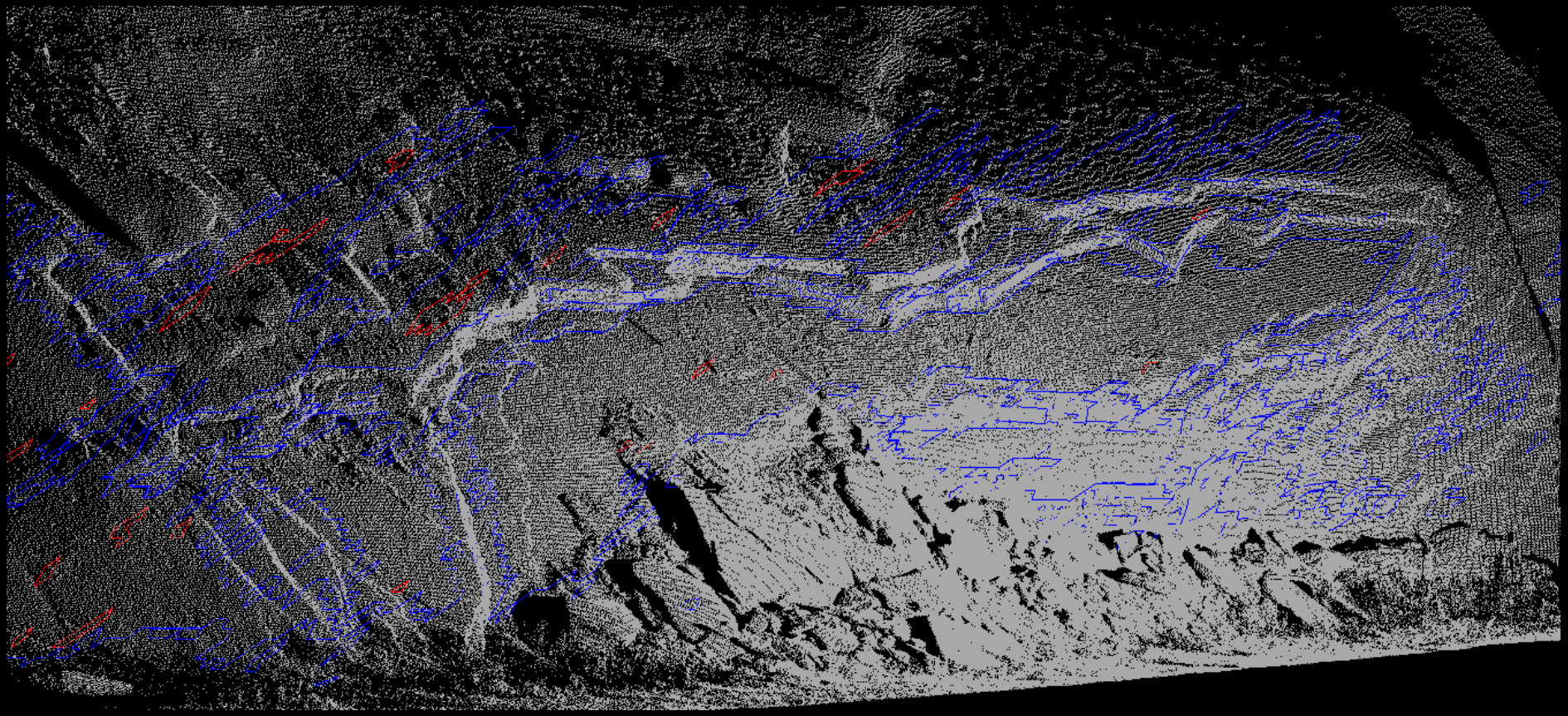
The Use of LiDAR for Evaluating Geologic Structure Related to Rock Slope Safety and Stability

