Slope Monitoring Methods in the Mining Industry

Stanley J. Michalek, P.E.
Chief, Mine Waste and Geotechnical Engineering Division
Pittsburgh Safety and Health Technology Center
Mine Safety and Health Administration

Slope Stability Hazards in Mining

- Open pit mining creates the highest man-made rock faces on earth – presenting slope stability hazards.

Bingham Canyon Mine, Utah. Pit slopes up to 3,500 feet (1,100 m) high.

Slopes can present a hazards to assets

(personnel, equipment, ore reserves)

Gold Mine - Montana

Coal Mine - Wyoming

Copper Mine - Arizona

Slope Monitoring

- Detect movement
- Measure displacement
- Determine displacement trend
  - Uniform
  - Decelerating
  - Accelerating

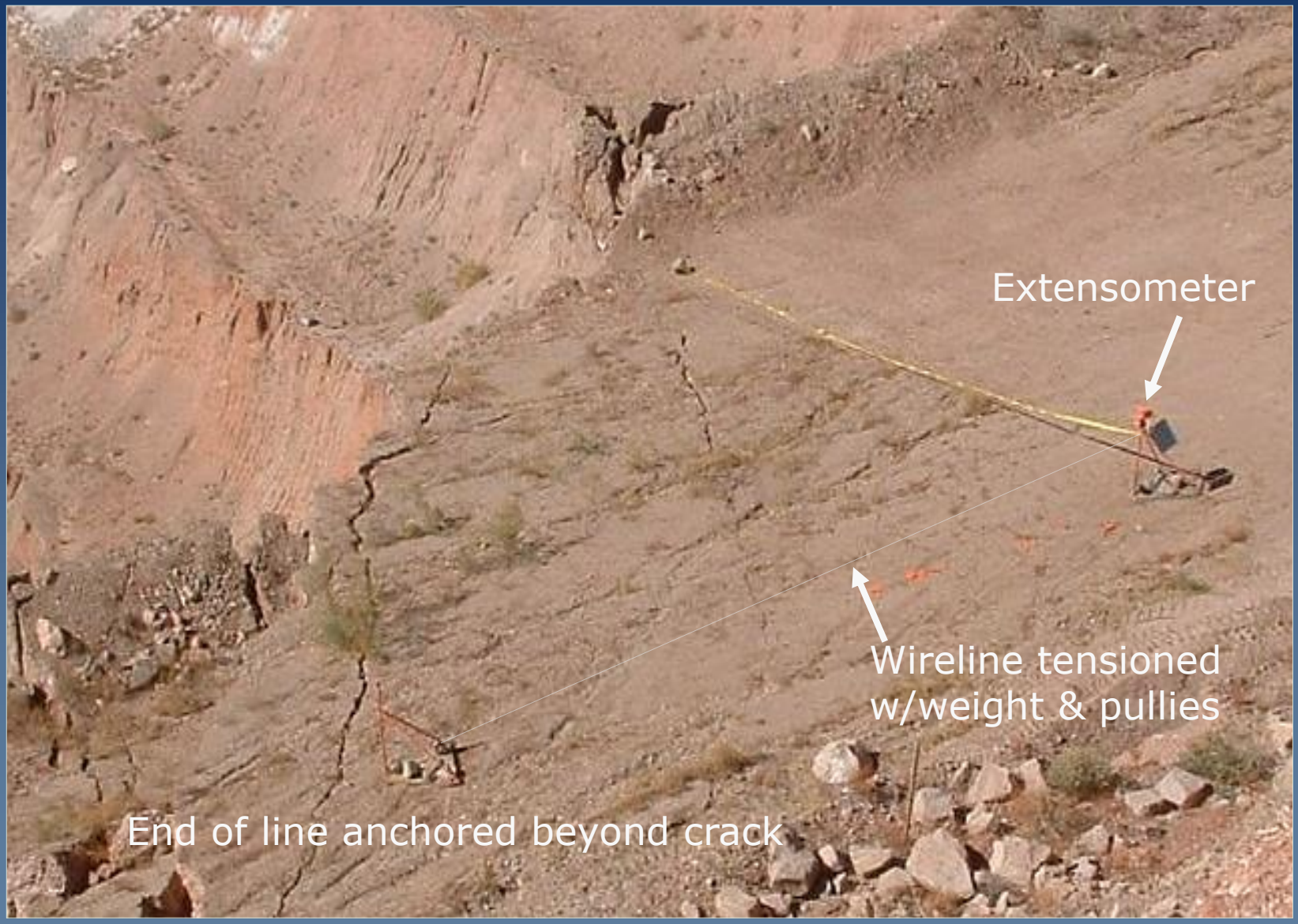
Slope Monitoring Methods
(Low to High Tech)

- Visual observation
- Crack monitors
- Wireline extensometers
- Surveying with prisms
- Slope Stability Radar
- LiDAR
- InSAR

Crack Monitoring

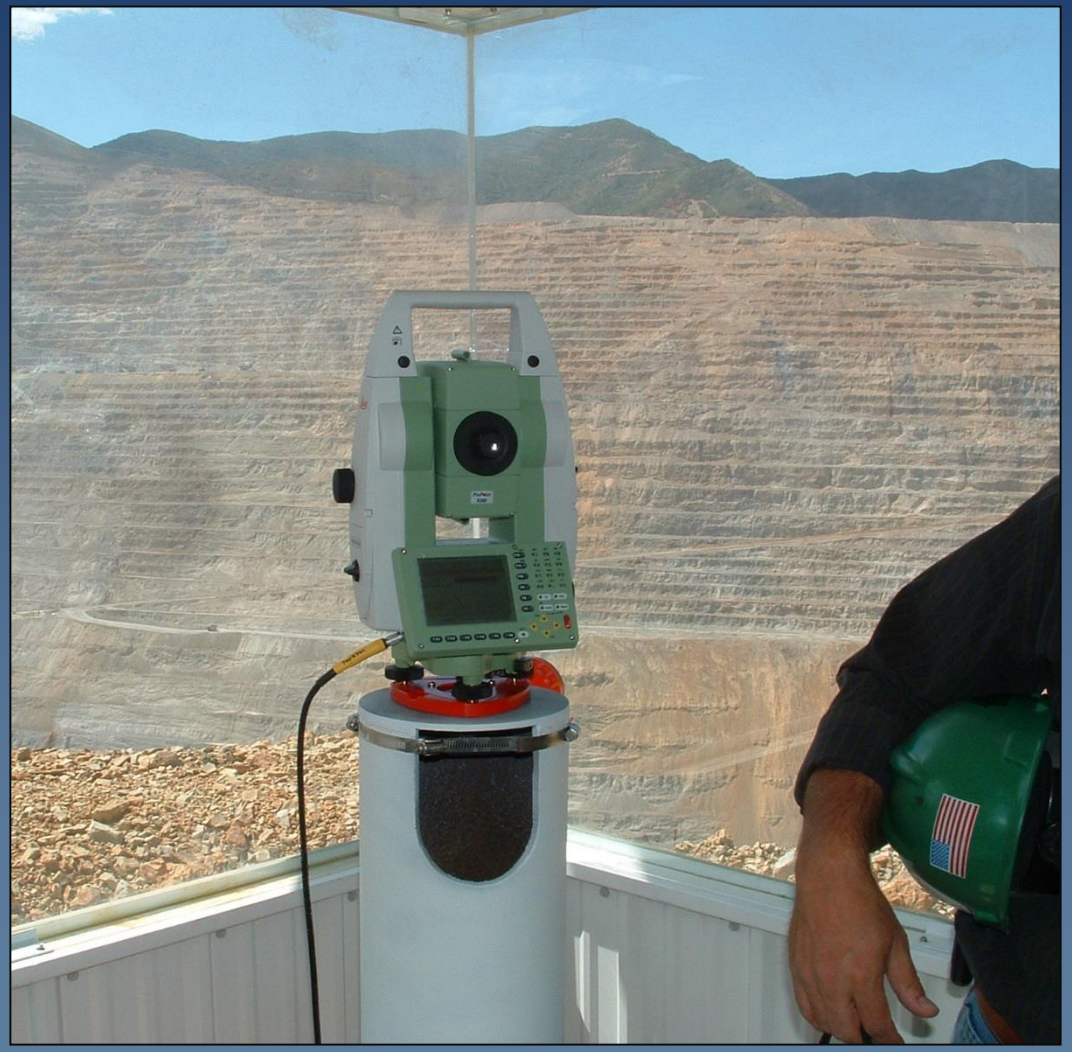
- Small cracks at the top of the pit or unstable area are often an early warning sign of instability.
- Crack monitoring can start with simple makeshift devices as soon as the crack is noticed.

