Photogrammetric 3-D Rock Slope Modeling, Discontinuity Mapping, and Analysis Utilizing an Unmanned Aerial Vehicle*

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Abstract

An Unmanned Aerial Vehicle (UAV) was utilized to collect aerial photography of a hazardous cut rock slope located on the north shore of the Monongahela River in Glassport, PA. The road cut under investigation is over 100 feet tall and 2,700 feet long. This exercise is directed toward gaining an understanding of the local geology (bedding, lithology, fractures, and joints), including the structure and stresses within the rock. Three-dimensional photogrammetric slope modeling and discontinuity mapping were utilized to help identify and organize rockfall hazards. The commercial intent of this exercise was to conduct a rockfall hazard analysis for the Pennsylvania Department of Transportation. Further iterations of this modeling may be used to project geologic structural data down into the subsurface. Surface outcrops have long been used as analogs for the subsurface, allowing petroleum geologists to understand depositional systems. The ability to bring this information into the office in a true three-dimensional model, integrating it with seismic data or wells logs, is a powerful tool. While the end product of our workflow is an engineering/ geologic hazard analysis, the path to get there produces information that is useful to petroleum geologists as well. Through our analysis, we have identified distinct lithological units that experience different modes of failure; resistant Morgantown Sandstone undergoing planar failure and weaker Clarksburg Claystone undergoing wedge failure. A hybrid failure is possible in the lithologic units between the above-mentioned layers. Though methodologies and case studies exist for similar workflows, we have optimized our workflow to improve upon existing procedures. The flight plan was designed to maximize exposure to the rock face and fracture and joint orientations as discerned in a previous field visit. Traditionally, this type of work has been conducted in large rock quarries using stereo-pair imagery and ground based cameras at a large distance. The utilization of UAV's allows for resolution of one-half inch or less and ensures data is collected without distortion from the base of the slope to the top of the outcrop. By utilizing our work flows over a large expanse, perhaps coupled with multispectral imagery to distinguish lithologic boundaries and mineralogy, the process described may be utilized for large-scale structural mapping and analysis.

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Erich Zorn – Senior Geologist
DiGioia Gray & Associates

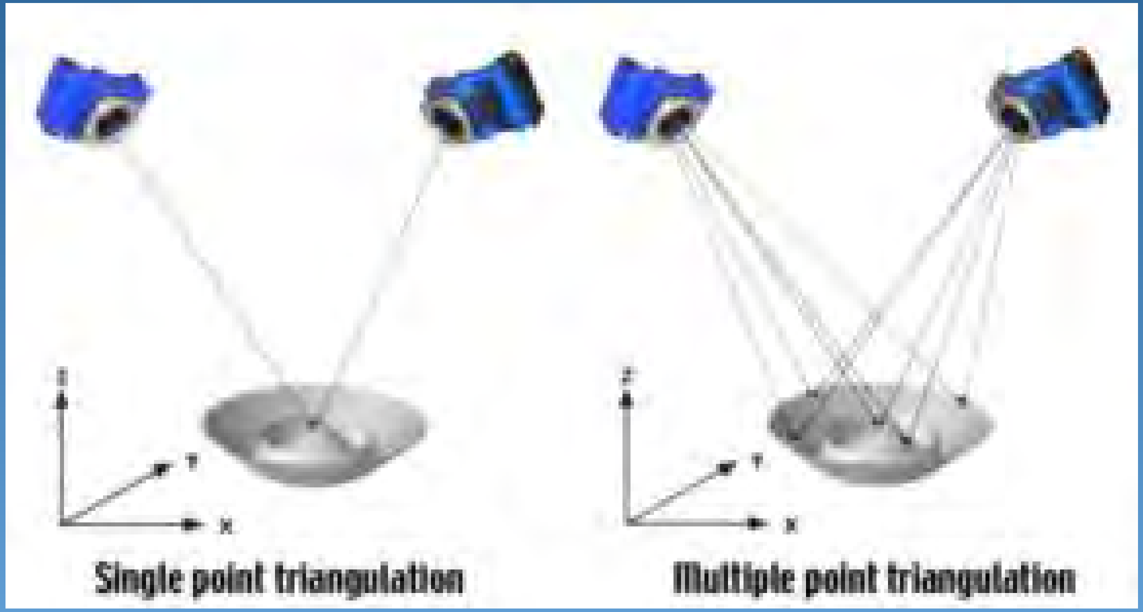
ACE 2018 ANNUAL CONVENTION & EXHIBITION
ACE 101: Bridging Fundamentals and Innovation

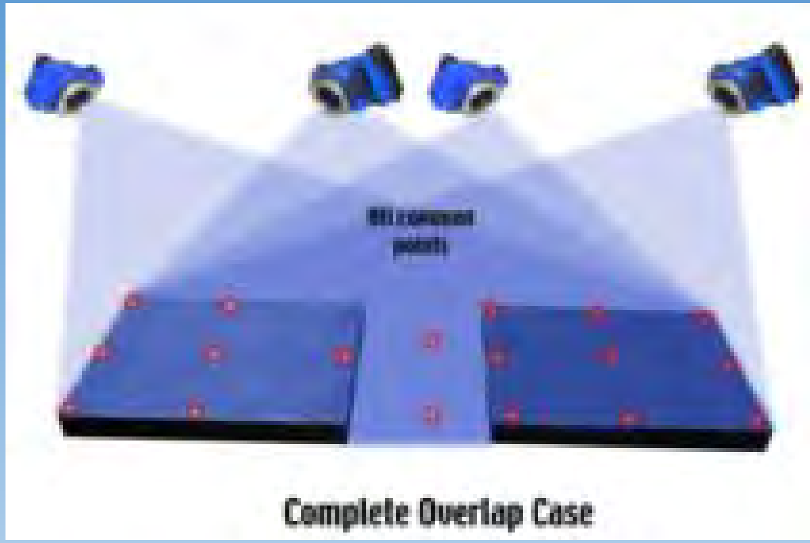
OUTLINE

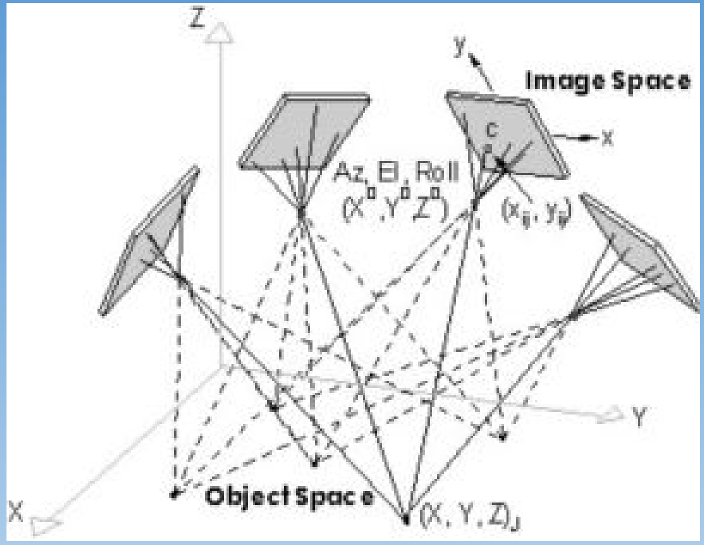
- What is photogrammetry?
- What is the hazard we are investigating?
- Reconnaissance level – define the geologic context
- Set-up and data acquisition
  - Programmed / engineered flight plan gets the best results
- Create the digital outcrop
- Hazard identification
  - Falling blocks
  - Wedge, plane, and toppling failures (Hoek Bray stereonet analysis)
- Beyond engineering applications…
  - How could this technology help you in your work or education?
  - Understanding the subsurface through surface analogs
  - Visualize outcrop-scale structures…what would you see on seismic?

PHOTOGRAMMETRY

- REVERSES PHOTOGRAPHIC PROCESS; BACK TO 3D
  - MINIMUM OF 2 IMAGES
- SCIENCE OF MAKING MEASUREMENTS FROM PHOTOGRAPHS
  - OPTICS, PROJECTIVE GEOMETRY
- 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 CAMERA POSITIONS AND ANGLES
- DENSIFICATION
  - TAKES KEY POINTS (POI) AND FILLS IN THE SPACES
  - CAN DEFINE THE RESOLUTION
    - IMAGE SIZE AND POINT DENSITY







