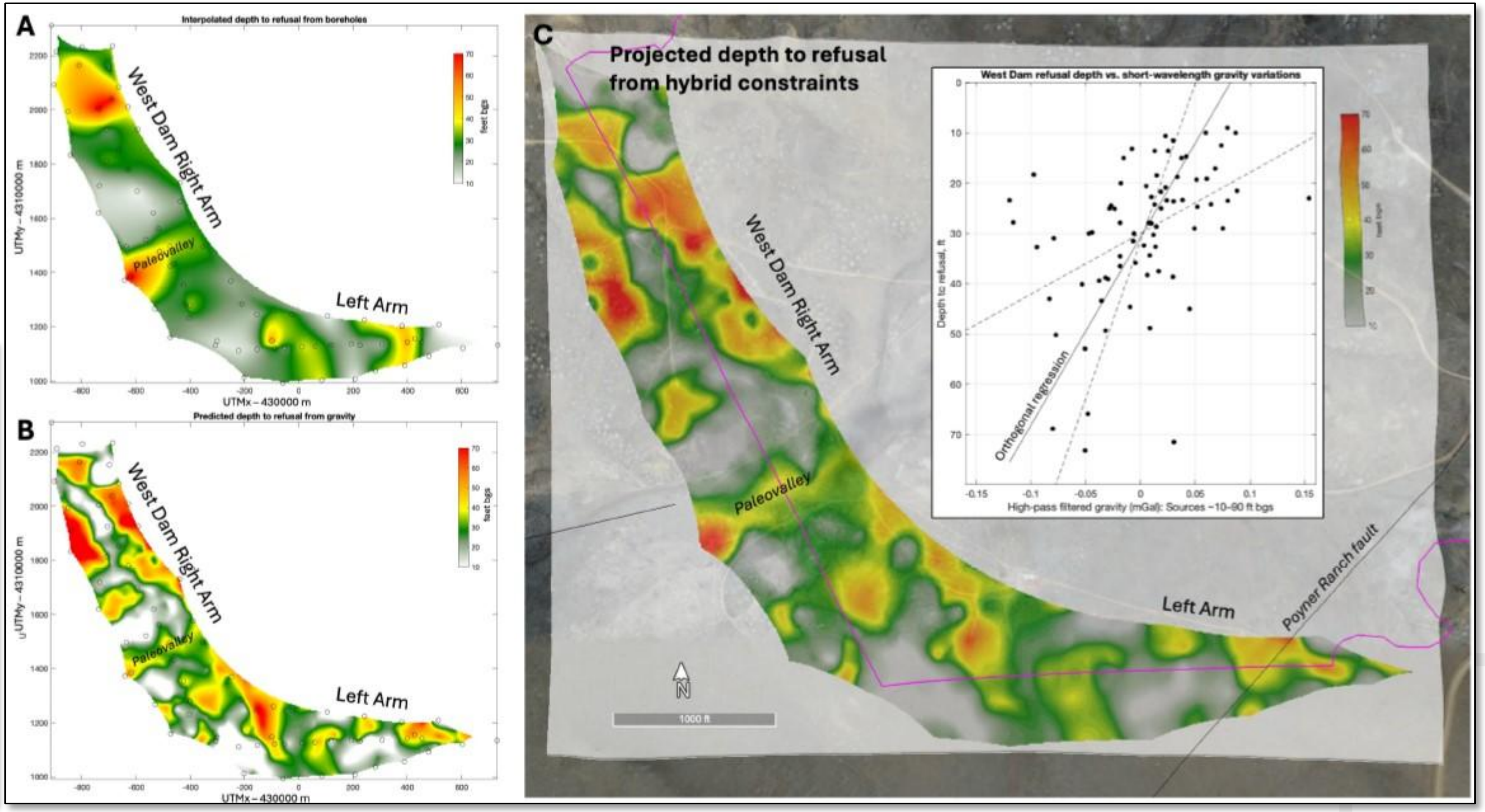


Microgravity Method – Not Your Parents' Gravity

Direct Correlations to Inform Engineers, not just Geologists

Microgravimetric Data:

- Density
- Depth to Refusal SPT N=50
- Depth to Crystalline bedrock, including blind structures (anticlines, synclines, faults)
- RQD in Granite



