The Use of Small Unmanned Aerial Vehicles (sUAVs) to Evaluate Rock Slope Stability and Assess Performance of Rockbolts on Inaccessible Slopes

Presented by:

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Co-Collaborators:

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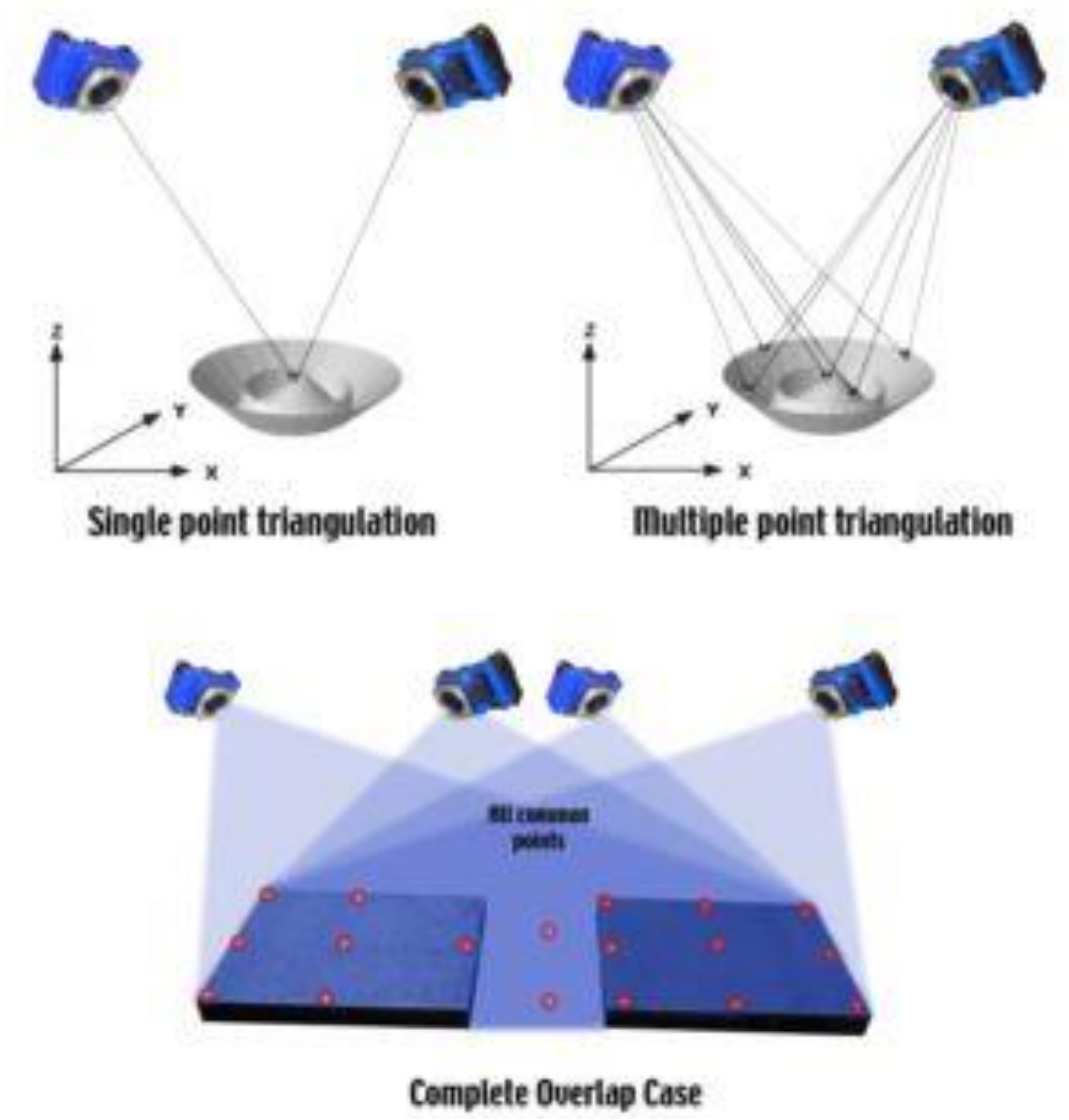
OUTLINE

- What is photogrammetry?
- What are we investigating?
- Step 1: Reconnaissance
- Step 2: UAV flight planning and data acquisition
- Step 3: Create the digital outcrop
- Step 4: Hazard identification
  - Falling blocks (for rockfall simulation programs like CRSP)
  - Wedge, plane, and toppling failures (Hoek Bray stereonet analysis)
  - Undercutting, corrosion, general damage (Rock bolt performance assessment)
- Step 5: What did we learn and how can we improve the workflow?

PHOTOGRAMMETRY

- Reverses photographic process; back to 3d
  - Minimum of 2 images
- Points of interest
  - Identify poi in 2d images
    - Thousands to tens of thousands per image
  - Compare poi across all images to create matches
    - Can set number of matches necessary
- Triangulation
  - Intersecting lines in space are used to compute the location of a point in all three dimensions
  - Need multiple camera positions and angles



ROCKFALL HAZARD

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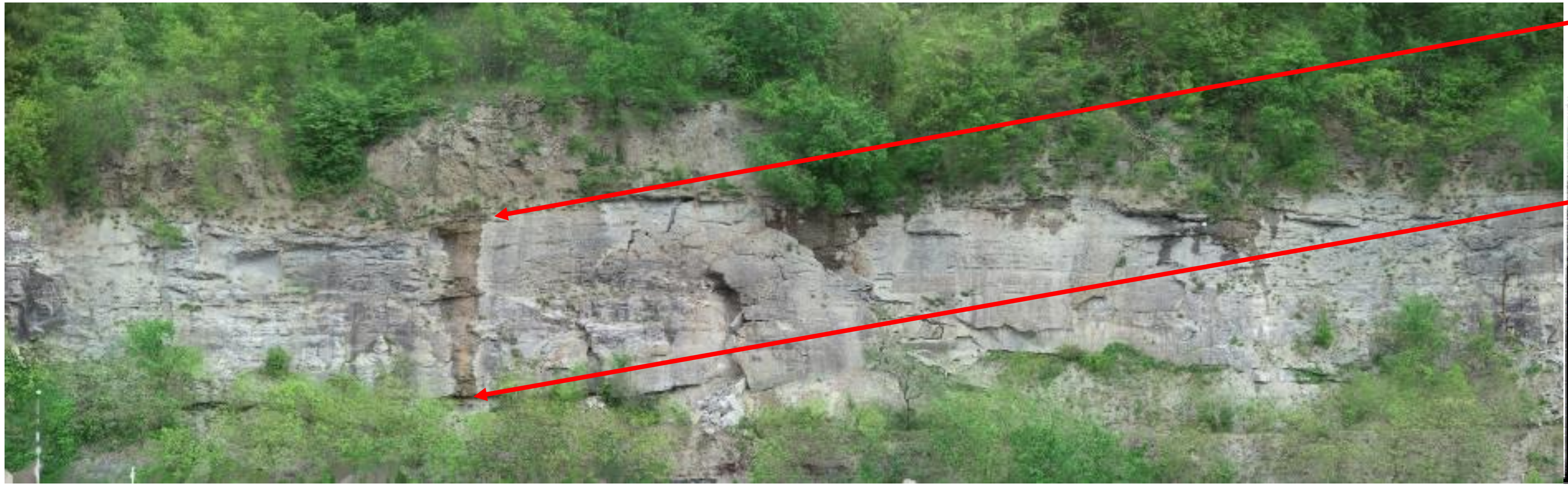
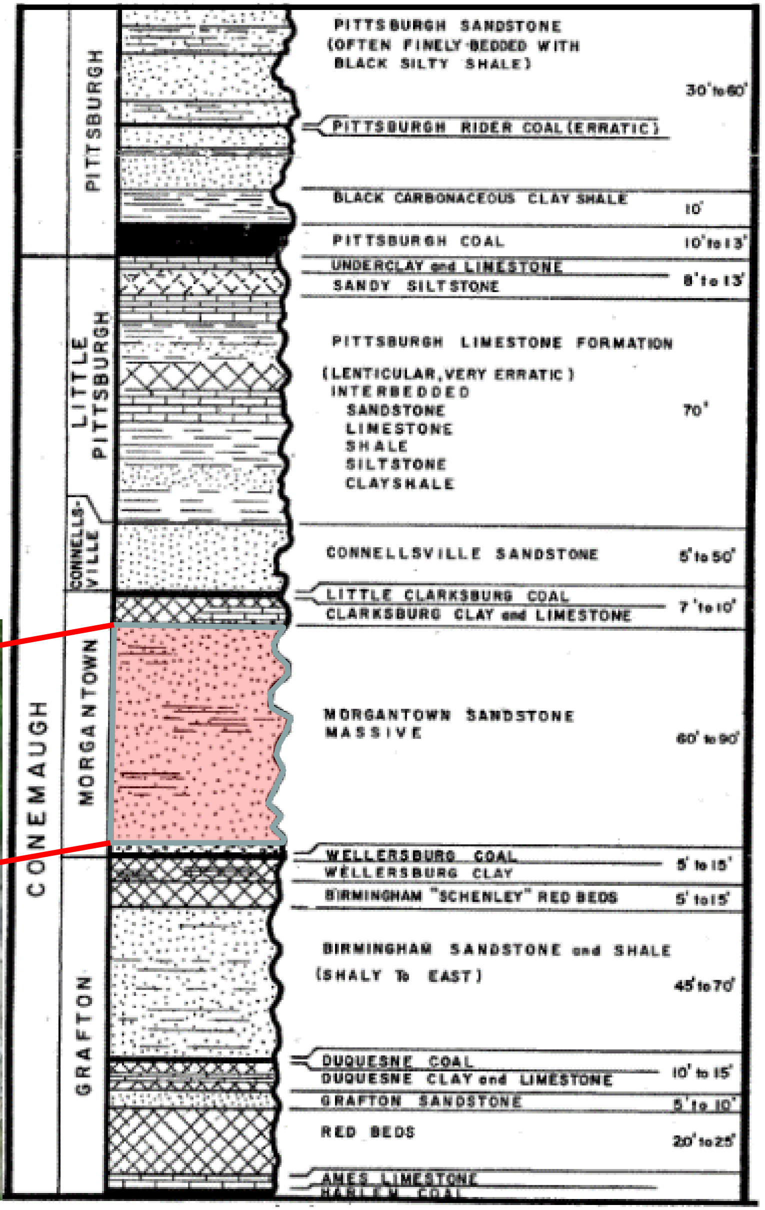
DESKTOP STUDY / FIELD RECONNAISSANCE