ROCKFALL HAZARD

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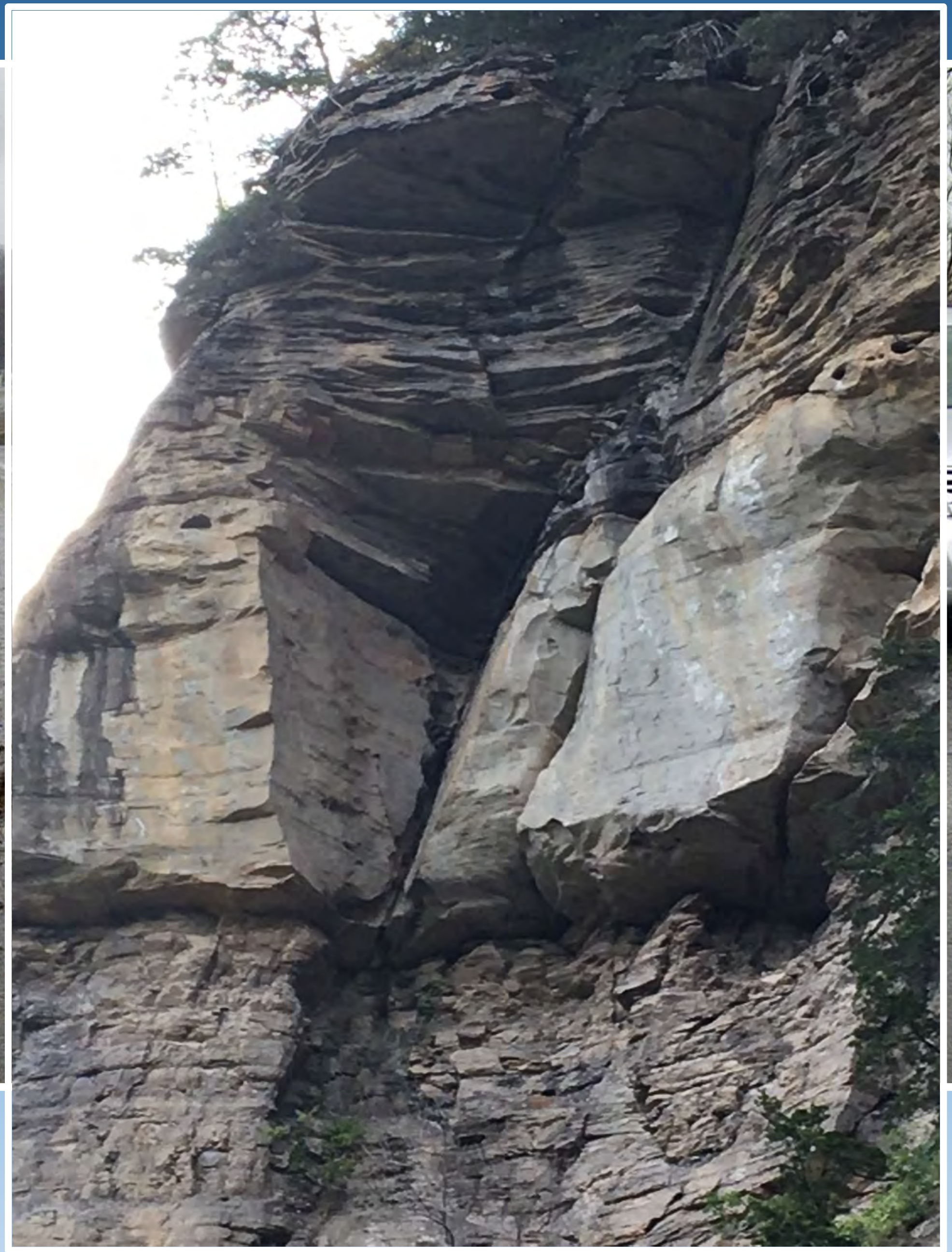
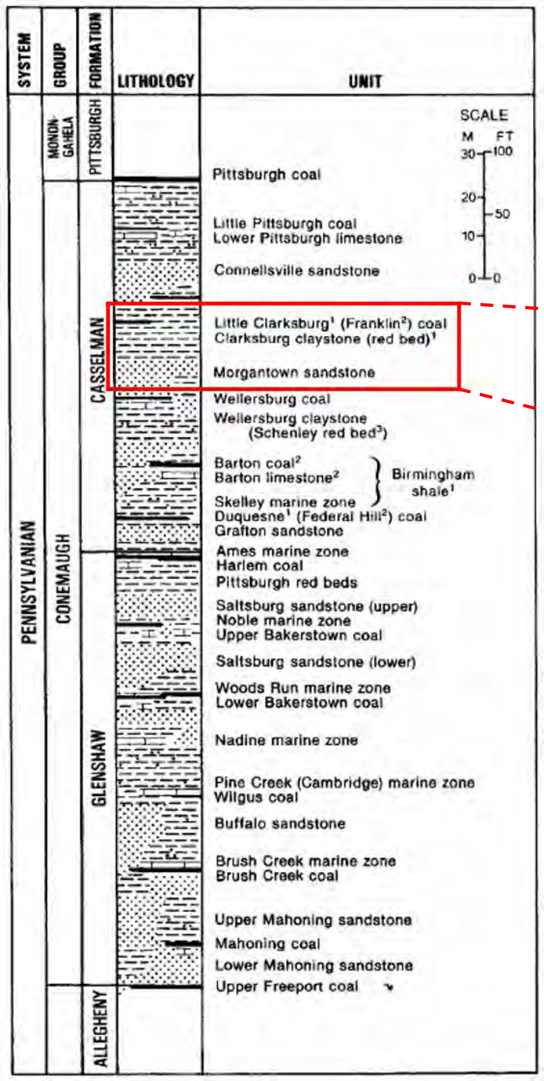
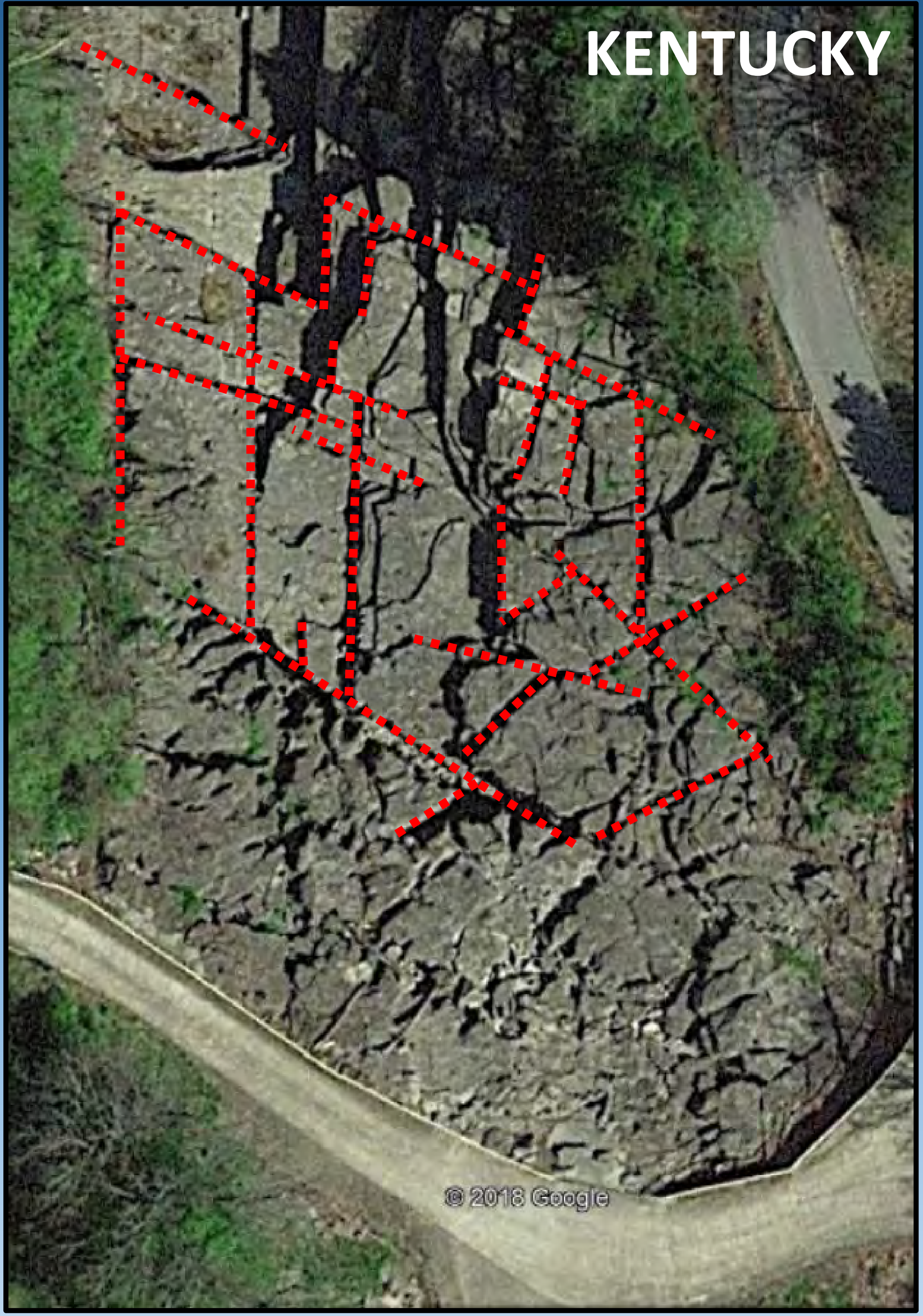


DESKTOP RECONNAISSANCE / FIELD RECONNAISSANCE



EXPOSURE SHOWING JOINTS AND BEDDING
-PRINCIPAL SET BETWEEN 0°N AND N10°E
-SECOND SET BETWEEN N56°E AND S58°E (66° RANGE)



SETUP AND DATA ACQUISITION

1. UP CLOSE AND PERSONAL

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2. SURVEY GROUND CONTROL POINTS

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SETUP AND DATA ACQUISITION

1. UP CLOSE AND PERSONAL

2. SURVEY GROUND CONTROL POINTS

3. PROGRAMMED / ENGINEERED FLIGHT

SETUP AND DATA ACQUISITION

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2. SURVEY GROUND CONTROL POINTS
3. PROGRAMMED / ENGINEERED FLIGHT

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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