Microgravity Method – For AML Sites

A Non-Intrusive, High-Value, and Adaptable Void-Screening Tool

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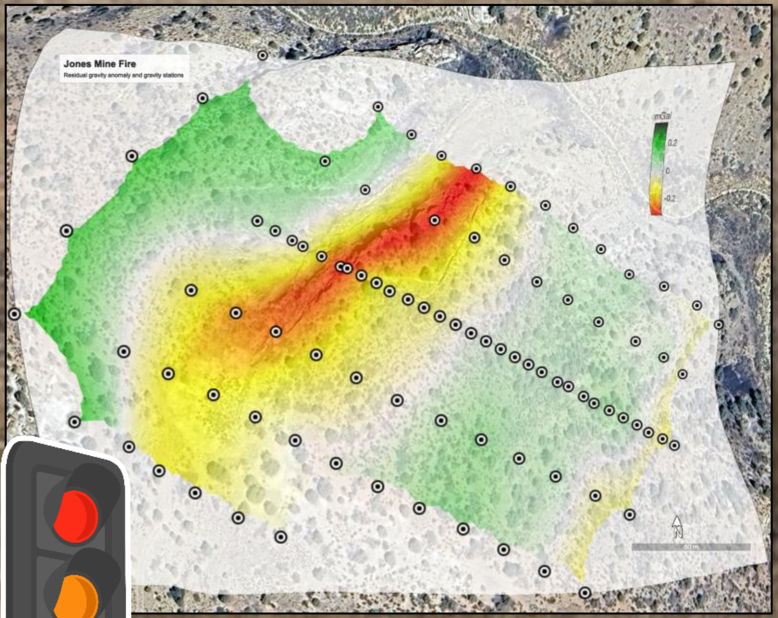

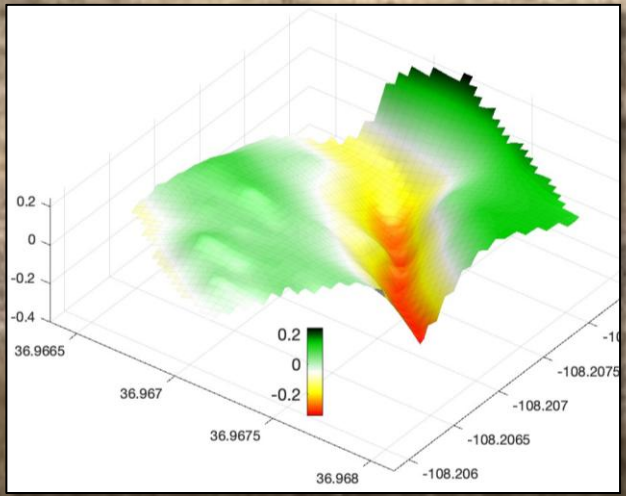

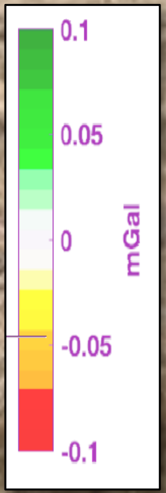

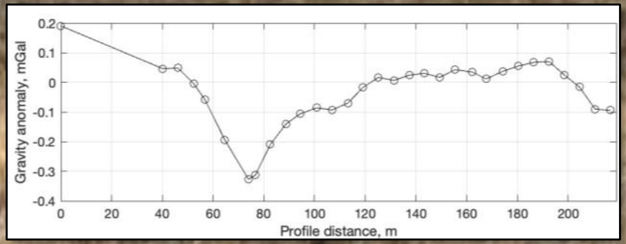

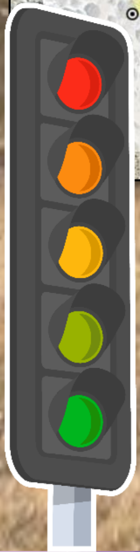

Microgravity results are displayed in terms of relative high and low gravity

- **Highs** = solid rock
- **Lows** = fractured, rubblized, or open void zones
- Absolute values matter less
- Survey design can be adjusted on-the-fly
- Data acquisition is fast; 30-90 seconds per station, 65-150 stations per day
- Constant QA/QC built in

Microgravity Method – For AML Sites

Built-in QA/QC helps to prove the survey before we set foot in the field

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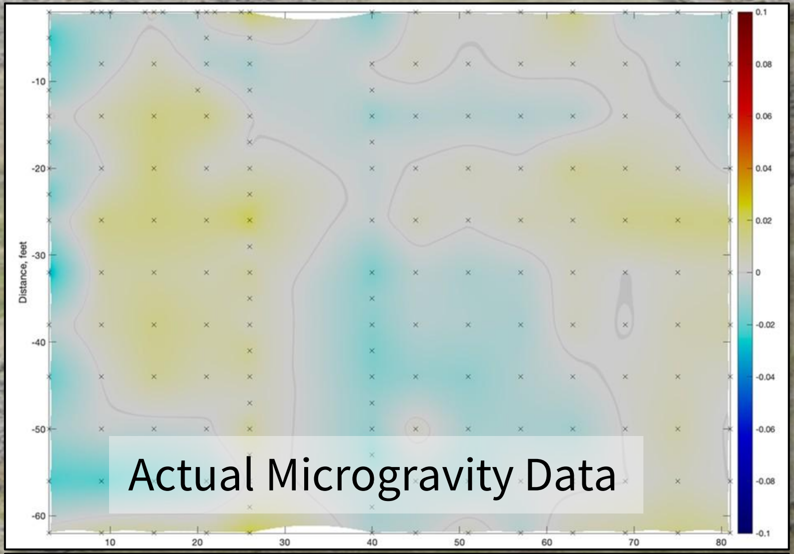
Actual Microgravity Data


Modeled Void in the same data

Forward models demonstrate the exact signal type we expect from a void based on:

- Site history
- Geology
- Topography
- Mine geometry

We use forward models to:

- Screen for voids
- Illustrate an anomaly
- QA our field program
- QC our geophysical data