C.F. Watts
Radford University - cwatts@radford.edu



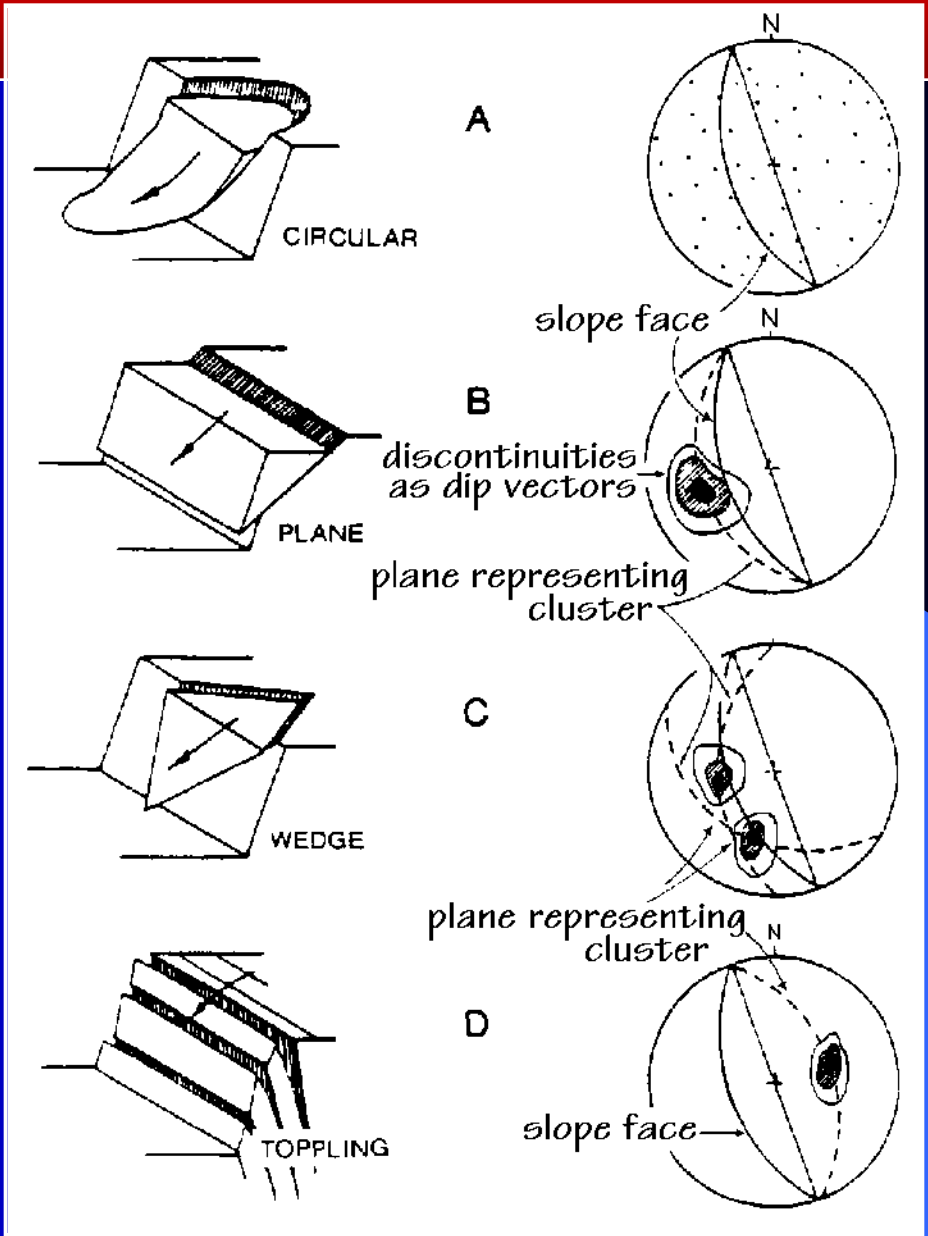
Geohazards Impacting Transportation in Appalachia - 13th Annual Technical Forum
Harrisonburg, VA - August 1, 2013