Wireline Extensometer



Surveying with Prisms

- Precise (millimeter precision) 3-axis slope movement monitoring of very large areas.
- Most widely used slope monitoring system in mining.

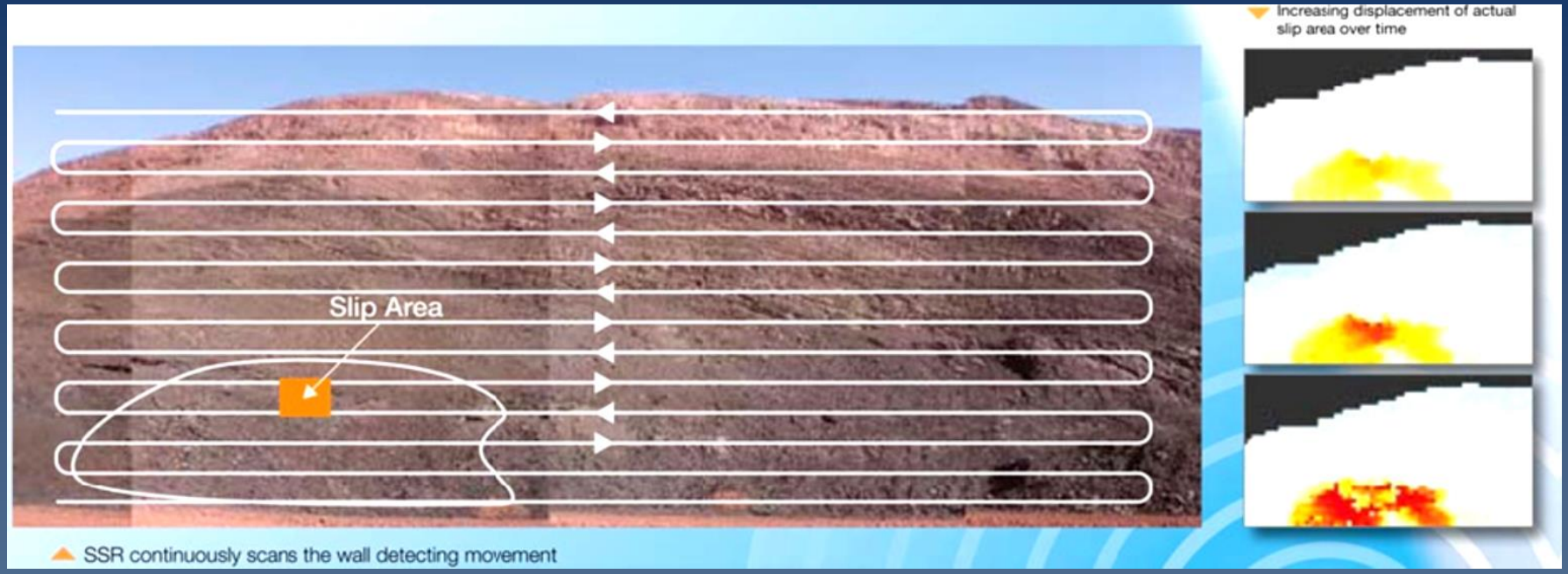


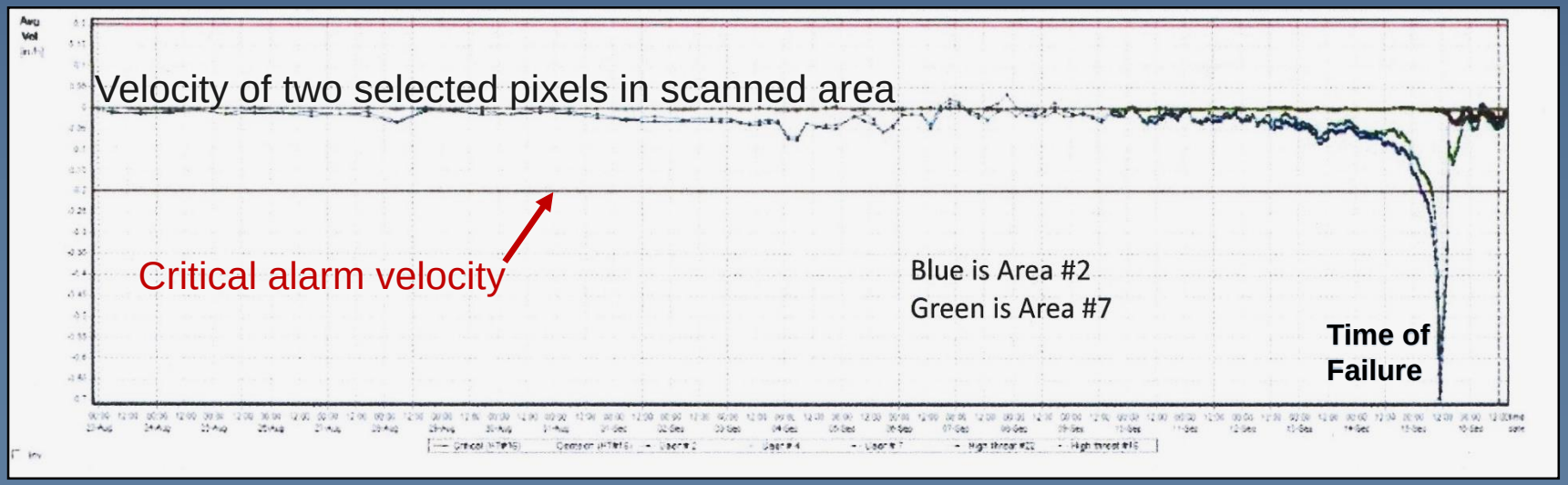
Slope Stability Radar

Slope Stability Radar (SSR)

- Sub-millimeter distance range measurements between antenna and continuous points on slope over a set scanned area.
- Range up to 3 ½ km.
- Rapid “tactical” deployment and setup.