Case Study: Leadville Historic Mining District

Rapid Subsidence-Hazard Screening for a Transmission Line Rebuild

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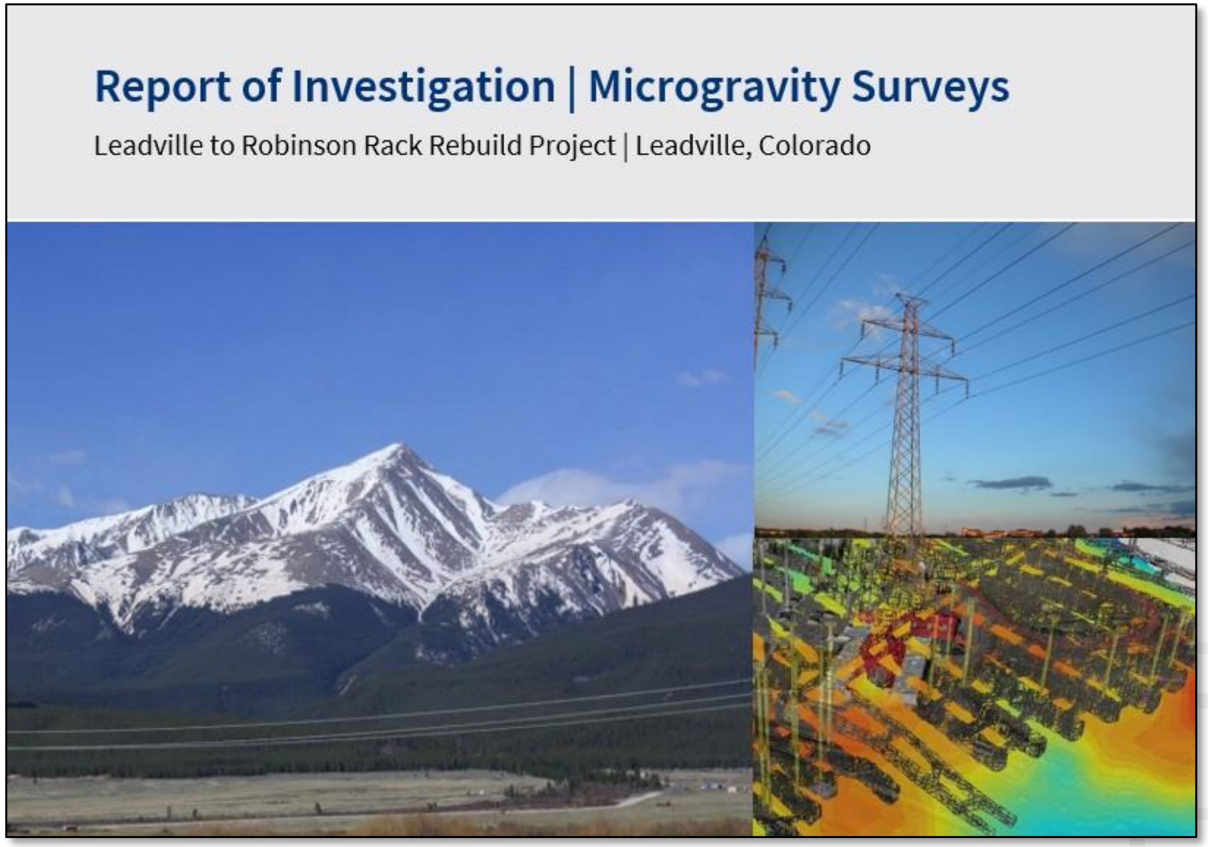
- Five Miles of ROW through Mining Region
- Unknown/Unquantified Subsidence Hazard
- Planned Heavy Construction Activities
- Expedited Project Schedule – Get it Done Now!