Types of rock slope failures

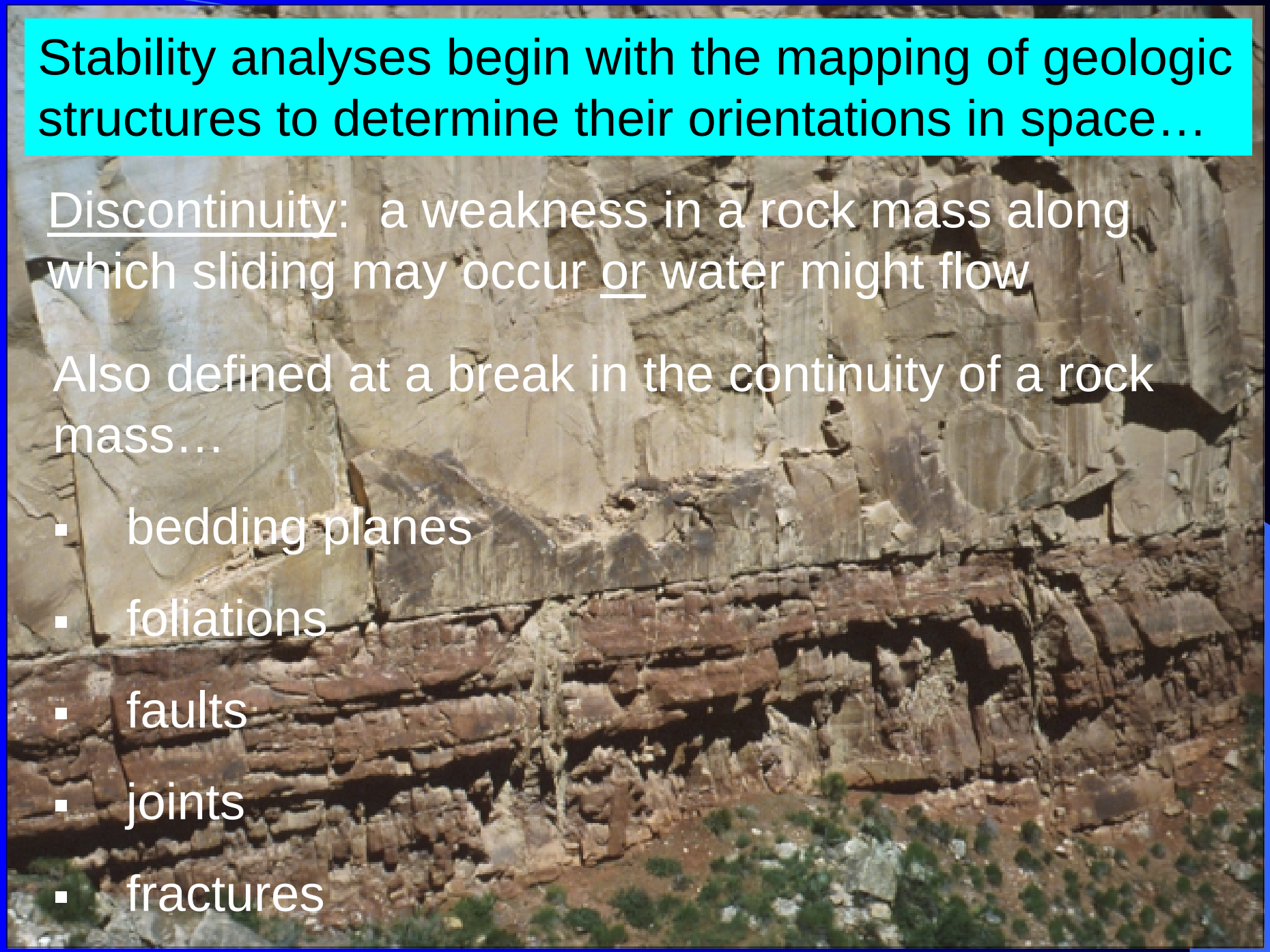
Failure Types based on geologic structure

- Circular
- Planar
- Wedge
- Toppling

Different types of slope failures plot differently on dip-vector stereonets. Some examples are shown here.



Stability analyses begin with the mapping of geologic structures to determine their orientations in space…