SETUP AND DATA ACQUISITION

1. UP CLOSE AND PERSONAL

2. SURVEY GROUND CONTROL POINTS

3. PROGRAMMED / ENGINEERED FLIGHT

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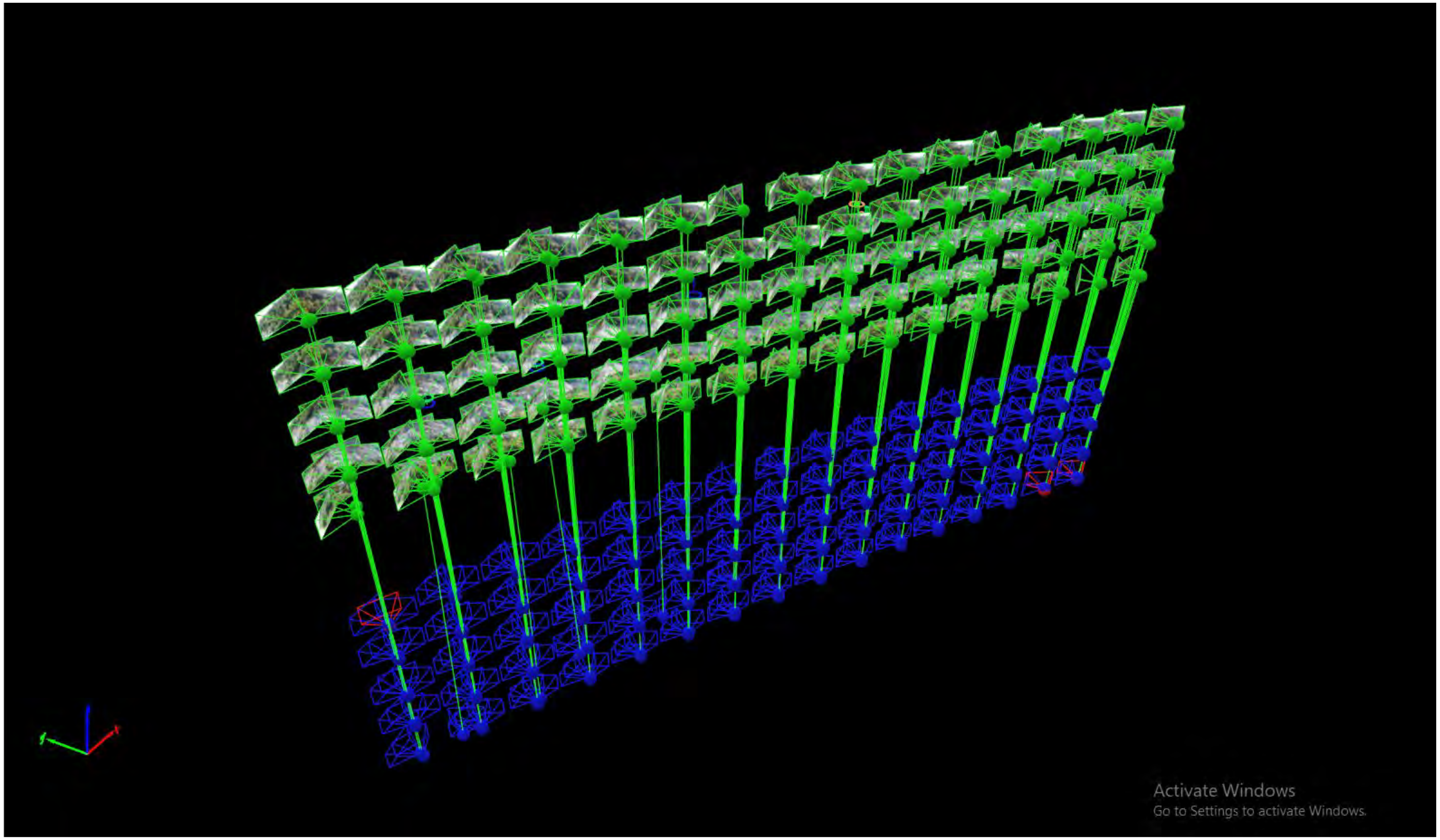
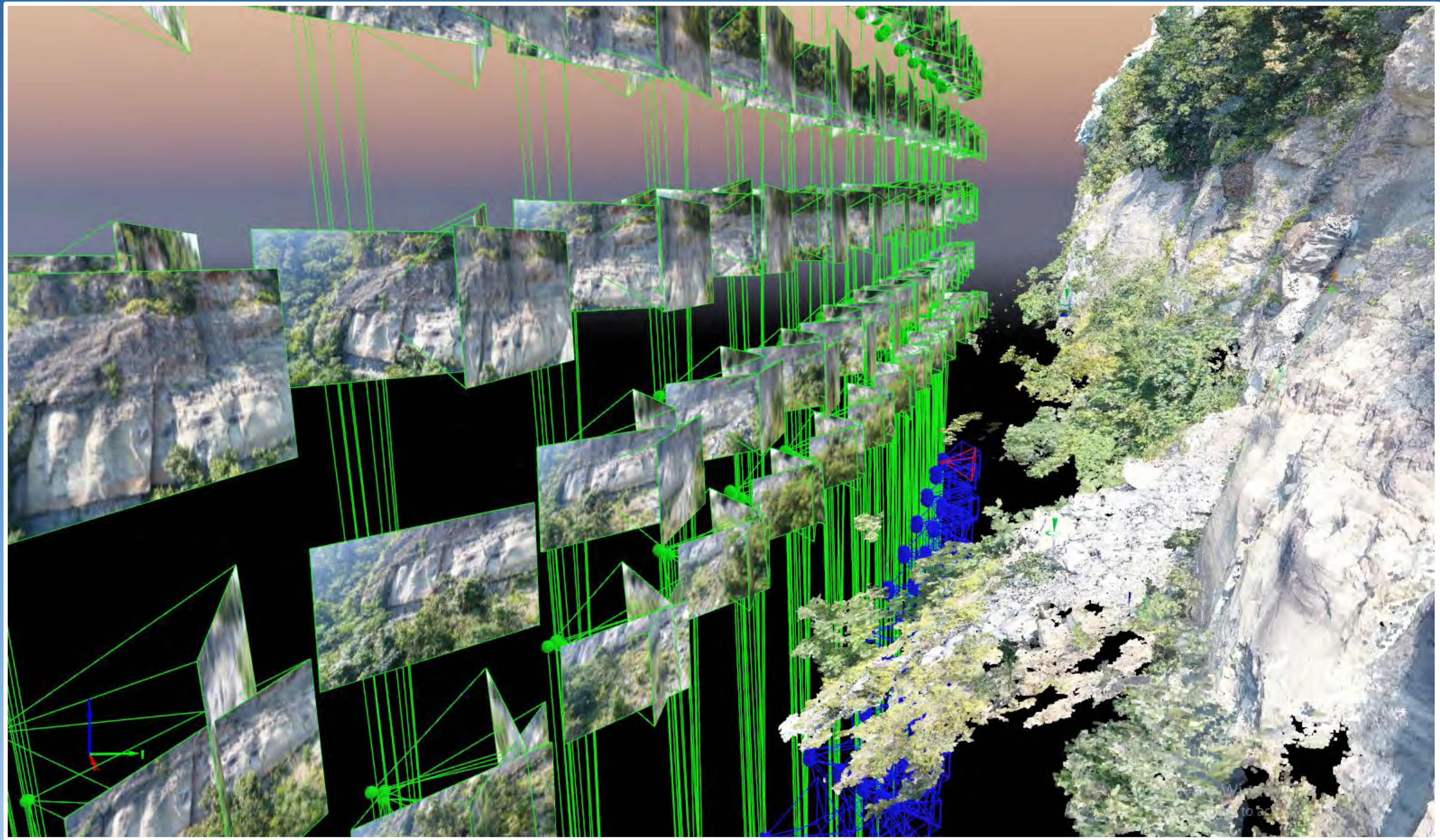
PROGRAMMED FLIGHT PLAN

