Close-Range Photogrammetry: Applications to Rock Mass Characterization

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Presented at the Seminar: “PERICOLI IDROGEOLOGICI”, Trento, Italy, Oct. 27, 2016.

Outline

- Background
- Principles of Photogrammetry (Covered by FBK)
- Accuracy
- Limitations of Photogrammetry
- Comparison with Laser Scanner
- How can Photogrammetry be Used in Slope Applications?
- Case History:
    - Hanging Lake Slope, CO
    - Mount Brione, Italy

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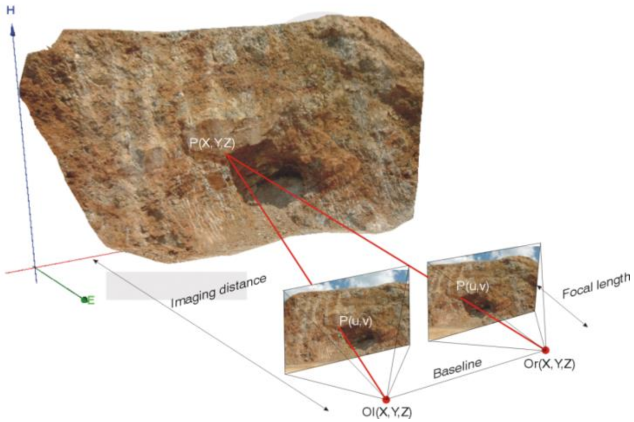
Background

- Laurea in Ingegneria Civile, Universita' di Padova, 1994;
  Prof. A. Bernardini, Ing. A. Mammino (Co-relatore)
- Ph.D. Civil Engng.: University of Colorado, Boulder, 2000, Prof. B. Amadei
- Senior Tunnel Engineer, Parsons Corporation, 2000-2002
- Assistant Professor, Geological Engineering, University of Utah, 2002-2005
- Assistant Professor, Civil Engineering, University of Texas at Austin, 2005-2012
- Chair, ASCE Rock Mechanics Committee 2009-2015
- Habilitation, Associate Professor, Geotechnical Engineering, Italy
- Adjunct Professor, Developer and Director, On-line Certificate in Tunneling, University of Colorado Boulder, USA, 2014-present
- President and Principal Engineer, Tonon USA and Laboratorio Rocce e Ricerca Tonon

Current Activities



PHOTOGRAMMETRY

ROCK MECHANICS LAB (ISO 9001; AUT. MIN 410, SETTORE ROCCE)

USE OF UNMANNED AERIAL SYSTEMS (UASs) FOR AERIAL DATA ACQUISITION (AUTHORIZED BY FAA IN THE USA, ENAC IN ITALY)

ON-LINE CERTIFICATE IN TUNNELING, ITA ENDORSED

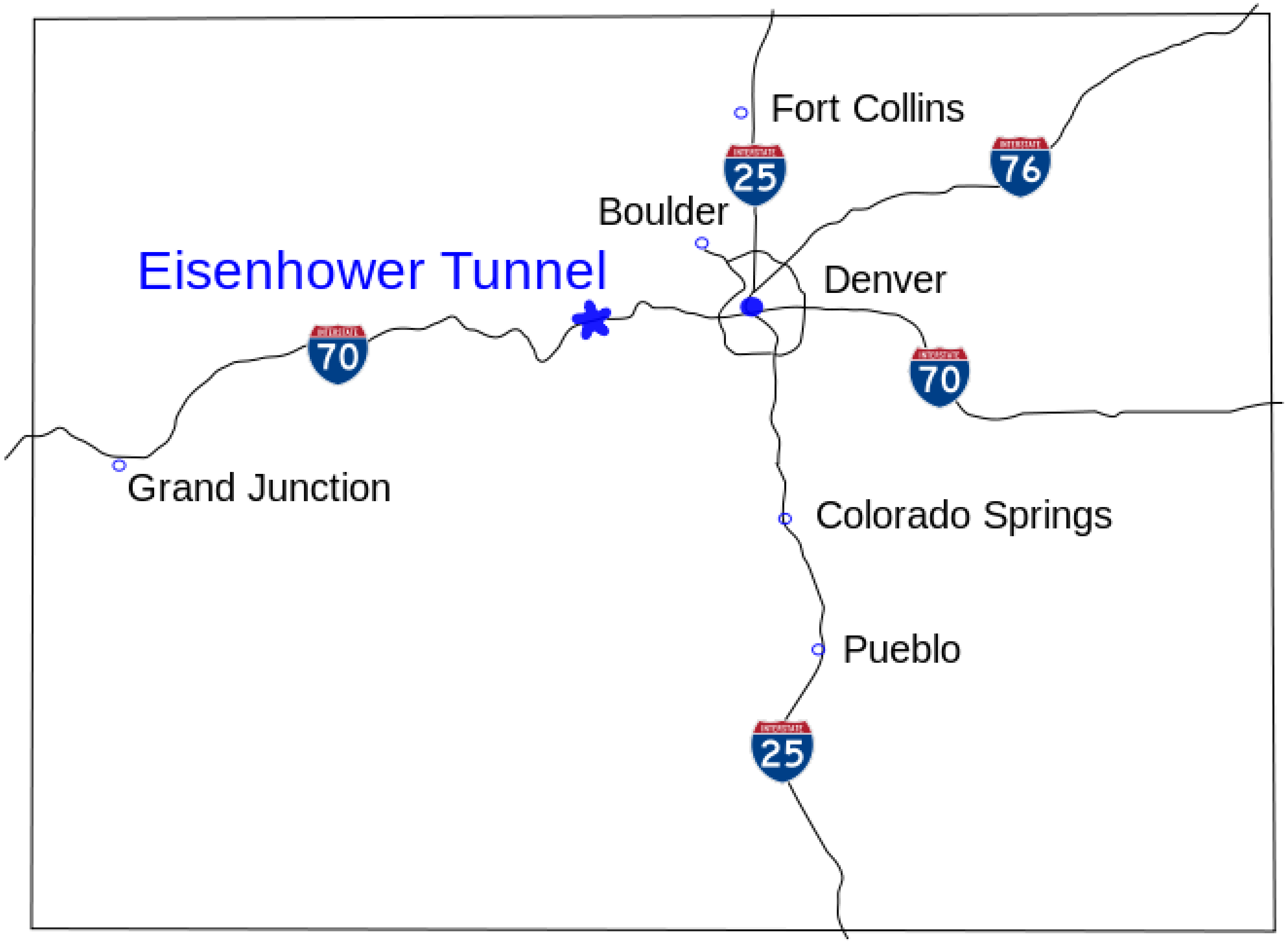
CONSULTING

Photogrammetry Applications

Chesapeake Bay Bridge and Tunnels (VA)

Opened: 1968
Length: 1600 m

Eisenhower-Johnson Tunnels (CO)

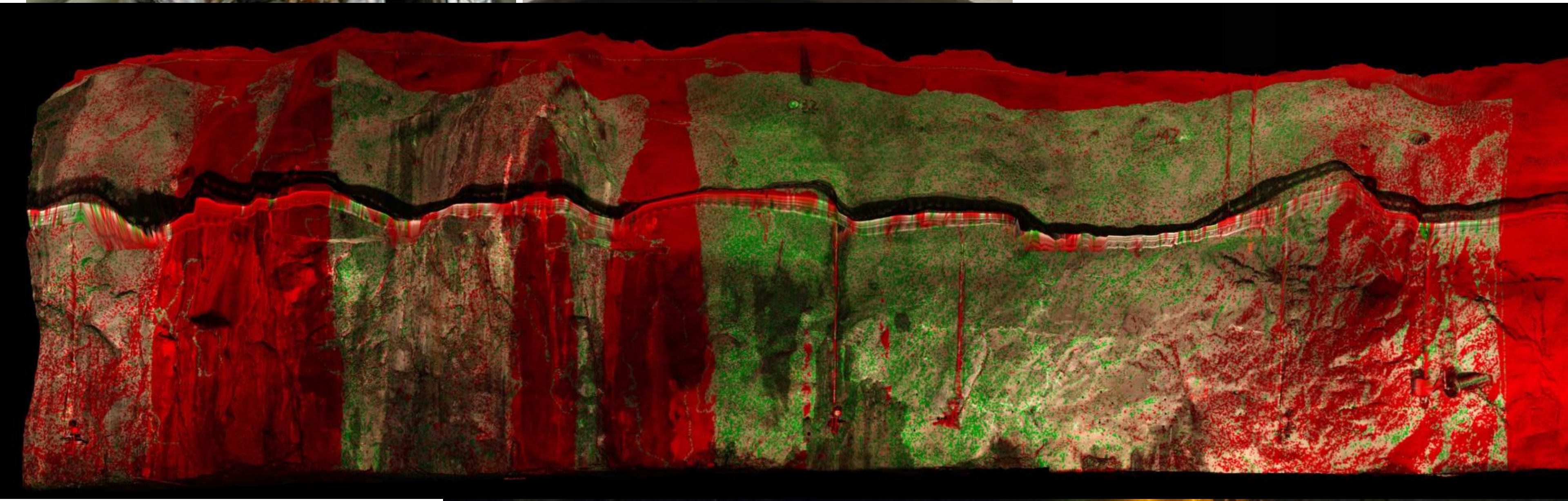


Opened: 1973-1979
Length: 2.7 km
Elevation: 3,400 m a.s.l.

Eisenhower-Johnson Tunnels (CO)

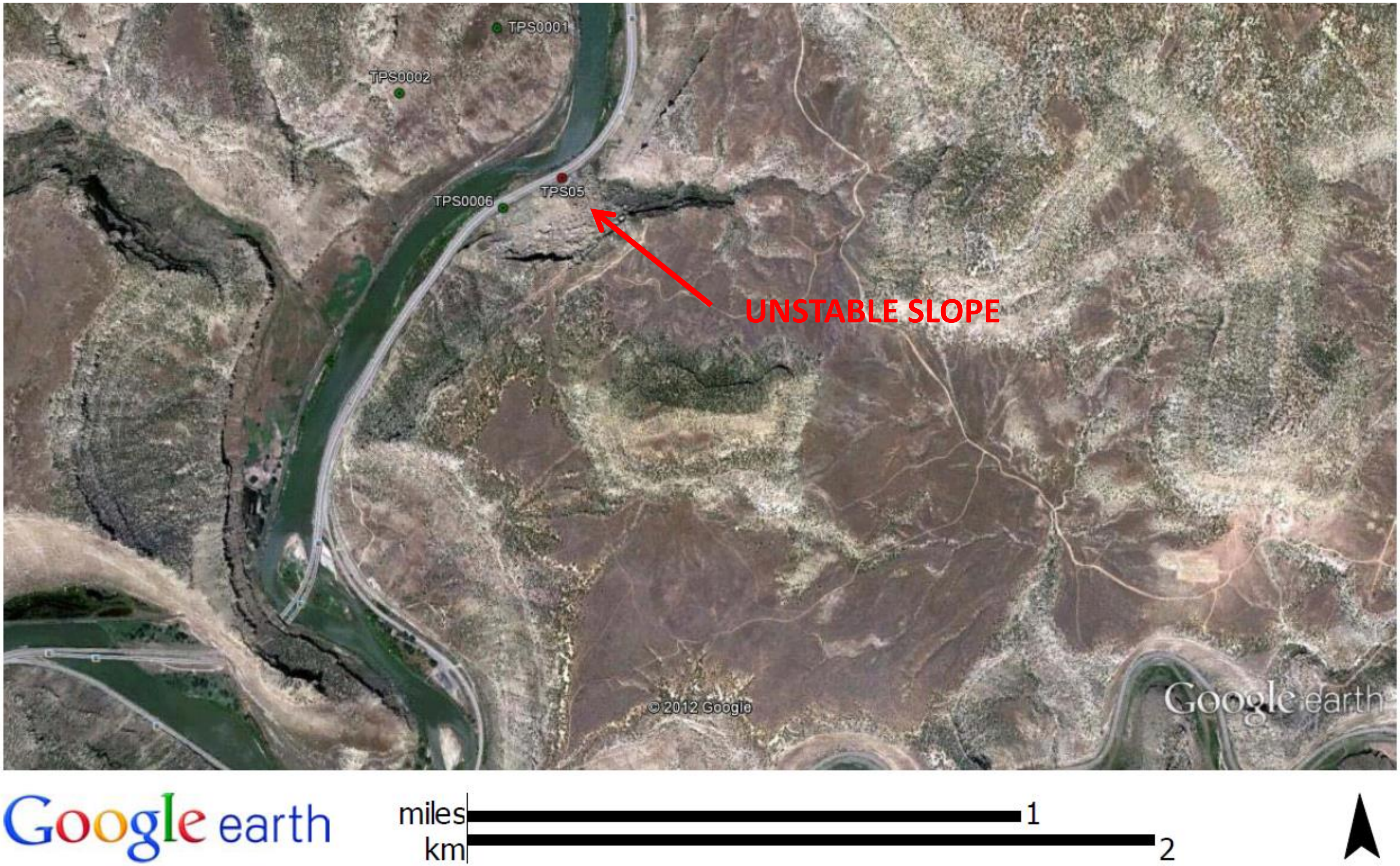
Cowee Tunnel (NC)

Helms Pumped Scheme (CA)

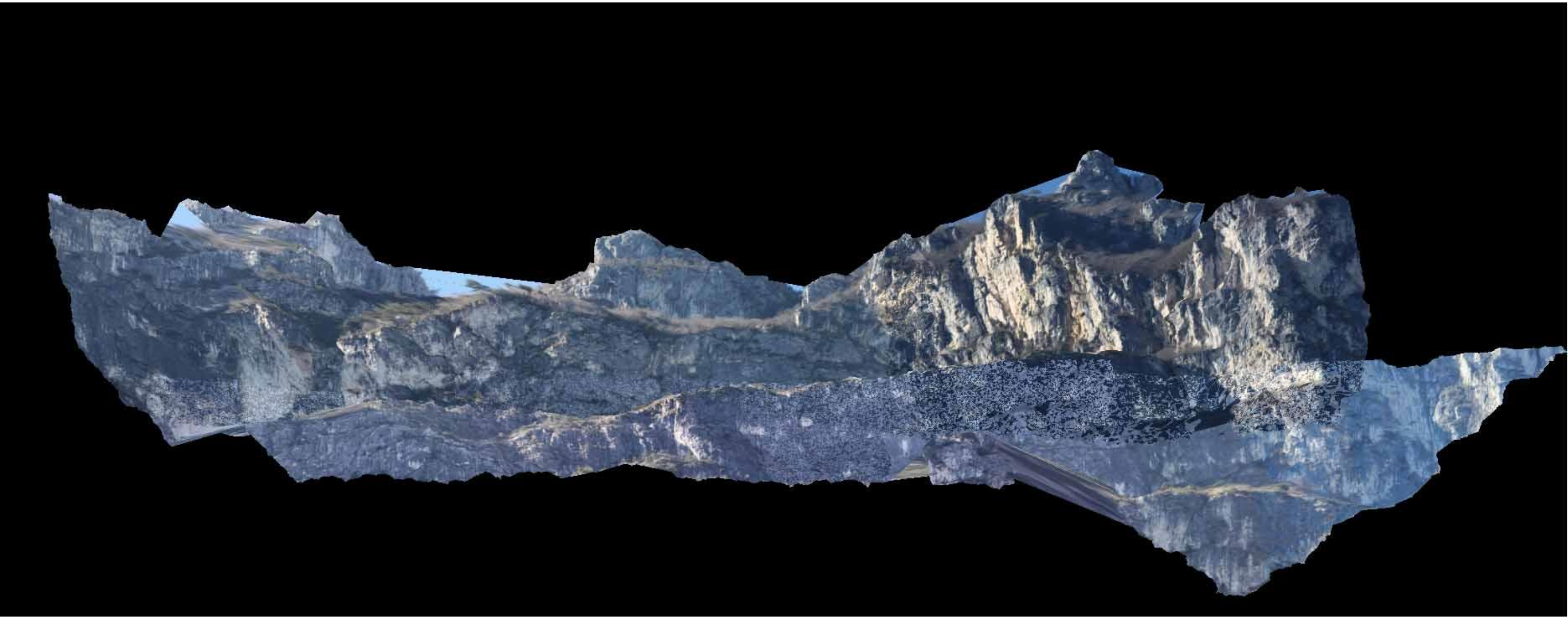


Tassullo Underground Storage (TN)

De Beque Slide (CO)



Riva del Garda (TN)



Hanging Lake Slope (CO)