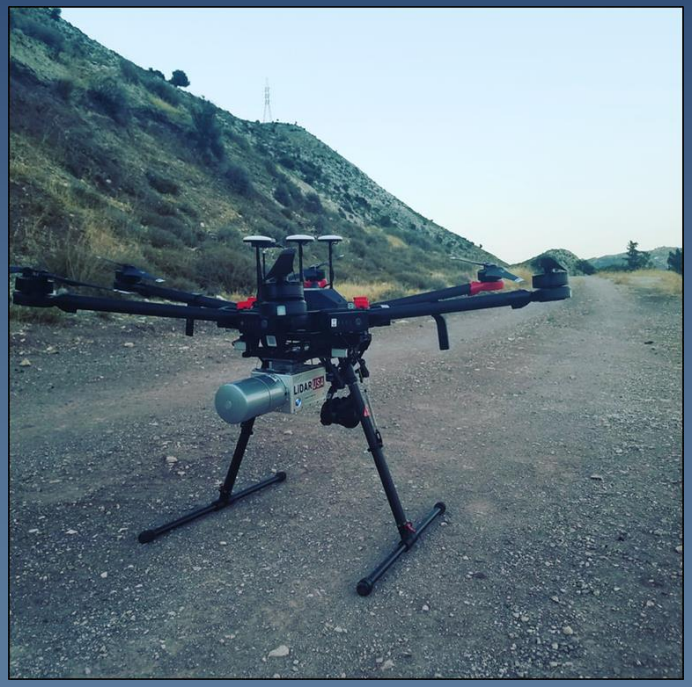
SSR Data Presentation

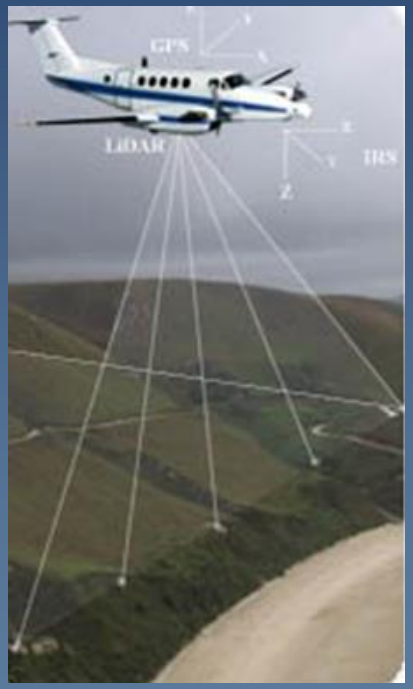




LiDAR
(Light Detection and Ranging)

- Uses speed of light to measure distance from instrument.
- Ground- or aerial-based surveys.



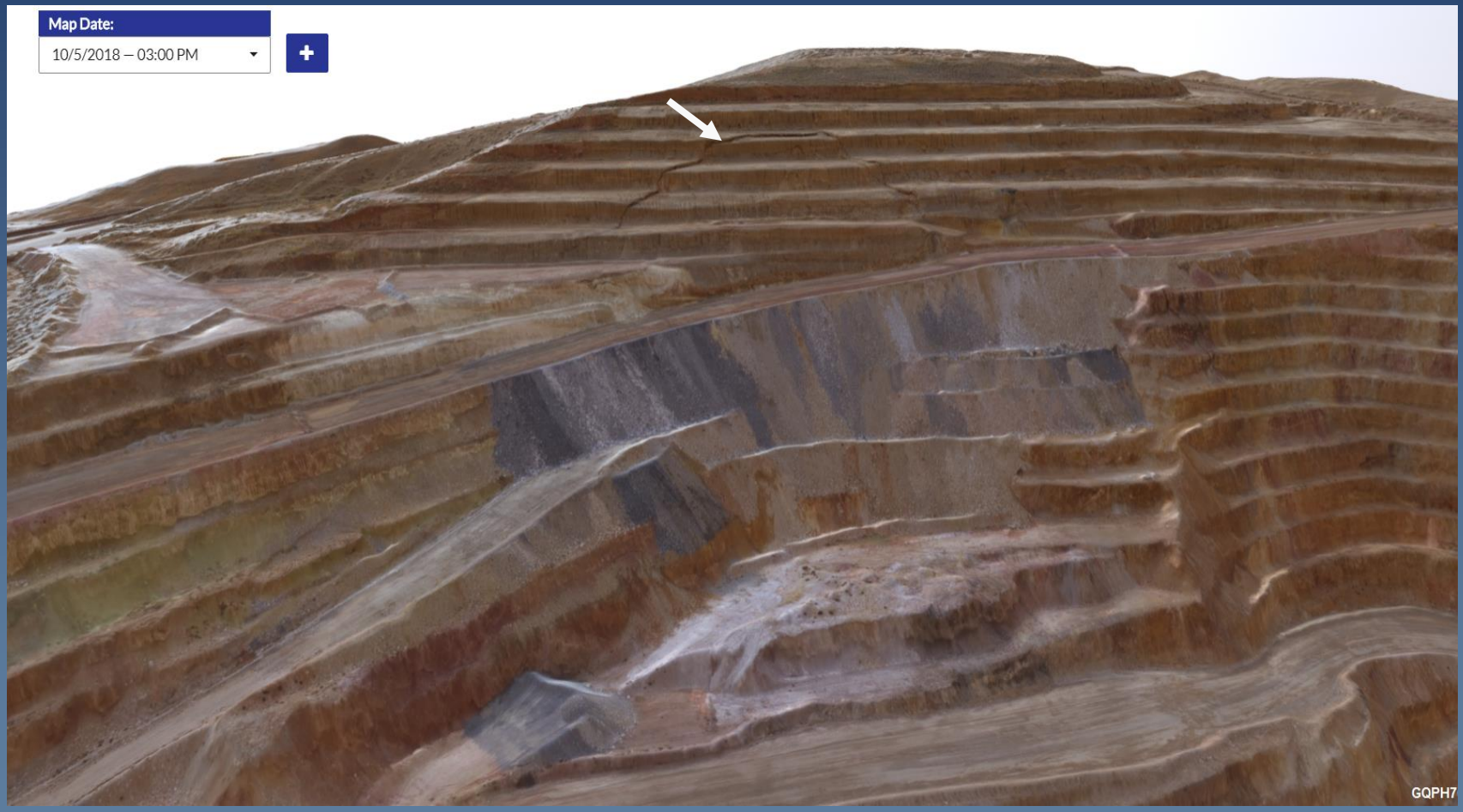


LiDAR Capabilities

- High precision, geo-referenced, 3-D “point cloud” data and imagery of rock faces.
  - Examine rock faces from inaccessible perspectives (drone-based systems).
  - Obtain detailed geometry of cracks, fractures, joints, and other discontinuities on the rock face.
  - Point-cloud computer analysis software can plot discontinuity data and determine potential rock slope failure modes.