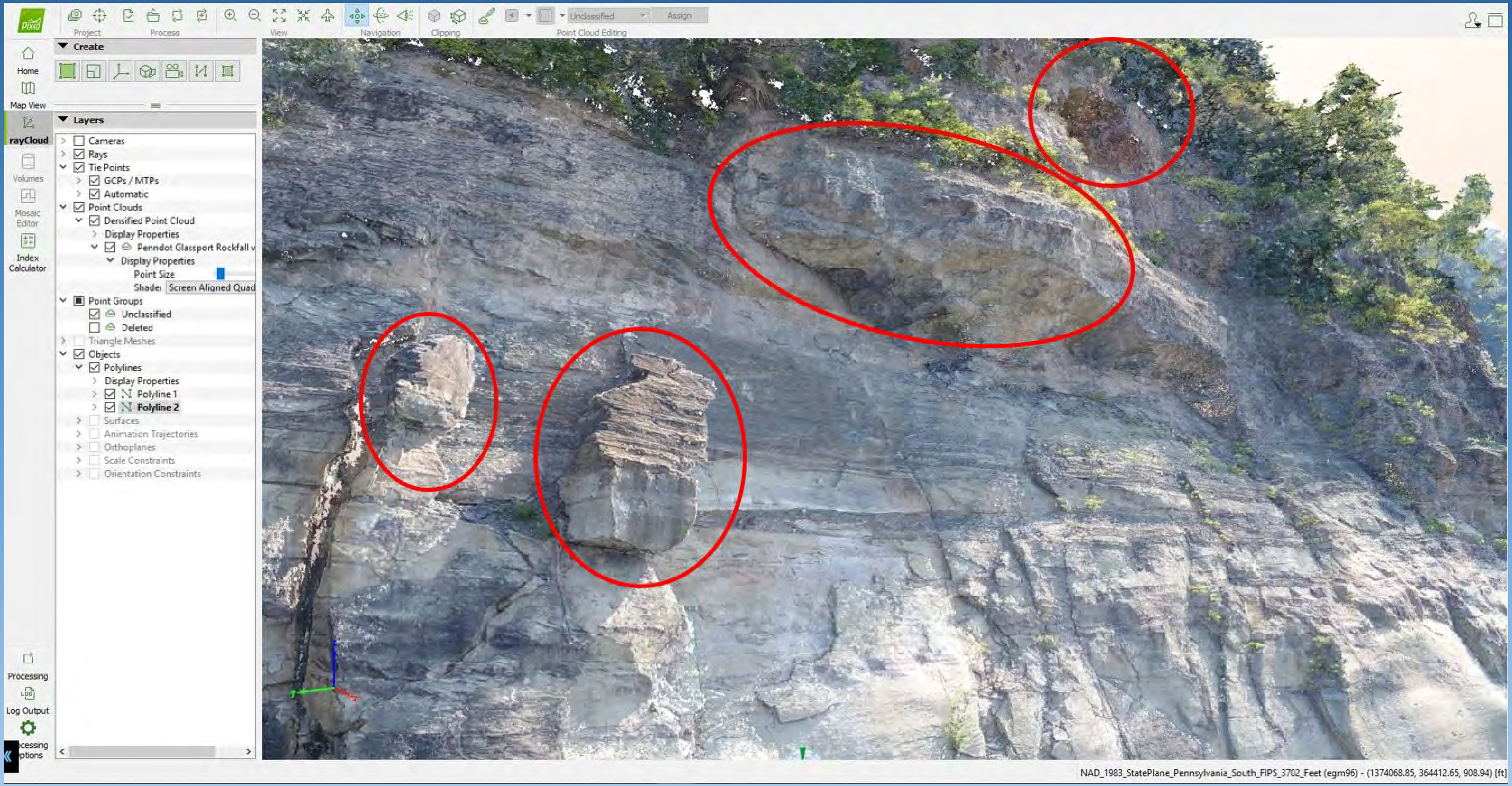


PROGRAMMED FLIGHT PLAN



CREATING THE DIGITAL OUTCROP

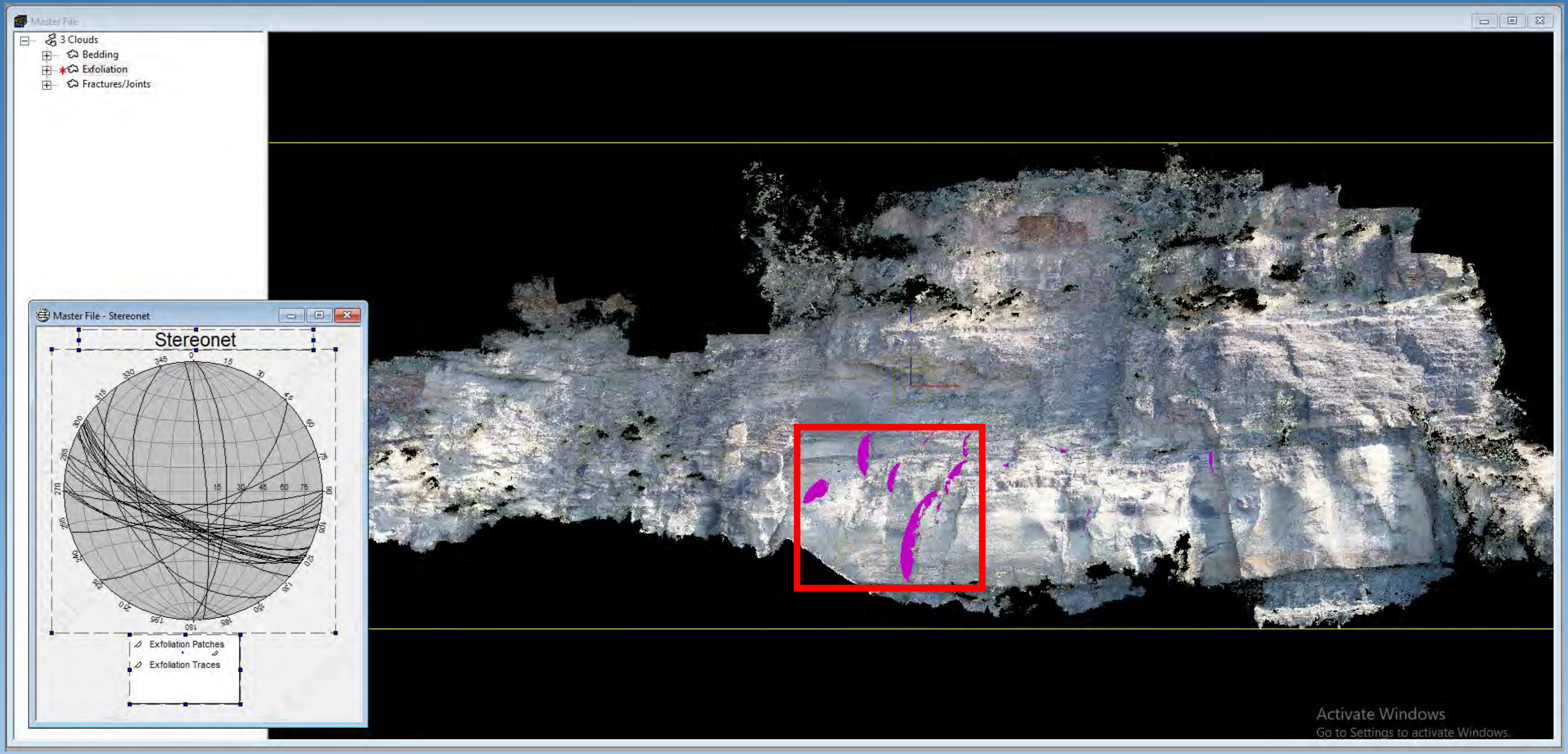
THE LOW-HANGING FRUIT



SUMMARY OF HAZARDOUS BLOCKS

Object	Volume (Cubic Feet)	Volume (Cubic Yards)	Volume (Cubic Meters)	Rock Mass (Tons)	Rock Mass (Kg)	Height (ft)	Height (m)	Potential Energy (Joules)	Lithology
A	78.2	2.9	2.2	5.8	5257.4	97.3	29.7	1528010.6	Siltstone
B	56.6	2.1	1.6	4.2	3803.5	83	25.3	942987.6	Siltstone/Sandstone
C	171.1	6.3	4.8	12.7	11497.8	83	25.3	2850581.0	Silstone/Sandstone
D	338.9	12.6	9.6	25.1	22776.8	68	20.7	4626394.8	Sandstone
E	1028.4	38.1	29.1	76.2	69108.2	104	31.7	21468604.7	Siltstone/Sandstone
F	295.9	11.0	8.4	21.9	19884.5	133.7	40.8	7941224.1	Claystone
G	201.0	7.4	5.7	14.9	13507.0	124.3	37.9	5014991.4	Claystone

DISCONTINUITY MAPPING



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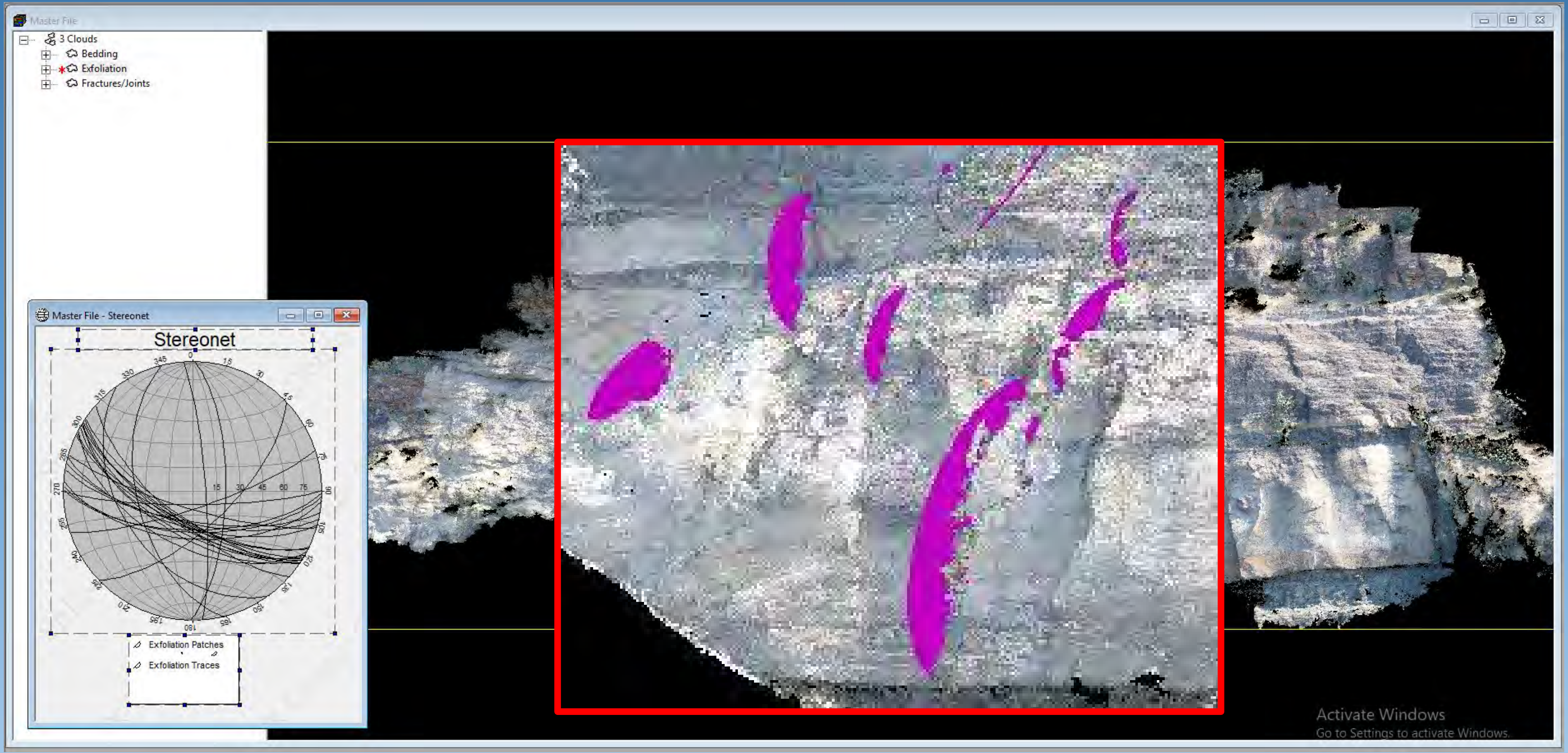

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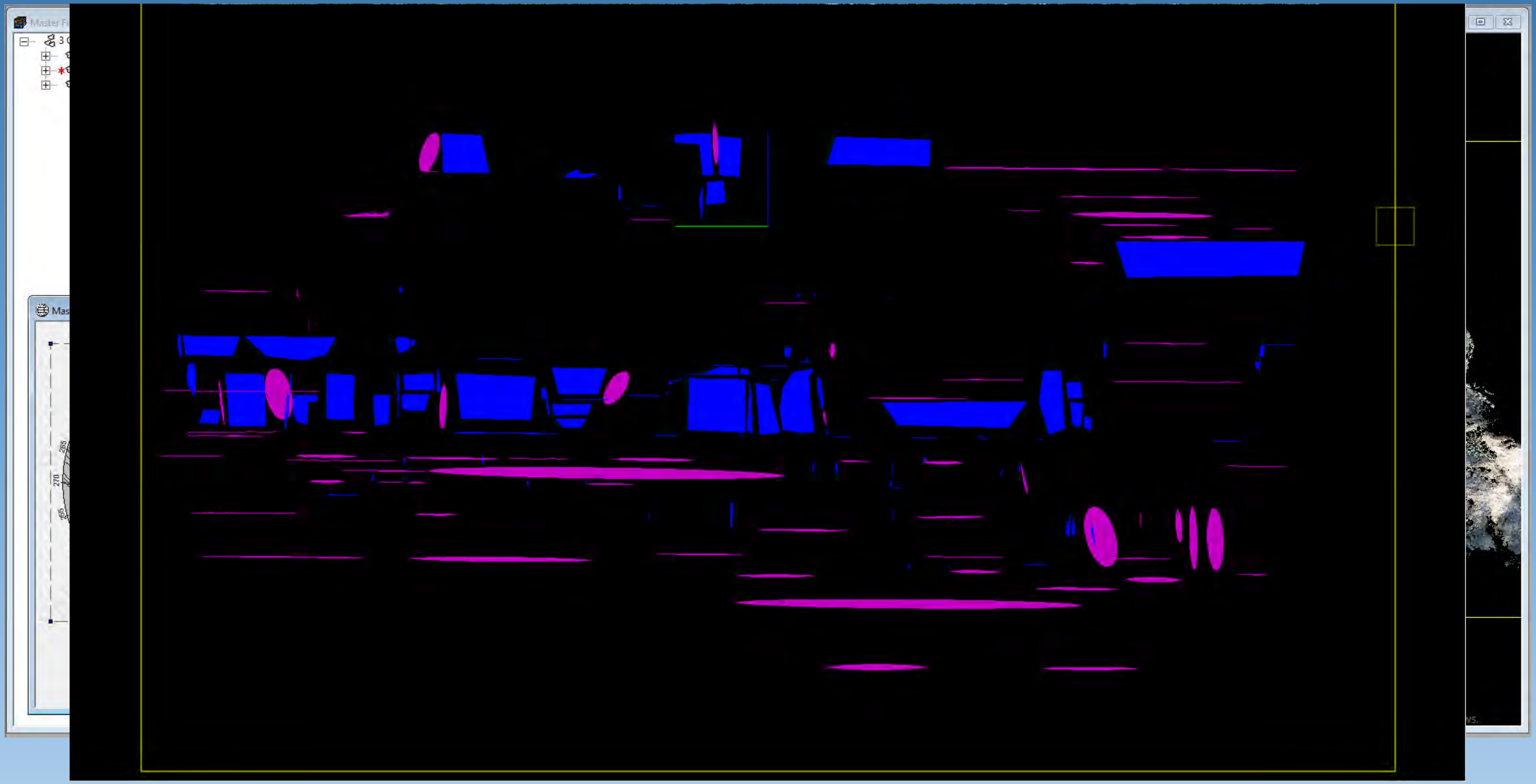