Historic Leadville Mining District

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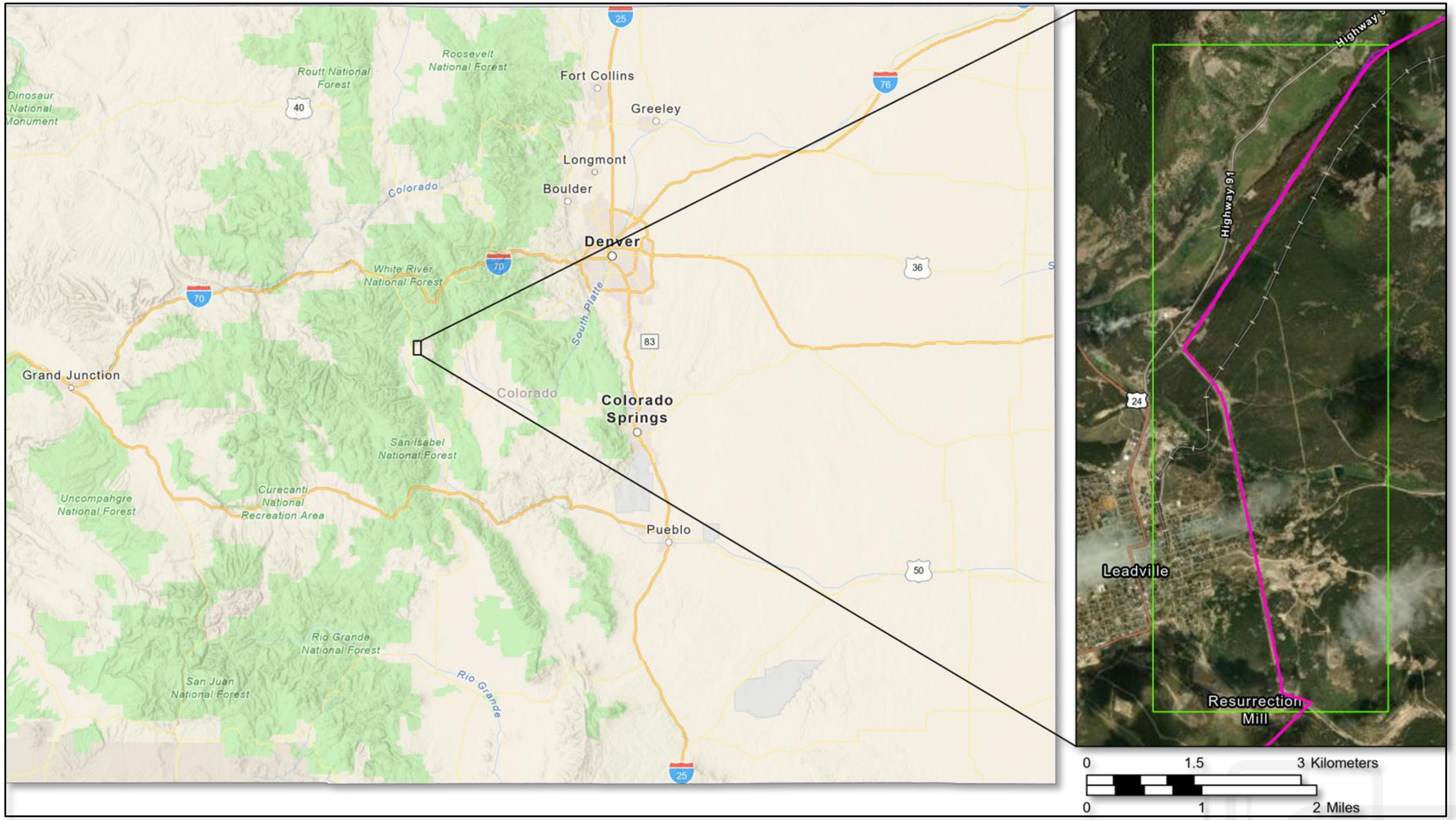
Leadville by the Numbers

- Mined from 1859-1963
- 240 Million Ounces of **Silver**
- 3 Million Ounces of **Gold**
- ~1 Million Tons of **Lead**
- 720,000 Tons of **Zinc**
- **67** Major Mines
- 20 Square Miles
- 40+ Smelters



Left: President Grant Touring Leadville in 1880.
Above: Map of Colorado showing Leadville, and the 5 Mile Abandoned Mine Project Area

Desktop Review > Field Reconnaissance > Geo Database

Building A Geo-Information Model to Validate Geophysical Results

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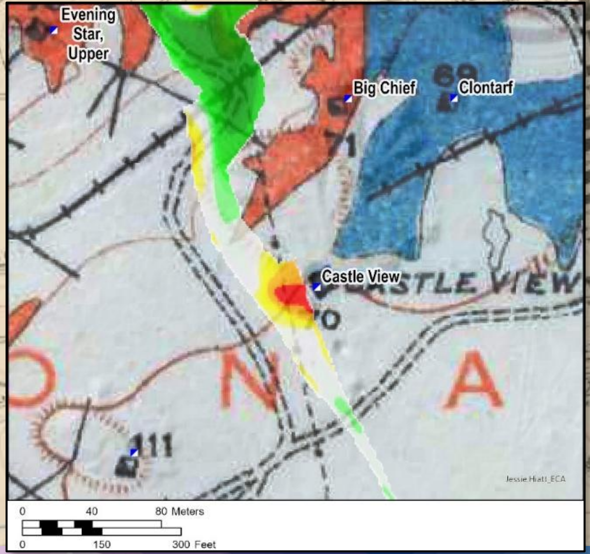
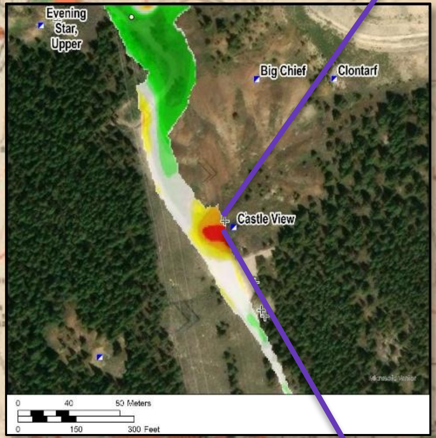


1. Corelate historic/existing site information
2. Field-correct the existing data
3. Capture relevant information for geophysical data screening