Source: Mining and Physiography, Allegheny County, A.C. Ackenheil & Associates, Inc., 1968

Geology Overview

- Thick, resistant, massive layer is the Morgantown Sandstone.
- Overlain and underlain by weak, coal-bearing clay rocks (Clarksburg Clay and Wellersburg Clay).
- Three Problems:
  1. Undercutting of Morgantown Sandstone removes vertical support.
  2. Sub-vertical / slope-face-parallel valley stress relief joints result from ancient and modern removal of lateral support…form sliding wedges, sliding blocks, and toppling blocks.
  3. Erosion of weak rocks above allows water into joints behind the slope face…freeze/thaw separates slabs from intact slope…failure. In this case, a large sliding block / slab.





SETUP AND DATA ACQUISITION

1. UP CLOSE AND PERSONAL

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2. SURVEY GROUND CONTROL POINTS

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3. PROGRAMMED / ENGINEERED FLIGHT

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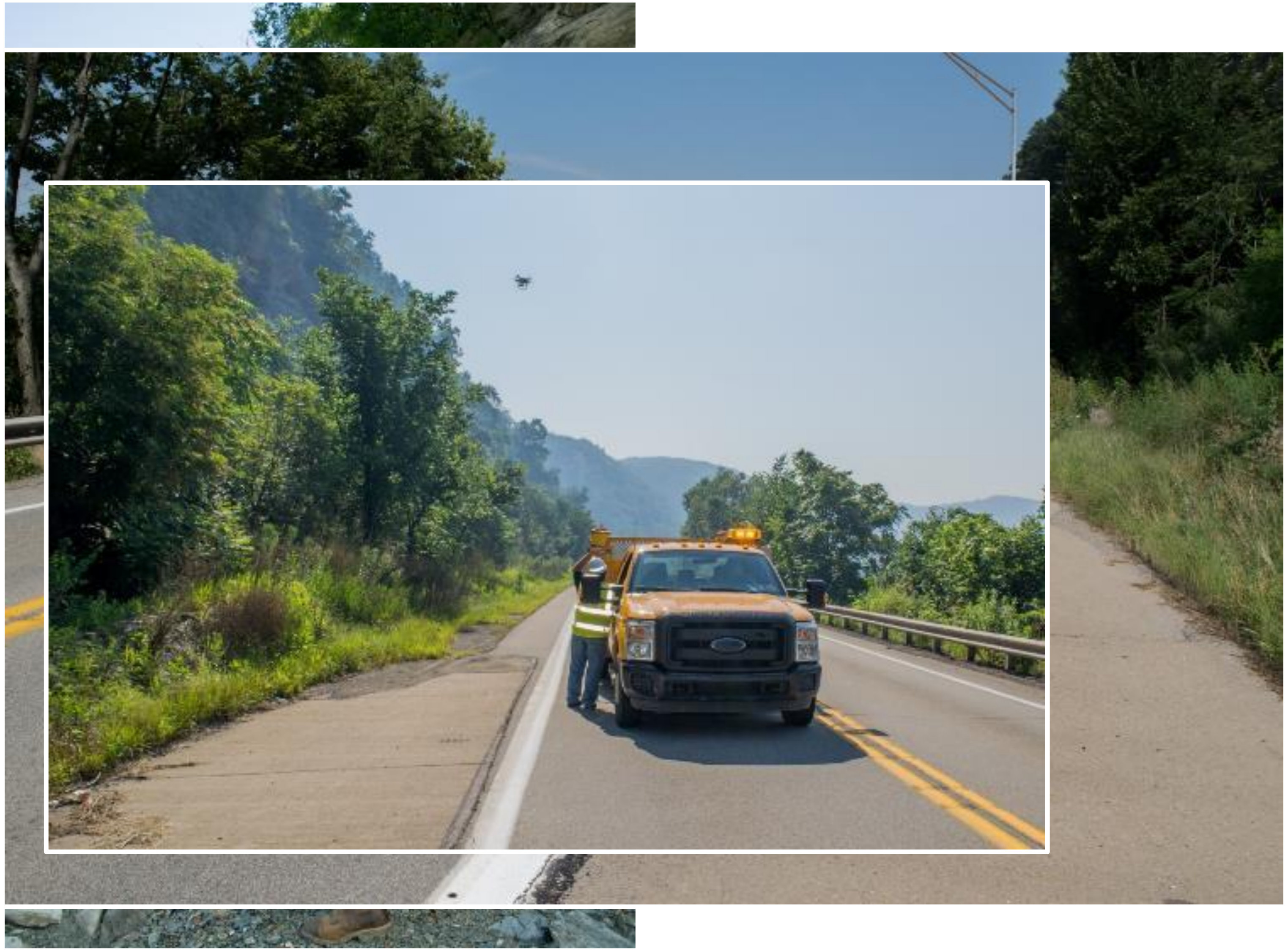

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SETUP AND DATA ACQUISITION

1. UP CLOSE AND PERSONAL

2. SURVEY GROUND CONTROL POINTS

3. PROGRAMMED / ENGINEERED FLIGHT

4. GLAMOUR SHOTS

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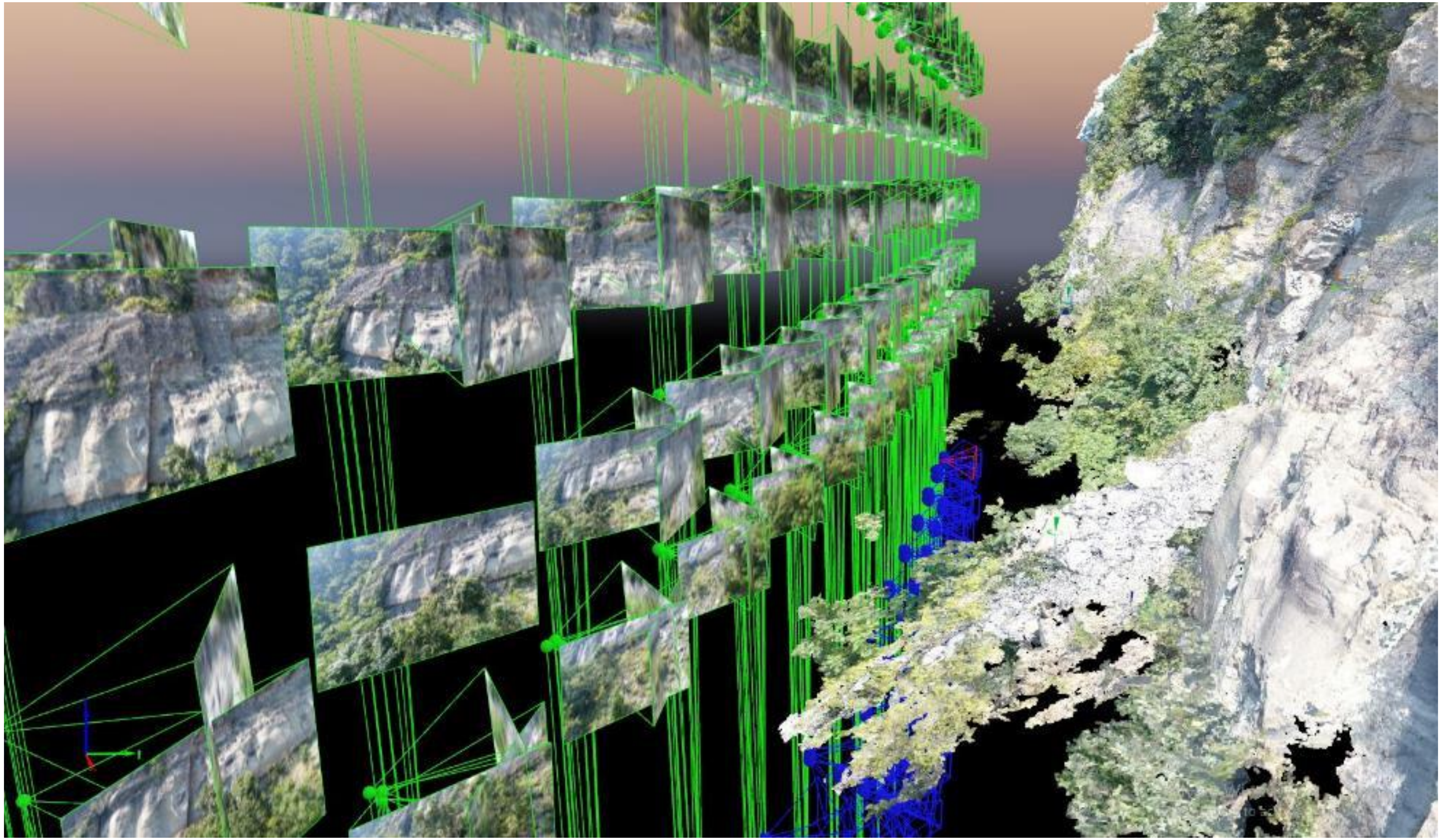
PROGRAMMED FLIGHT PLAN