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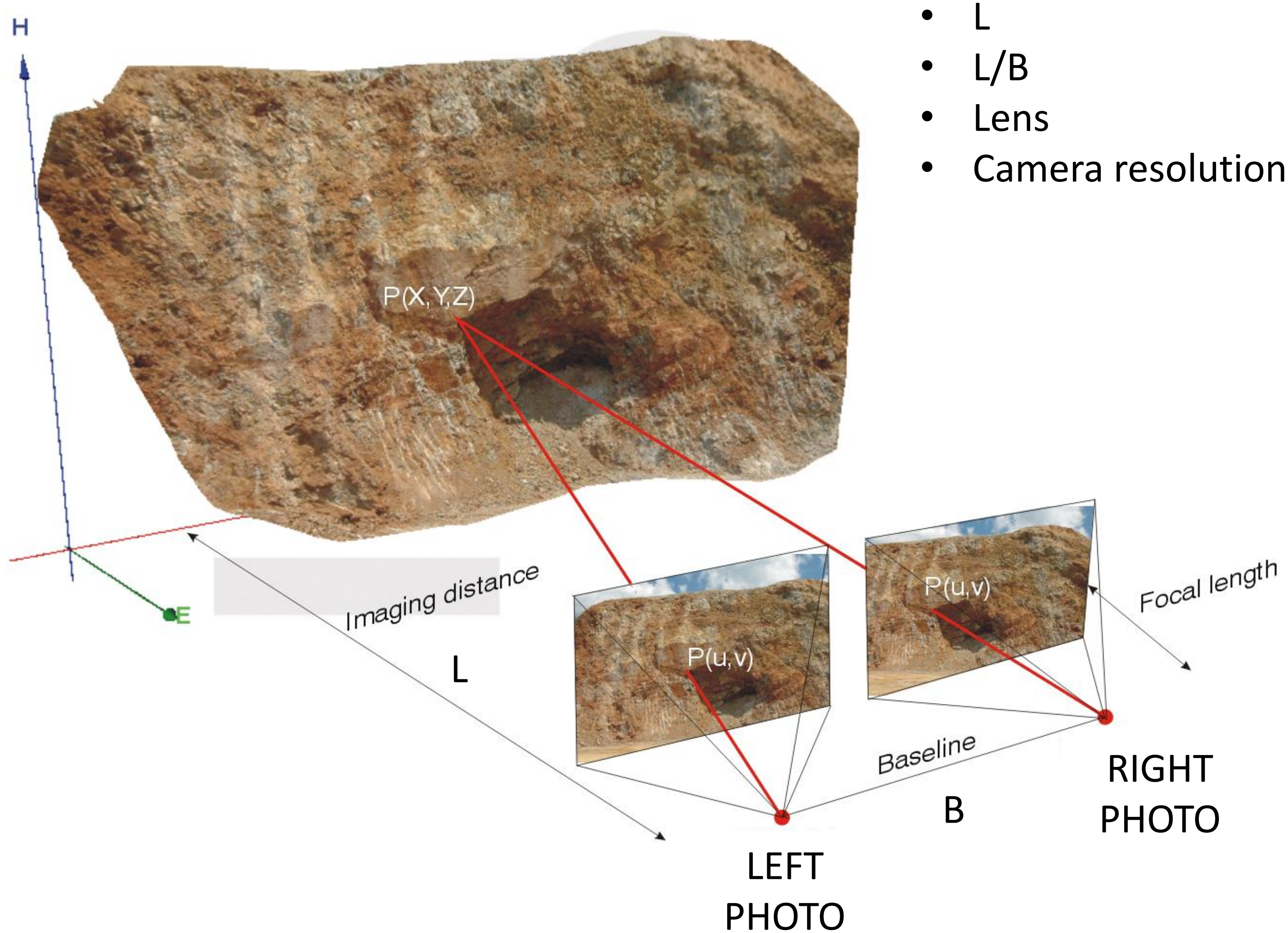
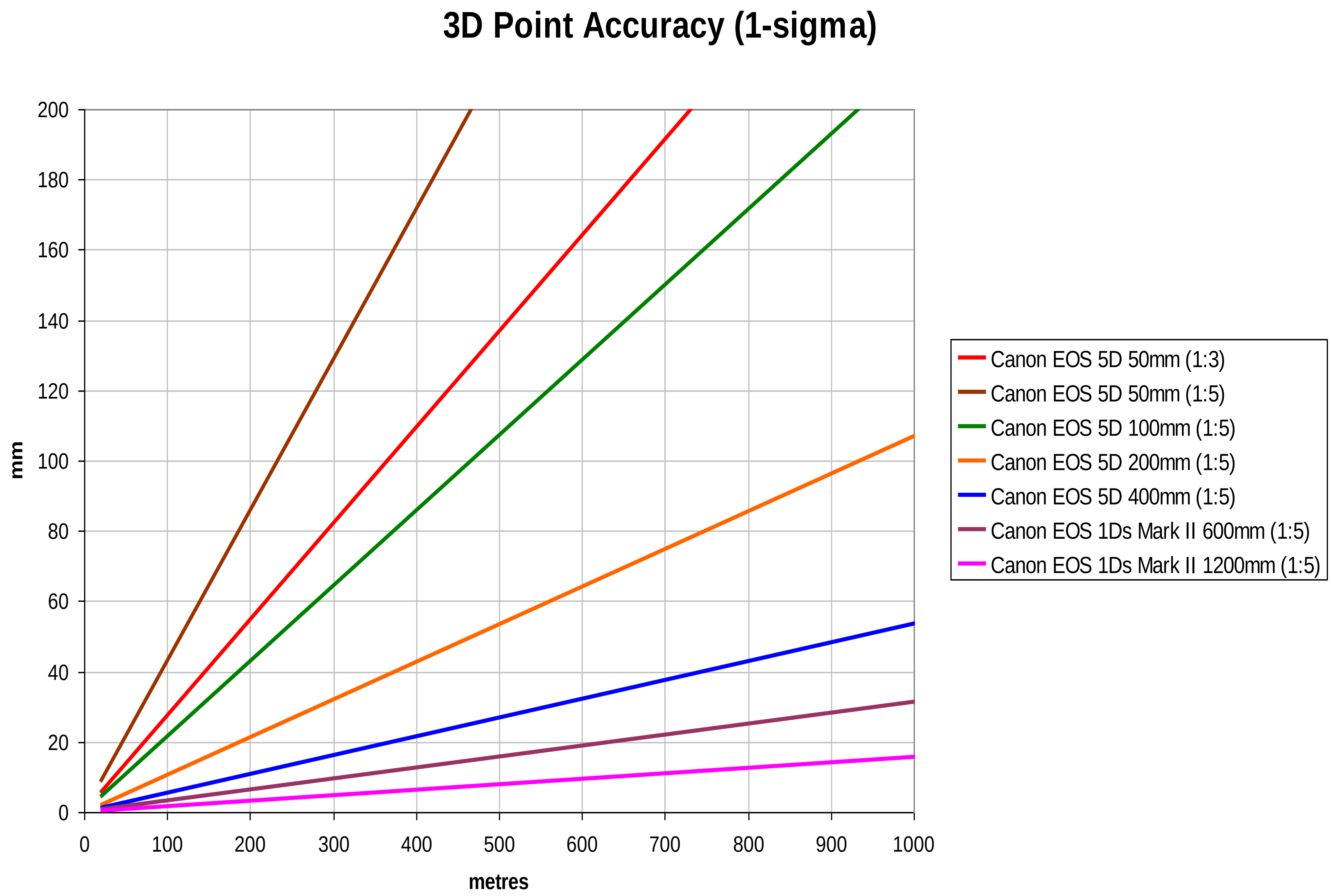
Accuracy

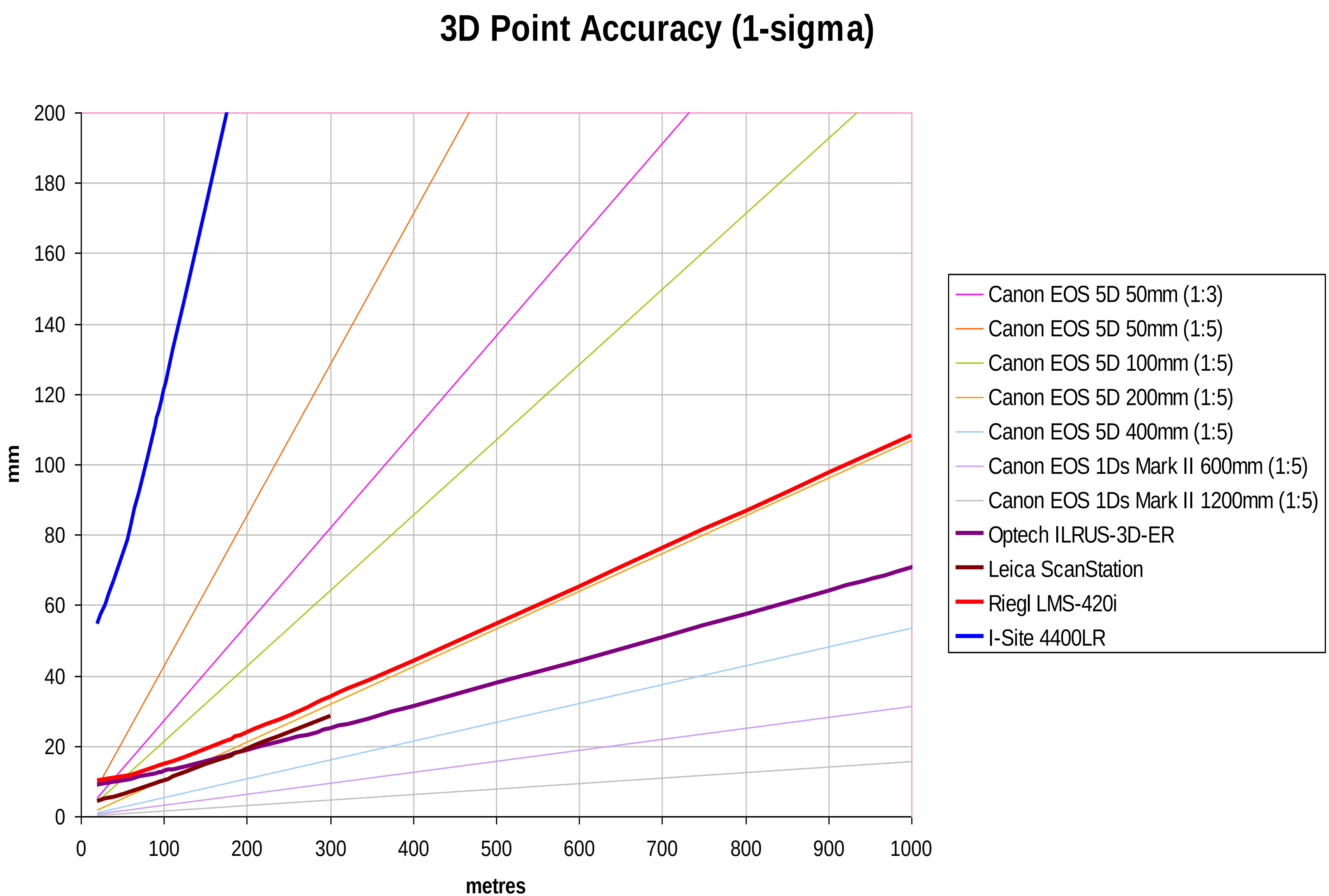


Depends on:
- L
- L/B
- Lens
- Camera resolution

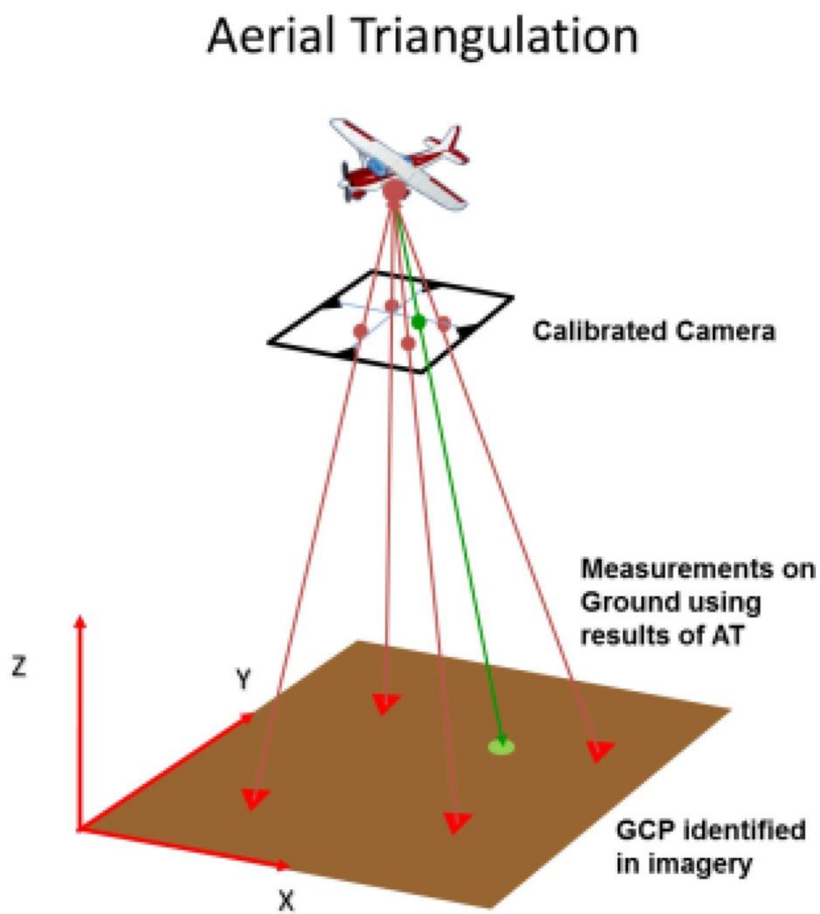
Visualizing Accuracy

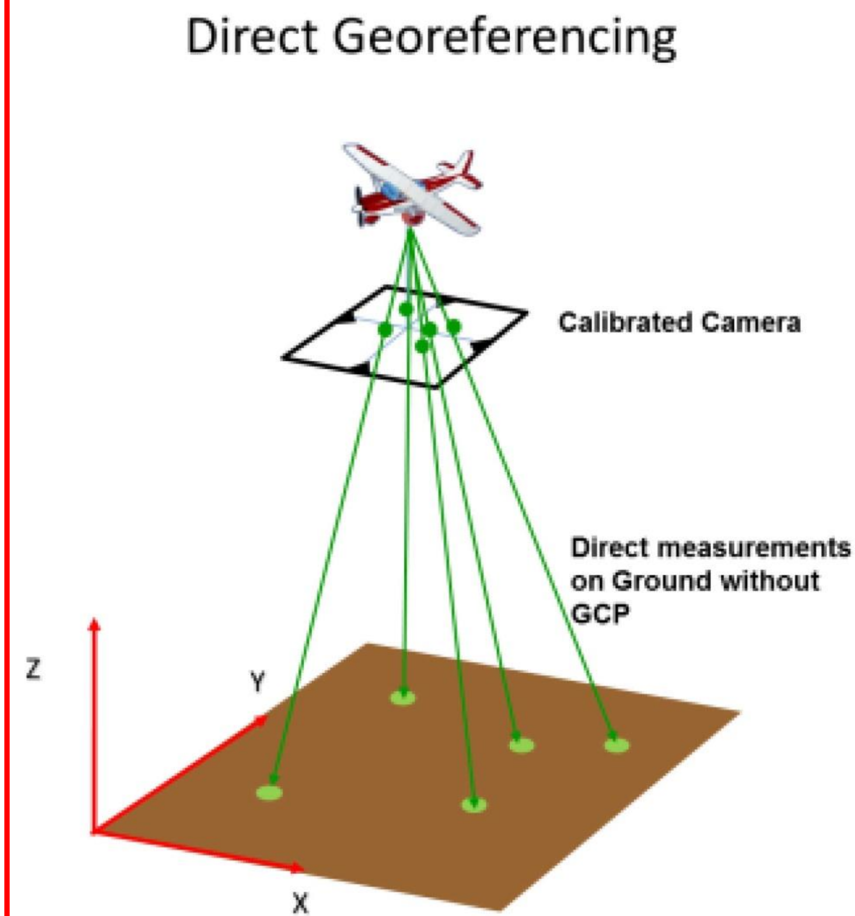


Visualizing Accuracy



Visualizing Accuracy





- NOT just accuracy of antenna position!!
- Camera Calibration!

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Limitations of Photogrammetry

- Surface must be textured — image matching doesn’t work on featureless surfaces
  - Natural surfaces are usually sufficiently textured
  - Pattern projector can be used
  - Targets can be used
- Must be able to see every point of interest from *two* locations — “shadowing” effect is twice as bad as a laser scanner
  - Taking additional images from different vantage points to fill in the shadows doesn’t add much time
- Subject should look similar in each image
  - Change in brightness or colour doesn’t matter; having lots of shadows in one (e.g. captured late afternoon) and no shadows in the other (e.g. captured mid-day) hinders matching because shadows look “interesting”

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Different from a laser scanner survey?

- Triangulated point cloud is generated from pixels => pixel to mesh assignment

Two fractures identified:
- From a face
- From a trace

Orientation is same because of perfect overlap between geometry and photos

This is NOT possible with laser scanner because:
- Traces cannot be identified from point clouds
- Photos obtained are poorly calibrated
- Pixels are not perfectly overlapped (assigned to) onto triangulated mesh

Different from a laser scanner survey?

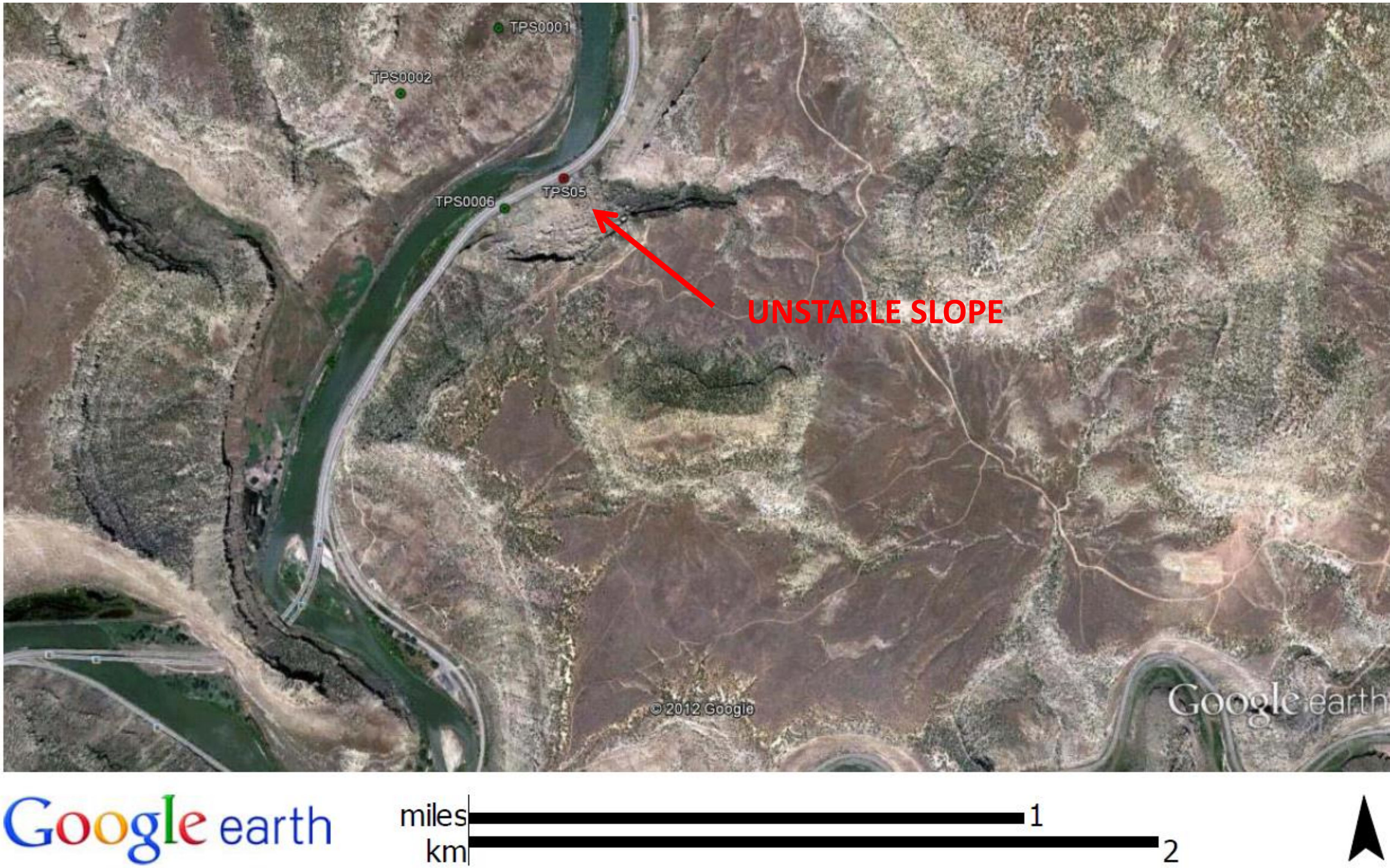
- Triangulated point cloud is generated from pixels => pixel to mesh assignment
- Measure of accuracy for each pair of photos (mesh patch)
- Accuracy and point density are input from client, not an equipment constraint
- Much higher photo resolution; e.g., at 600 m: 4” ground pixel size for I-Site 8800
- Laser:
    - Projects a cone => signal from ground anywhere from footprint on ground

Different from a laser scanner survey?