Field Observation Points - Tt - Data Collect Point: Pit edge

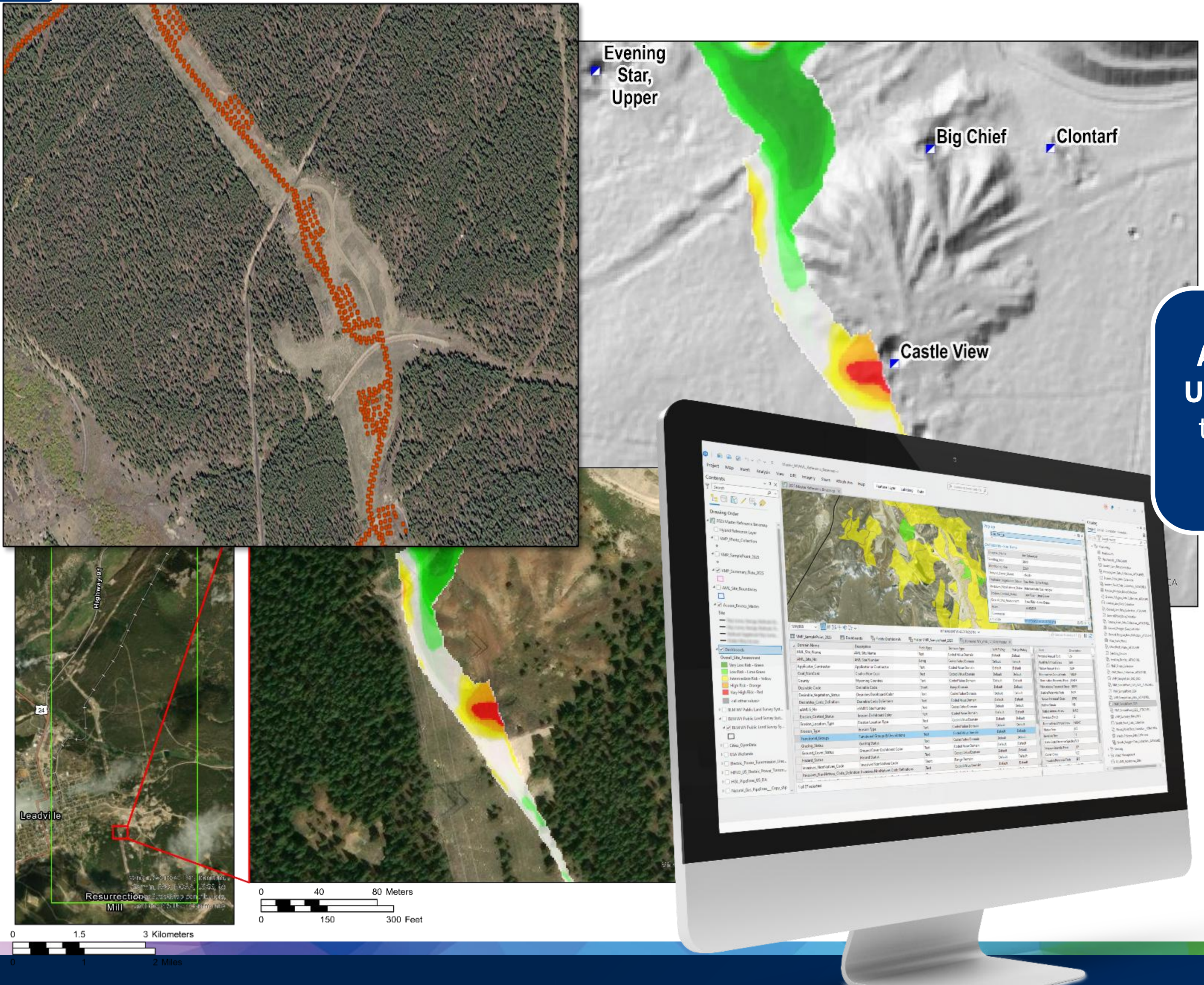
Point Information

OBJECTID	156
Latitude	39.246244
Longitude	-106.275773
Altitude	3218.097319
Feature Type	Pit edge
Notes	25-30 feet deep, 30-35 feet wide. Photo looking east
Position source type	External GNSS Receiver
esrignss_receiver	R2, 5916S12073: Trimble

Case Study: Leadville Historic Mining District

Strategic Data Capture and Real-Time Processing to Accelerate the Program

TETRA TECH



Survey Design – Optimize the Microgravity surveys to prioritize the progression of on-site activities and areas of high-hazard (perceived hazard)

Data Acquisition – Adjustable acquisition plans allow data processors to tailor the survey based on results