CREATING THE DIGITAL OUTCROP

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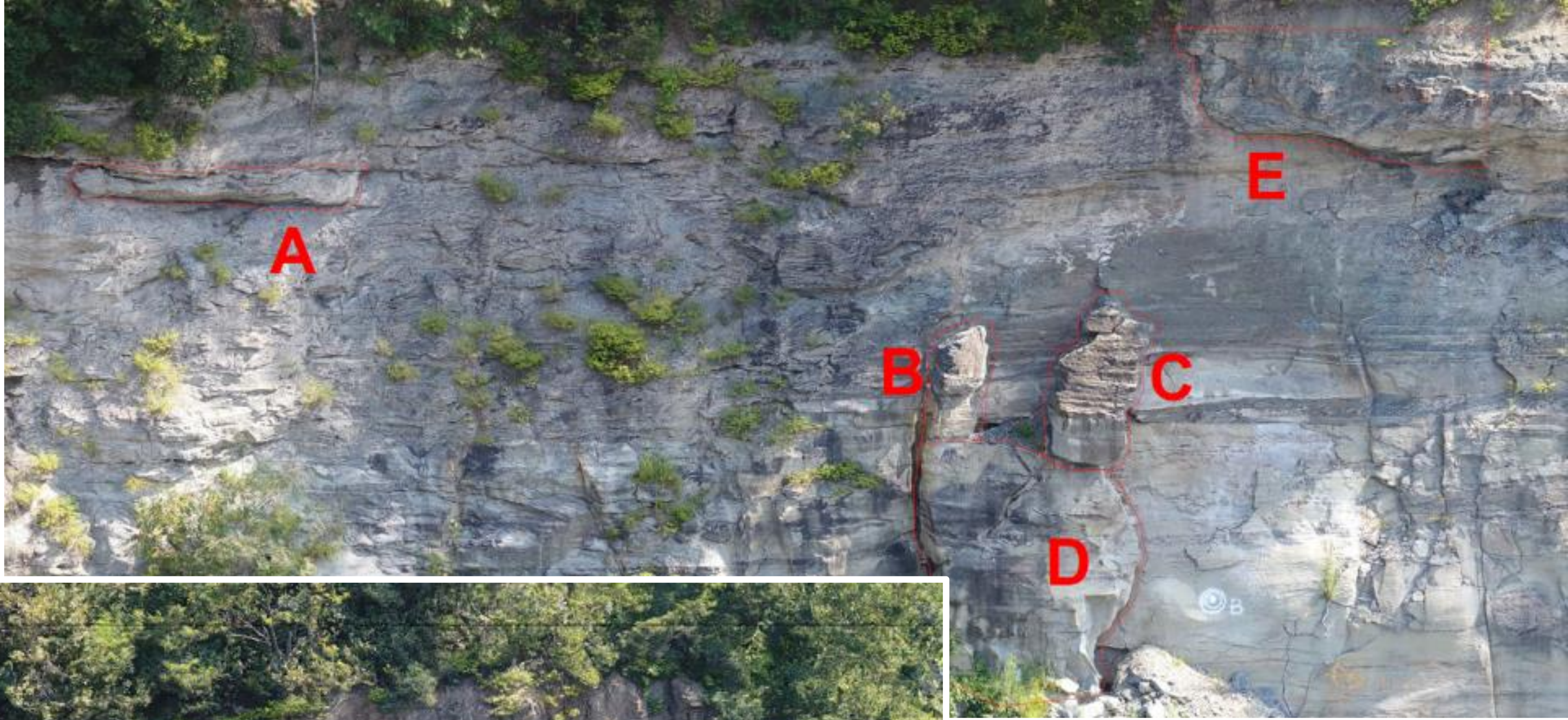
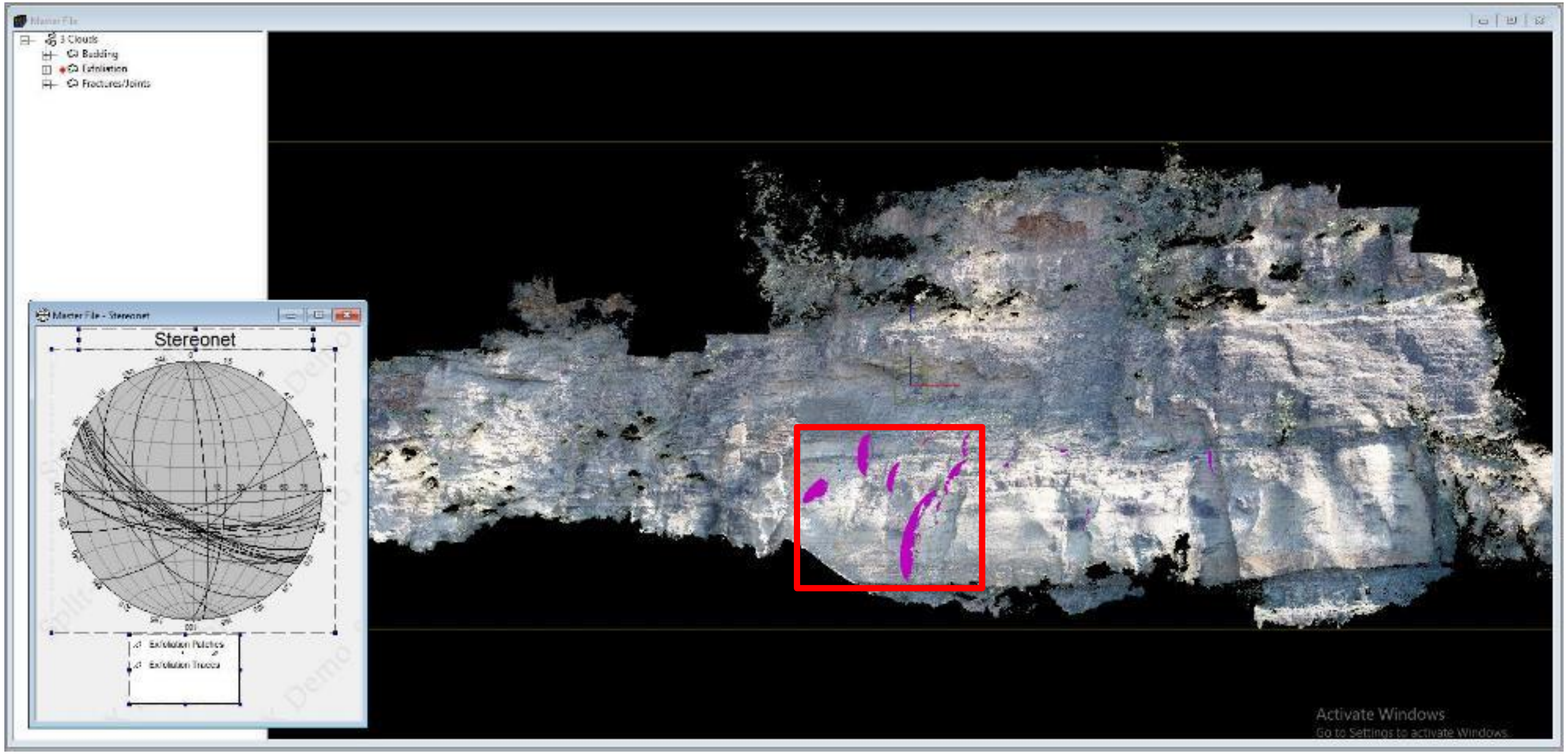
THE LOW-HANGING FRUIT