Example: DeBeque Slide, CO

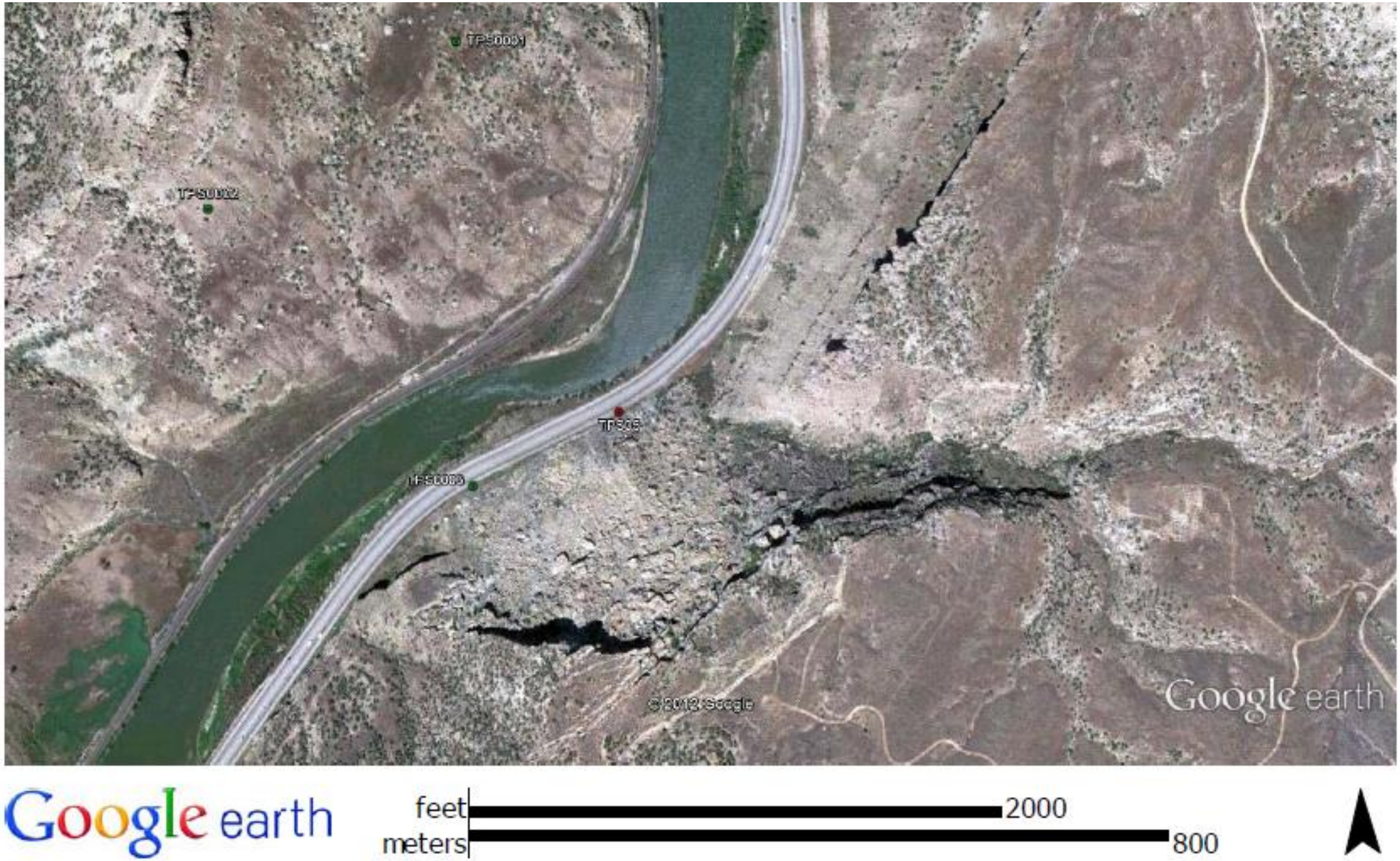
Challenge: to create a textured 3D model of a 400 x 400 m slope accurate within 10 mm from 850 m distance across a river

Different from a laser scanner survey?



1.5 mi (2.5 km) from parking lot to base of stations 1 and 2! => 45 min to Station 2

Different from a laser scanner survey?



Different from a laser scanner survey?

De Beque Slide, CO:
Composite picture of slope from camera station located 1,500 to 2,500 m to slope; this is the composite of about 350 21-megapixel photos.

Different from a laser scanner survey?

Footprint projected by a single laser scanner beam at 700m distance (Maptech I-site 8810).

Different from a laser scanner survey?

Footprint projected by a single laser scanner beam at 700 m distance (Maptech I-site 8810).

Different from a laser scanner survey?

PFG - Photogrammetrie Fernerkundung Geoinformation, 2009, Heft 4, pp. 301-314.

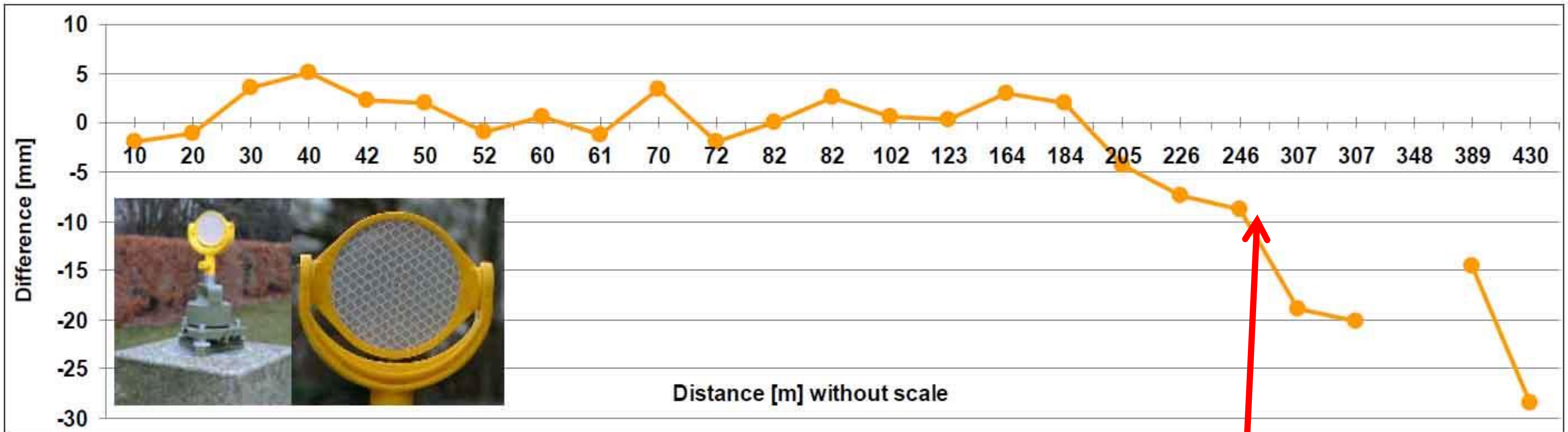


Figure 7: Comparison of the differences between scanning and reference distances for the Riegl LMS 420i using the reflective target (test campaign in December 2007)

Kersten et al. 2009

Footprint on target larger than target!!

Different from a laser scanner survey?

15 cm dia. target on slope, Hanging Lake Slope, CO; 22 Megapixel picture from 100 m

Different from a laser scanner survey?

15 cm dia. target on slope, Hanging Lake Slope, CO; 22 Megapixel picture from 100 m

Different from a laser scanner survey?

- Triangulated point cloud is generated from pixels => pixel to mesh assignment
- Much higher photo resolution; e.g., at 2,000 ft: 4” ground pixel size for I-Site 8800
- Measure of accuracy for each pair of photos (mesh patch)
- Accuracy and point density are input from client, not an equipment constraint
- Can be easily used from a helicopter or UAV
- Laser:
  - Projects a cone => signal from ground anywhere from footprint on ground

    e.g., at 600 m: **30 cm** for I-Site 8800, Riegl LMS Z420i etc.
  - Angular accuracy; e.g., at 600 m: **30 cm** for I-Site 8800
  - Registration; e.g., at 600 m: **8 cm** for Riegl LMS Z420i (the entire point cloud is shifted left or right by 8 cm!!!)
  - Compensator; e.g., at 600 m: 8 cm for ALL Riegl scanners (0.008 deg) (point on ground is moved up or down by 8 cm)

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How Can it be Used in Slope Applications?

Advantages:

- Dangerous Areas
  - For those who climb the slope
  - For the infrastructure/people at the toe of the slope
- Large Areas
- Areas Difficult to Reach
- Permanent Documentation
- Objective Documentation
- Documentation can be Studied Several Times, not Pressed by Time/Weather

How Can it be Used in Slope Applications?

Photogrammetric Data May be Acquired:

- From the Ground
- From the Air =>
  - Laboratorio Rocce e Ricerca Tonon Operatore Autorizzato ENAC per Operazioni Specializzate

  - Tonon USA is authorized by FAA for Commercial Use of UASs (Aerial Data Collection): Part 107; Part 333 Exemption

How Can it be Used in Slope Applications?

Laboratorio Rocce e Ricerca Tonon**: Mezzo Dichiarato Inoffensivo da ENAC**

- Tutte le operazioni diventano NON critiche
- Possibilita’ di volare sopra (incluso buffer!!): strade, autostrade, ponti, viadotti, ferrovie, infrastrutture ecc.
- Resta divieto sorvolo assembramenti (security, not safety problem!)
- Restano limitazioni spazi aerei:
  - ATZ
  - CTR
  - Spazi aerei non classe G

ENTE NAZIONALE PER L'AVIAZIONE CIVILE

Funzione Organizzativa
Coordinamento Omologazioni

Laboratorio Rocce e Ricerca Tonon S.r.l.

Via Nazionale 206

38123 Trento

Pec fulvio.tonon@ingpec.eu

Ogg.: Inoffensività [redacted] secondo art. 12 Regolamento Mezzi Aerei a Pilotaggio Remoto

Si fa riferimento alla Vs. richiesta datata 25.2.2016, prot. ENAC 94448 del 15.9.2016.

A seguito degli accertamenti effettuati da questo Ente si riconosce l'APR tipo [redacted] con configurazione doc. [redacted] del 12.9.2016 e con Manuale di Volo [redacted] del 20.9.2016 avente aspetti progettuali e tecniche costruttive con caratteristiche di inoffensività.

Secondo il Regolamento Mezzi Aerei a Pilotaggio Remoto ai sensi dell'art. 12 comma 1 le operazioni specializzate condotte con l'APR in oggetto sono considerate non critiche in tutti gli scenari operativi, pertanto l'operatore potrà operare dopo la pubblicazione sul sito istituzionale di pertinente Dichiarazione sottoscritta dall'operatore ai sensi dell'art. 9 comma 2.

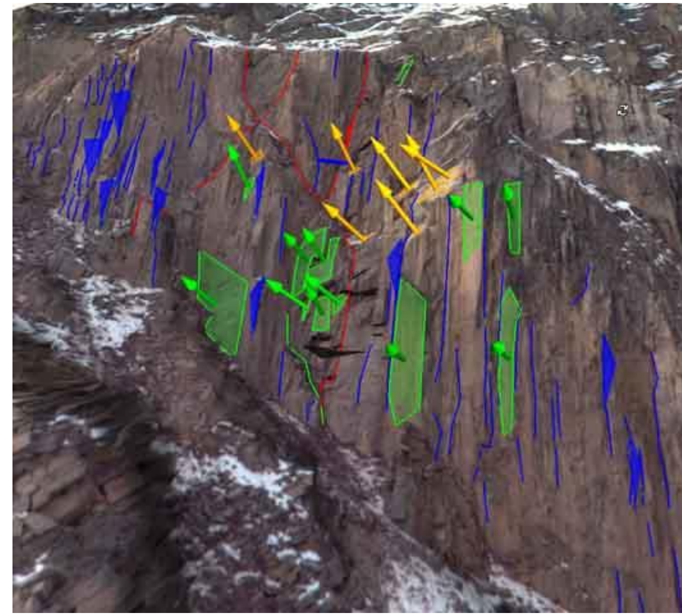
Ogni modifica alla configurazione comporta il decadere di questo riconoscimento.

Le caratteristiche di inoffensività sono riferite a impatti accidentali contro persone, non si riferiscono altresì a caratteristiche di impatto contro altri aeromobili, rimangono per cui sempre applicabili gli articoli del Regolamento Mezzi Aerei a Pilotaggio Remoto sezione V pertinenti le Regole di circolazione e utilizzo dello spazio aereo.

Cordiali saluti

How Can it be Used in Slope Applications?

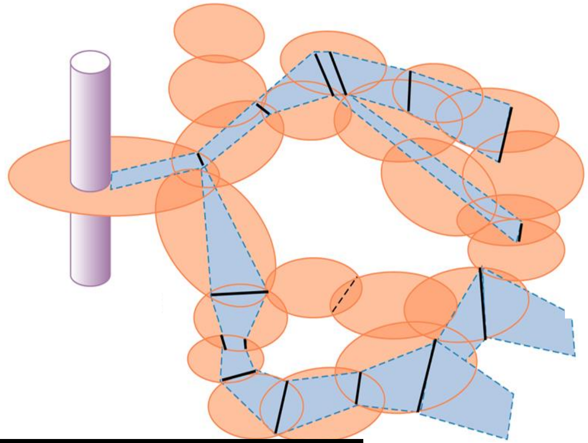
- Georeferenced 3D model textured with high res pictures
- Fracture mapping:
  - Coordinates of center of fractures
  - Orientation from traces or planes
  - Fracture sets
  - Spacing
  - Trace lengths
  - Fracture intensity measures (Dershowitz's P_{xy})

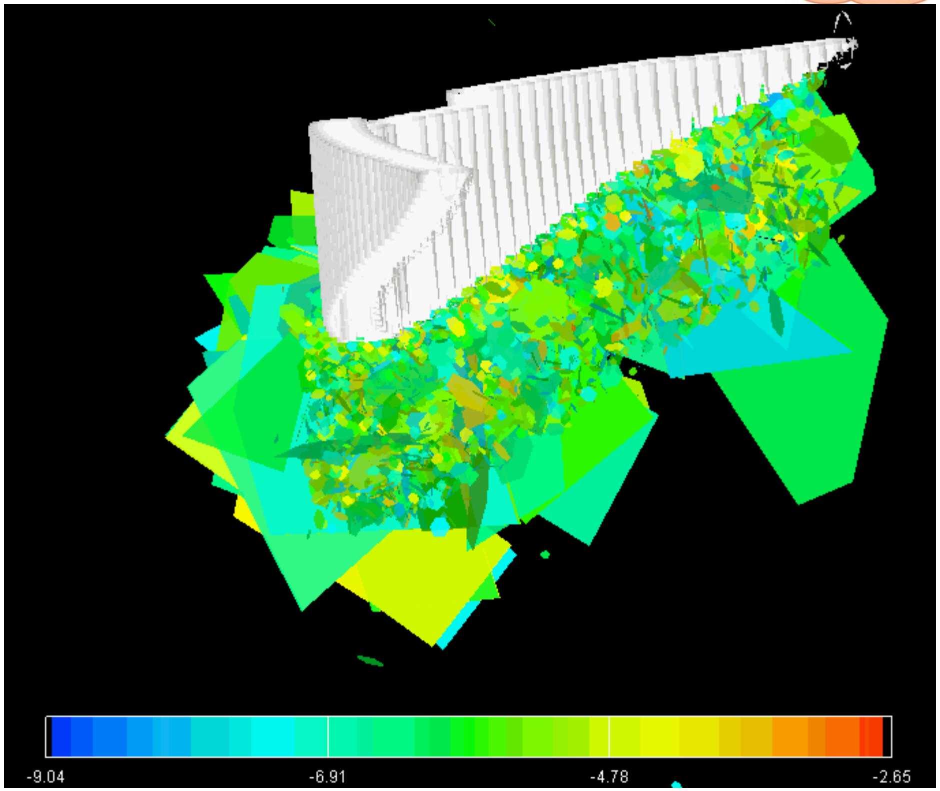


		Dimension of Measurement				
		0	1	2	3	
Dimension of Sample	1	P10 *No of fractures per unit length of borehole*	P11 *Length of fractures per unit length*			***Linear Measures***
	2	P20 *No of fractures per unit area*	P21 *Length of fractures per unit area*	P22 *Area of fractures per area*		***Areal Measures***
	3	P30 *No of fractures per unit volume*		P32 *Area of fractures per unit volume*	P33 *Volume of fractures per unit volume*	***Volumetric Measures***
		Density		***Intensity***	***Porosity***	

How Can it be Used in Slope Applications?

Portugese Dam,
Courtesy of W.
Dershowitz

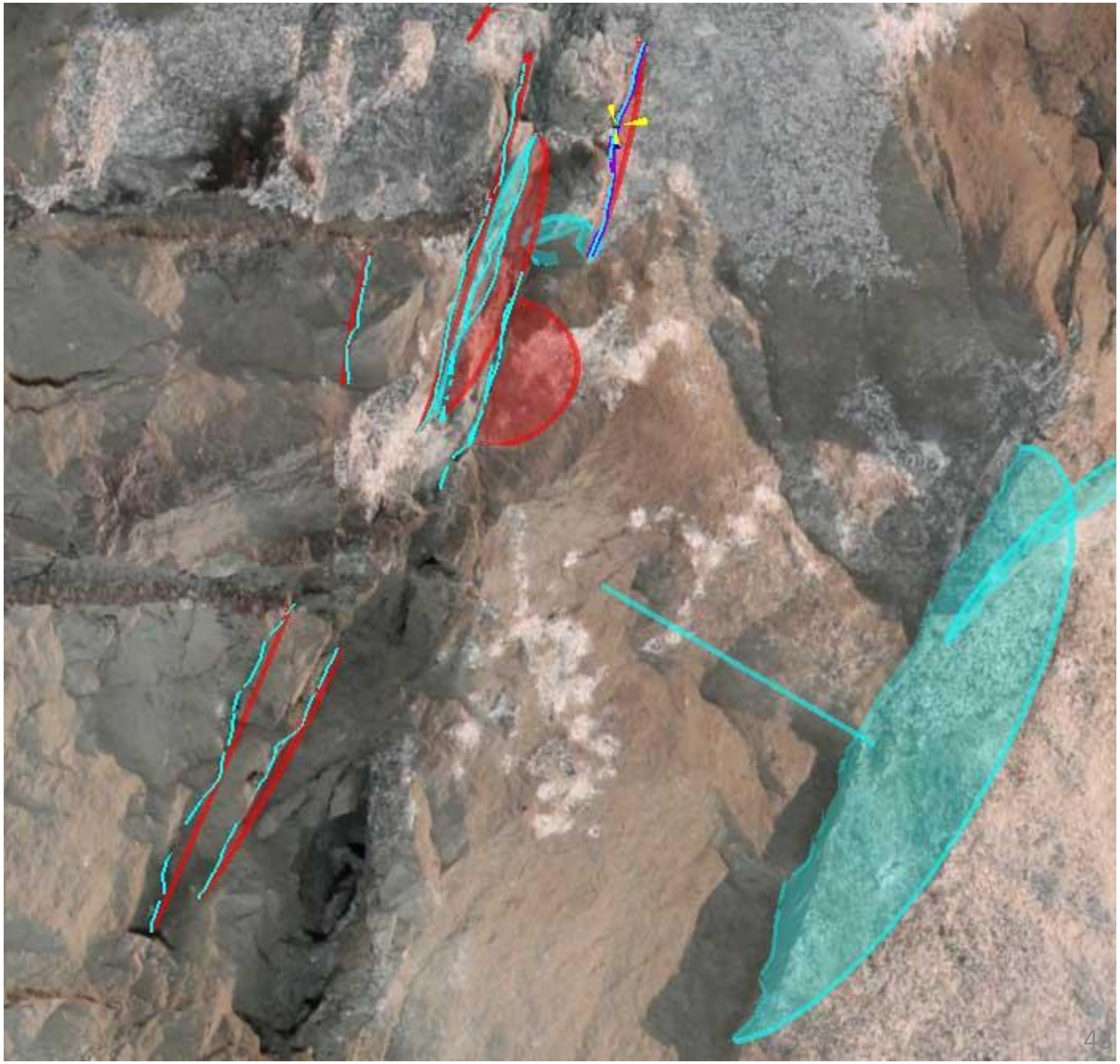




20% Shears,Meta-Conglomerate & 10% Background Fractures, Colored by Transmissivity, Looking Down Right Abutment (10% transparent)

How Can it be Used in Slope Applications?