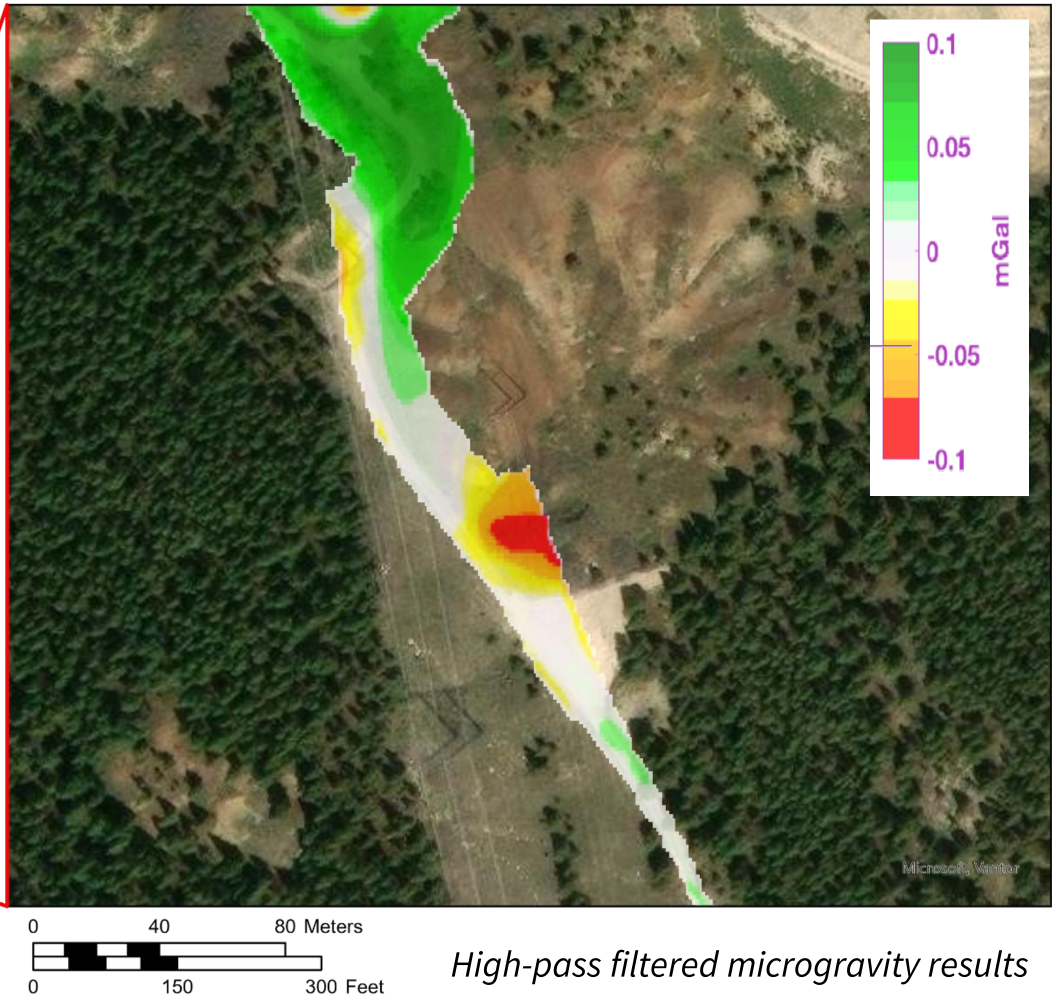
Near Realtime Data Processing Daily updated site models inform the field teams of data gaps and the project team of potential exclusion zones

AGOL and Risk Matrix Updates – Daily updates to the online database and risk matrix

Case Study: Leadville Historic Mining District

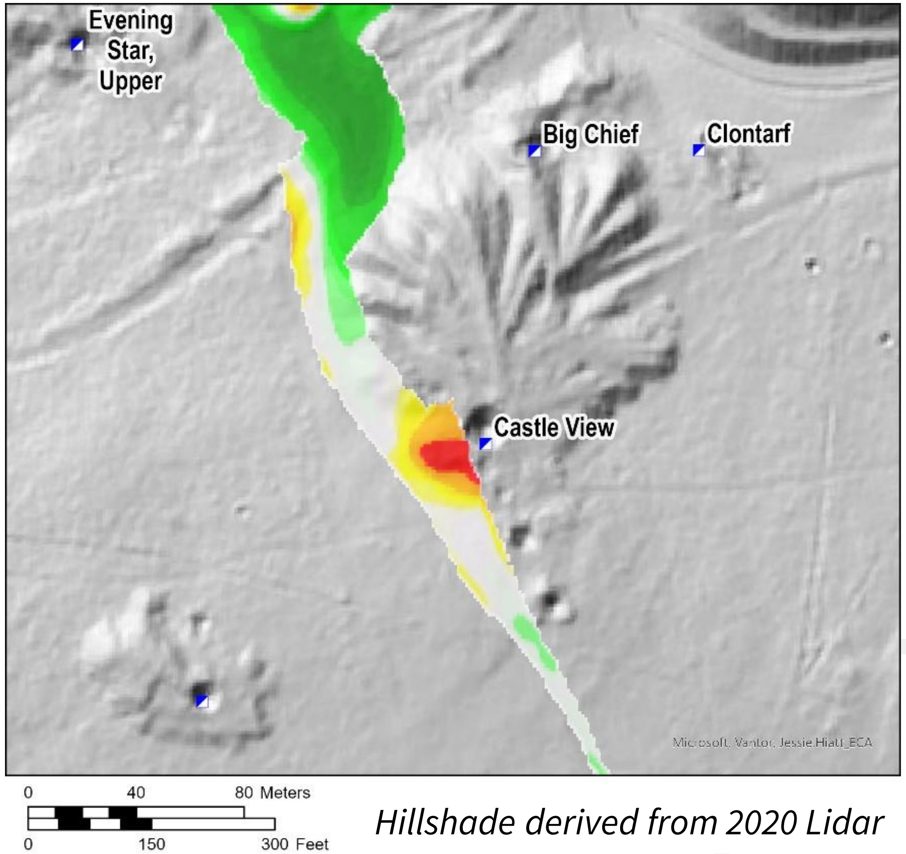
Illuminating the subsurface hazard with Microgravity surveys