SUMMARY OF HAZARDOUS BLOCKS

Object	Volume (Cubic Meters)	Rock Mass (Kg)	Height (m)	Potential Energy (Joules)	Lithology
A	2.2	5,257	29.7	1,528,011	Siltstone
B	1.6	3,804	25.3	942,988	Siltstone Sandstone
C	4.8	11,498	25.3	2,850,581	Siltstone Sandstone
D	9.6	22,777	20.7	4,626,395	Sandstone
E	29.1	69,108	31.7	21,468,605	Siltstone Sandstone
F	8.4	19,885	40.8	7,941,224	Claystone
G	5.7	13,507	37.9	5,014,991	Claystone

DISCONTINUITY MAPPING



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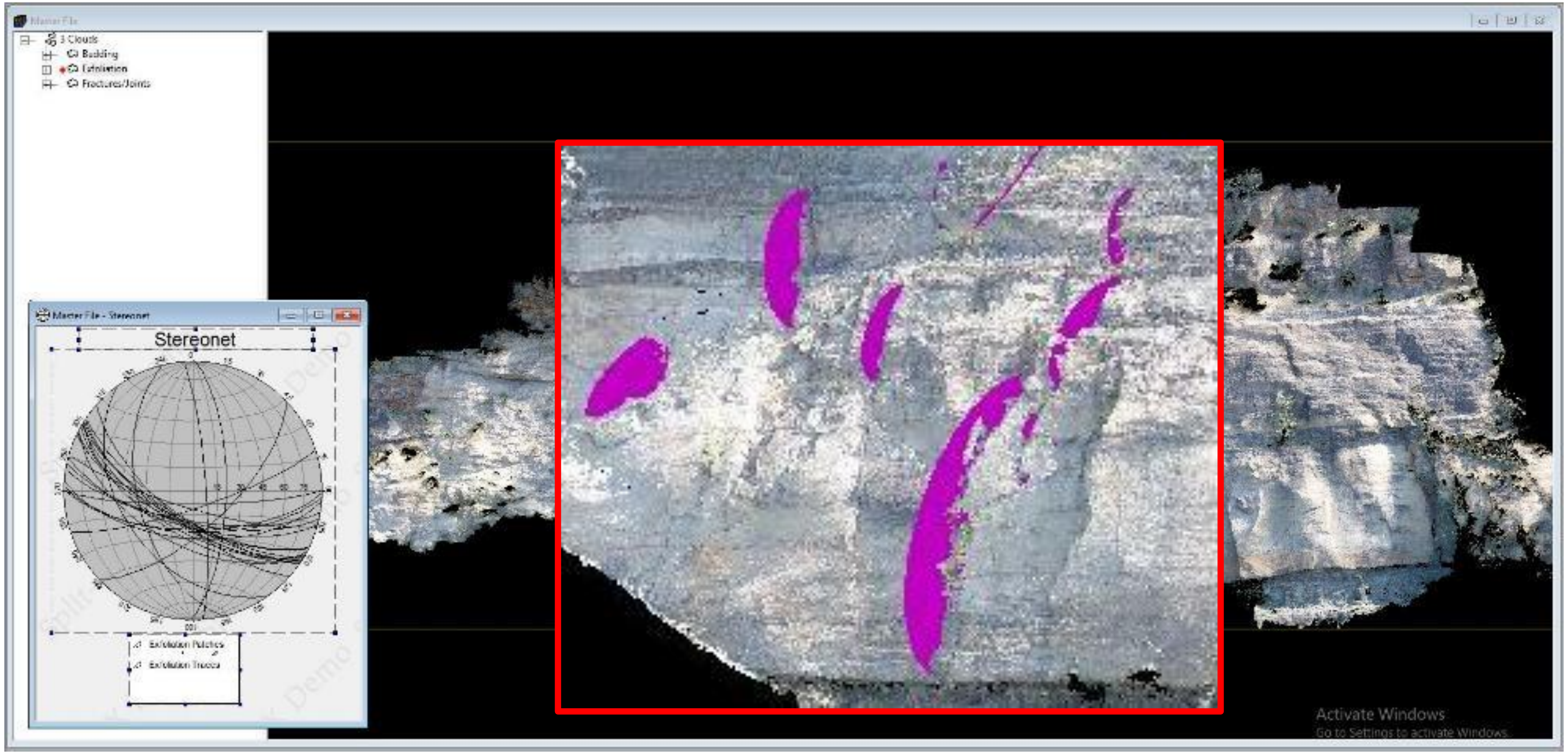

DISCONTINUITY MAPPING

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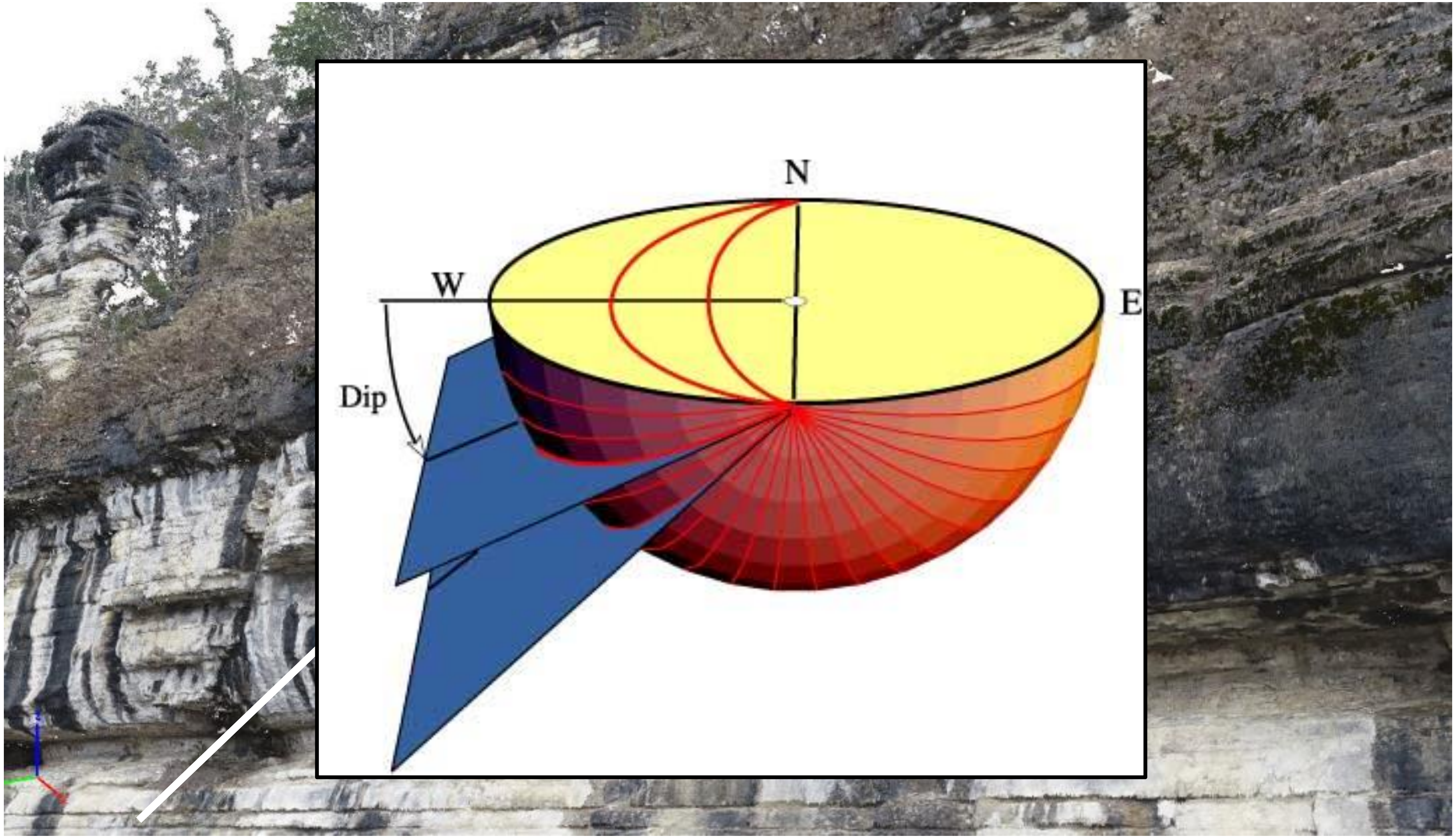
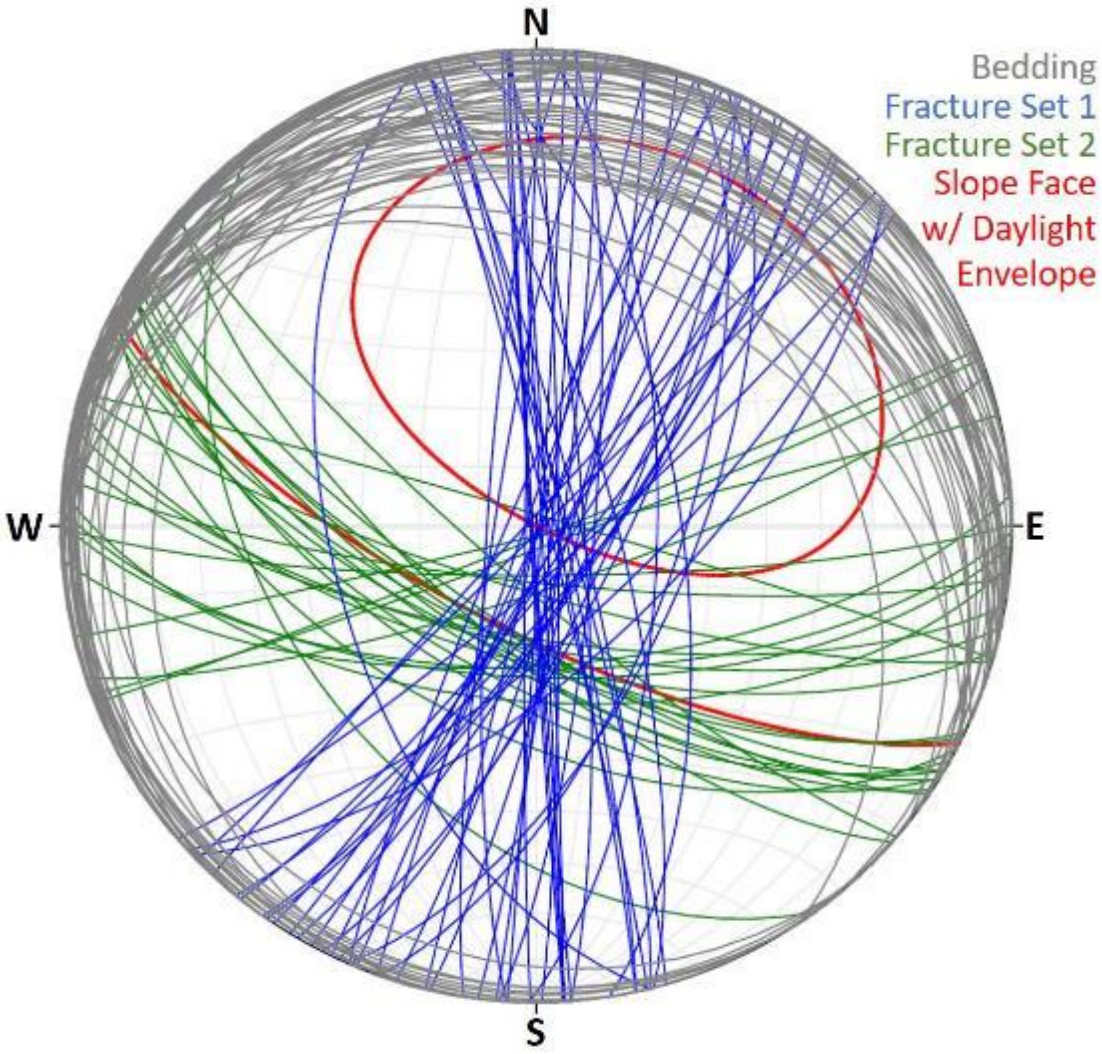
LINE TRACE