LiDAR Capabilities

- Drone based 3-D point cloud image of a failing pit slope (not a photograph). Images constructed from millions of geometric data points:

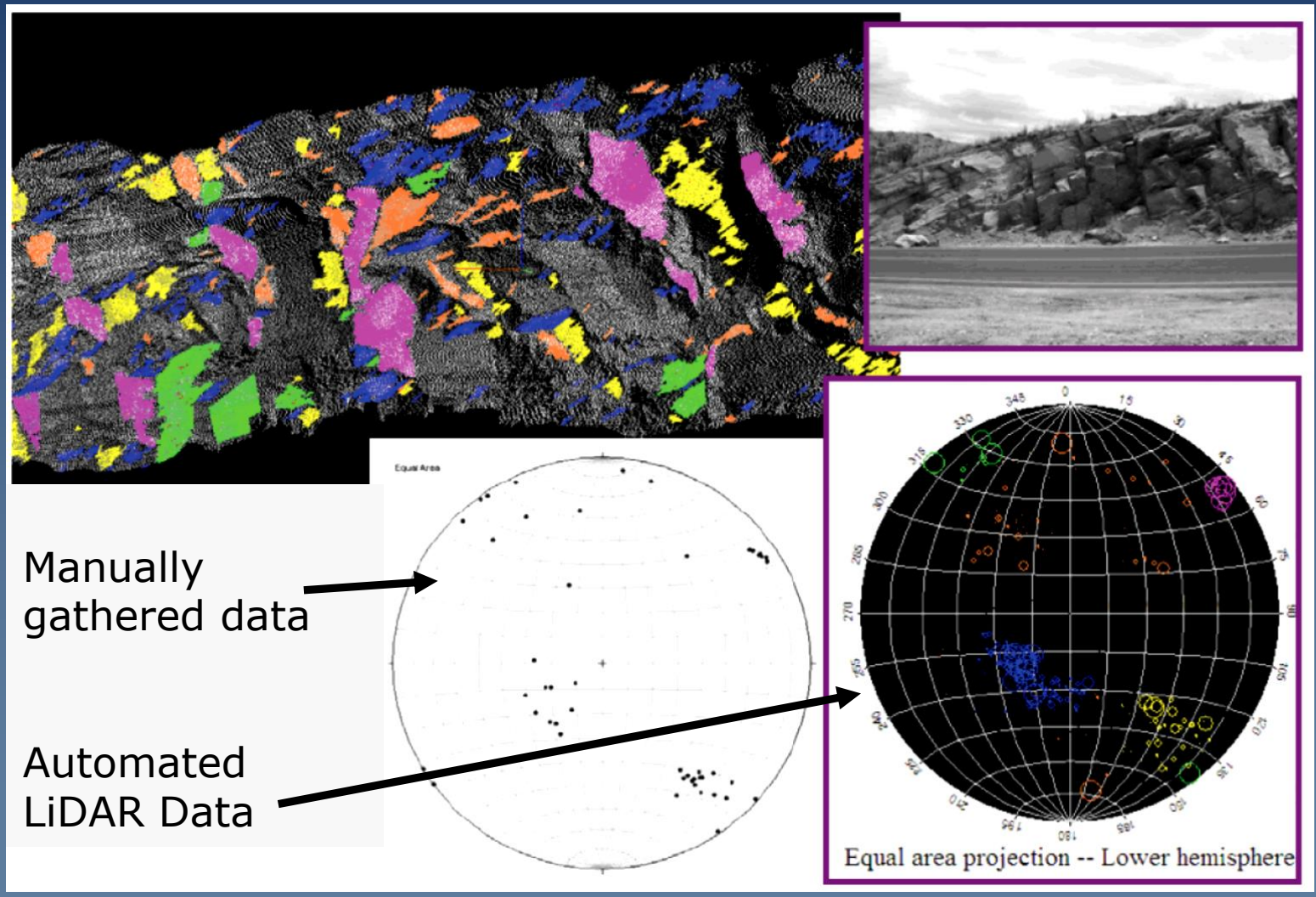


LiDAR Capabilities

- 3-D point cloud image of a rock face.
- Precise geometry of the discontinuities can be extracted from the data.