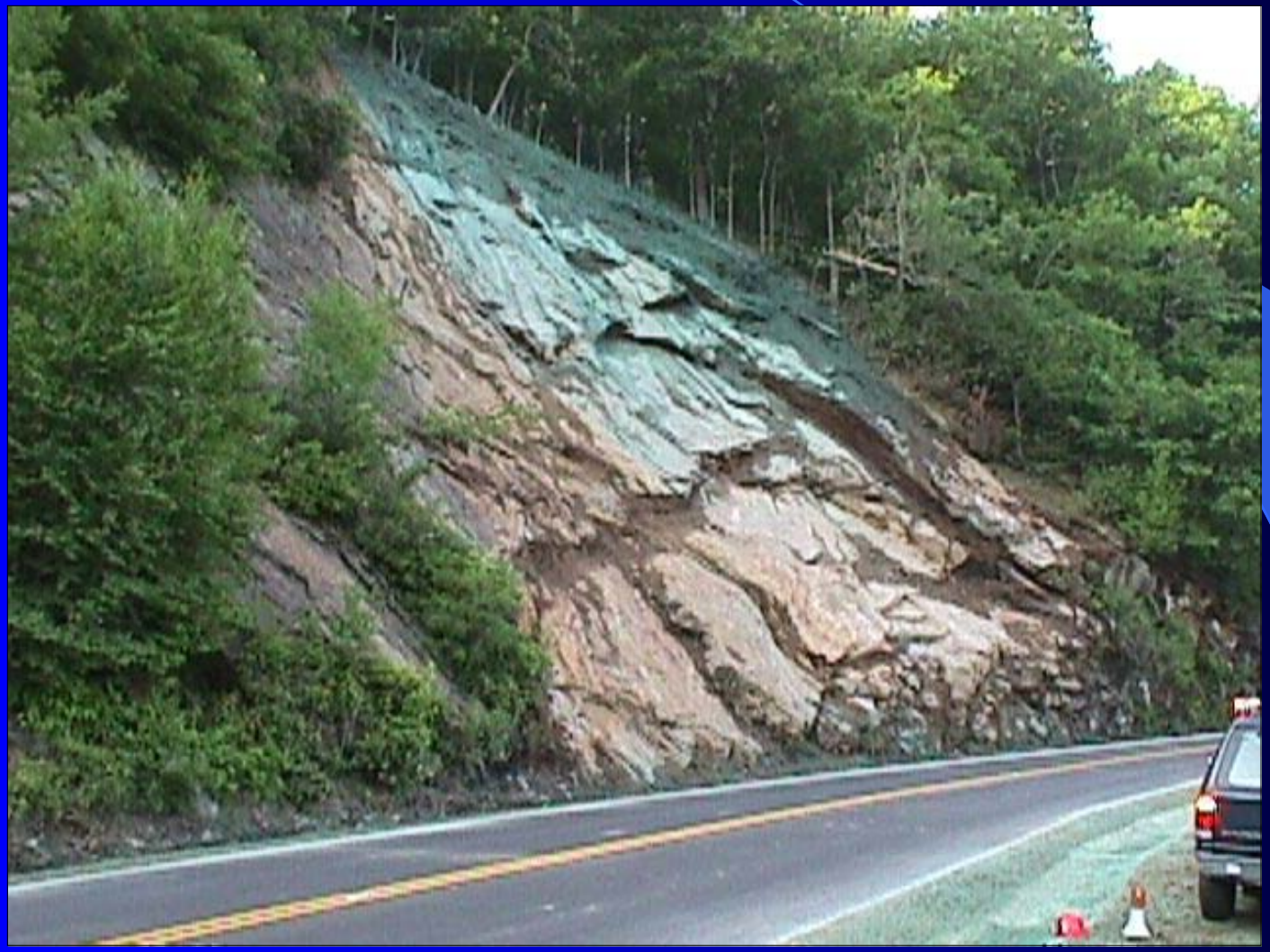


Discontinuity: a weakness in a rock mass along which sliding may occur or water might flow

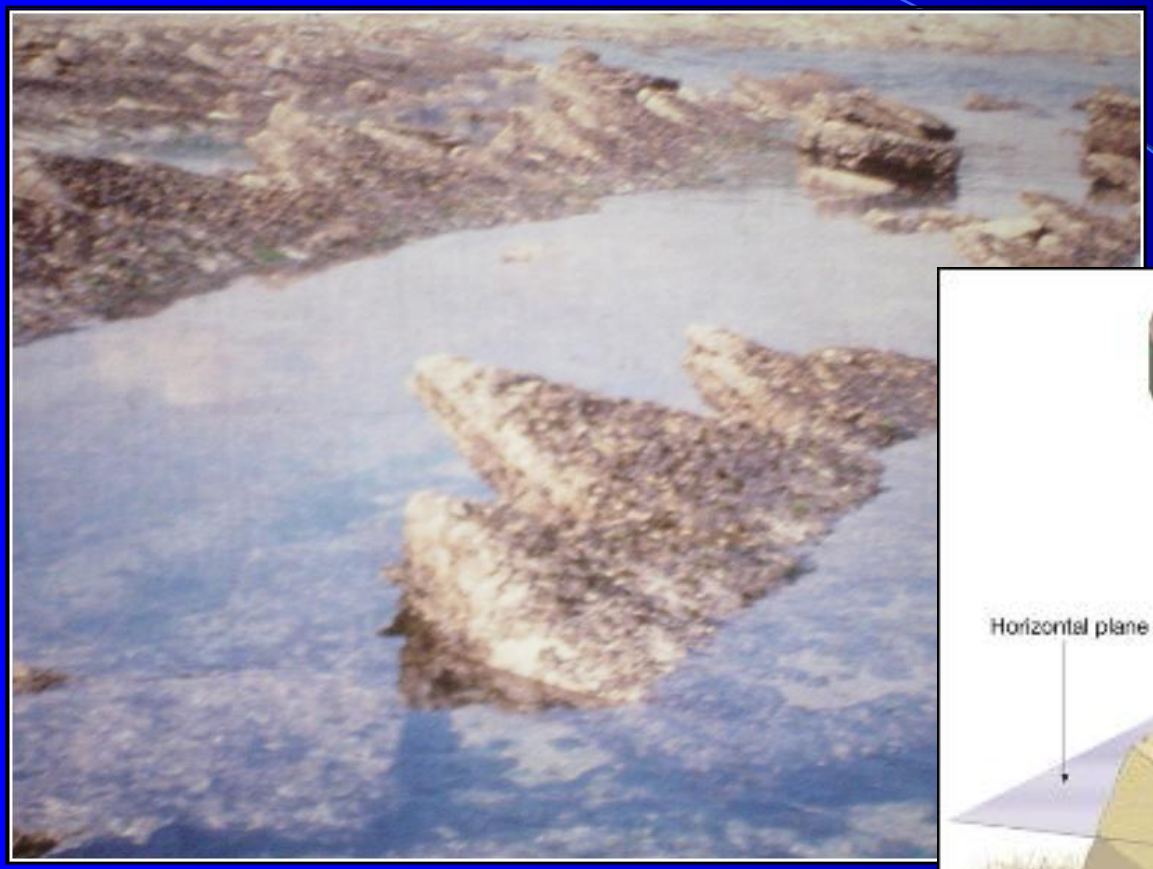
Also defined at a break in the continuity of a rock mass…