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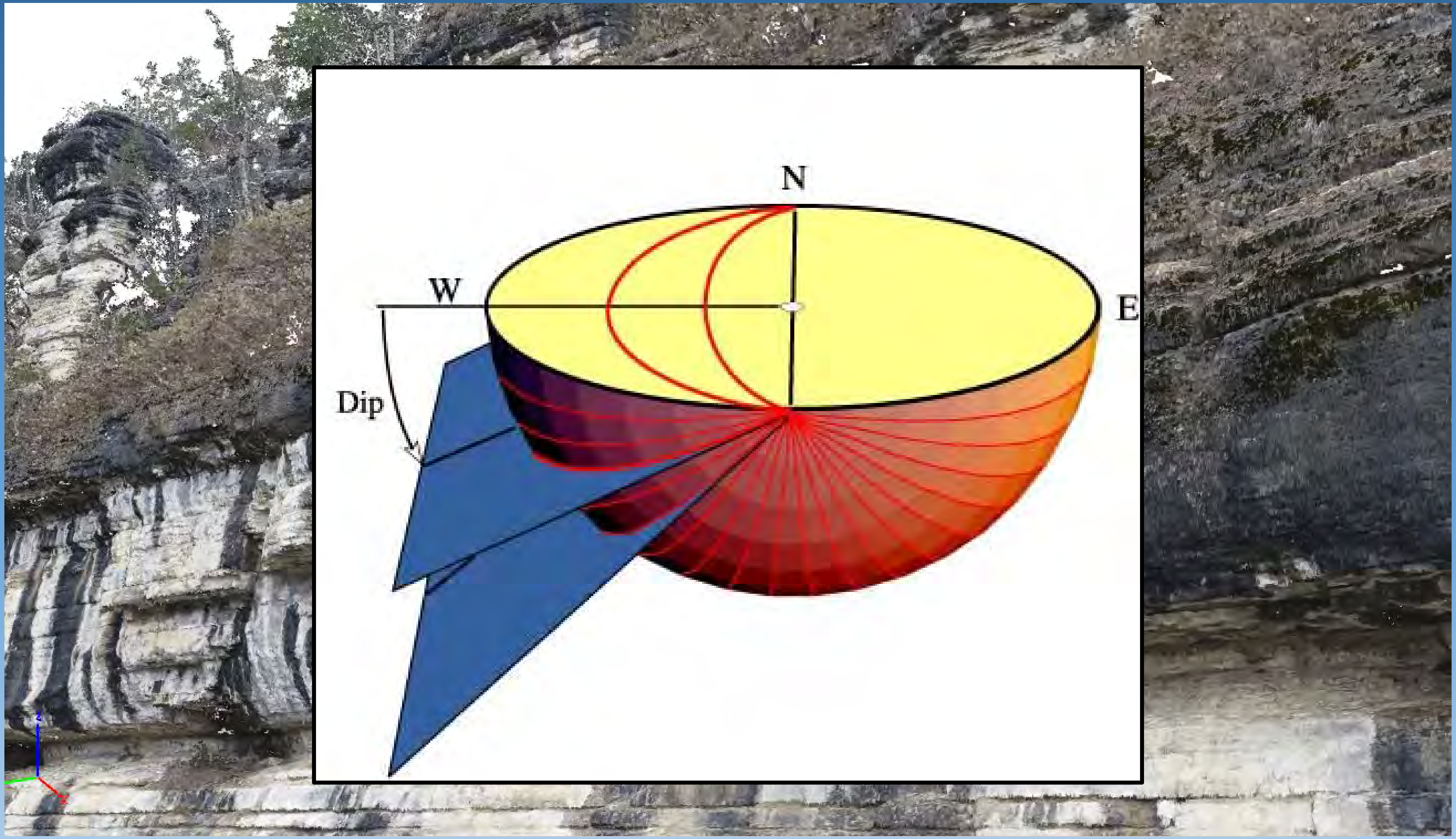
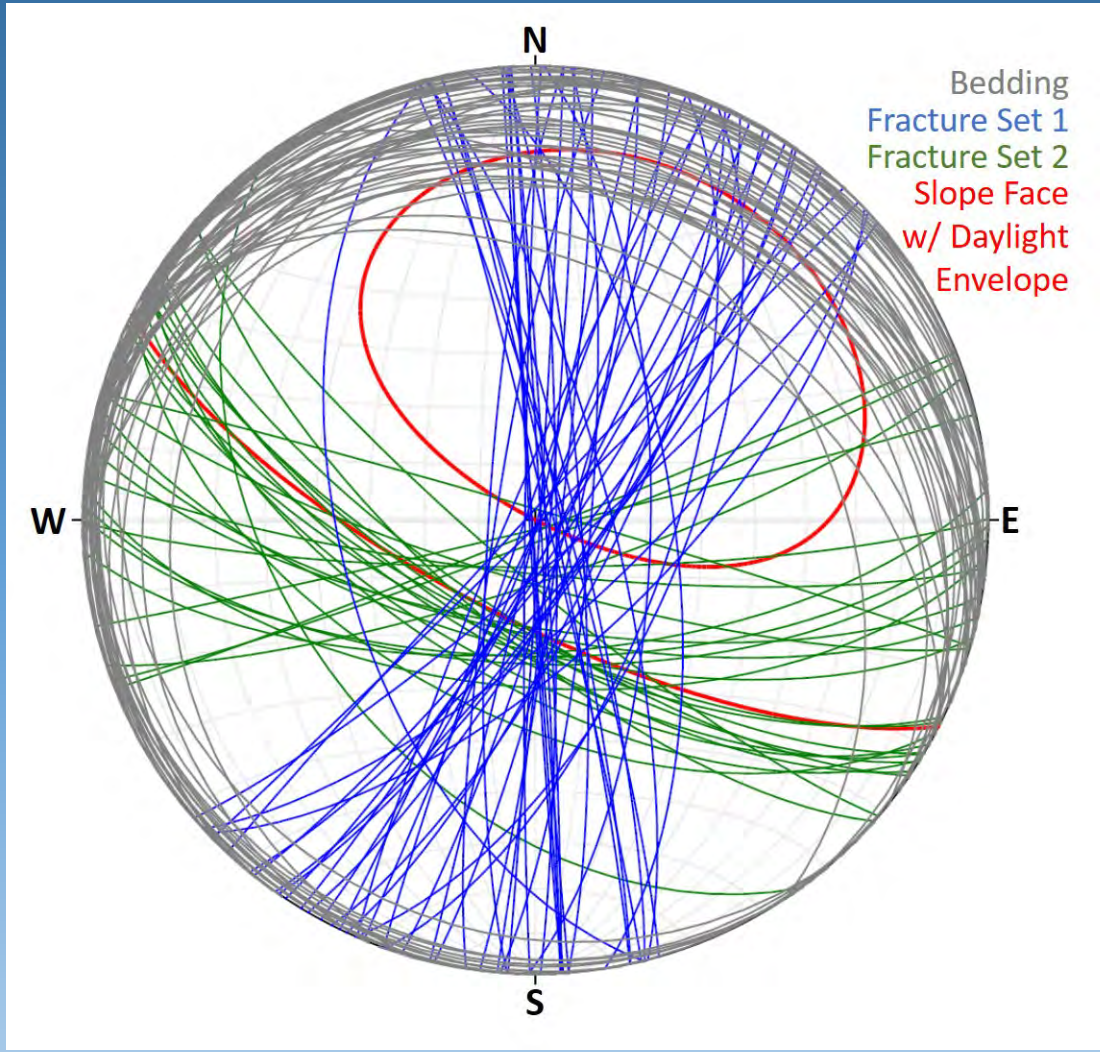
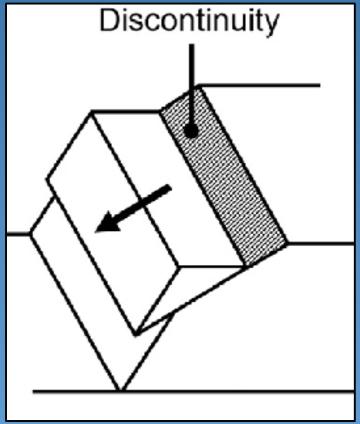
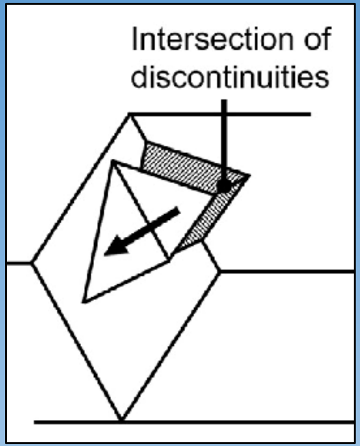
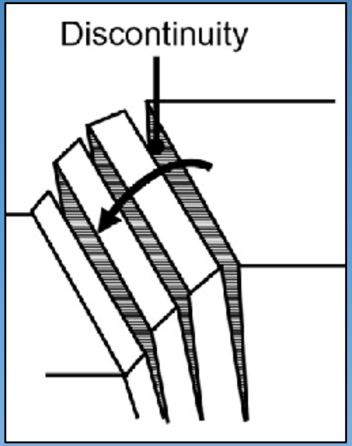


ALL OF THE DIGITALLY MAPPED PLANAR FEATURES









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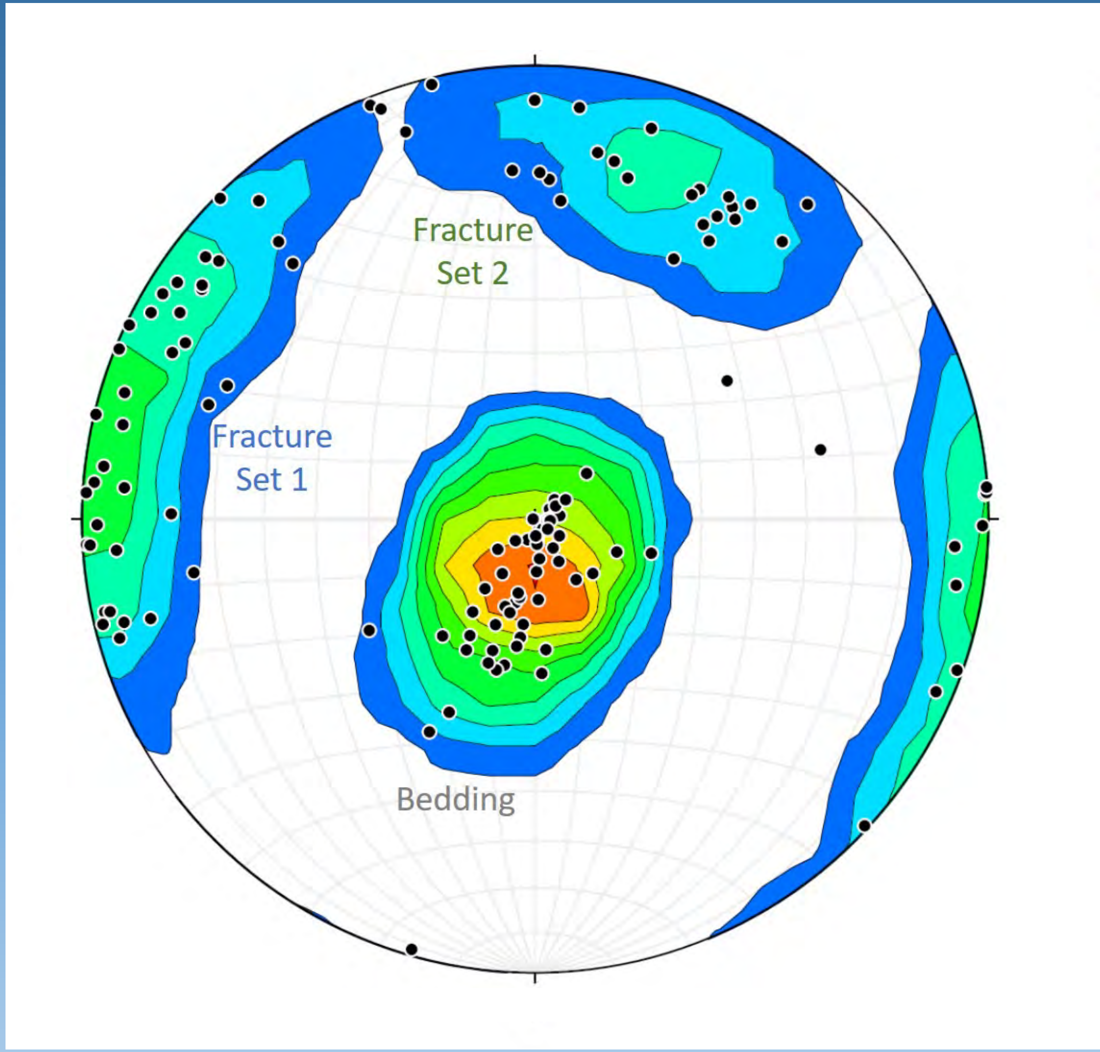