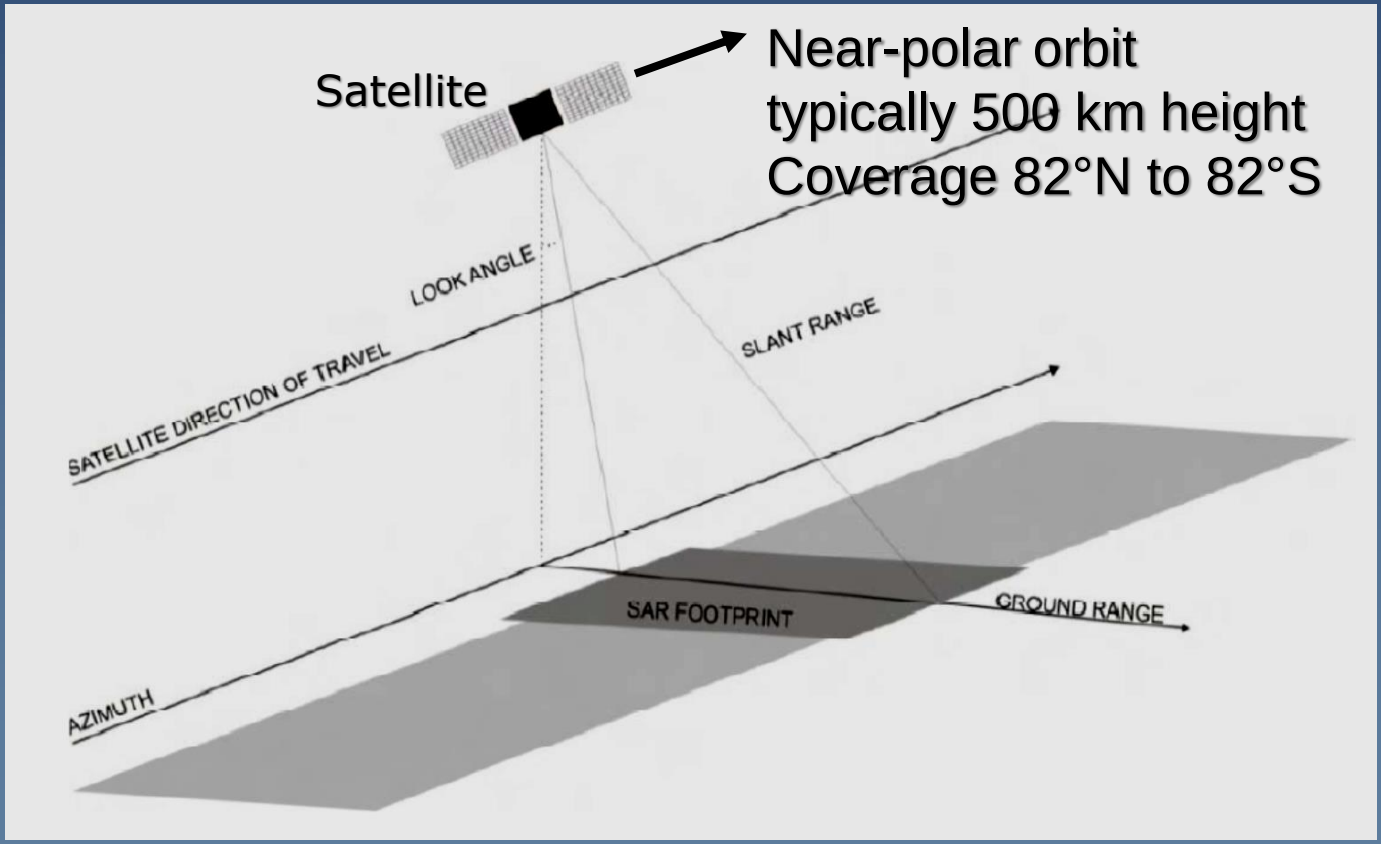
LiDAR Capabilities

- **LiDAR-generated data of rock face – point cloud and stereonet plots of the discontinuity orientations…**



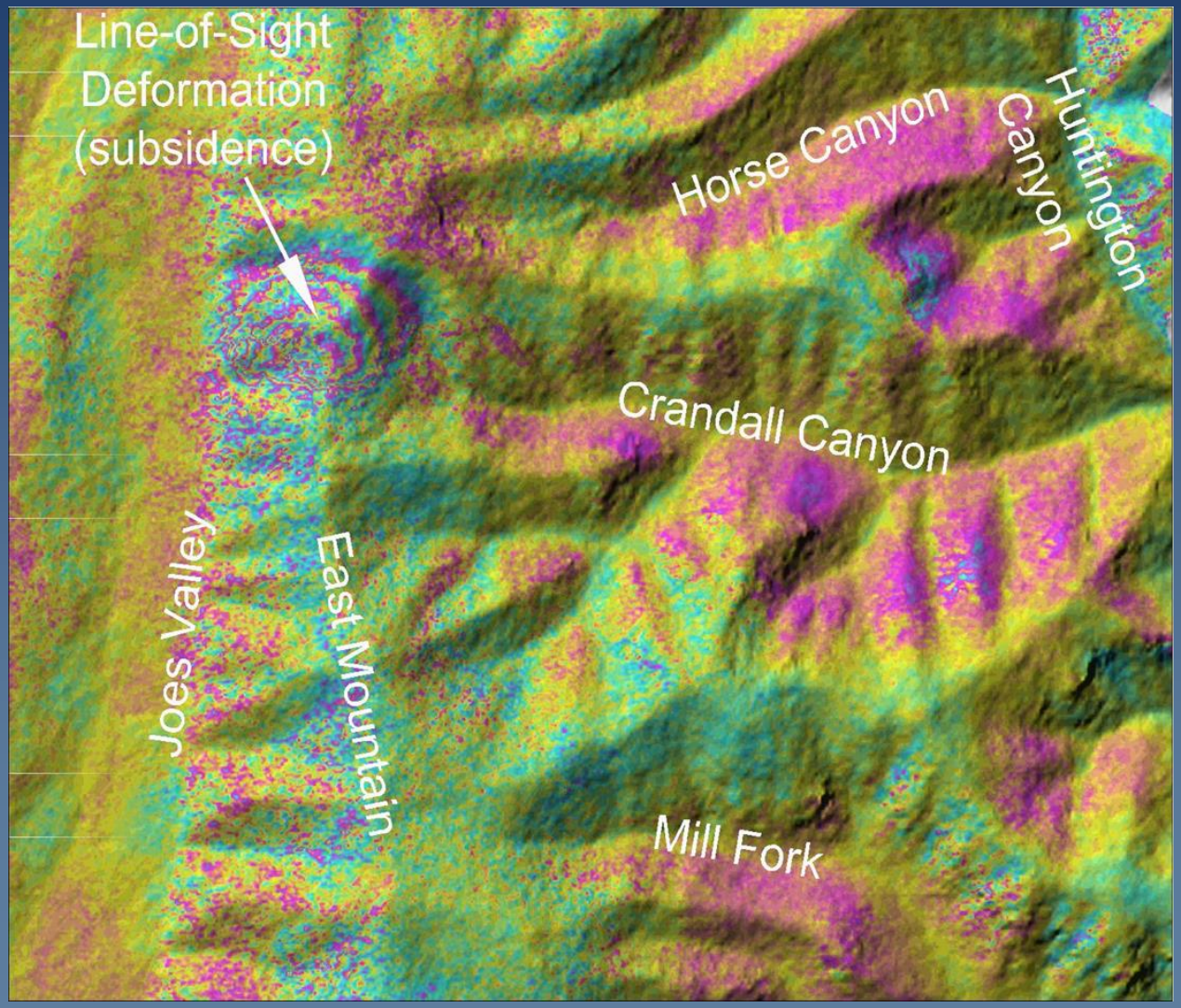
InSAR
(Interferometric Synthetic Aperture Radar)

- Various satellites in operation since 1992.
- Datasets provide 1-2 mm resolution coverage of ground movement for most of the Earth.