Characterize fracture clustering: fracture spatial distribution



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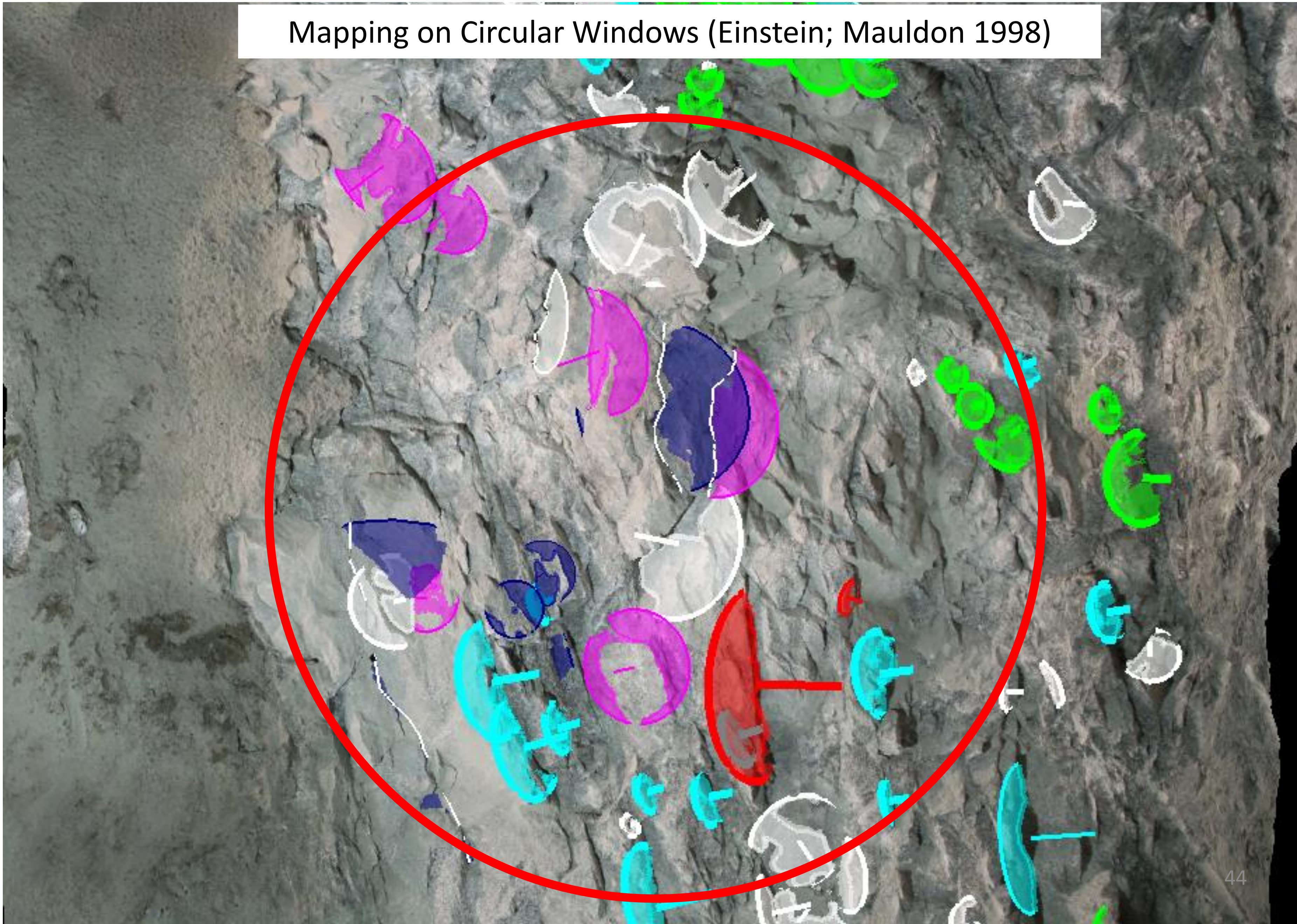

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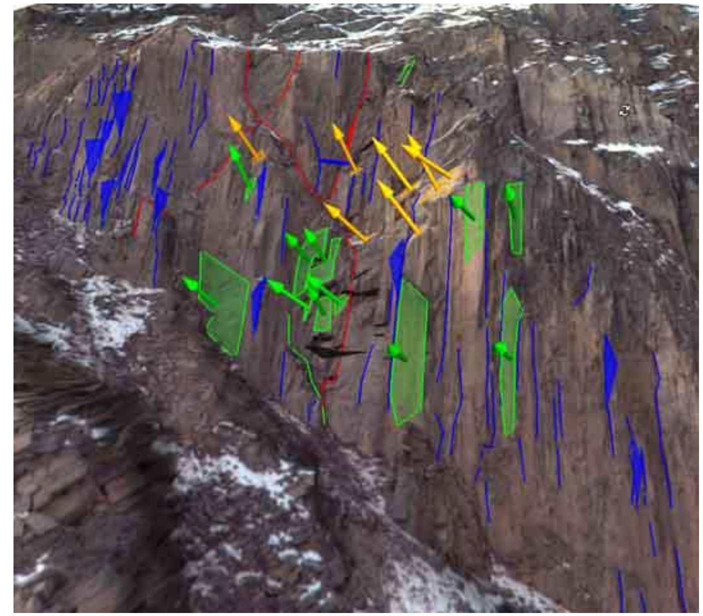
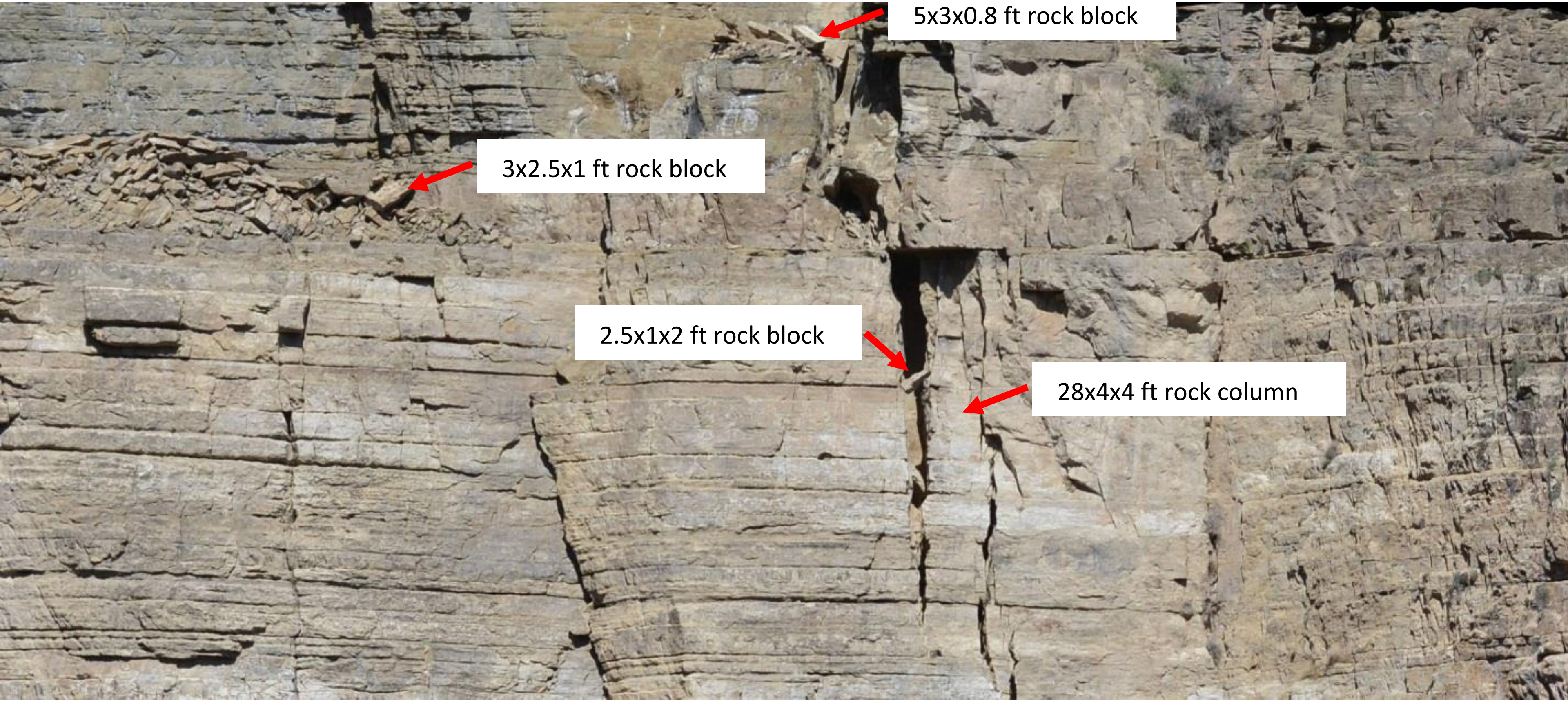
  - Orientation from traces or planes
  - Fracture sets
  - Spacing
  - Trace lengths
  - Fracture intensity measures



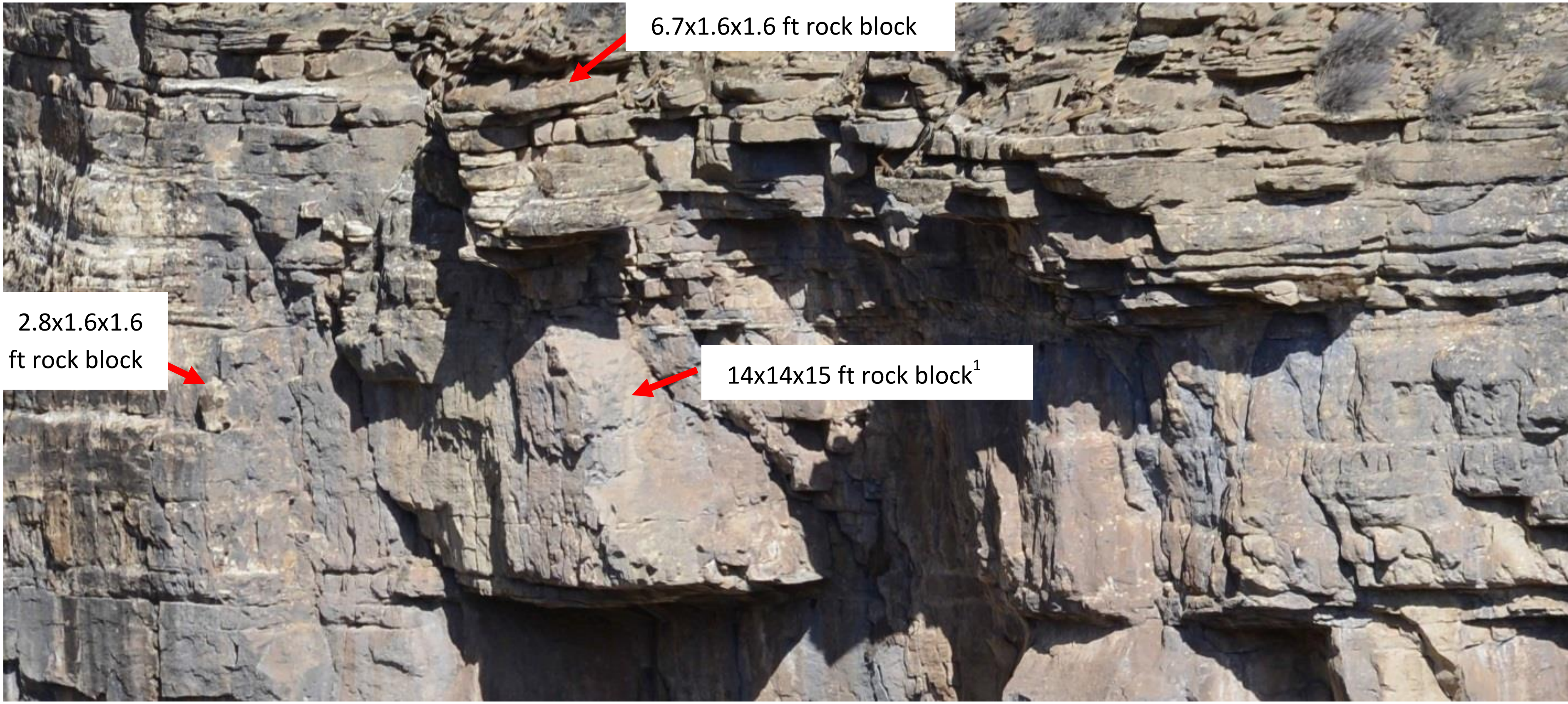
- Excavation volumes or fill volumes: high res photos document type of rock/fill
- Monitoring and Rock Fall Analyses:
  - Contours of displacements orthogonal to each mesh triangle
  - Measurement of crack opening
  - Detection of unstable blocks
  - Volume of unstable blocks
  - Identify climbing routes to blocks or areas of interest

How can it be used in slope monitoring?



Some unstable blocks identified on Hanging Lake Slope, CO

How can it be used in slope monitoring?



Some unstable blocks identified on Hanging Lake Slope, CO

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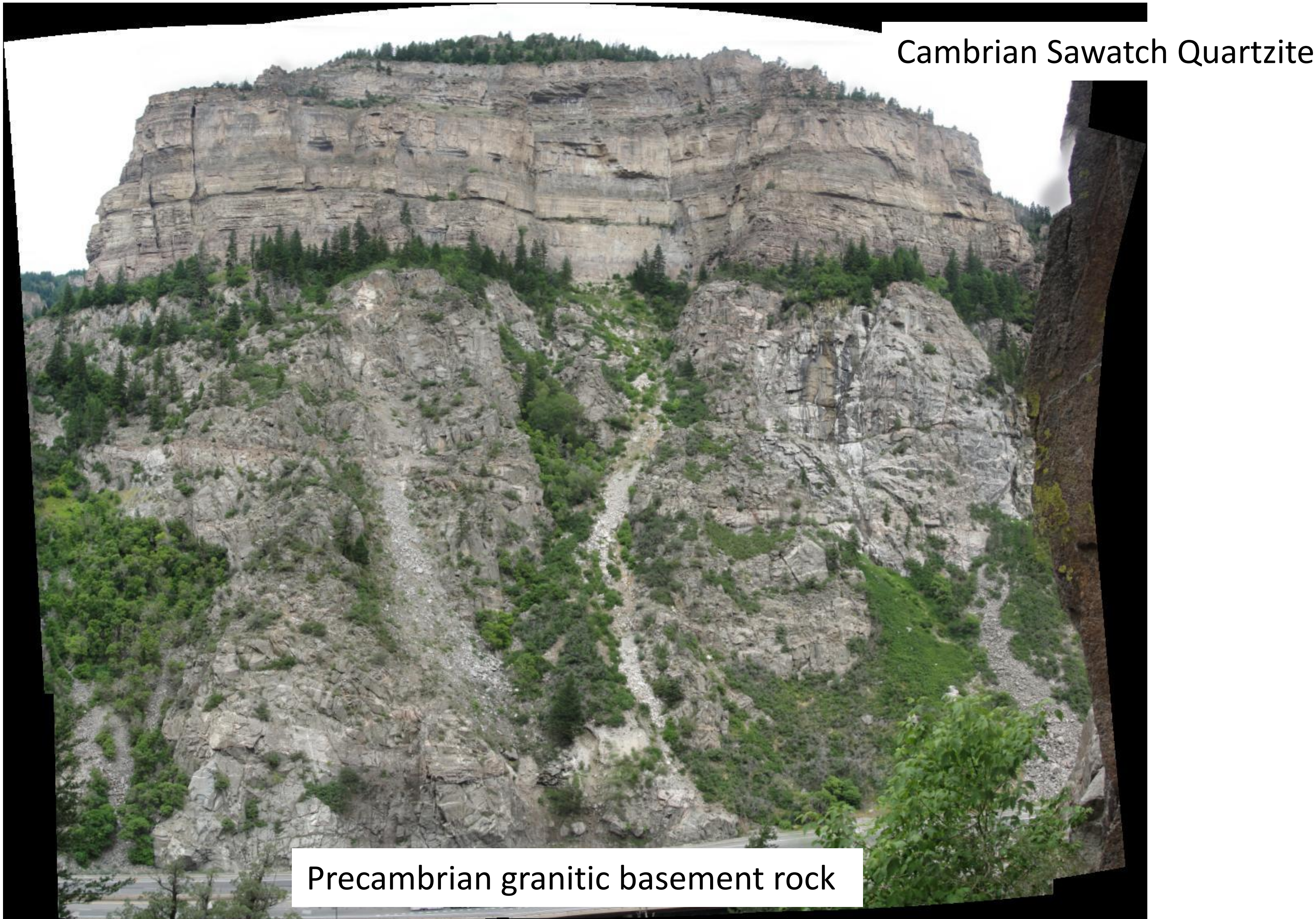
Case history: Hanging Lake Slope, CO