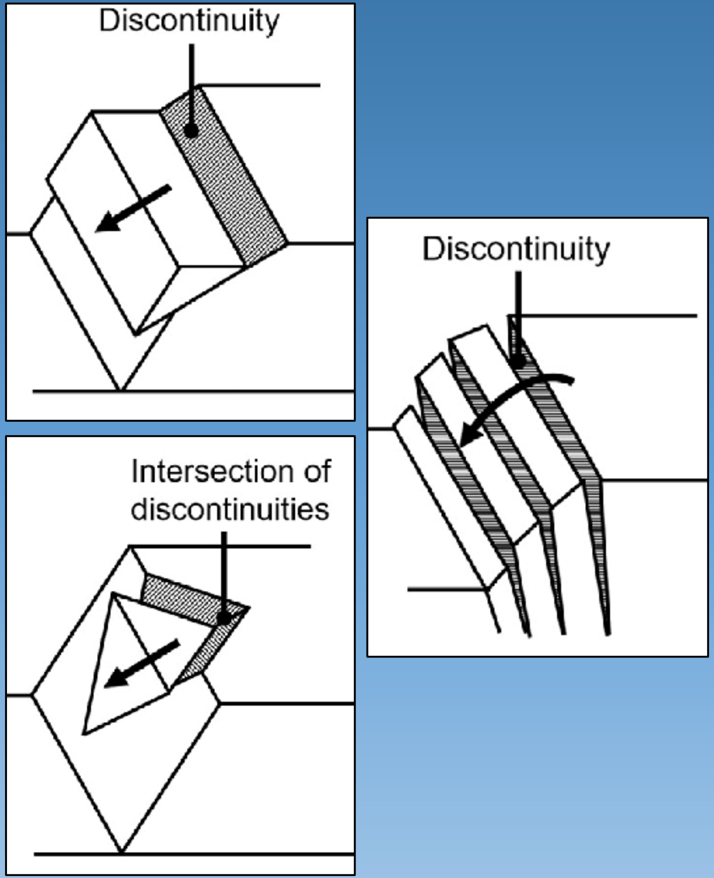

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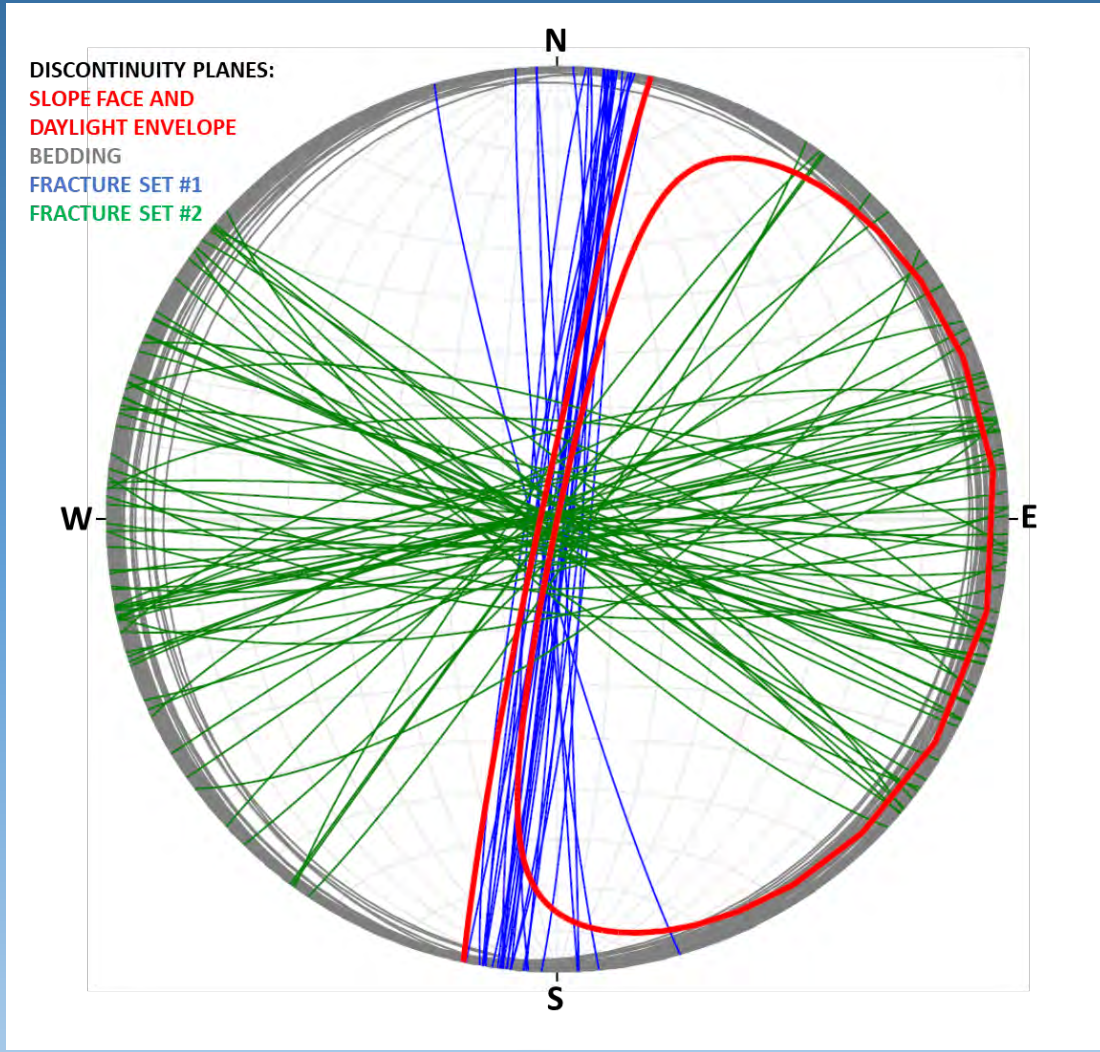

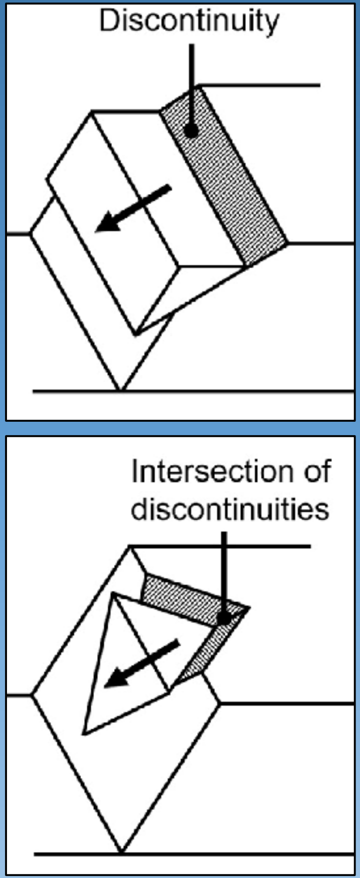

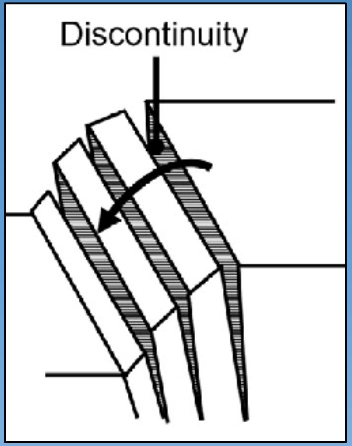

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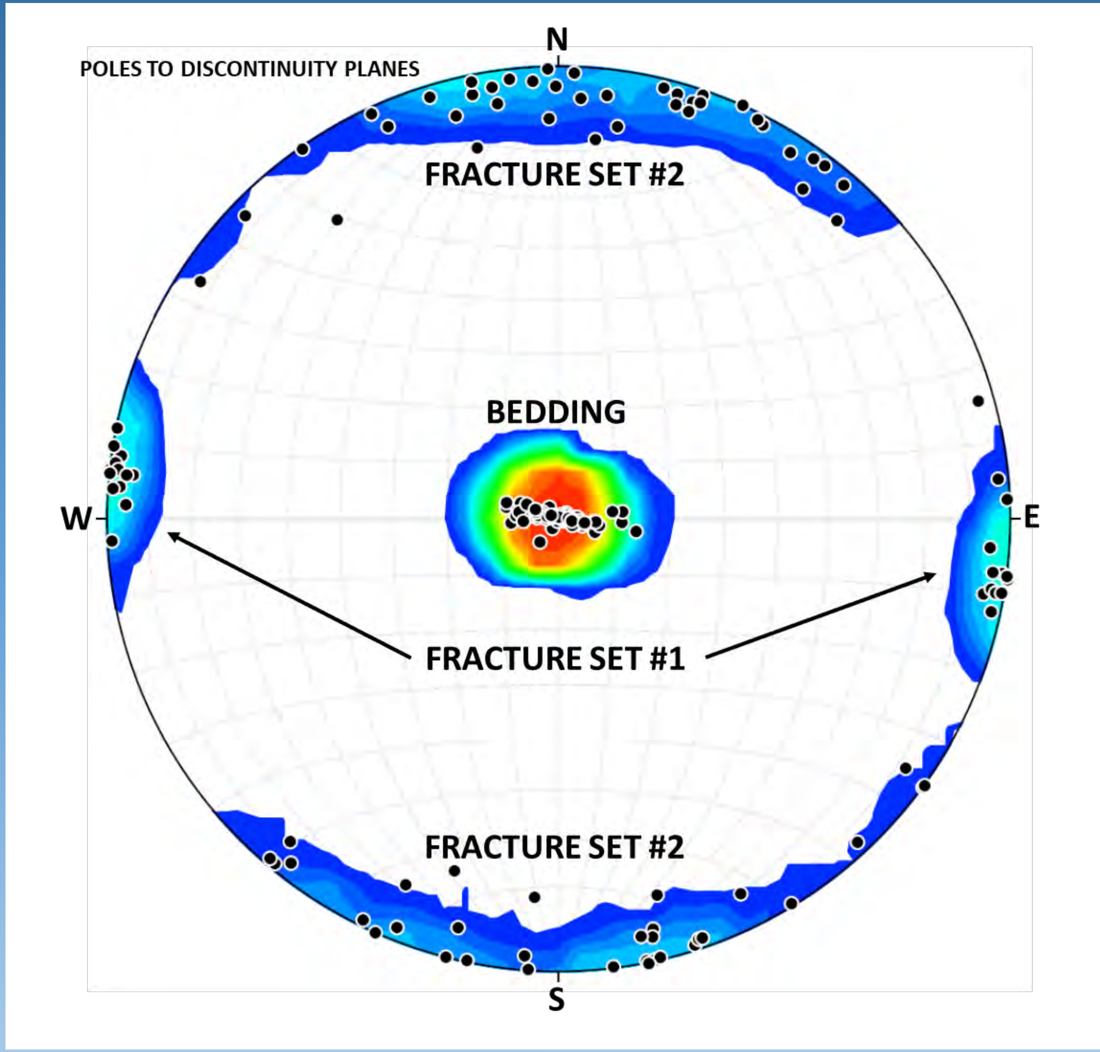
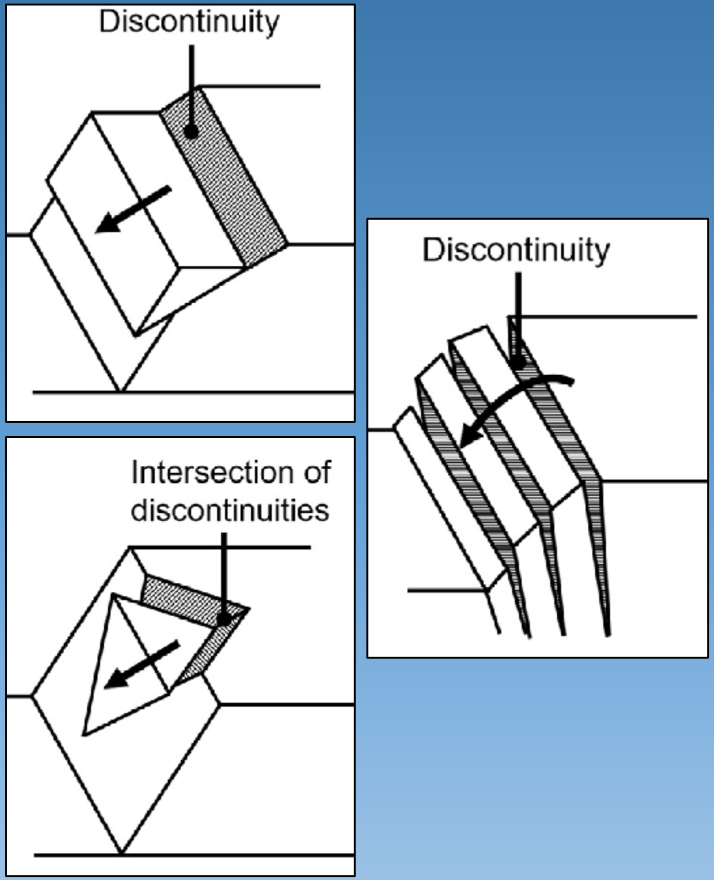