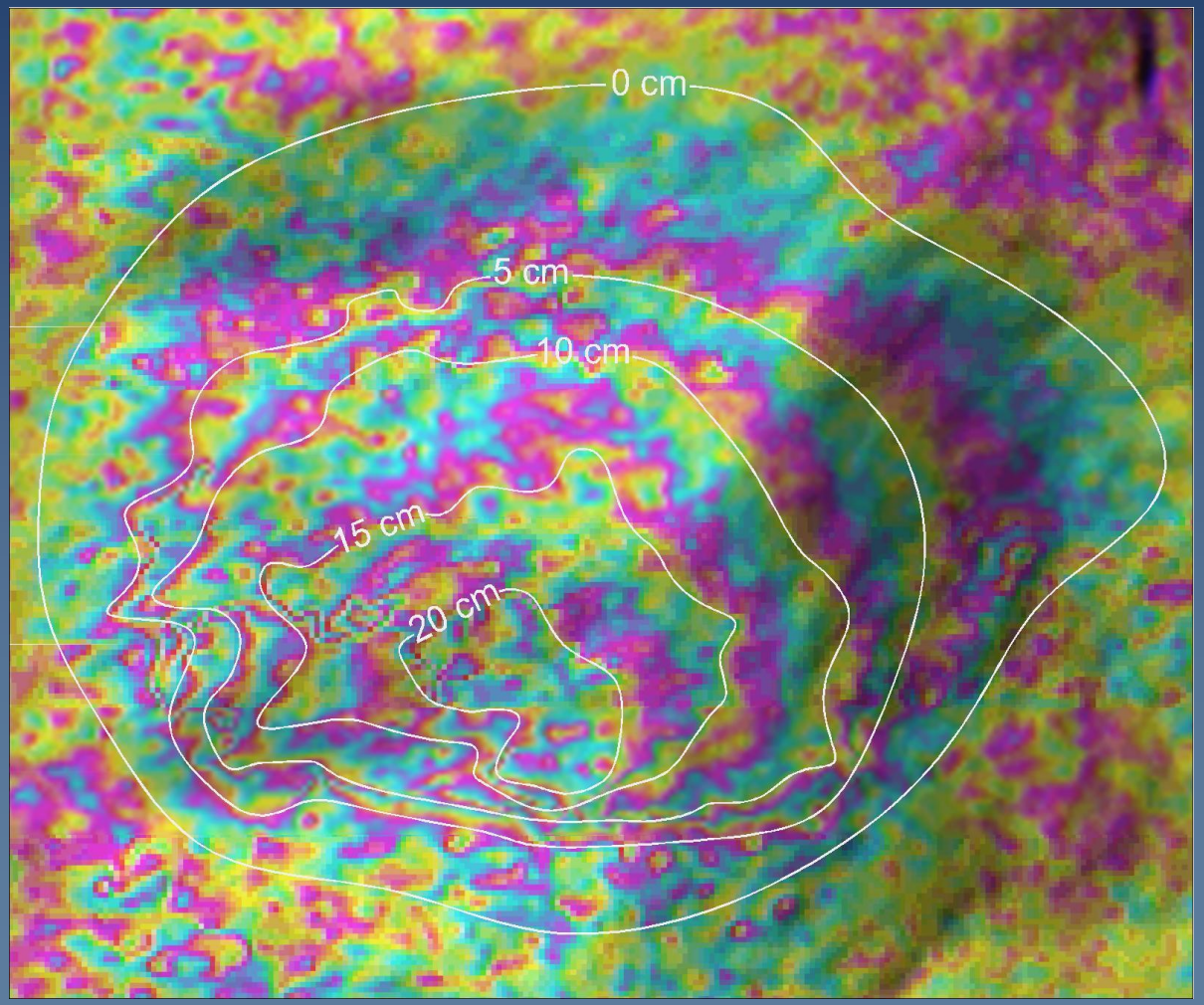
InSAR

Large-area application - investigating subsidence after underground coal mine pillar failure accident.



InSAR

- Surface Deformation from USGS InSAR.
- Each “fringe” depicts 5 cm of subsidence that occurred between successive satellite passes.



InSAR

Advantages:

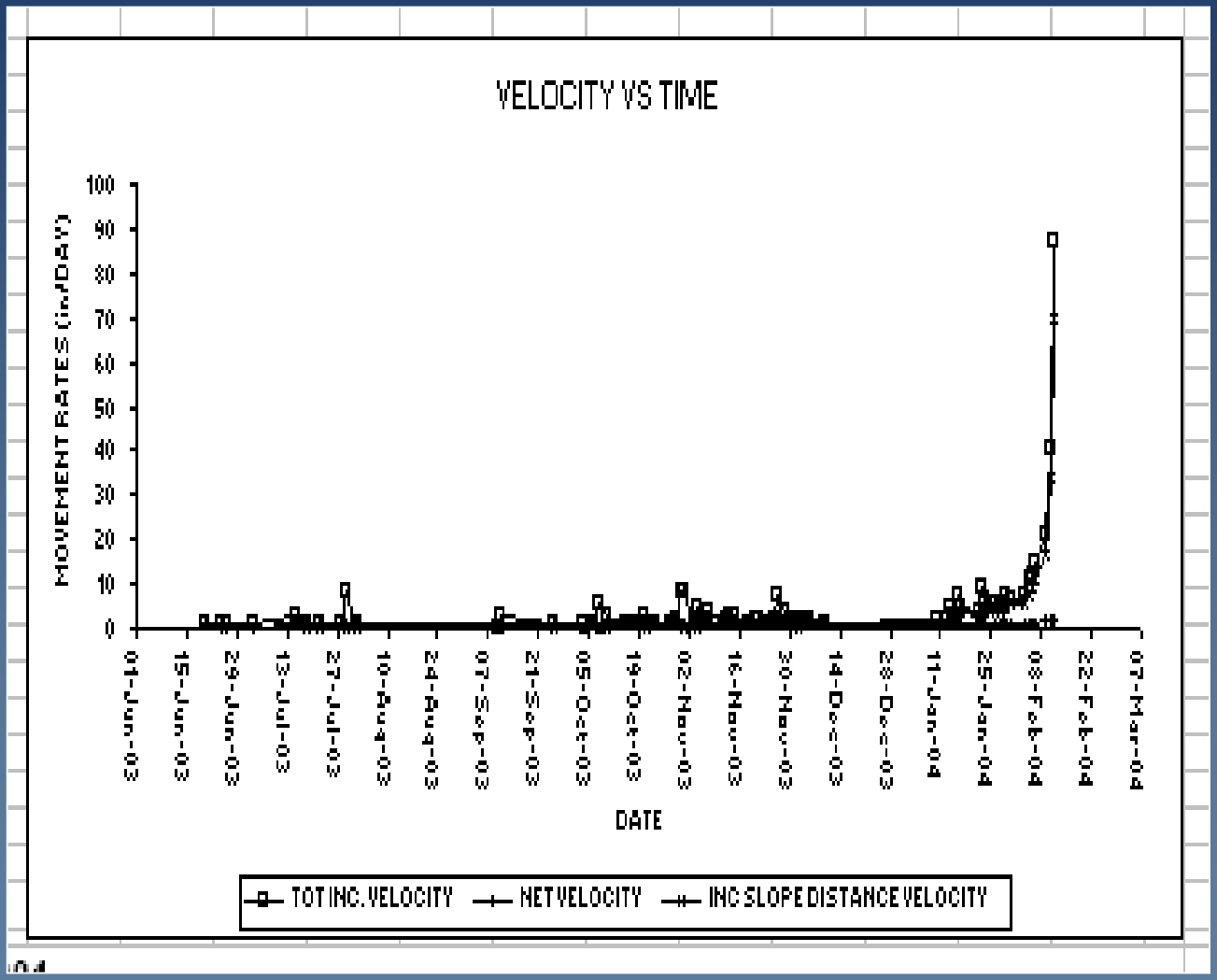
- High precision – can detect 1 to 2 mm displacements.
- Large coverage – data is available for most of earth back to 1992.
- Remote sensing – no ground instruments or site work needed.
- Full site monitoring – can detect movements where risk was not previously suspected.