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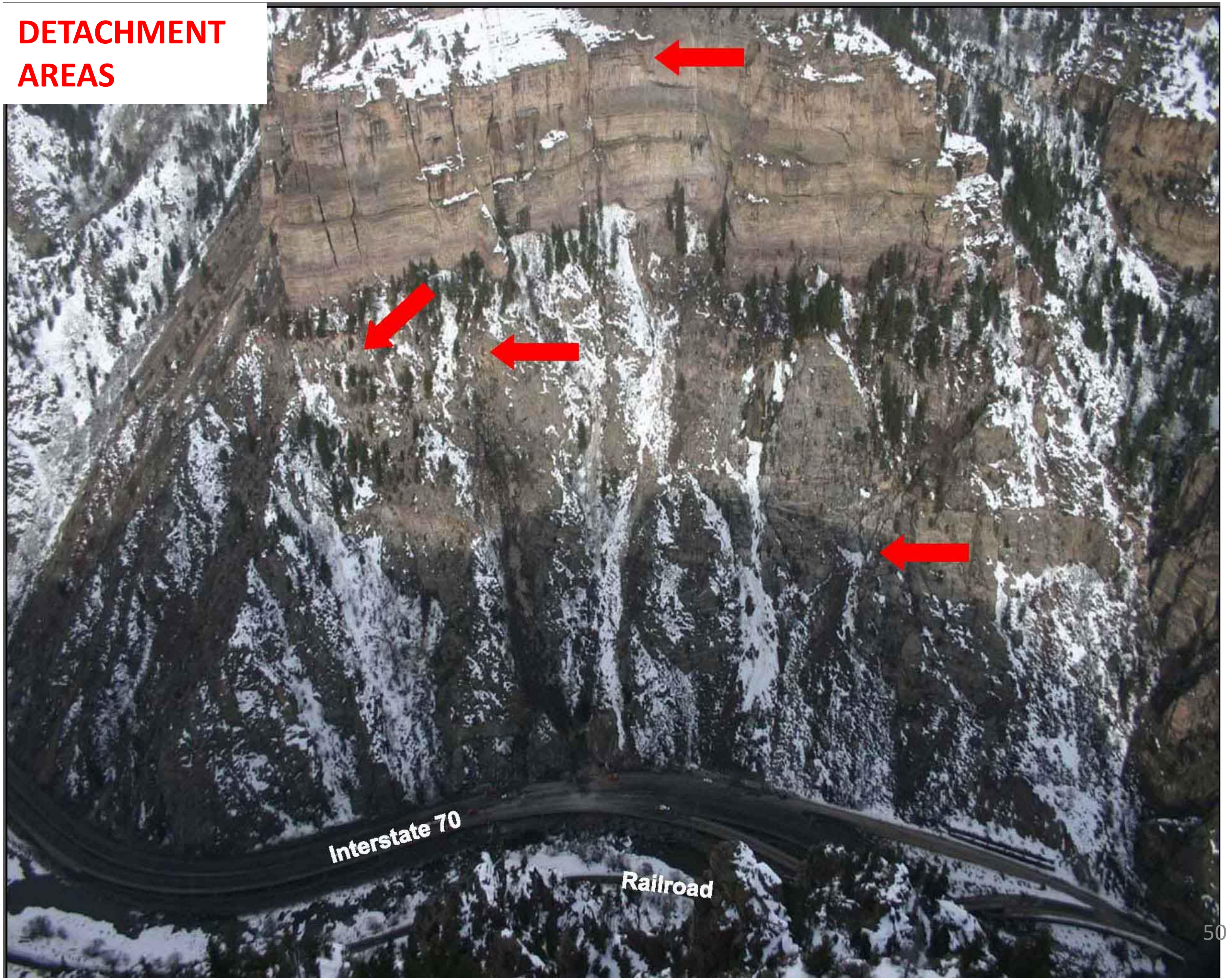
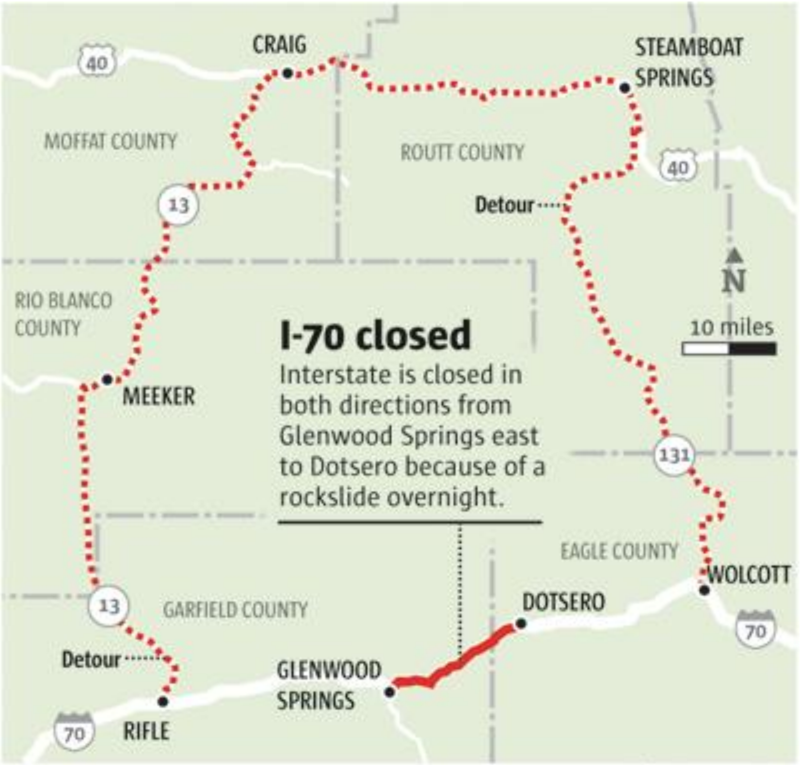


Case history: Hanging Lake Slope, CO

November 25, 2004 Slide:

- $700,000 Repair Cost
- 350 km Detour

http://www.youtube.com/watch?feature=player_detailpage&v=3MHoCskgWHo



The Denver Post

Case history: Hanging Lake Slope, CO

March 8, 2010 Slide:

- Unknown Repair Cost
- 350 km Detour
- 3-Day complete closure
- One lane in each direction for over 1 month

http://edition.cnn.com/2010/US/03/08/colorado.rock.slide/

http://www.youtube.com/watch?feature=player_detailpage&v=L9MtWqbjmoI

Case history: Hanging Lake Slope, CO

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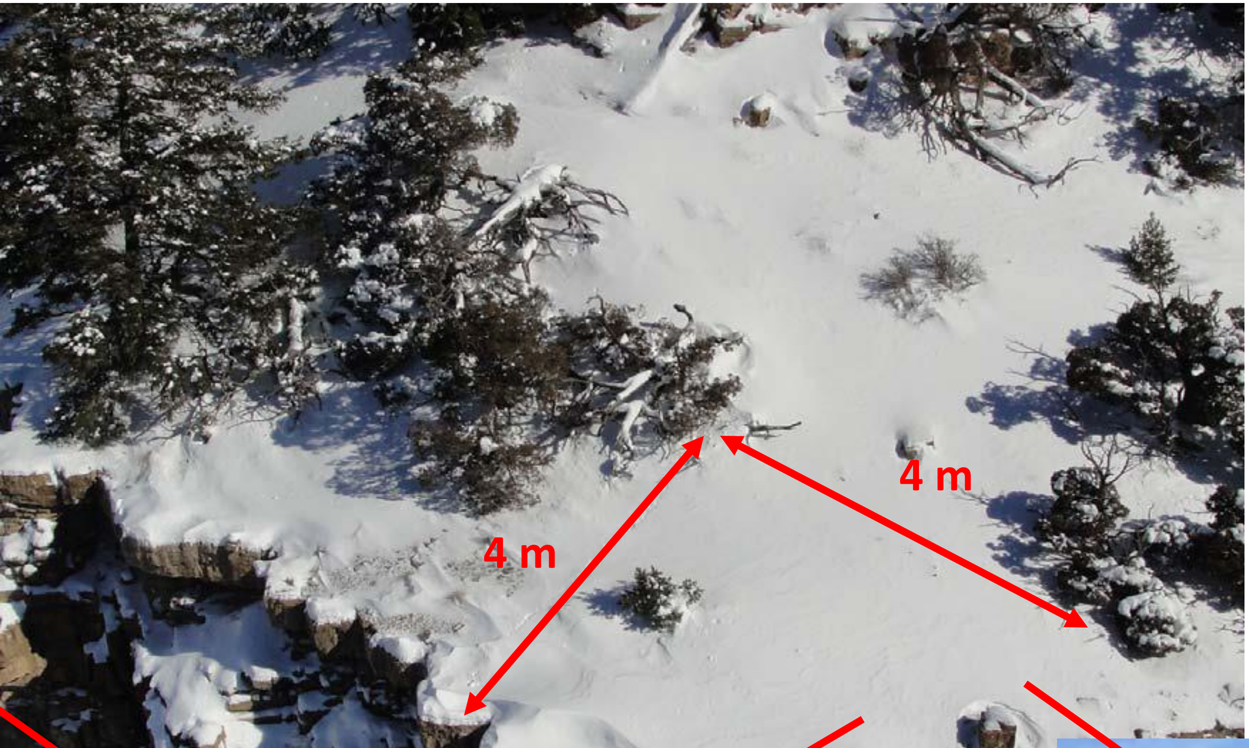
Only vantage point over 1 km from slope on opposite side of canyon

Case history: Hanging Lake Slope, CO



Case history: Hanging Lake Slope, CO

- Objectives:
  - Obtain 3D georeferenced model accurate to 2.5 cm
  - Detect movements of slope
- Challenges:
  - Large (850 m wide x 450 m high), nearly vertical slope
  - Narrow canyon with poor visibility of entire slope
  - Vantage point over 1 km from slope
  - Concave shape => shadowing

Case history: Hanging Lake Slope, CO (cont.)

Survey 1:

Target survey differences btw 2 TS:
(8, 4, 3) mm => 9 mm

Photogrammetric model residuals:
(9, 18, 8) mm => 21 mm => **achieved and DEMONSTRATED specified accuracy of 25 mm**

Survey 2 (5 months later):

Target survey differences btw 2 TS: N/A

Photogrammetric model residuals:
(25, 33, 60) mm => 73 mm => slope moved => necessary to re-survey targets and take new set of photos to determine where and how the slope moved

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Case history: Mount Brione, Italy

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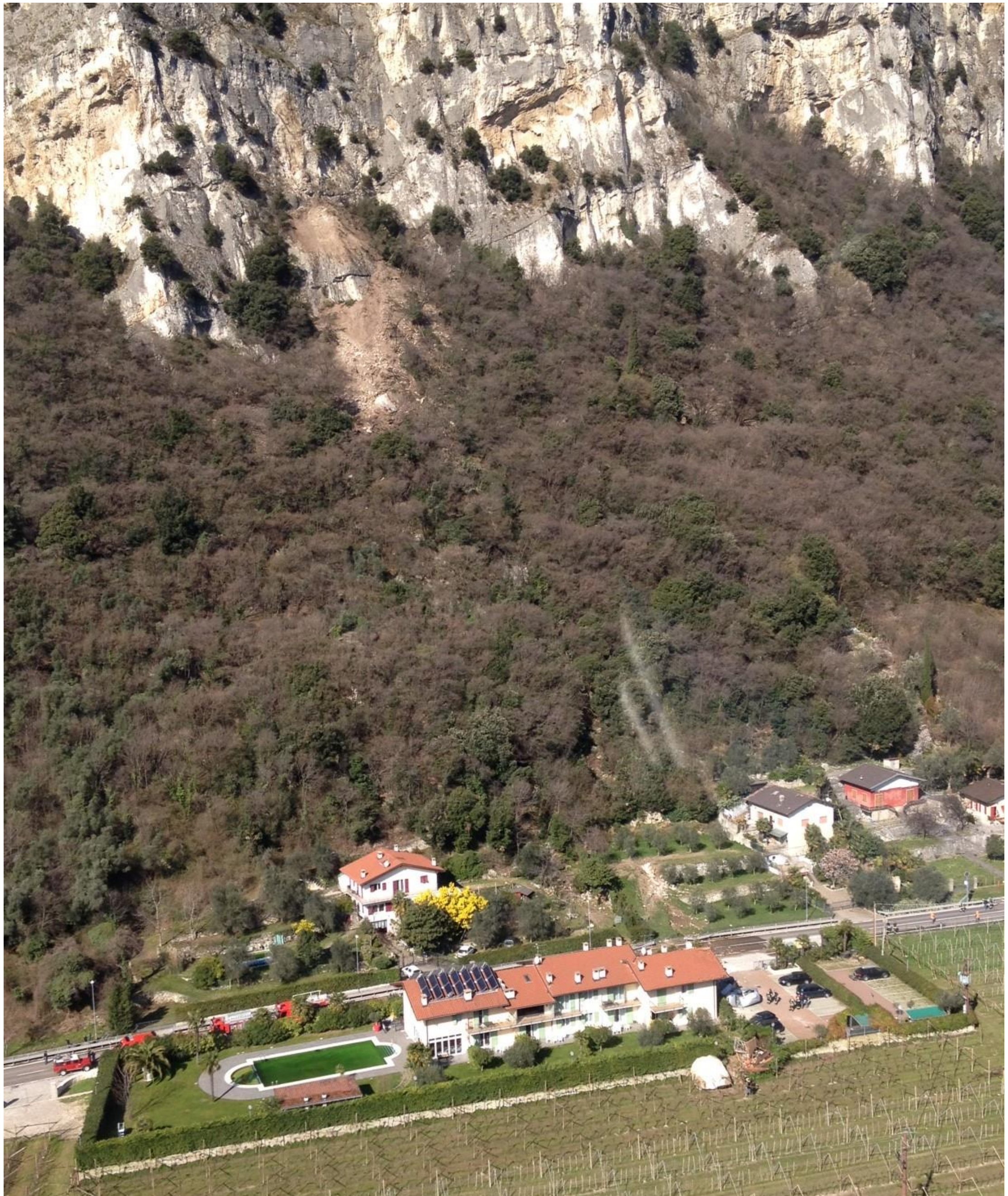


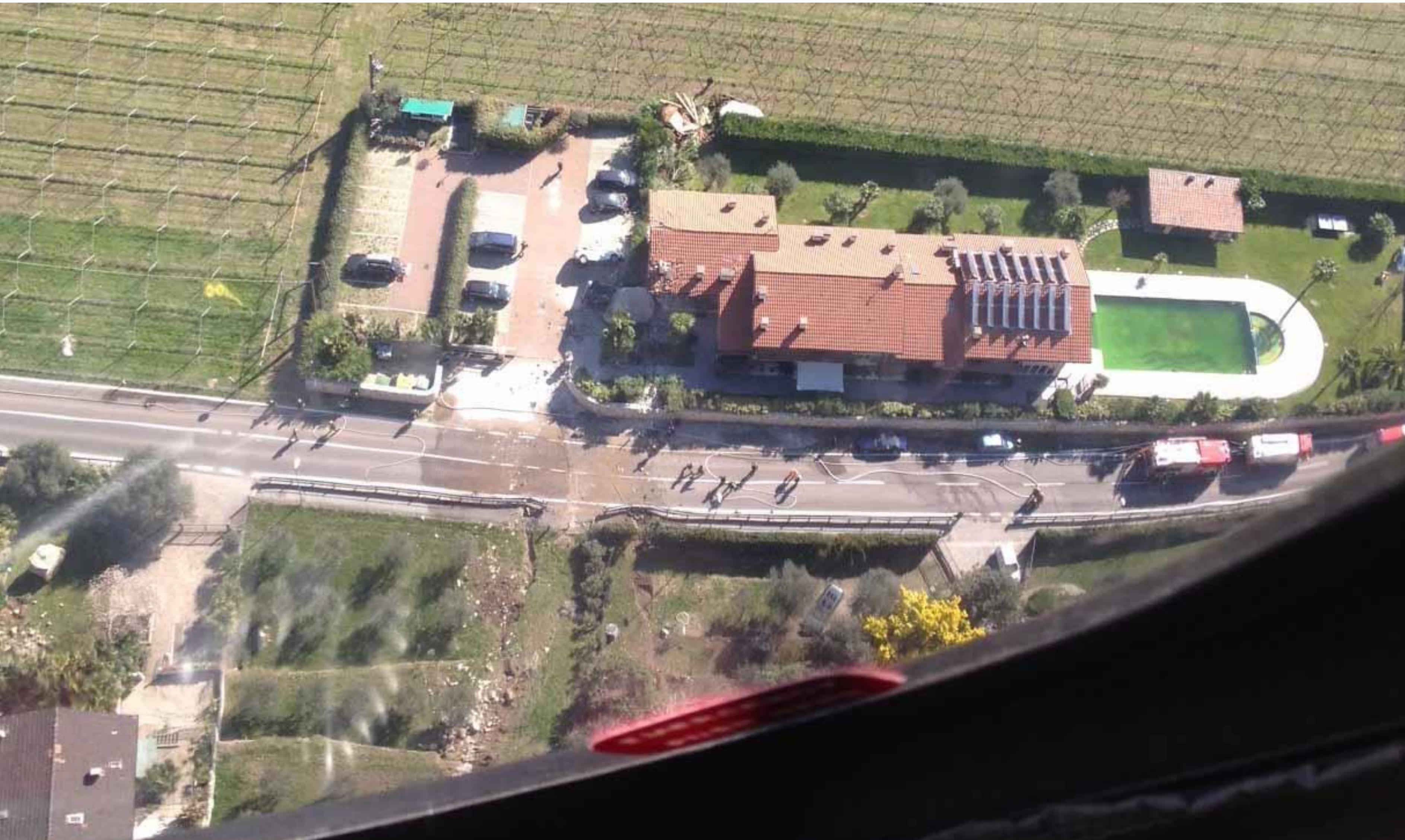
Last event:

- March 9, 2014; 9:45 AM

Case history: Mount Brione, Italy

Last event:

- March 9, 2014; 9:45 AM



Case history: Mount Brione, Italy

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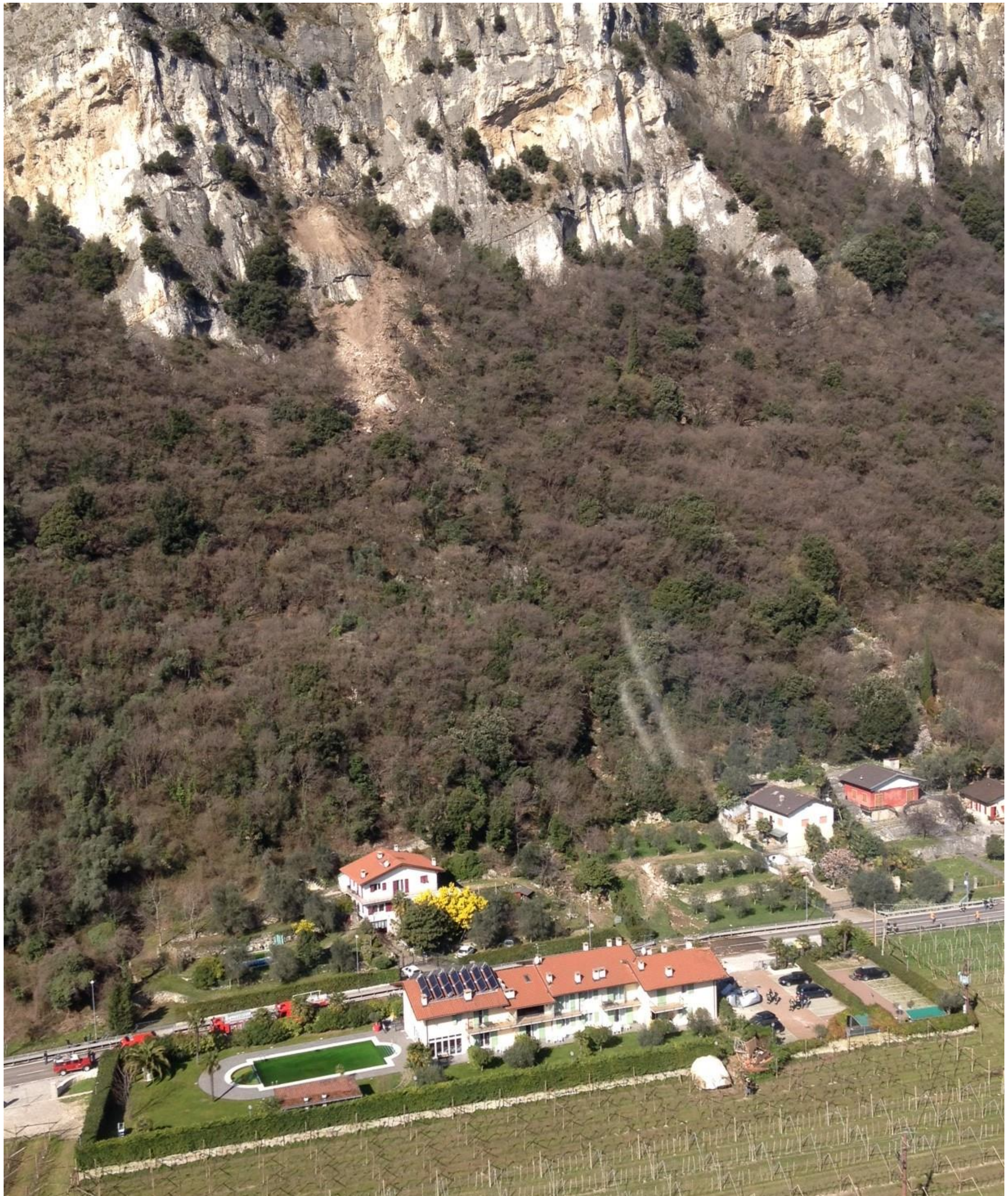