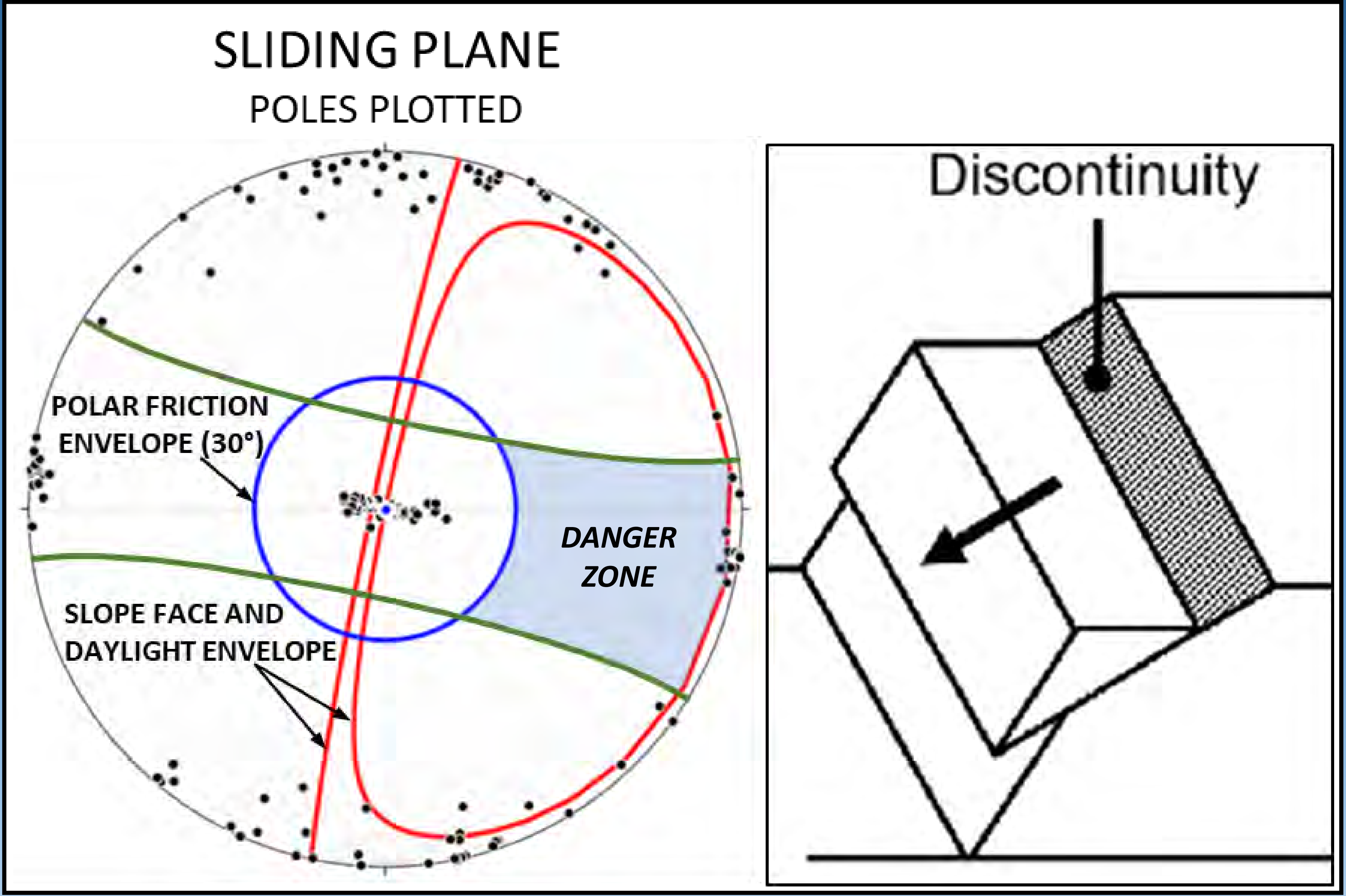
DISCONTINUITY STATISTICS

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				

DISCONTINUITY STATISTICS

Discontinuity Set	count (n)	Average Strike (azimuth)	Average Dip (degrees)
Bedding	84	018	4
Fracture Set 1	27	008	88
Fracture Set 2	72	258	85
Slope Face		192	87
	183		

HOEK-BRAY STEREONET ANALYSIS



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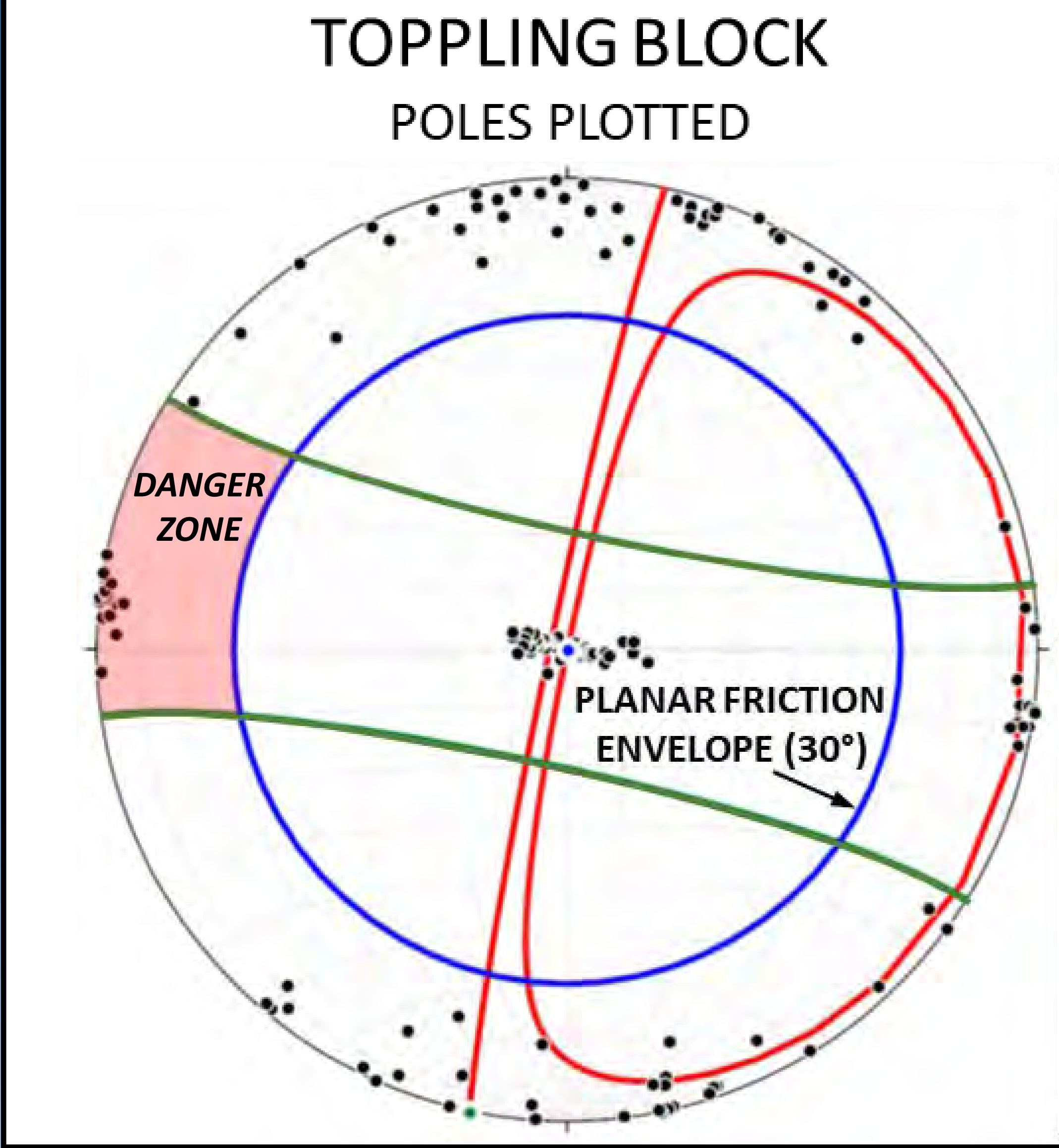
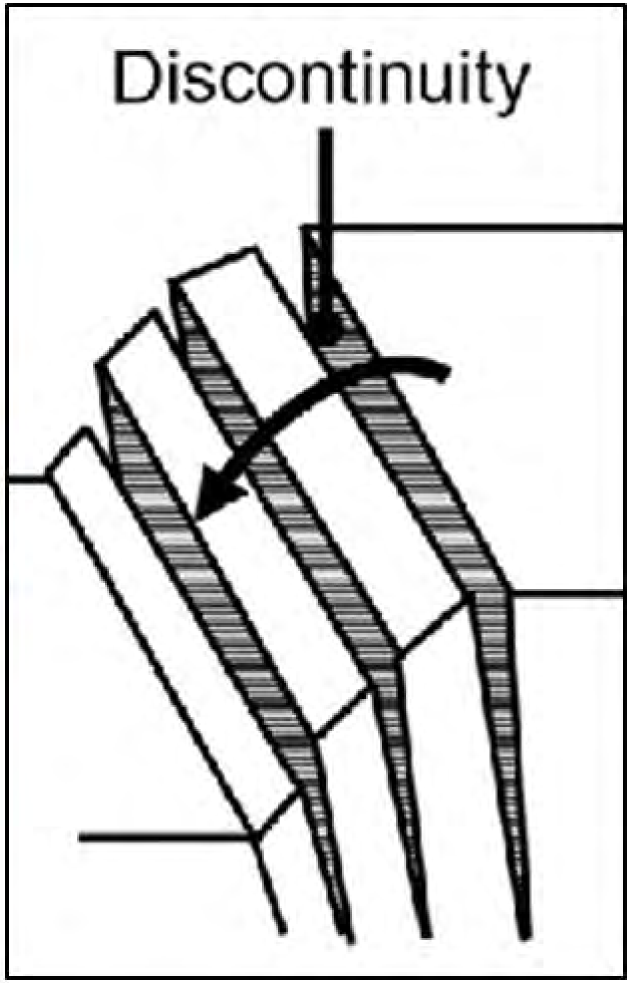
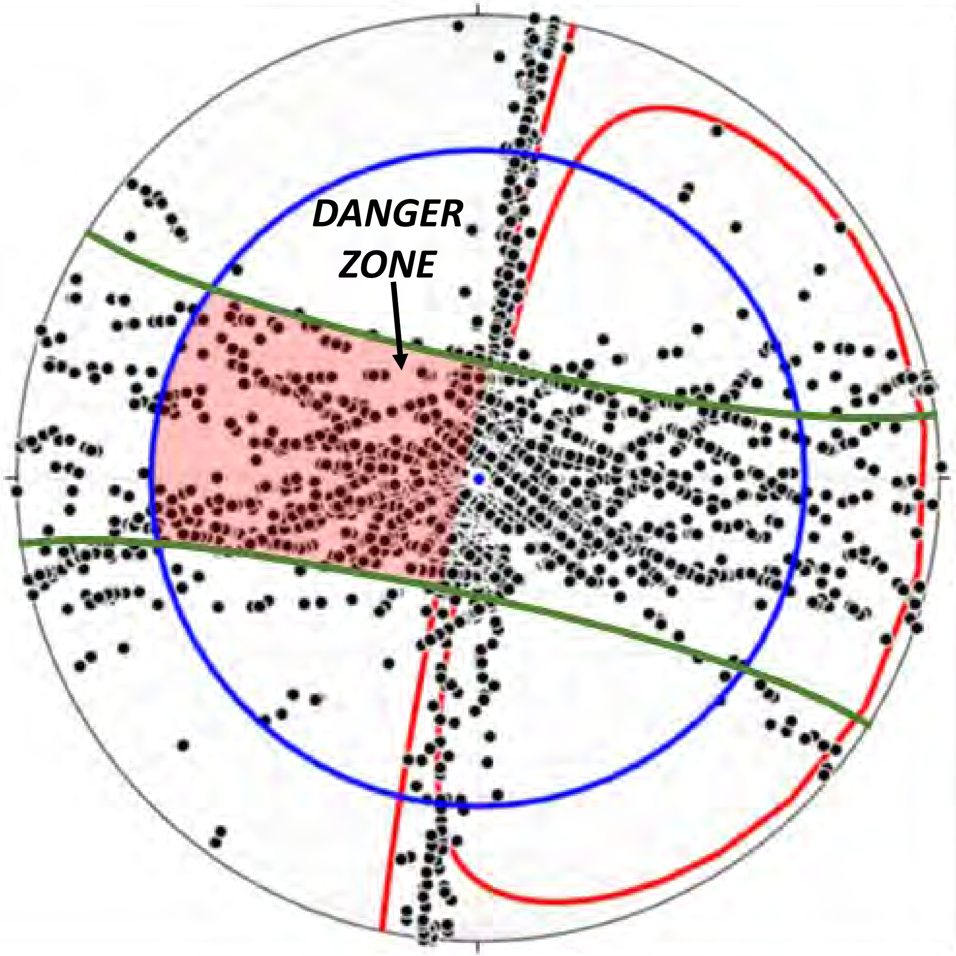