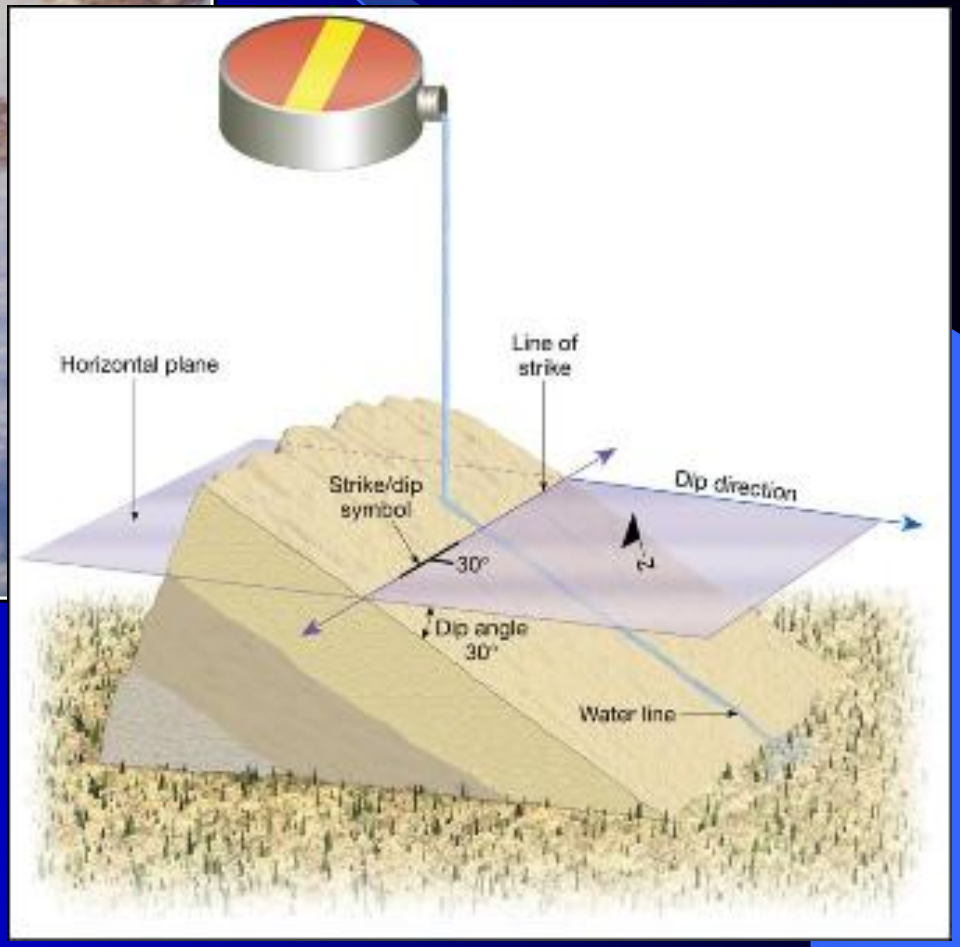
- bedding planes
- foliations
- faults
- joints
- fractures

Characteristics: dip, dip direction, structure, roughness, water, continuity, infilling material…