Disadvantages:

- Measurement frequency limited by satellite passes from 2 to 12 days.
- A supplement, not replacement, for local monitoring methods like prisms and SSR.

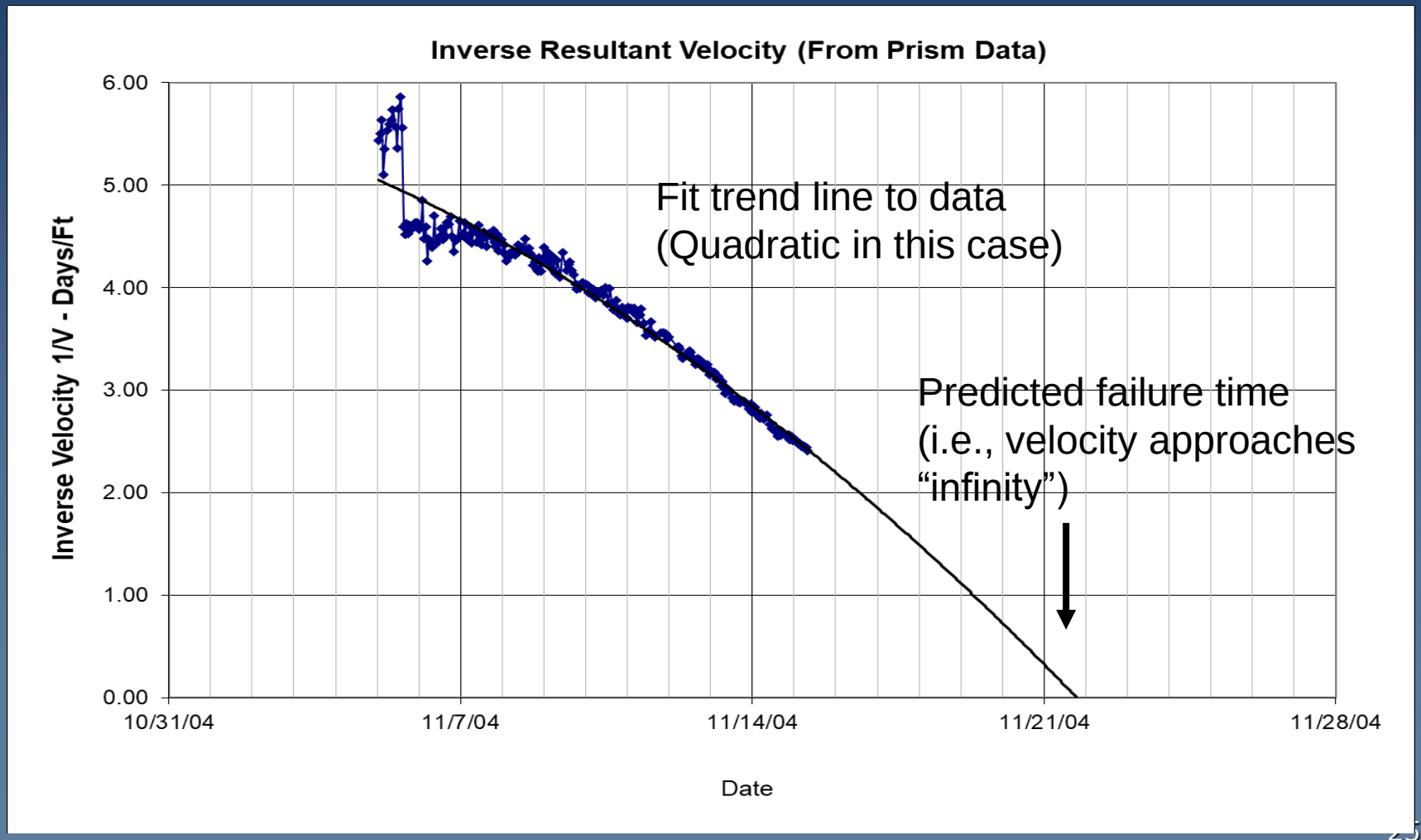
Data Interpretation

Progressive movement to failure…



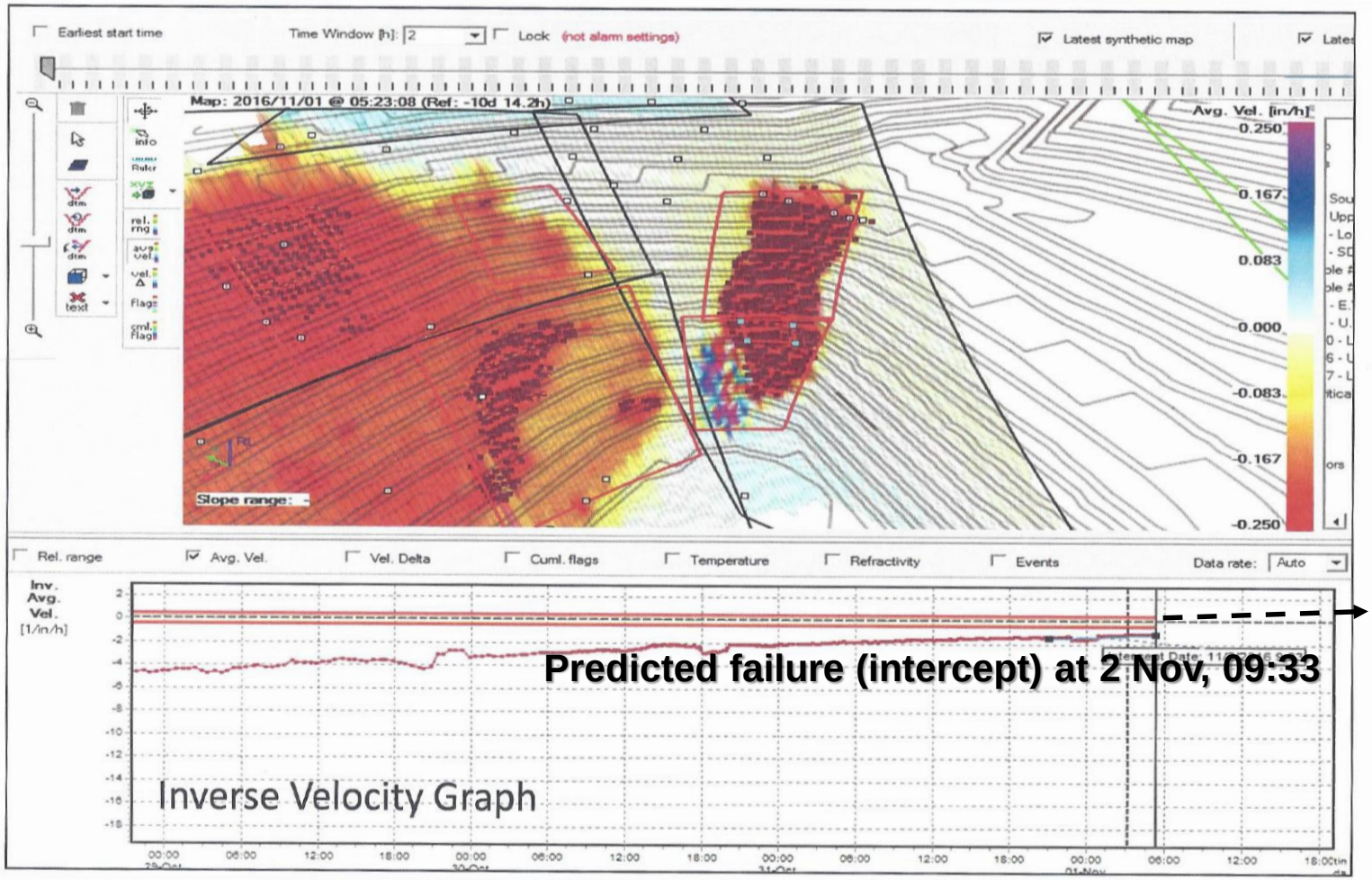
Predicting Time to Failure

Inverse velocity (1/v) often used in predictive models.



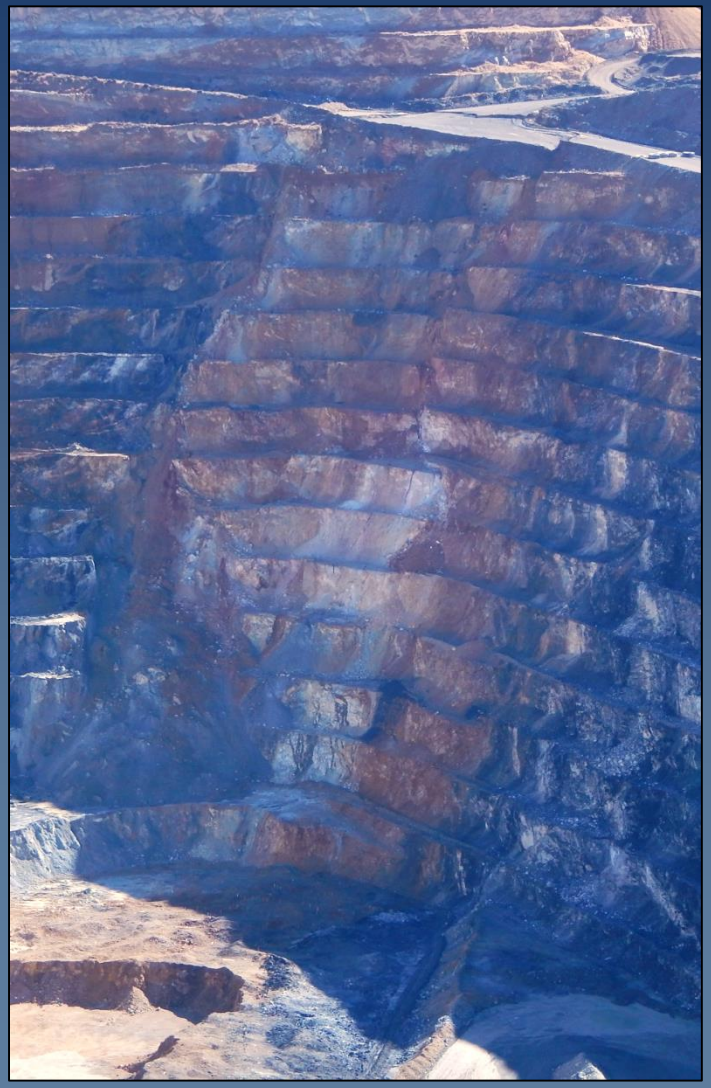