TETRA TECH



High-pass filtered microgravity results

Daily microgravity data is screened against mine features, topography, geology, and other field observations to calibrate risk



Hillshade derived from 2020 Lidar

Case Study: Leadville Historic Mining District

Build an Optimized Risk Matrix to Prioritize Intrusive Ground-Truthing

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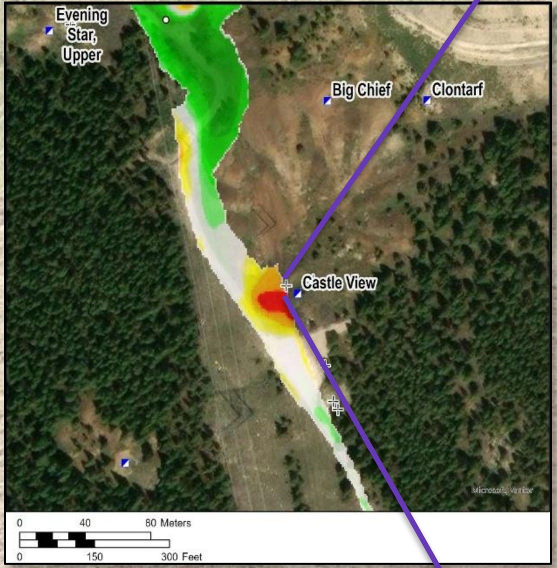
The Microgravity anomalies have more impact when supported by other data

The database established under the desktop phase serves as a screening tool for developing a subsidence risk matrix.



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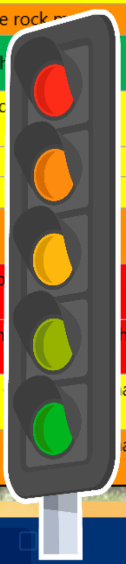
esrignss_receiver	R2, 5916S12073: Trimble

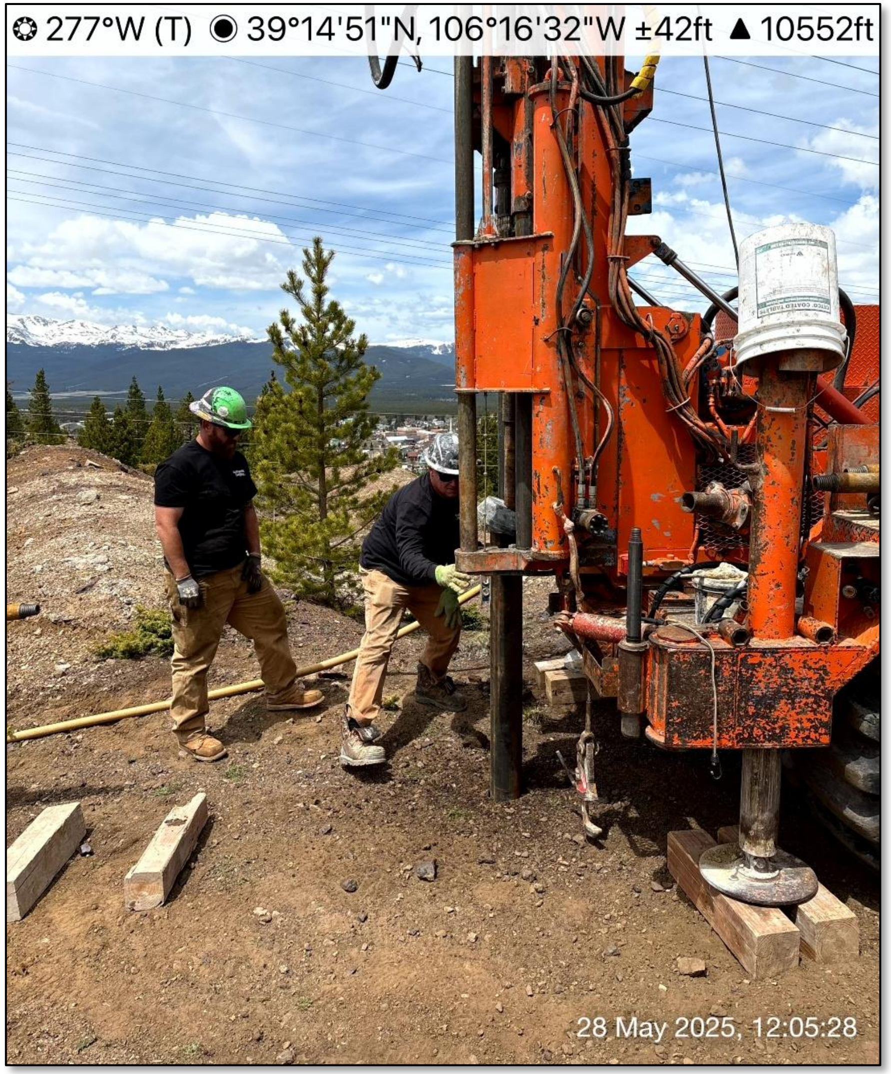
Table 1: Summary—Level of Concern: High Medium Low Negligible