Objectives:

- Create textured 3D model of Mt. Brione accurate to 3 cm
- Map fractures
- Identify all unstable blocks
- For each unstable block:
  - Outline it on 3D model
  - Determine center (reference point to be used as a starting point in rockfall analyses)
  - Determine mode of failure
  - Calculate volume => mass
- On 3D model:
  - Identify a handful of blocks where to focus geologists' field work
  - Identify with field geologists and alpine guide the climbing route to reach the identified blocks

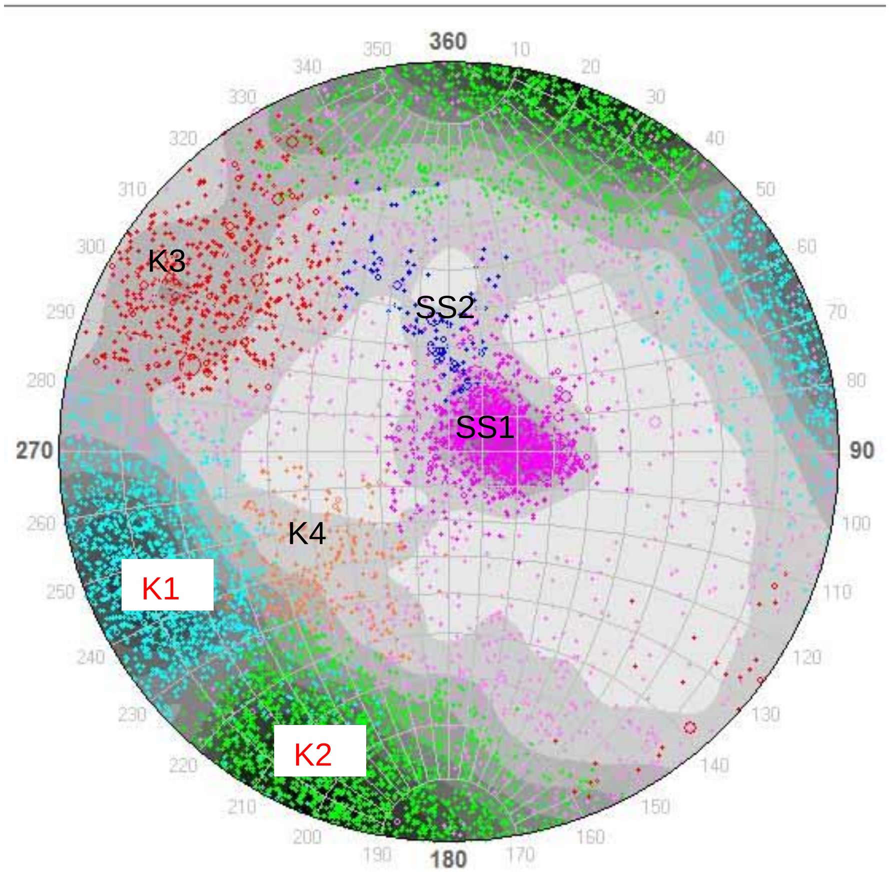
The entire project was to be set in ETRF2000, Epoch 2008.0, of ETRS89.

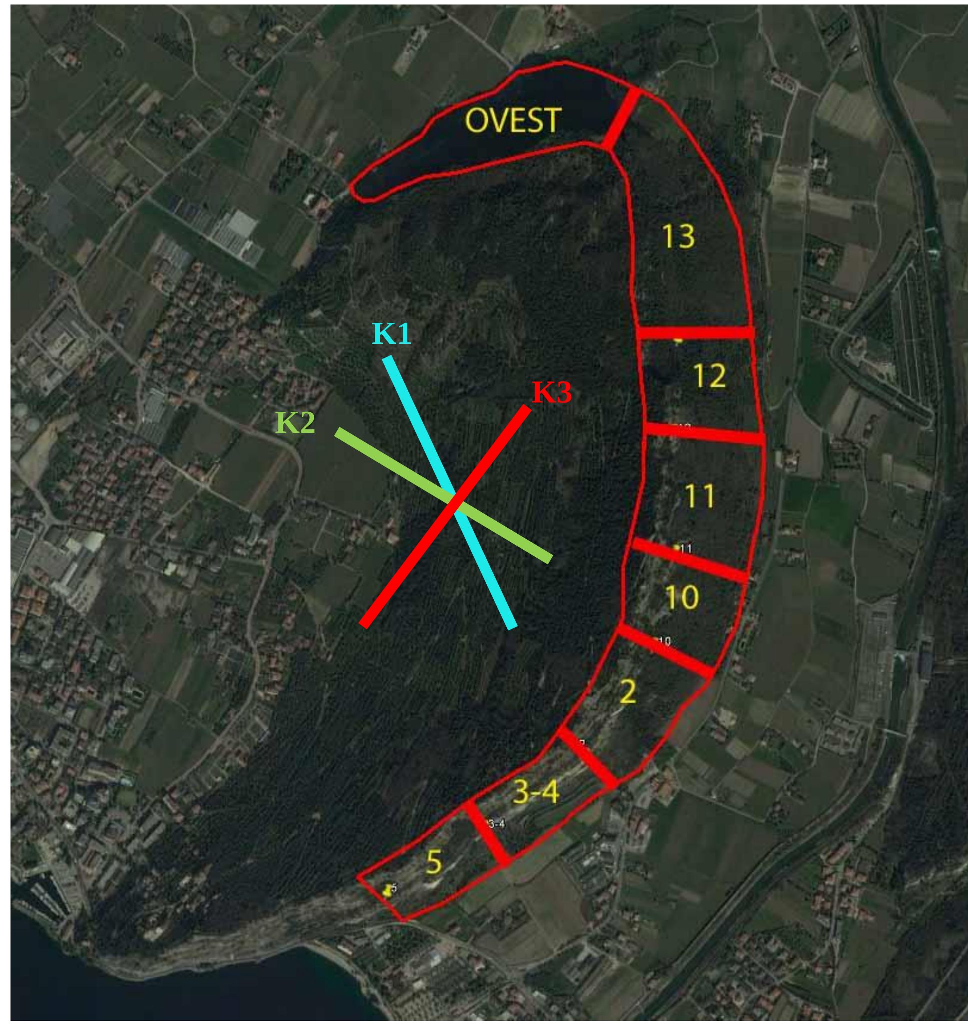
Case history: Mount Brione, Italy

Length: 3.2 km
Height: 150-300 m
Residuals: (30, 25, 27) mm
Residuals w/o p.s. calibration: >1 m
No. of Photos: 1,250
Pixel on ground: 13-19 mm

Case history: Mount Brione, Italy

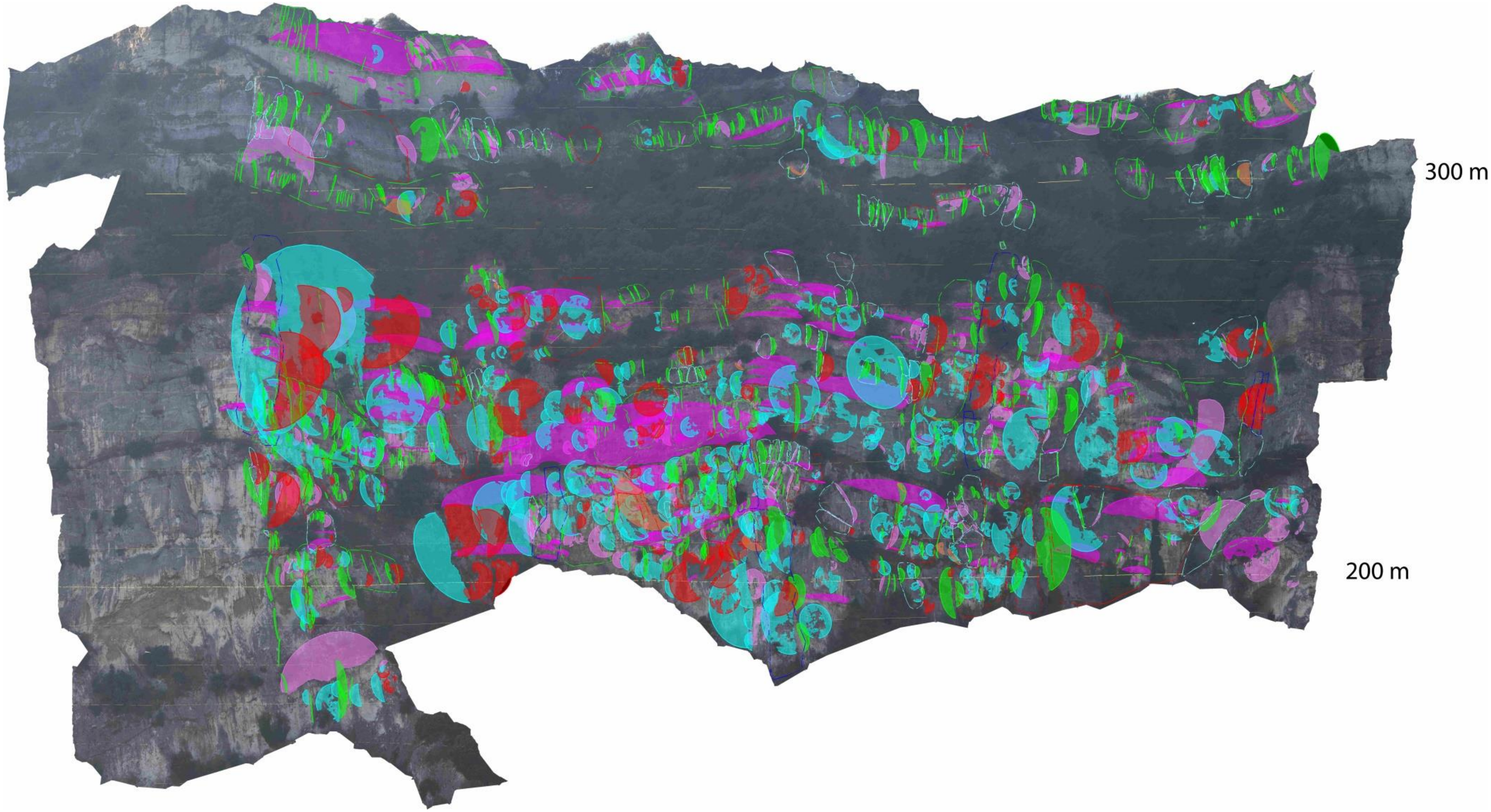
7,065 MAPPED FRACTURES





Case history: Mount Brione, Italy

Area 11: Fractures and Unstable Blocks



Case history: Mount Brione, Italy

Type 1: Spalls

Case history: Mount Brione, Italy

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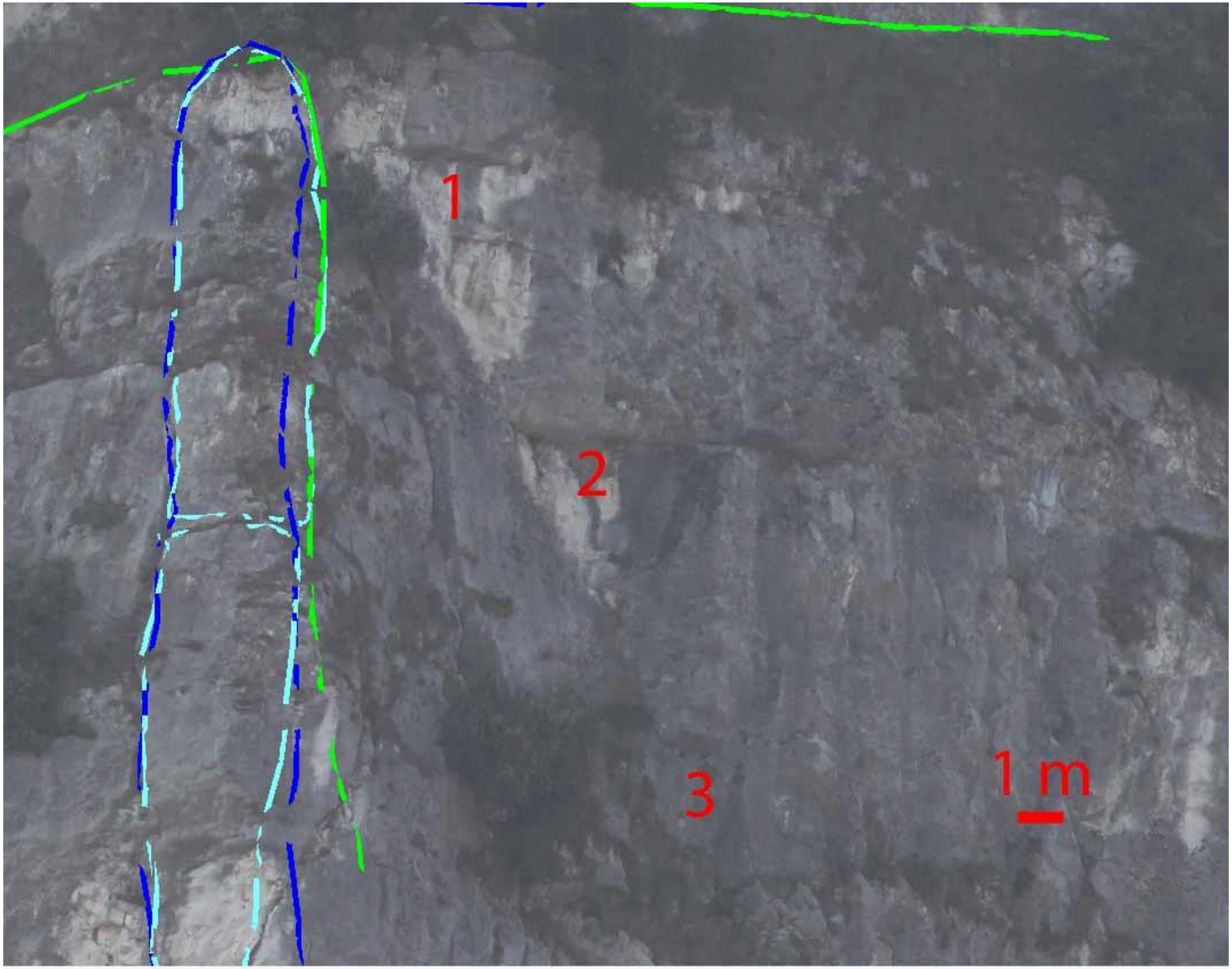
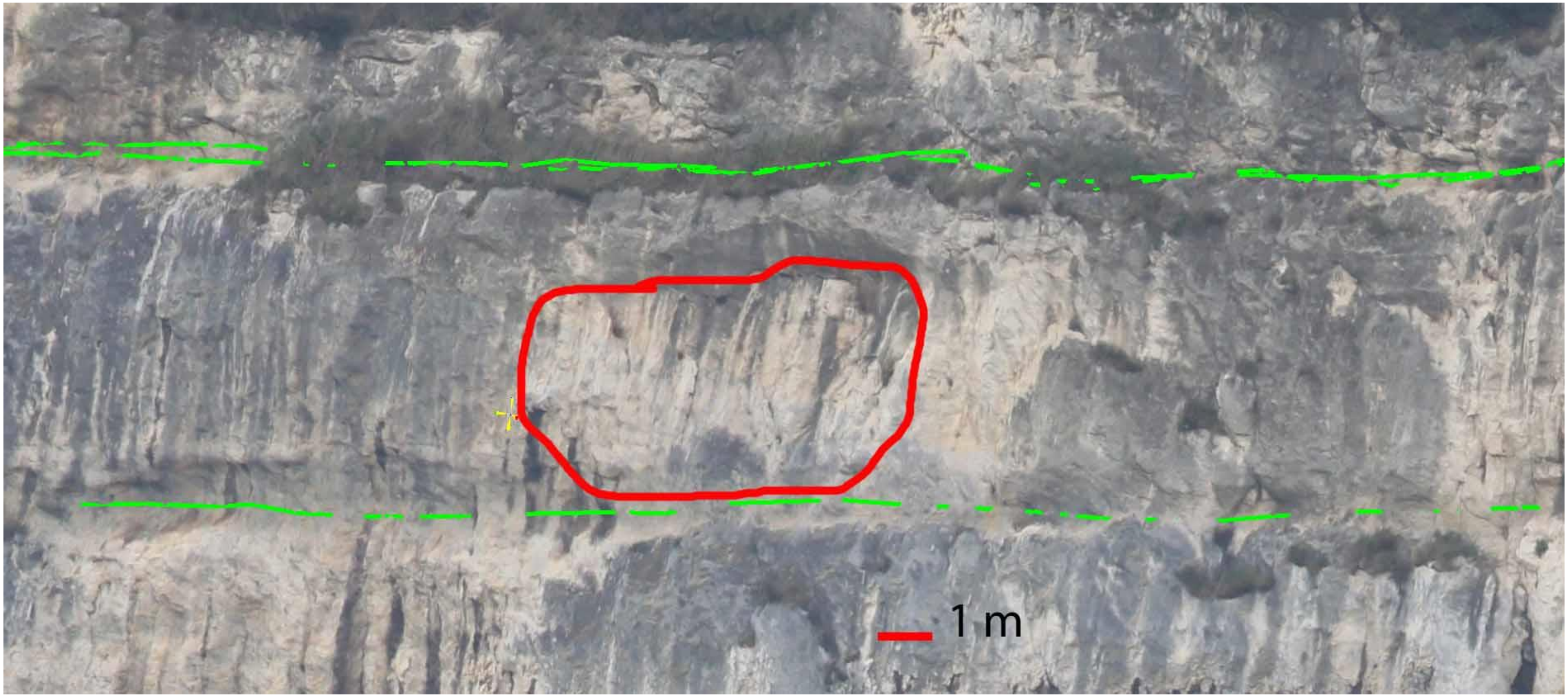
Type 1: Spalls