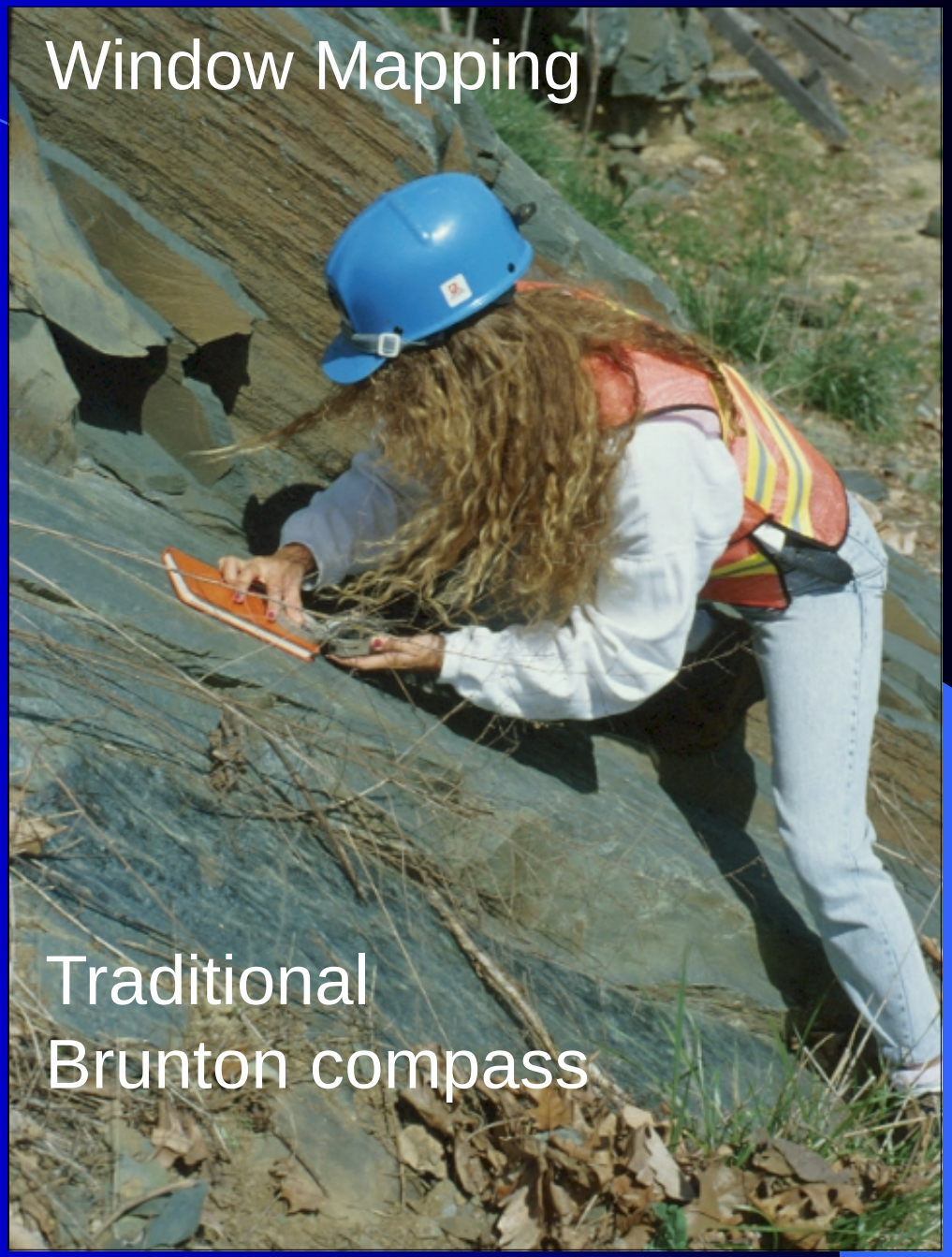


Orientation: strike, dip, dip direction…






Detailed line mapping…


Window Mapping
Traditional
Brunton compass

Clar compass

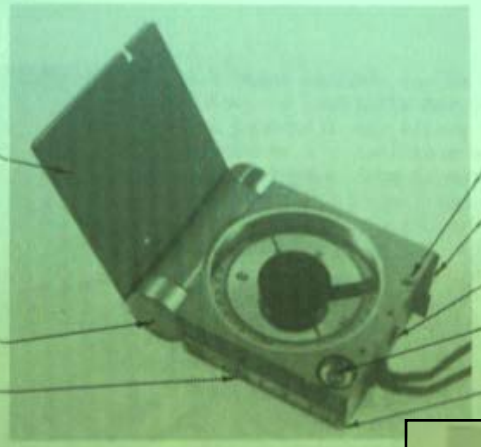


Figure 22 : Geological compass designed b
manufactured by F.W.Breithaup
Kassel 3500, West Germany.

Level compass, release clamp and turn compass until needle points north. Clamp needle.

Use coin to turn adjusting screw to correct magnetic deviation. Zero on scale now reads true north.

Place measuring plate against rock face and level compass, release needle clamp and re-clamp after needle has settled.

Read dip of plane. In this example, dip is 35 degrees.

Read dip direction of plane. In this case, dip direction is

The difference in magnetic declination in different hemispheres results in the needle jamming if a northern hemisphere compass is used in the southern hemisphere. Manufacturers will supply appropriate instrument if hemisphere is specified.