DISCONTINUITY MAPPING



LINE TRACE

STEREONET TIME!



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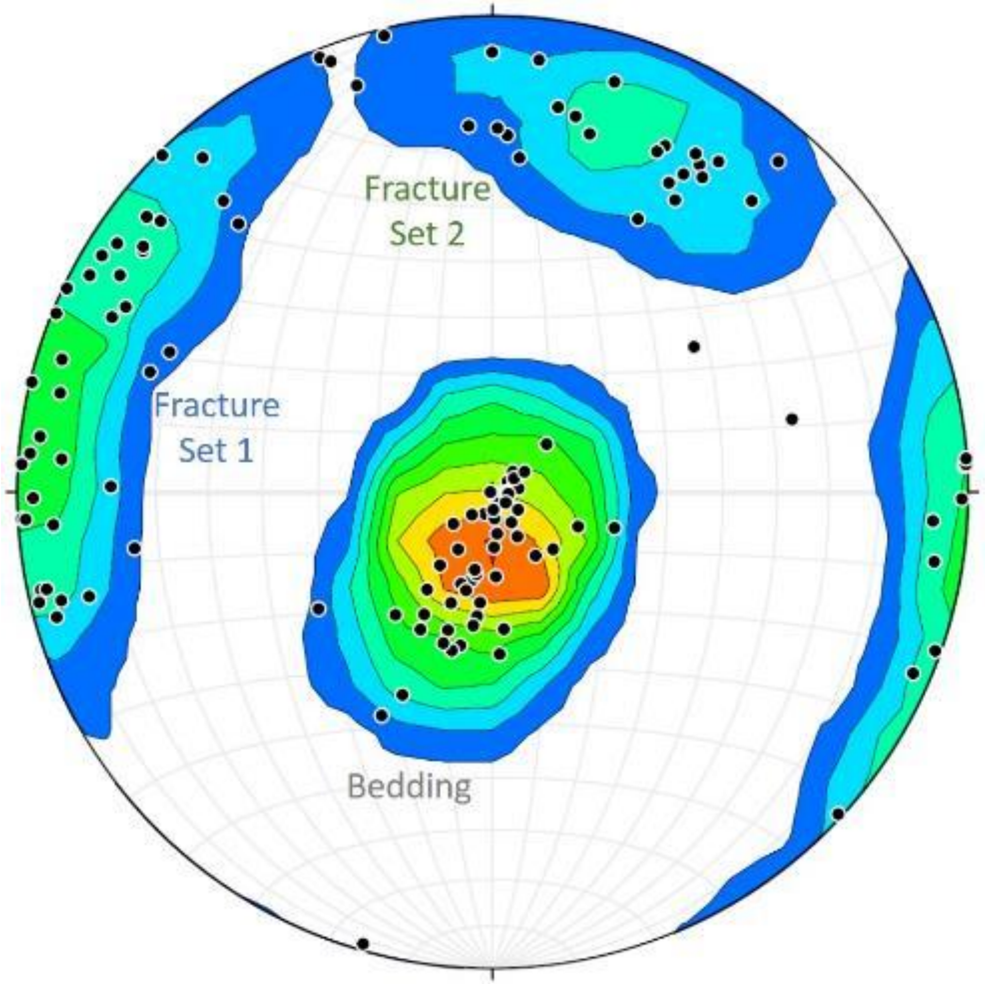

DISCONTINUITY STATISTICS

Discontinuity Set	Count (n)	Average Strike (azimuth)	Standard Deviation Strike (degrees)	Average Dip (degrees)	Standard Deviation Dip (degrees)
Bedding	55	278	41.7	11 NE	10.7
Fracture Set 1	47	018	19.7	75 SE	8.2
Fracture Set 2	28	105	20.2	69 SW	10.6
Slope Face		117		72 SW	
	130				