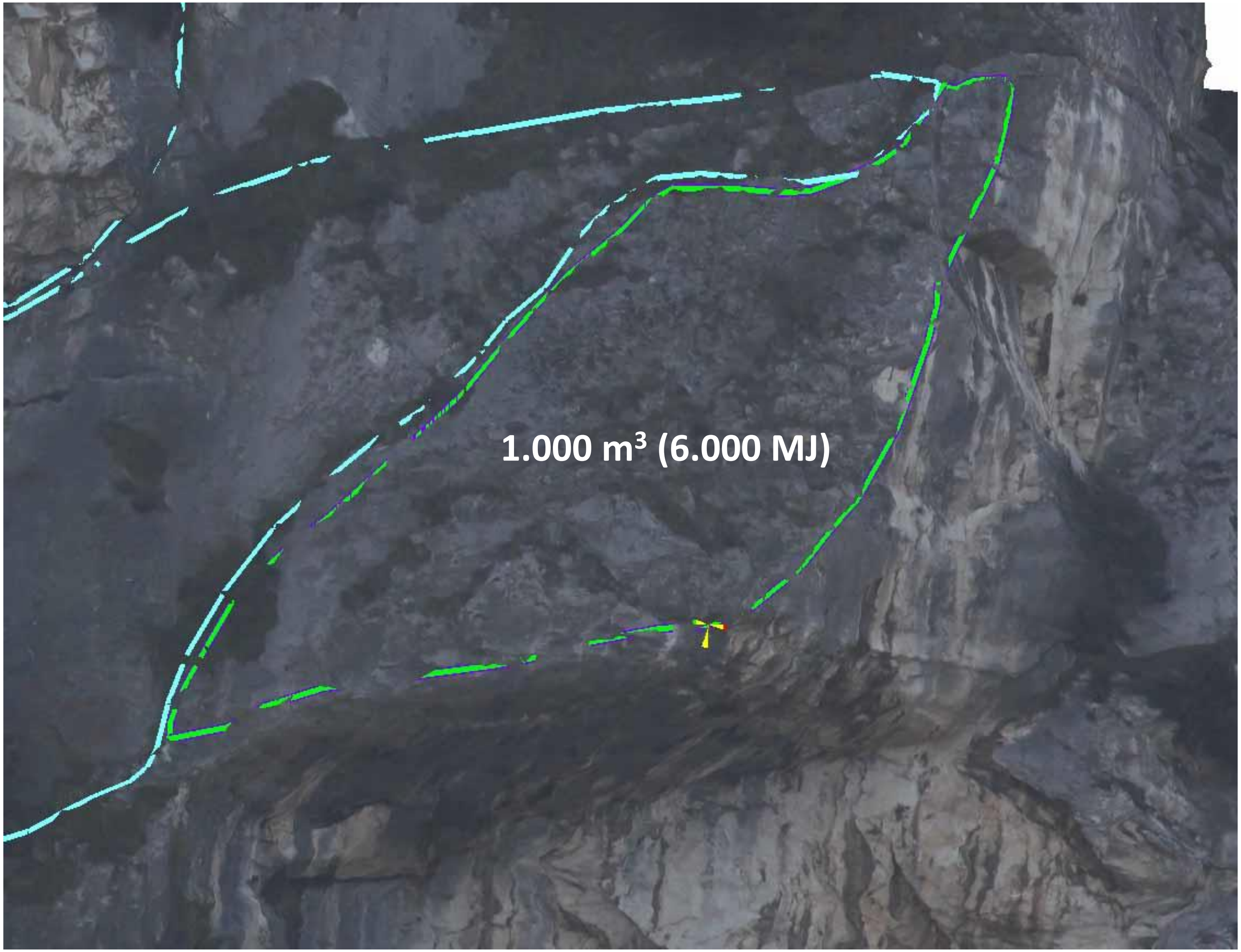
Case history: Mount Brione, Italy

Type 2: Overhangs



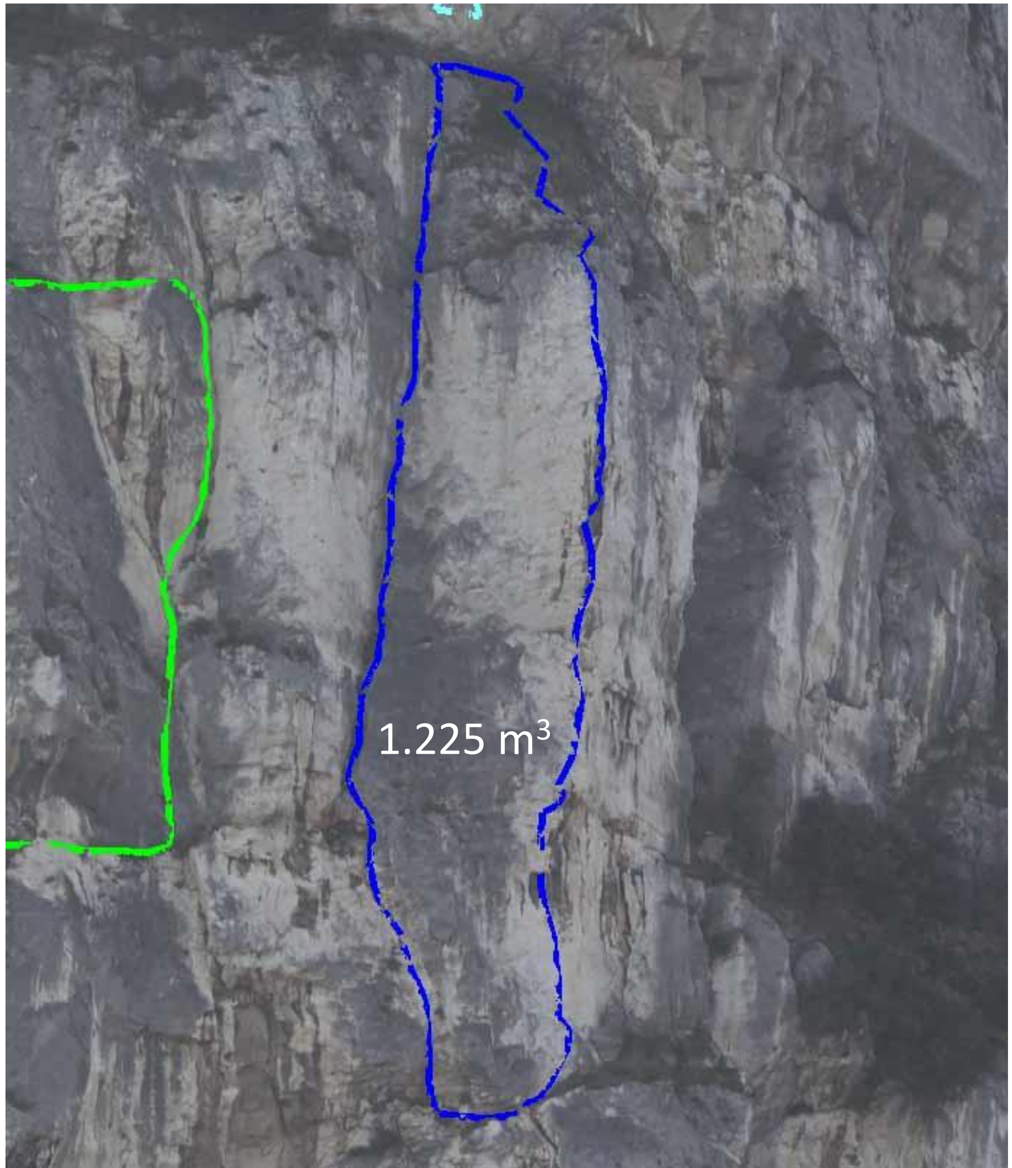
Case history: Mount Brione, Italy

Type 2: Overhangs



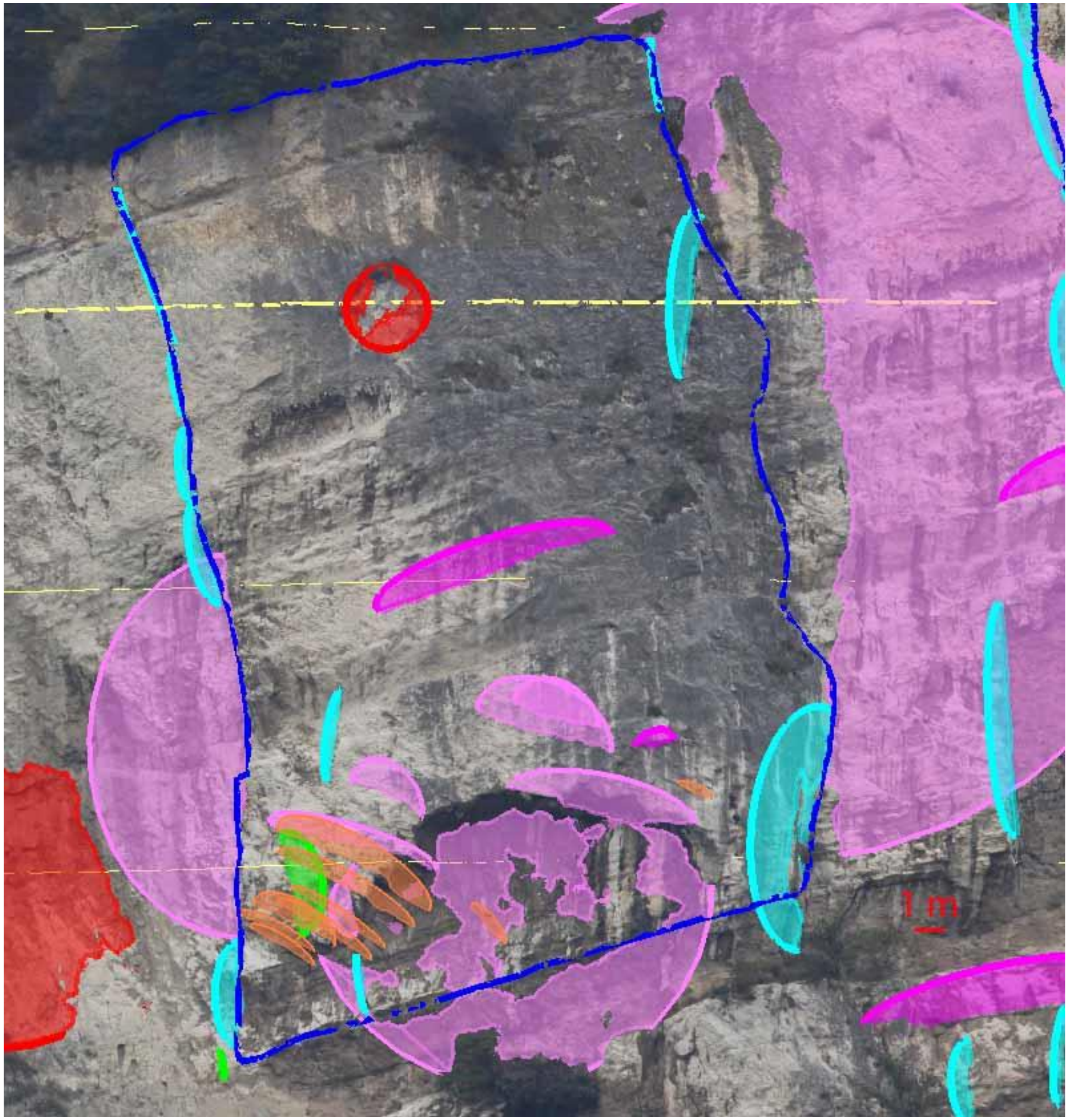
Case history: Mount Brione, Italy

Type 3: Columns



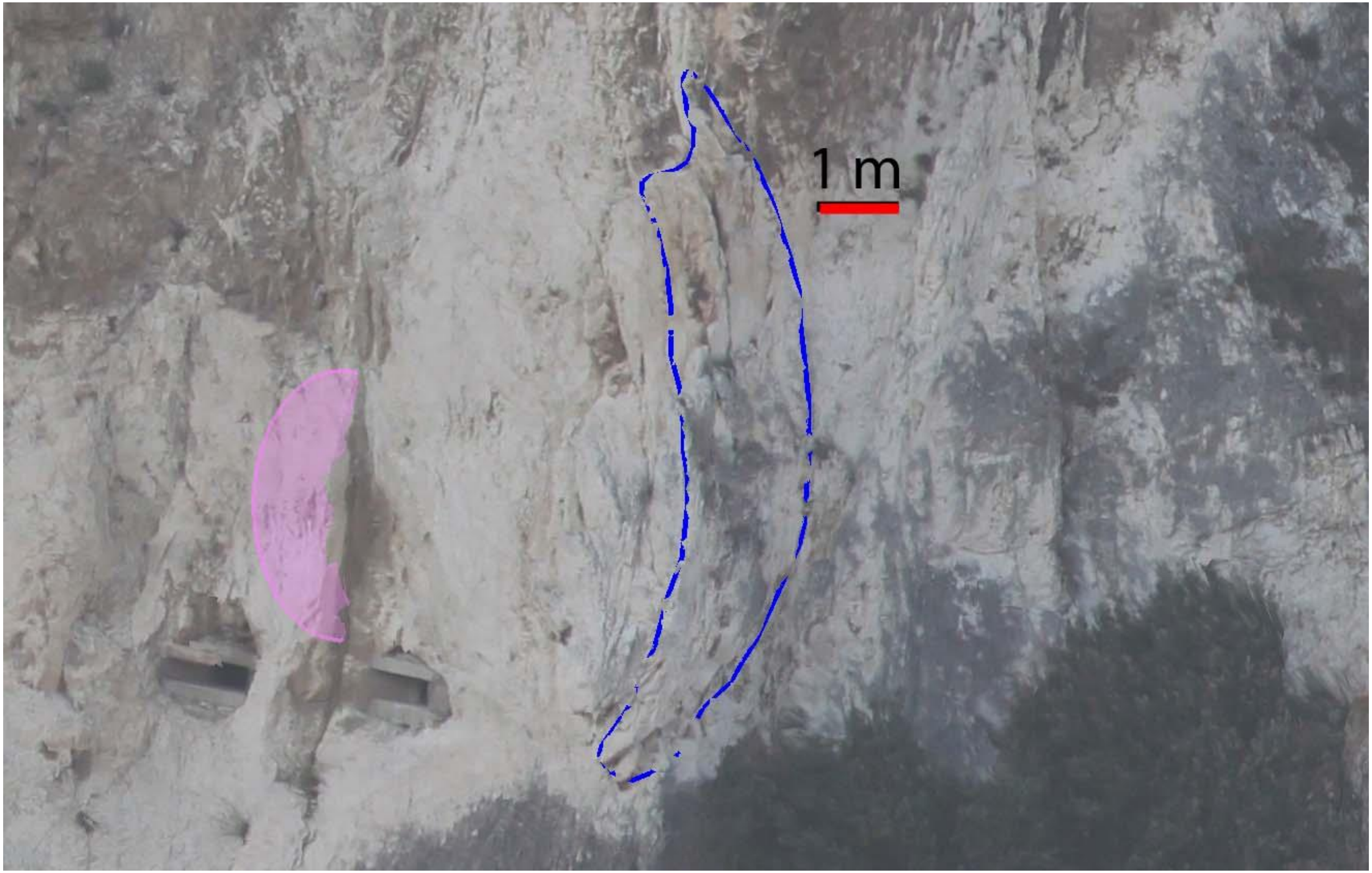
Case history: Mount Brione, Italy

Type 3: Columns



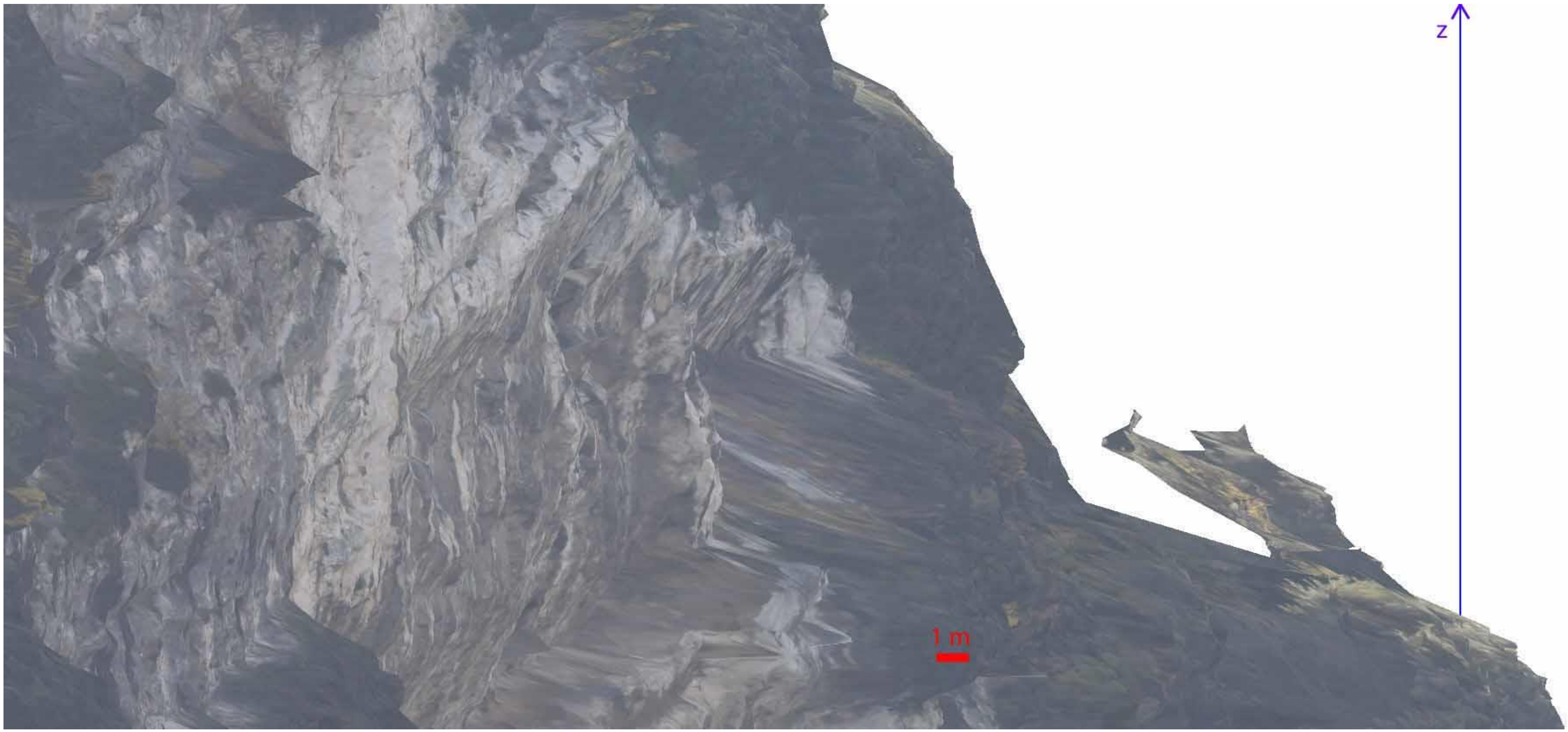
Case history: Mount Brione, Italy

Type 3: Columns + Karstic Erosion



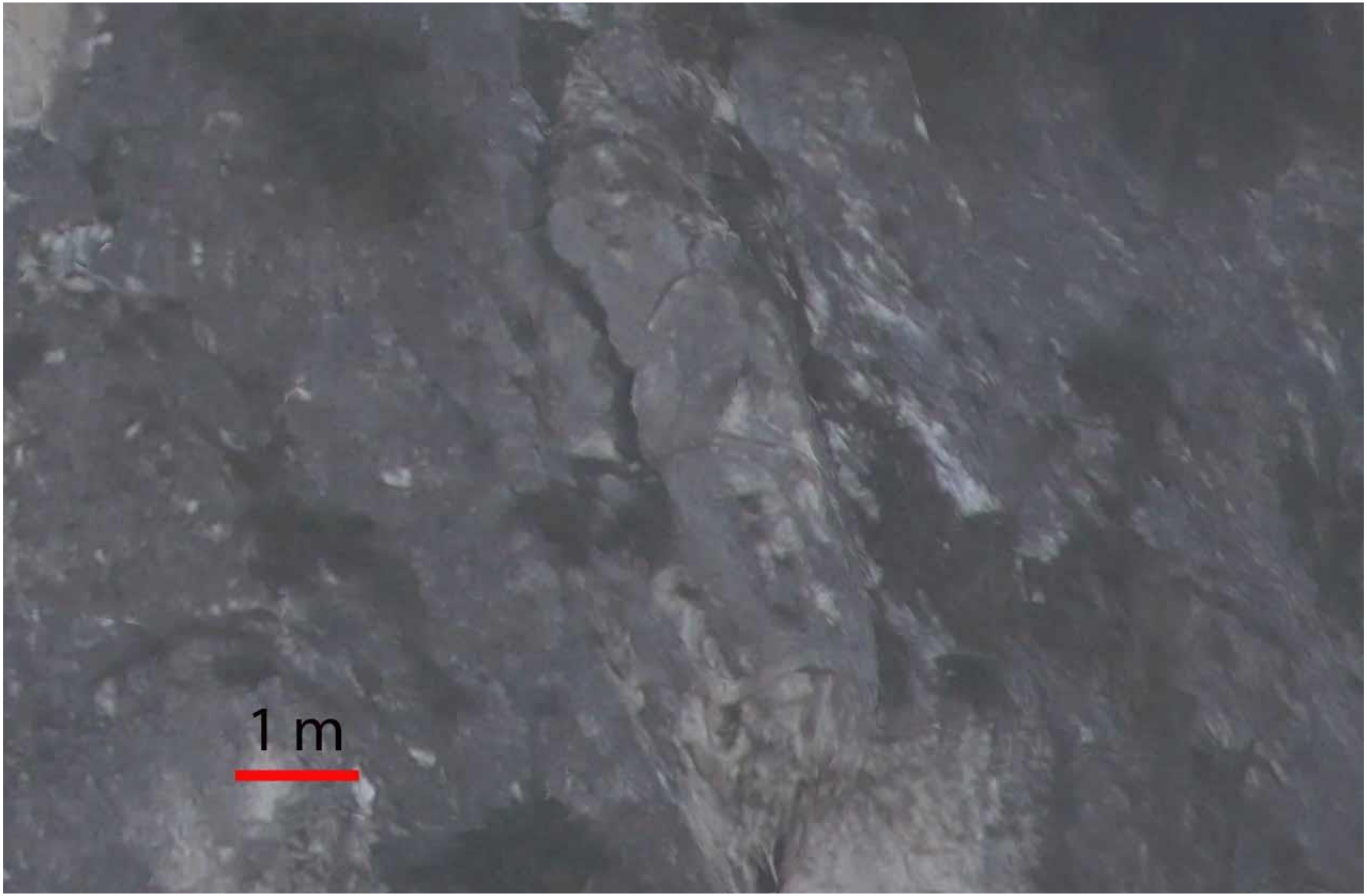
Case history: Mount Brione, Italy

Type 4: Toppling



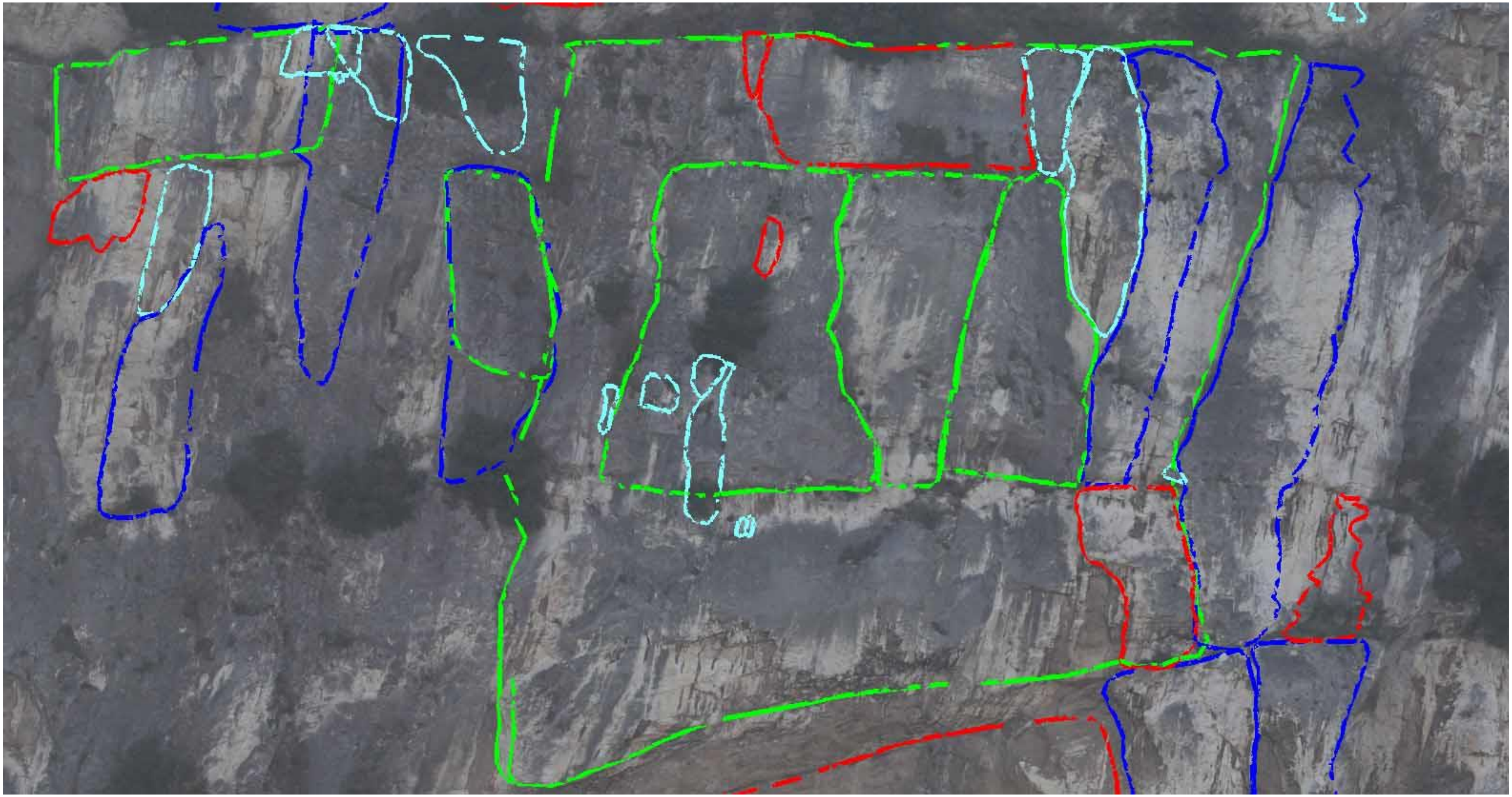
Case history: Mount Brione, Italy

Type 5: Wedges



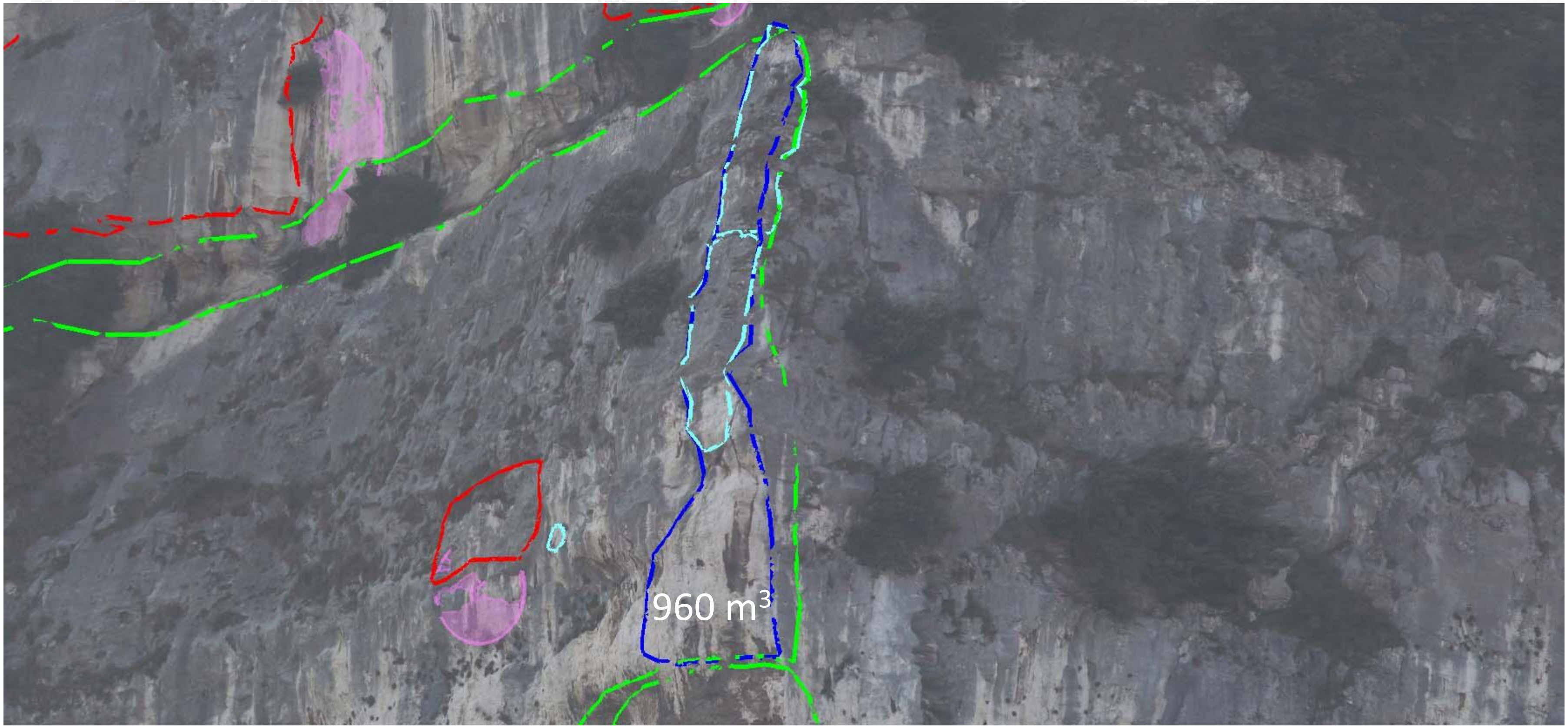
Case history: Mount Brione, Italy

Composite Failure Modes

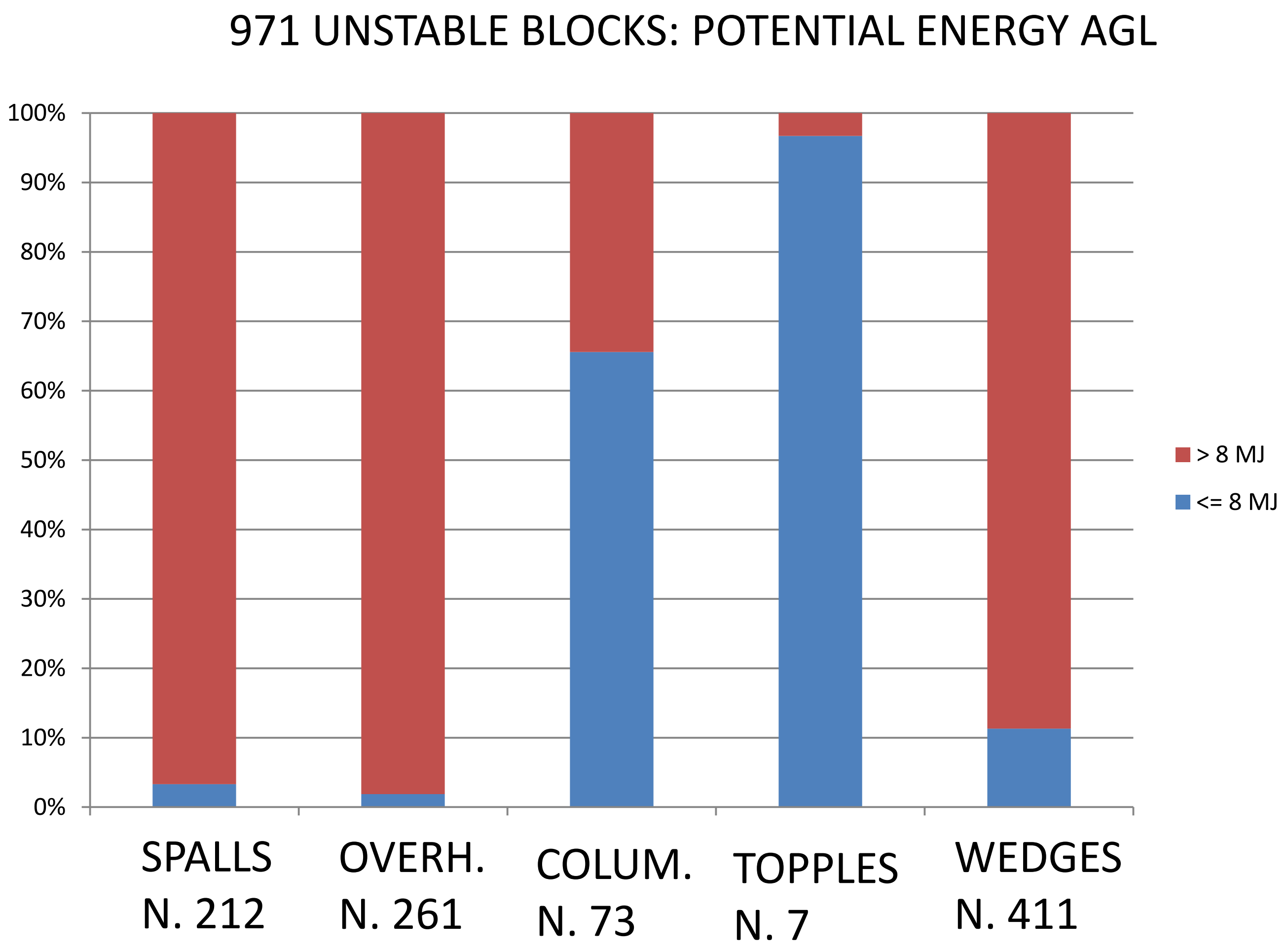


Case history: Mount Brione, Italy

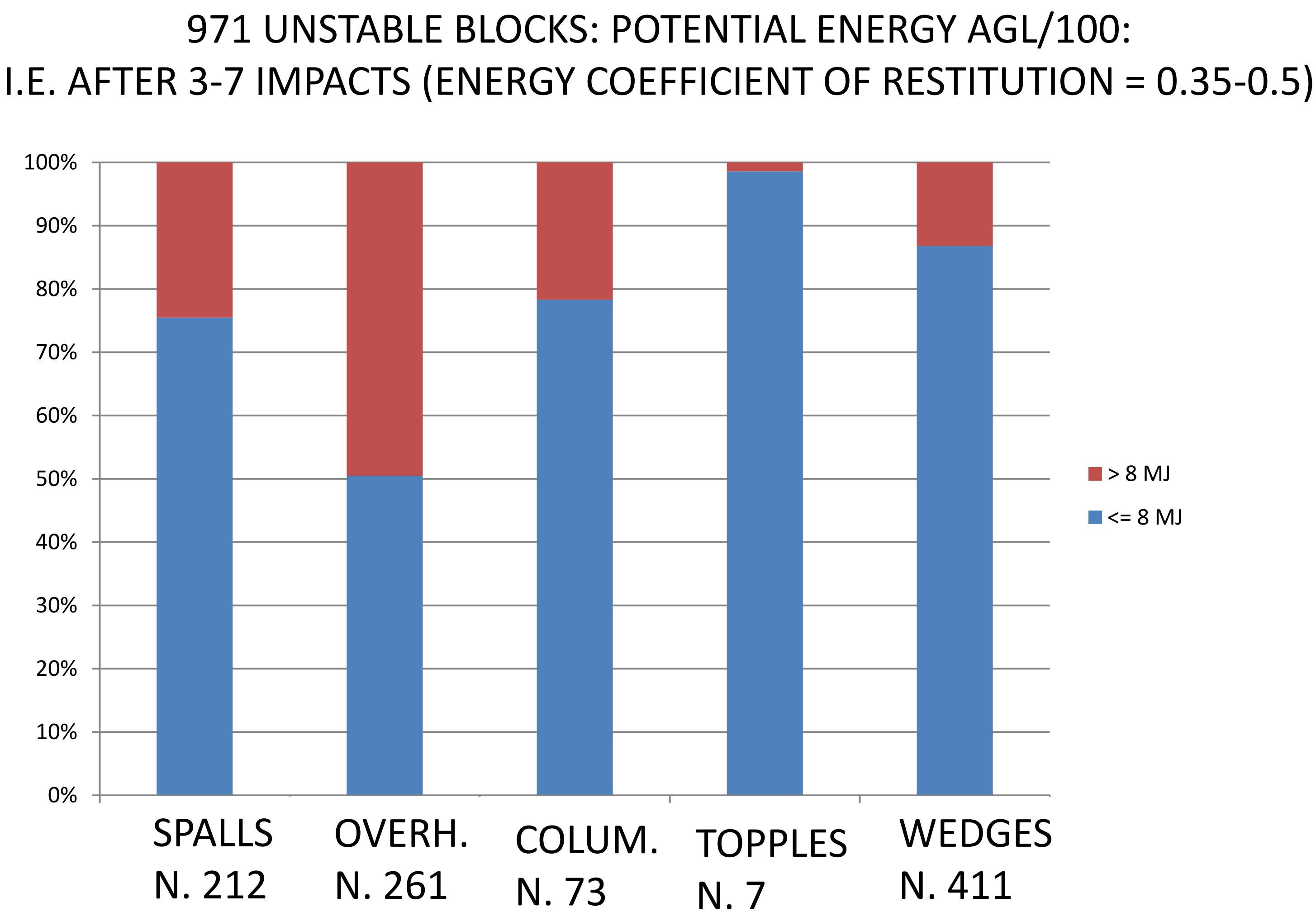
Composite Failure Modes



Case history: Mount Brione, Italy



Case history: Mount Brione, Italy



Conclusions

- Accuracy determined based on project needs
- Not constrained to ground topography
- Can be used in vertical and steep canyons even if the slope is concave
- 3-D georeferenced triangulated mesh textured with high res pictures
- Exact pixel-mesh match
- Results:
    - Fracture mapping
    - Excavation/fill volume calculations
    - Contours of displacements orthogonal to each mesh triangle
    - Measurement of crack opening
    - Detection of unstable blocks
    - Volume of unstable blocks

- Unmanned Aerial System (UAS) developed and used by LRRT and Tonon USA:
    - No need for targets on the ground
    - No need to re-survey targets
    - No need to rent large helicopter
    - Highly improved constraints in model
    - Italia, ENAC, Inoffensivita’