Anomaly Name	Location	Surficial subsidence feature(s)?	Notes
R2	Road between 2 & 3	Near mound(s)	~100 feet north to south (source depth <50 feet); extends at least 100 feet east and west of ROW
E5	Existing tower 5	Yes - pitted waste rock mound	Polygon encompasses pitted waste rock mound
E6	Existing tower 6	Yes - pitted waste rock mound	Appears to be a waste rock mound.
T7	Planned tower 7	Yes - waste rock mound	Planned site appears to be a waste rock m
R9	Spur between 9 & 10, south edge of track	No	Avoidable by eastern spur or north
E23	Existing tower between 23 & 24	Pit	Near foot of tower. May be related construction.
T28	Planned tower 28	No	North edge of debris flow
R30	Road between 30 & 31	No	Colluvium south of hill?
T32	Planned tower 32 - center of footprint	Pit SW of footprint	May be related to drainage ditch.
R32	Road between 32 & 33	Collapse features to the east, mine shaft north	Blocky colluvium at the surface; co gravity area in topographic swale
T33	Planned tower 33	Collapse features to the east, mine shaft northwest	Low-amplitude anomaly. North en hic swale (colluvium?).
R33	Road between 33 & 34, 90 meters south to north	No	Just south of mapped debris flow an mapped?
T34	Planned tower 34 - center of footprint	No	Just south of mapped debris flow an mapped?

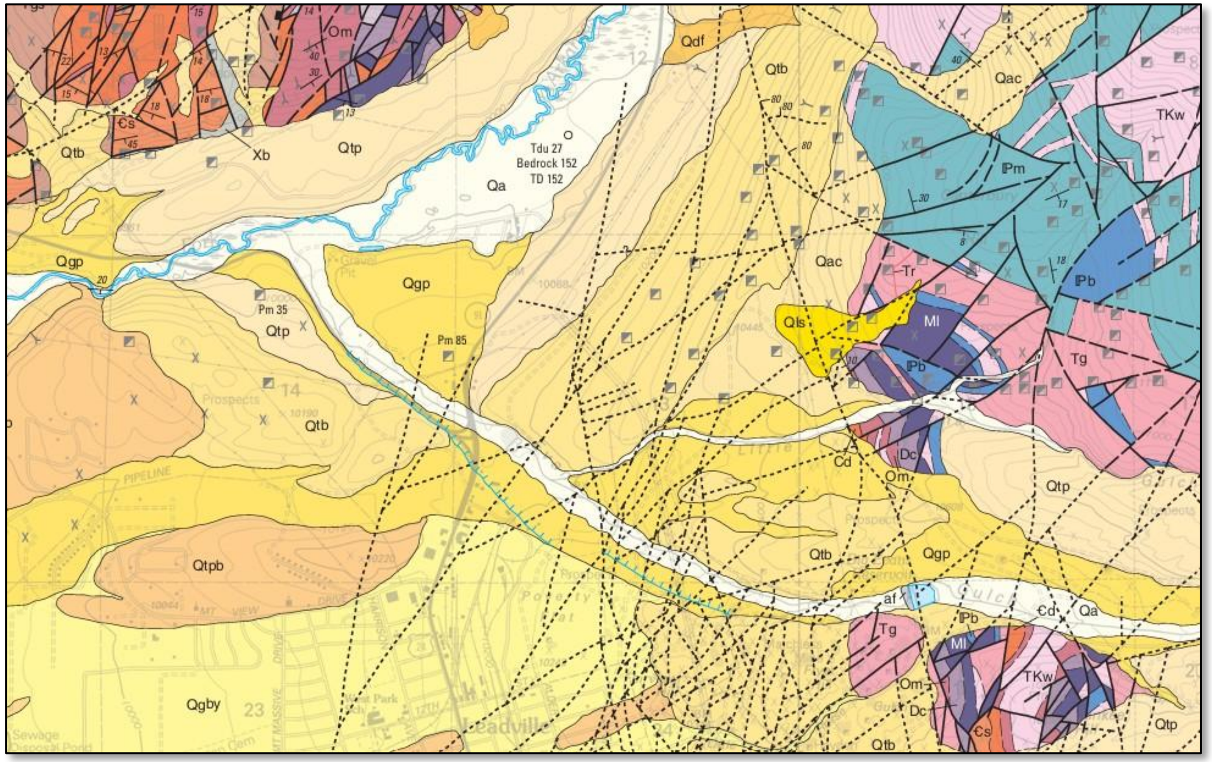


Case Study: Leadville Historic Mining District

De-Risk the Construction Activities Through Targeted Drilling & Excavations



- ✓ Confirm geophysical anomalies with drilling
- ✓ Capture enough geotechnical data to inform proper hazard mitigation
- ✓ De-risk specific areas based on project priorities



Thank You

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Leading with Science® to Evaluate AML Hazards

ASRS
Laramie, WY
June 7-11 2026