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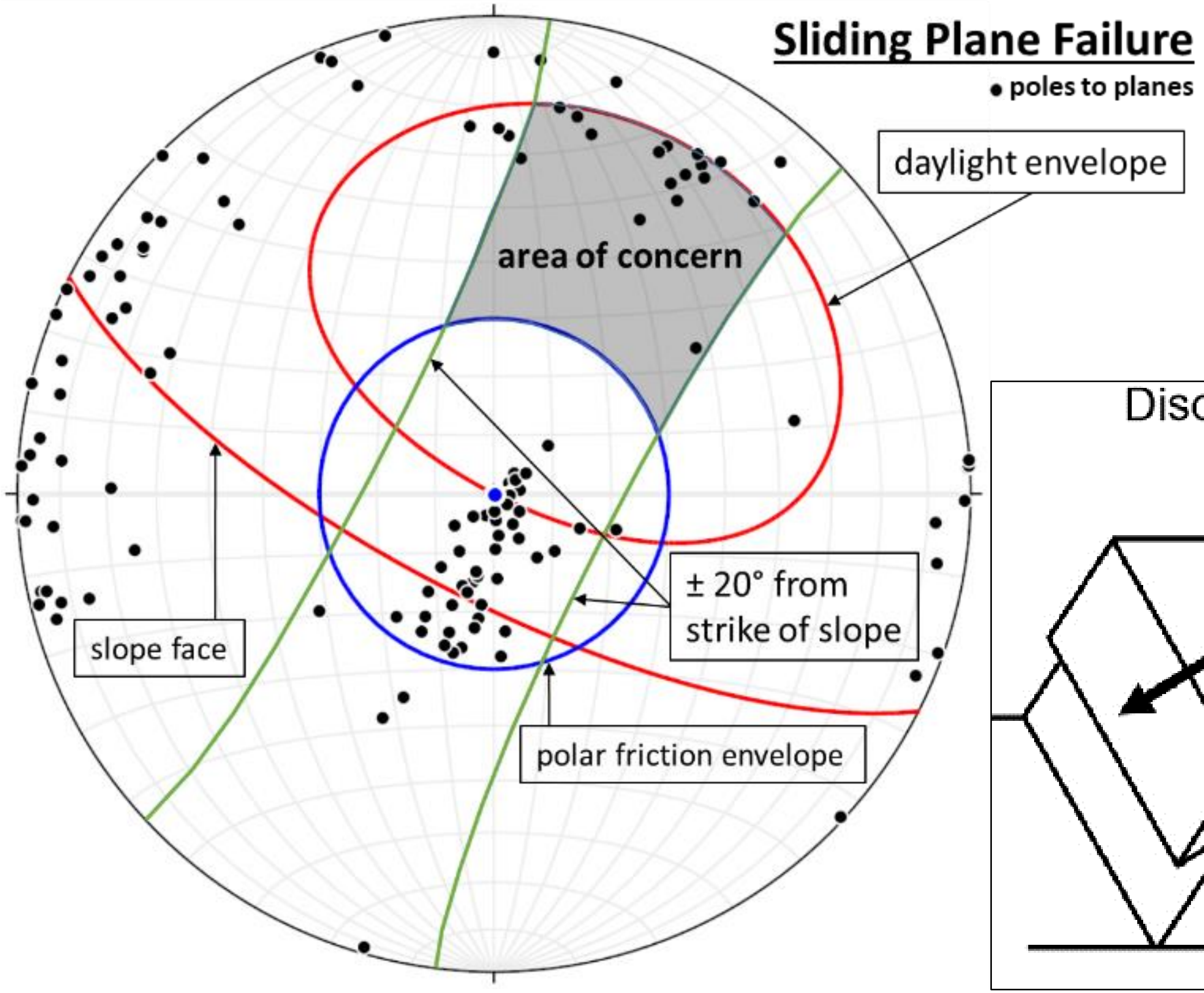
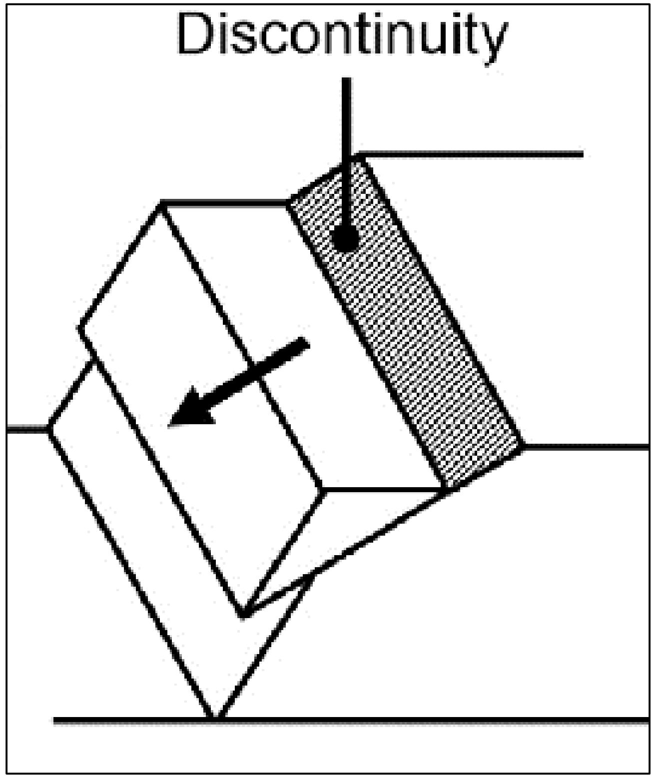
HOEK-BRAY STEREONET ANALYSIS





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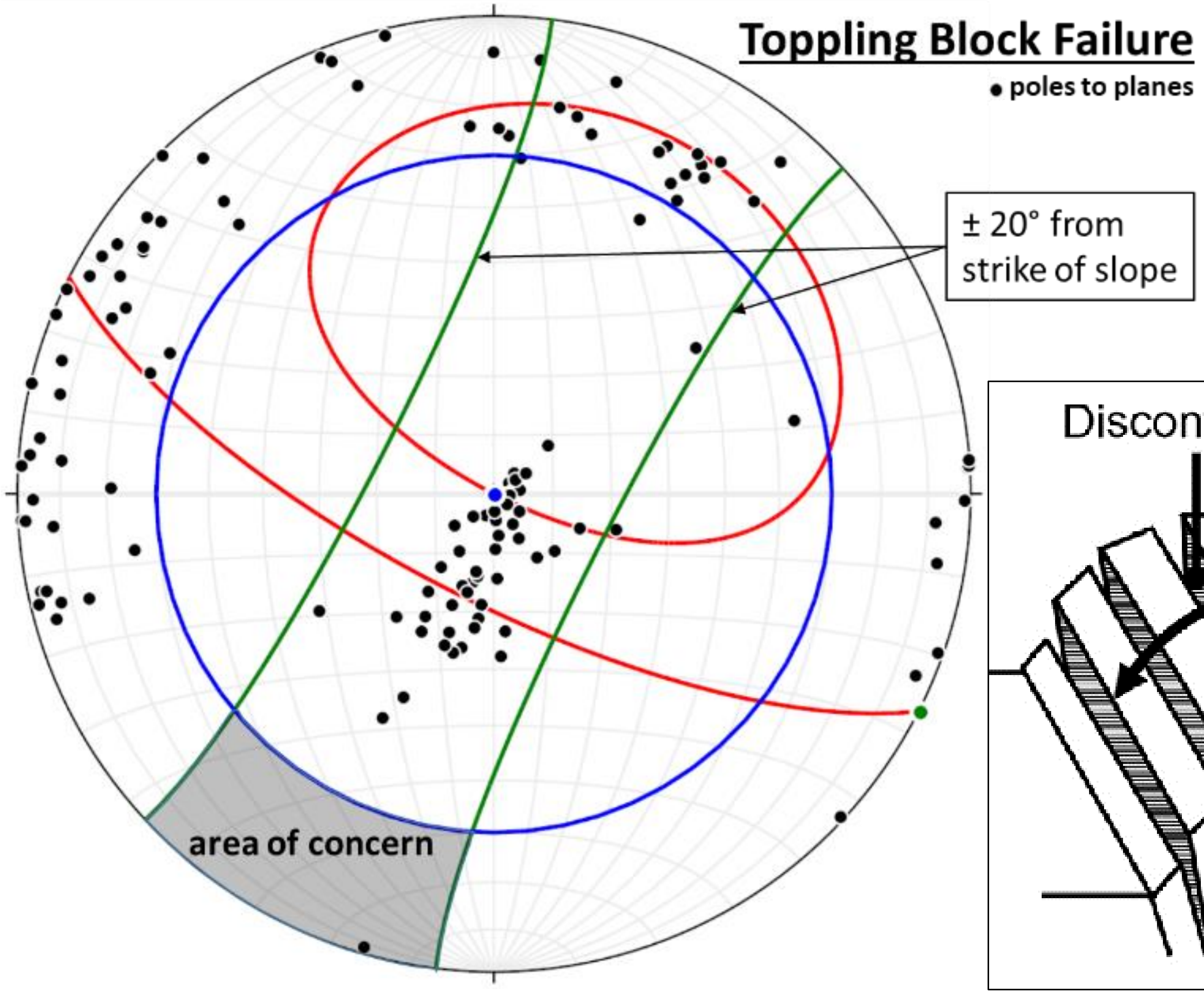