Latest Brunton compass

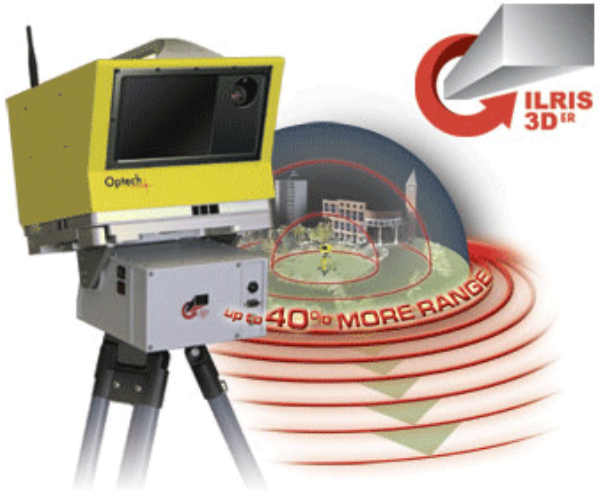
TruPulse 360b Laser

Now there's even…

"an app for that…"

Virtual Data Acquisition Systems

- Laser scanning
  - Optec
  - Leica Geosystems
  - Split-FX software



- Terrestrial photogrammetry
  - Sirovision
  - Adam Technology
  - 3G Joint Metrix

- Laser scanning
  - Optec scanner
  - Split-FX software

James Fisher with John Kemeny

Split-FX™ Software

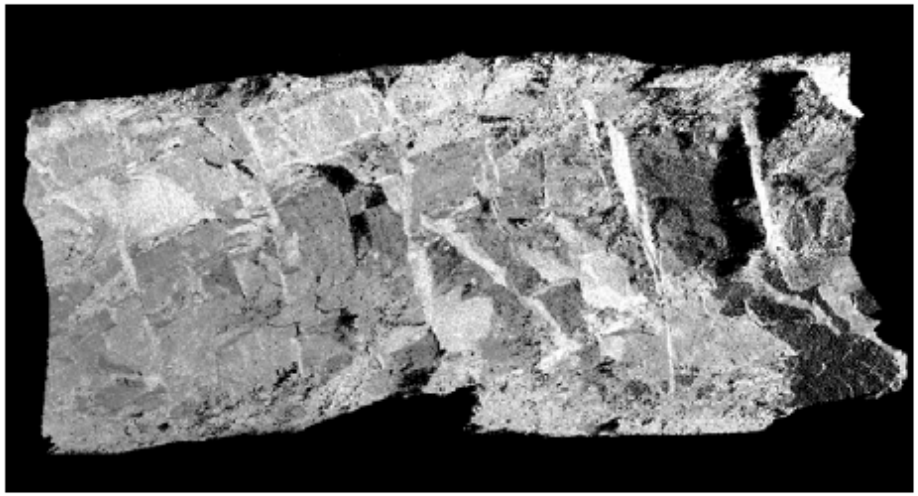
Automated Rock Mass Fracture Characterization

Version 1.0

New software is available to automatically perform rock mass fracture characterization on exposed rock faces.

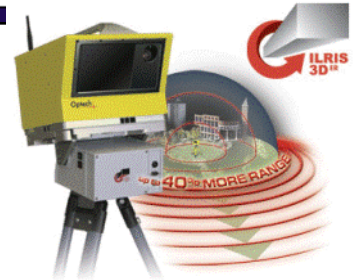
The Split-FX™ software can analyze rock slopes, underground excavations, dam and bridge foundations, and other rock engineering sites of interest.

Utilizing ground-based 3D LIDAR point clouds (LIDAR: Laser Imaging Detection and Ranging) and Digital Image Processing, the Split-FX software first requires a field survey, which can take as little as 10 minutes. The results of the field survey are then automatically processed with the Split-FX software, resulting in three-dimensional information about the rock mass, including stereo nets of fracture orientation, distributions of fracture size and a roughness estimation. From start to finish, you can accurately characterize the rock mass at a field site in less time than it takes to make a few strike and dip measurements manually!



Point Cloud.