Predicting Time to Failure

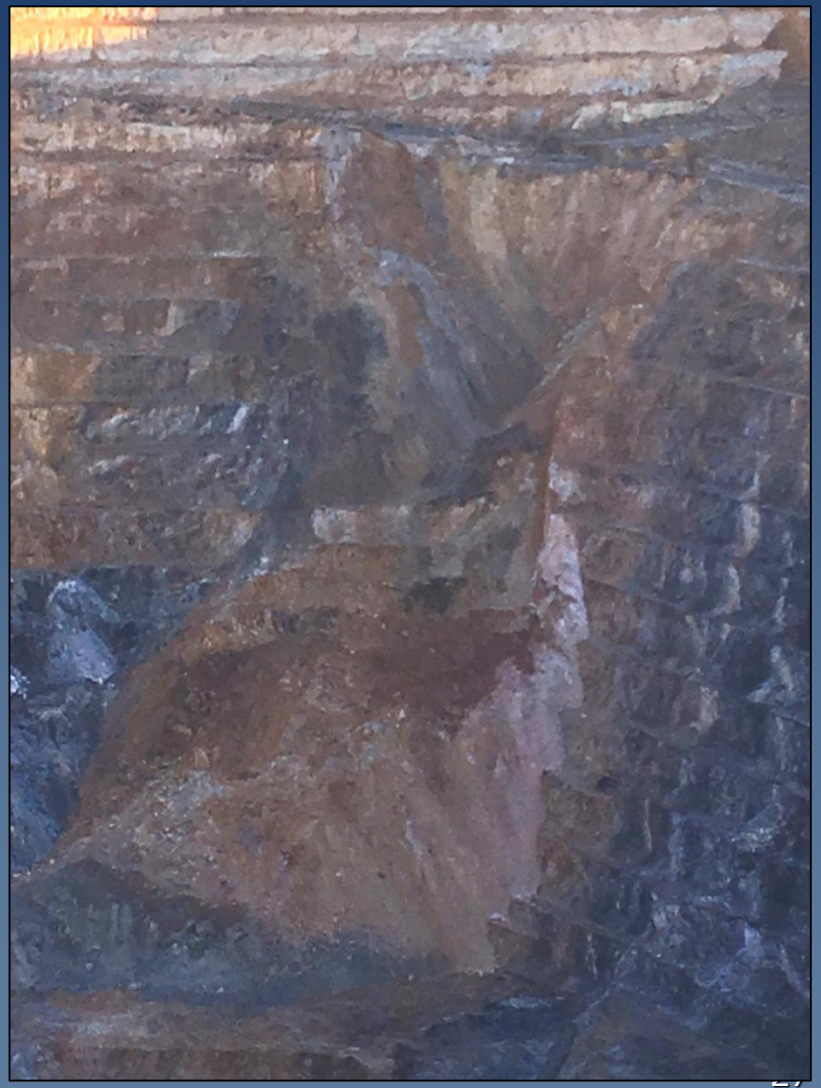
Inverse velocity (1/v) method – SSR data example



Predicting Time to Failure

Actual failure was on 2 November at about 1:00 p.m.





Copper Mine - Utah

Instruments and radar detected critical wall movements. Pit evacuated prior to failure.

Gold Mine - Nevada

- Radar monitoring detected critical movement. Pit evacuated ten hours before failure.