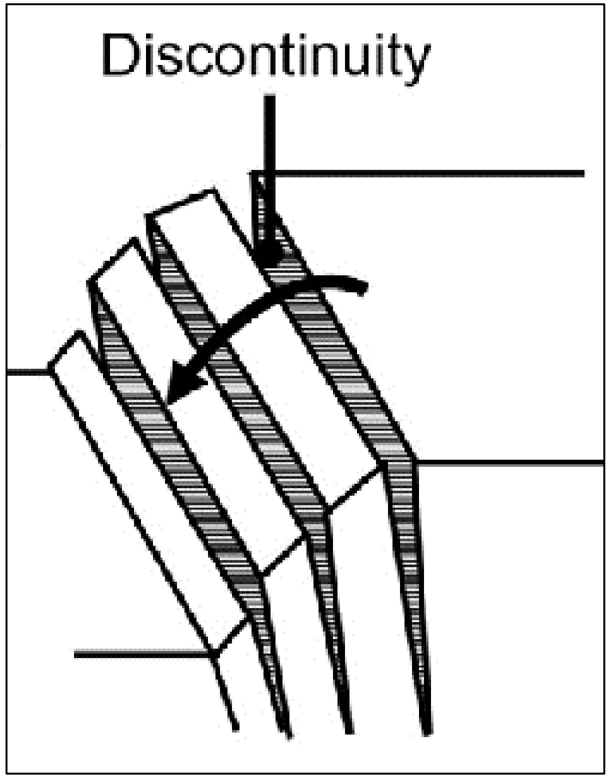

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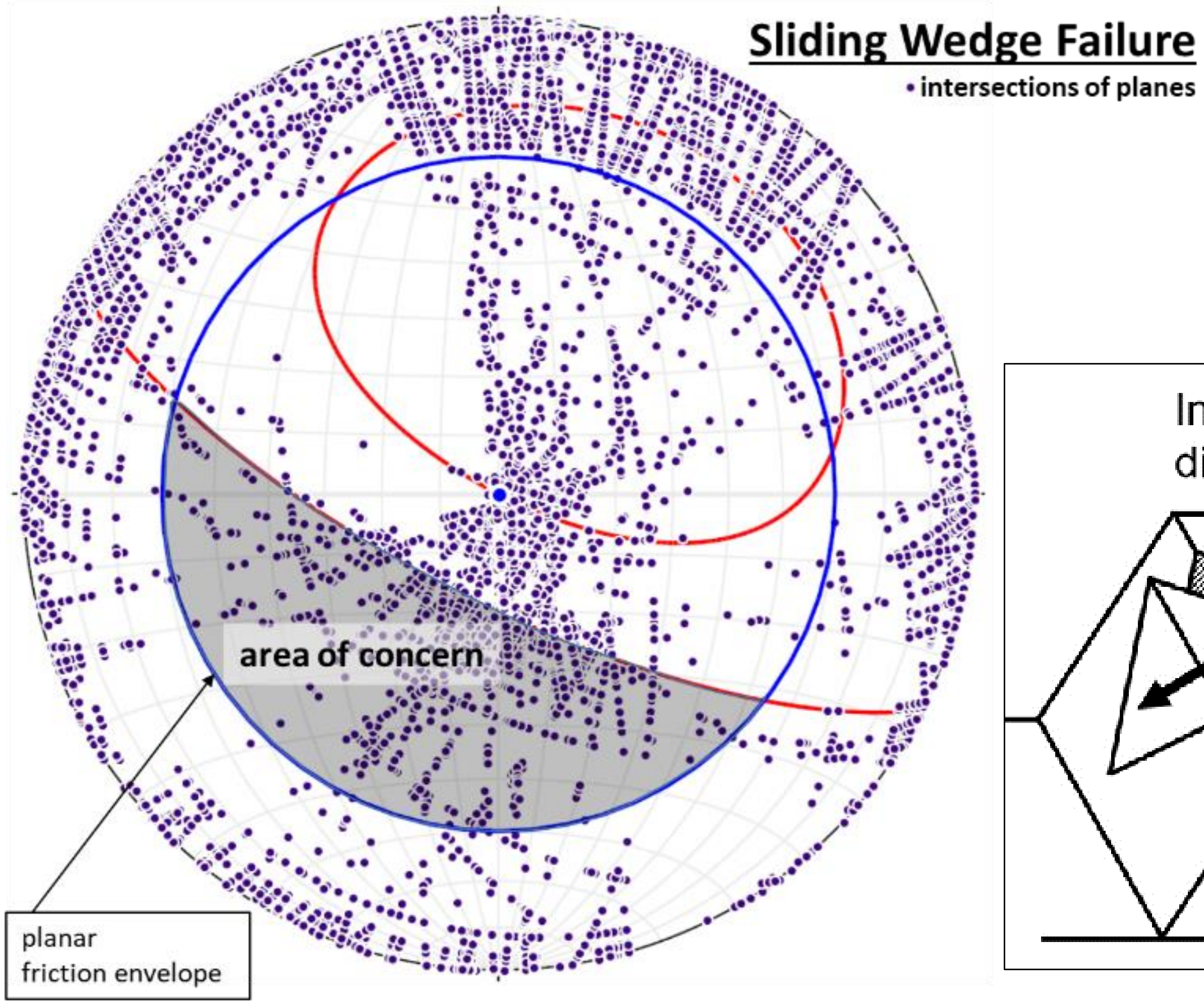
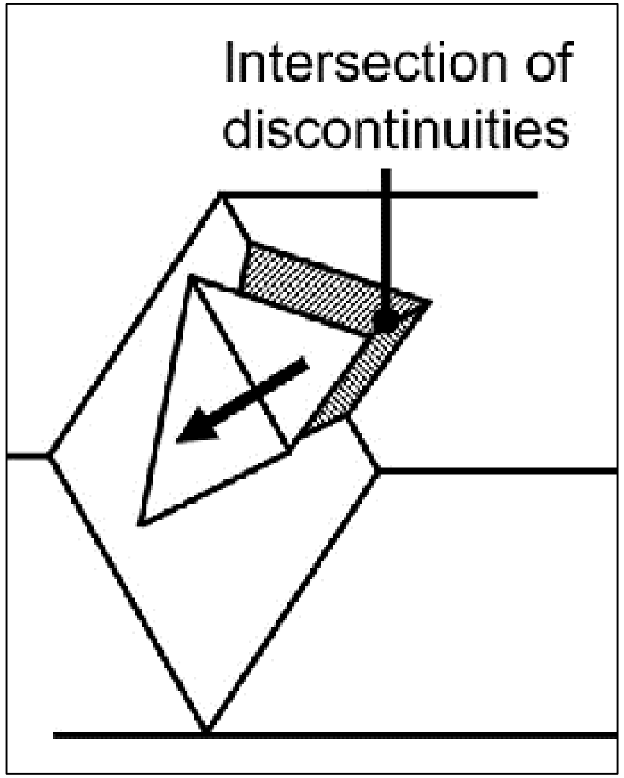
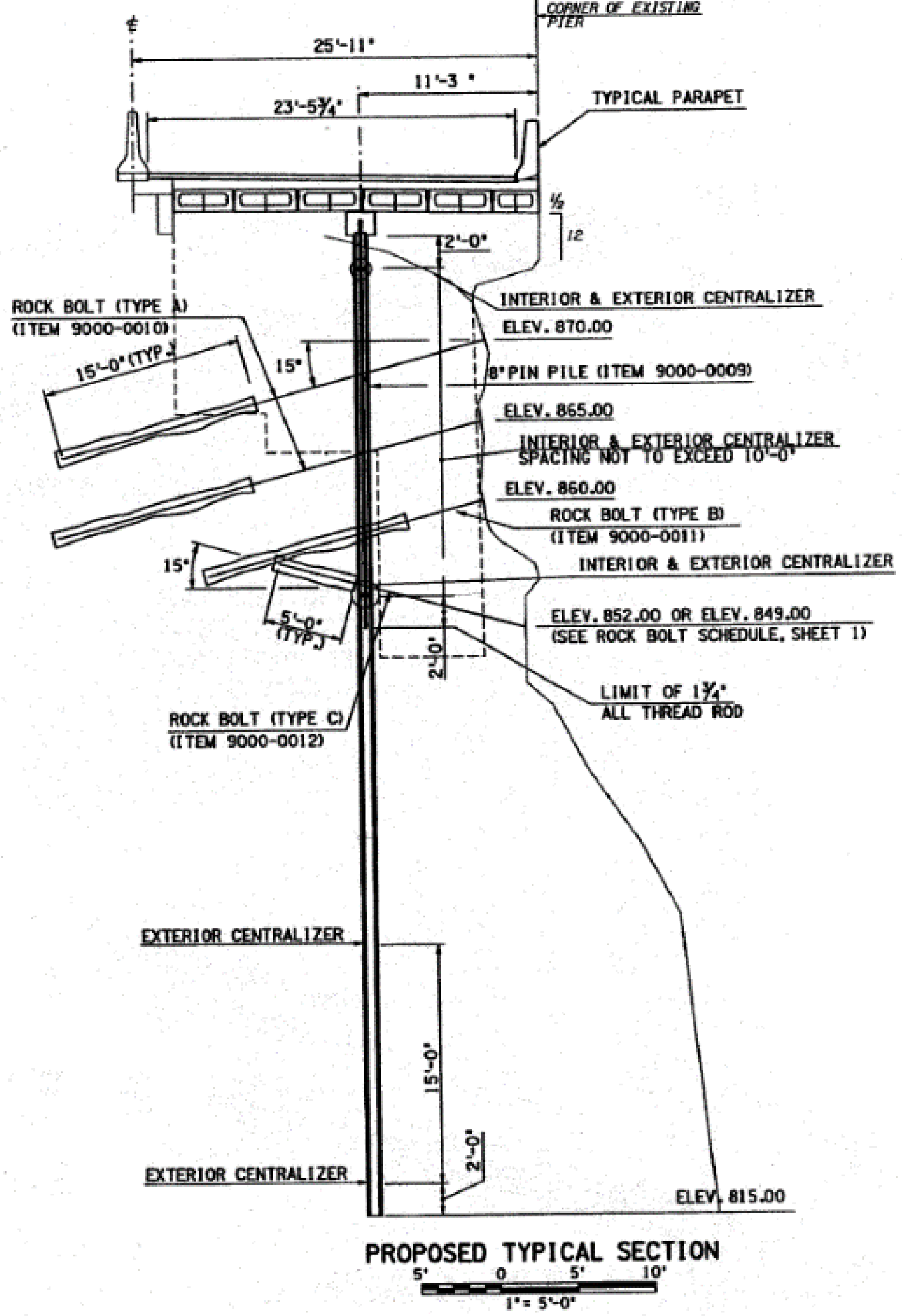