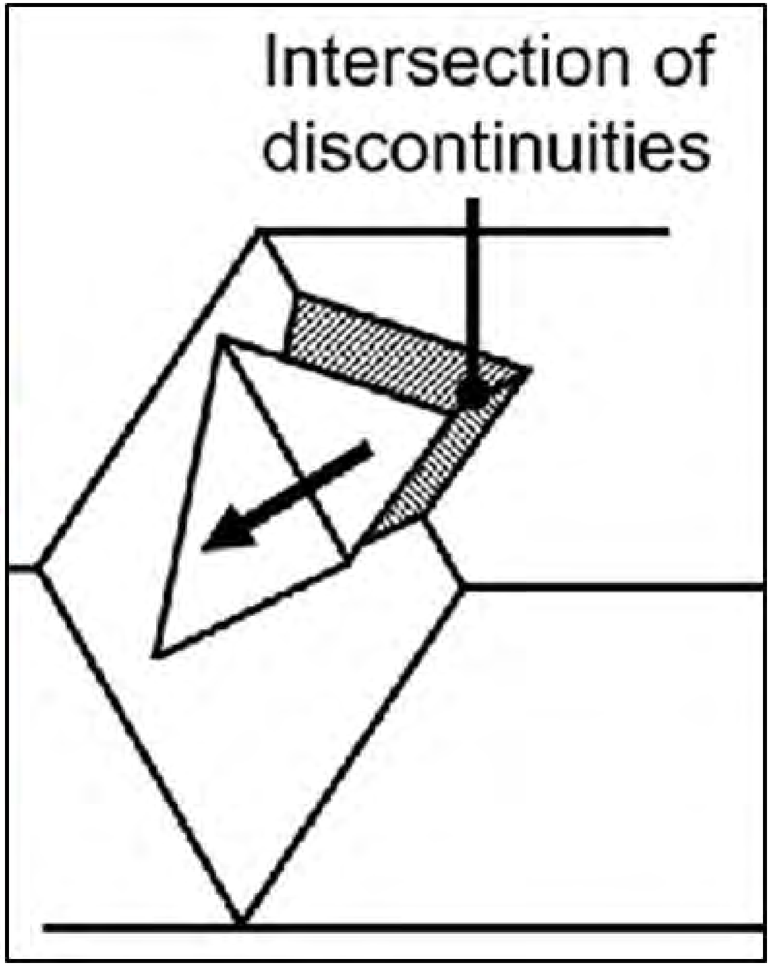


HOEK-BRAY STEREONET ANALYSIS

SLIDING WEDGE

PLANAR INTERSECTIONS PLOTTED

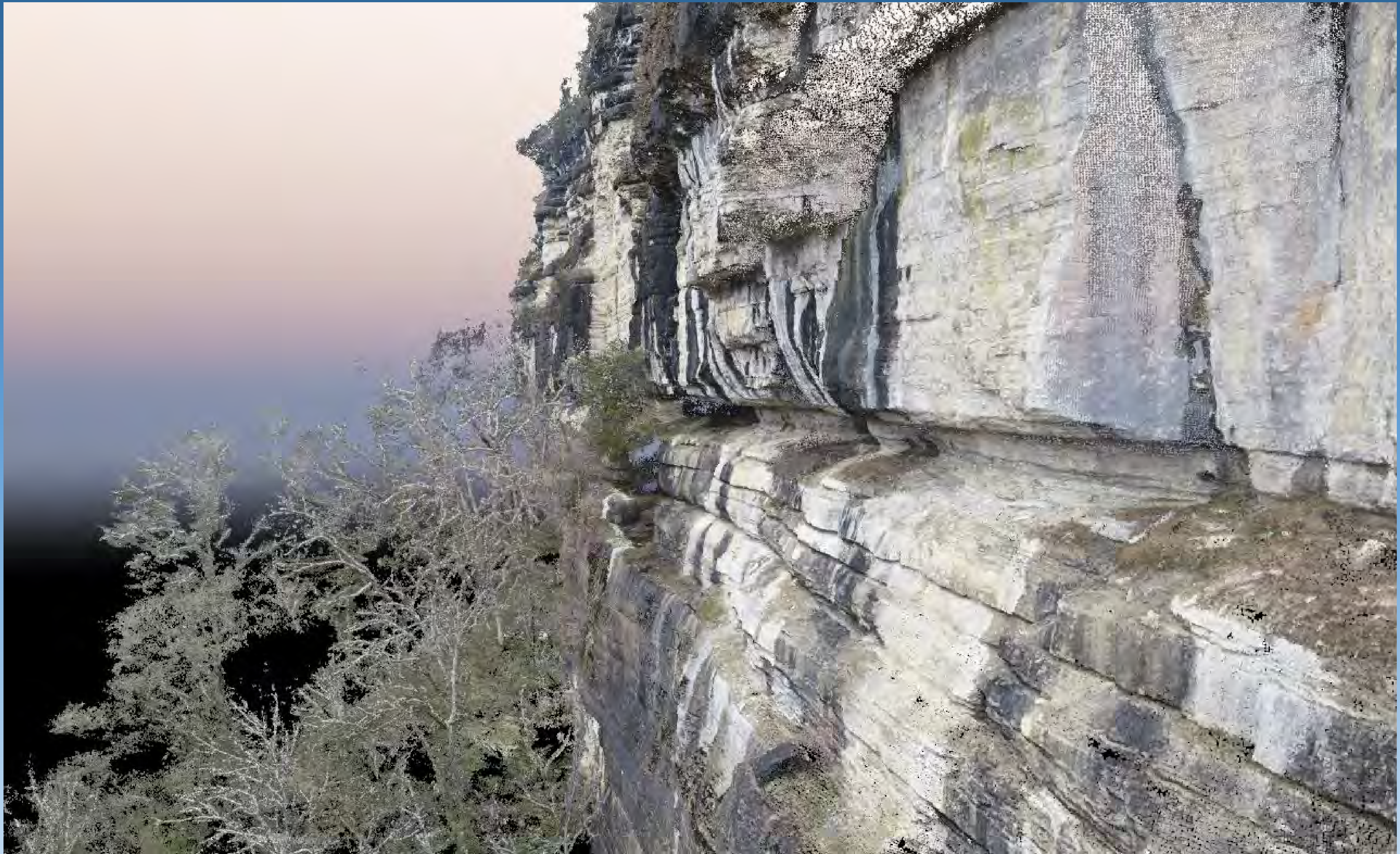




PHOTOGRAMMETRY IN OIL AND GAS…PRACTICAL TOOL OR MORE EDUCATIONAL?

Outcrop of parasequences at Woodside Canyon in Utah, overlain with seismic wiggles.
https://www.geoexpro.com/articles/2017/07/learning-on-the-rocks

PHOTOGRAMMETRY IN OIL AND GAS…PRACTICAL TOOL OR MORE EDUCATIONAL?



THANK YOU!

QUESTIONS AND COMMENTS?