SR885 – BOULEVARD OF THE ALLIES – DUQUESNE BLUFF… ROCKBOLT INVENTORY AND ASSESSMENT

- Change our focus from the performance of an engineered rock slope above a major roadway to the performance of engineered improvements below a major roadway



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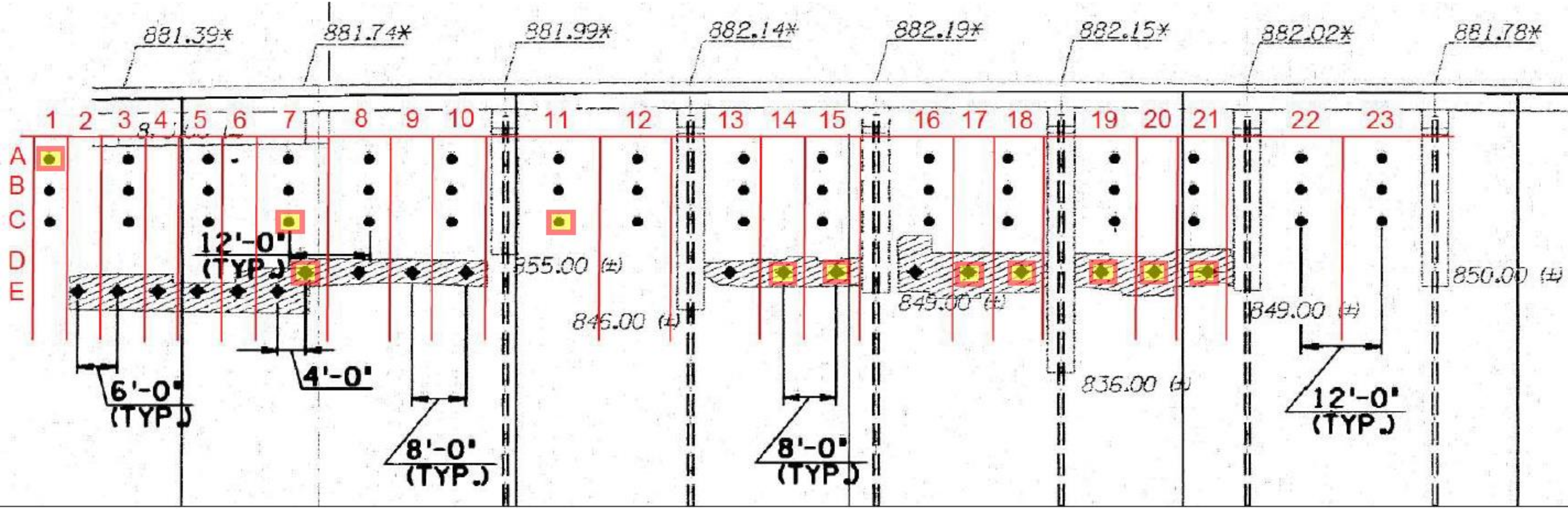
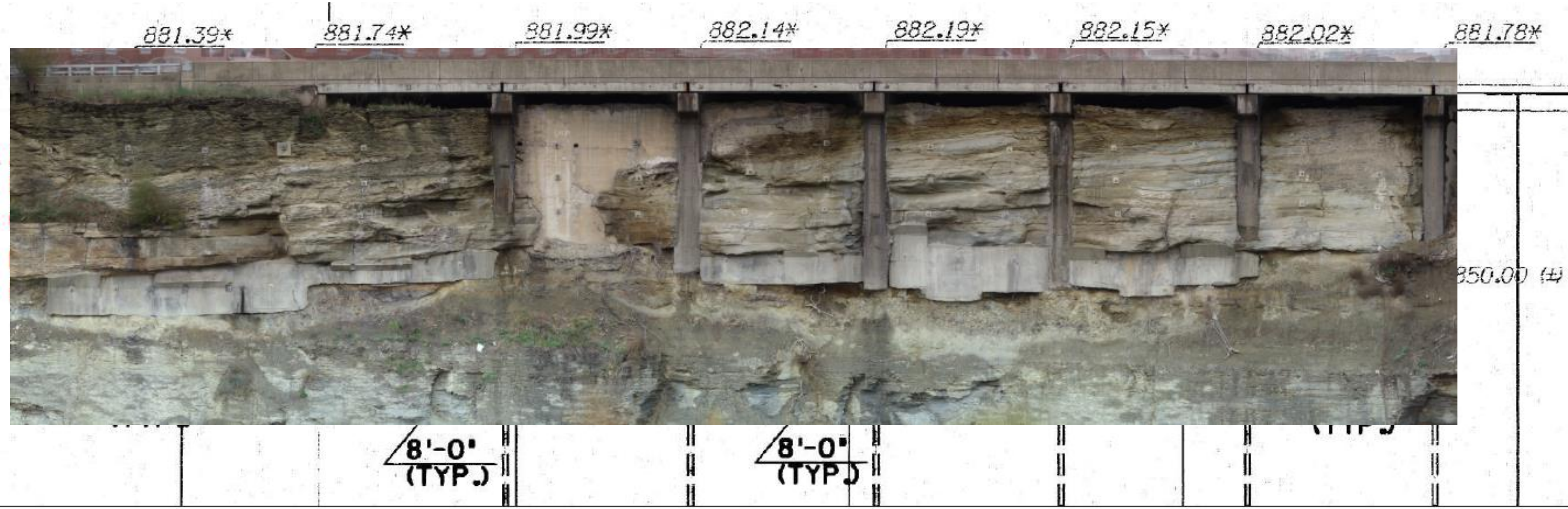


- ROCK BOLTS EXHIBITING DEFECTS



- ROCK BOLTS EXHIBITING DEFECTS

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12A
DRILL HOLE?


7C
ANCHOR ALMOST EXPOSED


15D
DENTAL CONCRETE AND PIER UNDERCUT


90B EXPOSED ROCK BOLT

STRUCTURE	ROCK BOLT ID	MINOR DEFECT
Structure 2 (S-23974)	1A	Small Void to Right of Bolt. Appeards to Be Weathered Bedding in Sandstone
	7C	Bolt Located Near Vertical Jointl Small Rockfall May Expose Bolt in Future
	7D	Plate Showing Surface Corrosion
	11C	Spalling Concrete to Right of Bolt
	12A	Void Behind Plate, Possible Abandoned Drill Hole
	14D	Dental Concrete Undercut
	15D	Dental Concrete Undercut
	17D	Tight Vertical Crack in Dental Concrete; Dental Concrete Undercut
	18D	Dental Concrete Undercut
	19D	Dental Concrete Undercut
	20D	Dental Concrete Undercut
	21D	Dental Concrete Undercut
Structure 3 (S-23975)	24A	Debris Collecting on Plate
	25A	Undercutting of Plate
	32A	Corrosion on Plate
	33A	Corrosion on Plate
	36B	Corrosion on Bolt
	39B	Corrosion on Plate
	43A	Corrosion Around Plate
	43B	Corrosion at Top of Plate
	43C	Significant Corrsion on Plate
	44C	Corrosion at Top of Plate
	45B	Void Nearby
	46C	Corrosion at Top of Plate
	47B	Corrosion at Top of Plate
	53C	Corrosion on Plate
	57C	Plate is Undercut
	58C	Plate is Undercut
	61A	Corrosion Around Plate
	65A	Plate is Undercut
	66B	Drillhole Adjacent to Bolt
	67B	Drillhole Adjacent to Bolt
	68B	Drillhole Adjacent to Bolt
	74B	Plate is Undercut
	77B	Plate is Undercut
	78B	Significant Corrsion on Plate & Bolt
	82B	Corrosion at Top of Plate
	83B	Corrosion at Top of Plate
	85B	Corrosion at Top of Plate
	86B	Dental Concrete is in Poor Condition; Void Adjacent to Bolt
	90B	Large Void Below Bolt; Bolt is Exposed Behind Plate

Table 1: Tabulation of Rock Bolt Defects. Highlighted Bolts are Exhibiting Major Defects.

!!!

A simple, actionable list of defects that require attention is the optimum deliverable from a study like this…

prioritize and provide to the client or a contractor for repair.

CONCLUSIONS

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- What did we learn?
  1. This is no replacement for the engineer or geologist's understanding or ground truthing.
  2. UAVs are only a tool for data collection…
  3. …but you do get an immense amount of data that would be otherwise inaccessible.
  4. Plan and program your UAV flights meticulously…
  5. …but be prepared to modify or expand your data acquisition to infill or focus.
  6. On a well-exposed rock face, airborne photogrammetry is an economical alternative to airborne LiDAR.
  7. Project benefits: increased safety, decreased field time, a visual record of the site for reference

- How can we improve the workflow?
  1. Treat large slopes with a zoned approach to spatially classify risk.
  2. Time of day and time of year are important for maximizing quality data (shadows and vegetation).
  3. Practice makes perfect…thank you to PennDOT and Gannett for these opportunities.

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THANK YOU!

QUESTIONS AND COMMENTS?