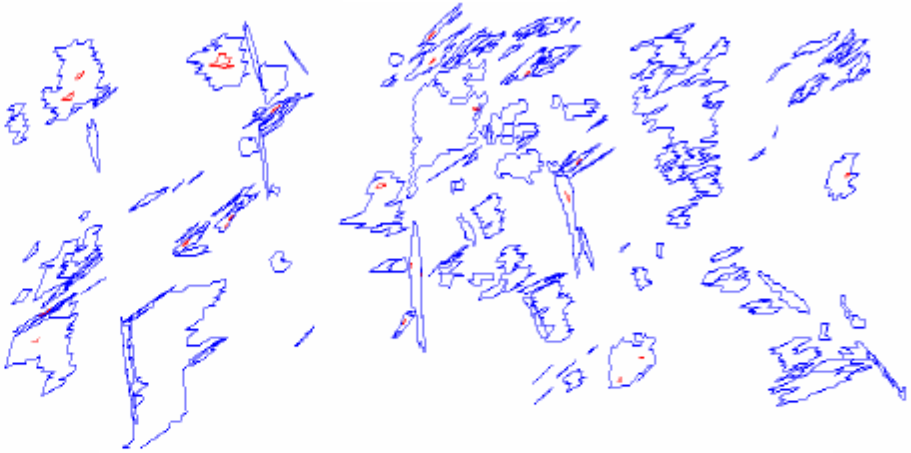
LIDAR



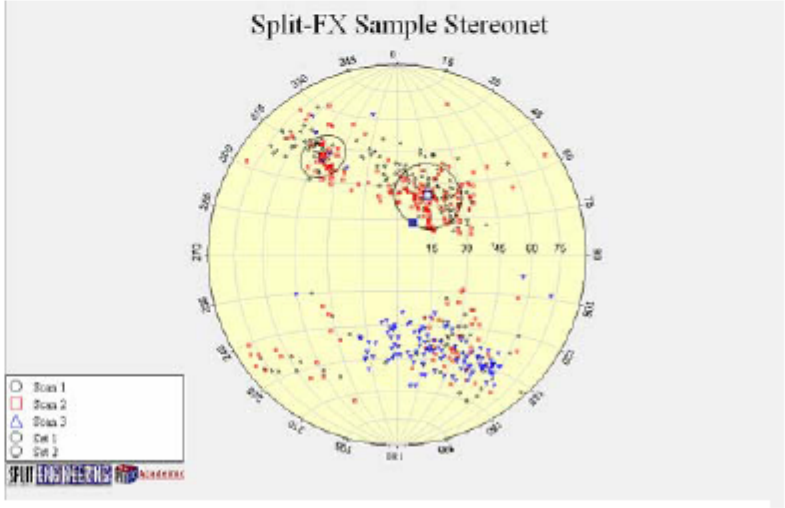
Automated rock mass characterization

WHY USE SPLIT-FX?

- Perform rock mass site characterization in a safe and timely manner.
- Conduct analysis at significant distance from the rock face where access to the face is not possible due to safety or other concerns.
- Produce a database of thousands of fractures for a rock site in less time than just a few fractures could be characterized using traditional techniques.
- Eliminates human bias by automating the process of collecting and processing rock mass data.



Fracture patches (surfaces) found with Split-FX.



Fracture poles on a stereonet.

3D Photogrammetry…

SIRO VISION

3D Imaging and Geotechnical Analysis For Geologists and Engineers

DATAMINE

CSIRO

Sirovision is a complete rock mass structure mapping and analysis system

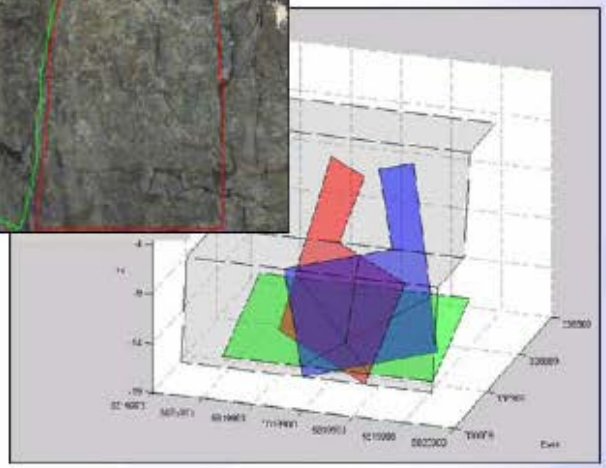
Sirovision is a completely new technology for mapping the geological features and interpreting the geotechnical characteristics of exposed mining faces using digital photography.

Using images taken with a commercially available digital camera, the Sirovision Siro3D system uses sophisticated image processing algorithms to generate an accurate, detailed 3D model of the rock face. This 3D model is then itself analyzed using the robust computational geometry in SiroJoint to extract un-biased and accurate geotechnical data.

FUNCTIONS

Create 3D models

- Import digital images
- Manage survey data
- Select mapping areas
- Create 3D models



View and Edit 3D models

- Extract measurements
  e.g. vectors from 3D models.
- Map single points or line strings etc.

Export 3D model data

- Data export formats are compatible with software such as Microsoft Excel® and mine design packages allowing easy input and use of 3D model data in these packages.

Structural and Geotechnical Analysis

- Mapping of trace location and orientation
- Mapping location and orientation of discontinutiy planes – dip direction etc
- Analysis and display of joint set statistics
- Visualisation of structure
- Data export in a range of formats including DXF, and Dips.

Check out our websites: www.datamine.co.uk www.sirovision.com

3G Software & Measurement

ShapeMetriX3D

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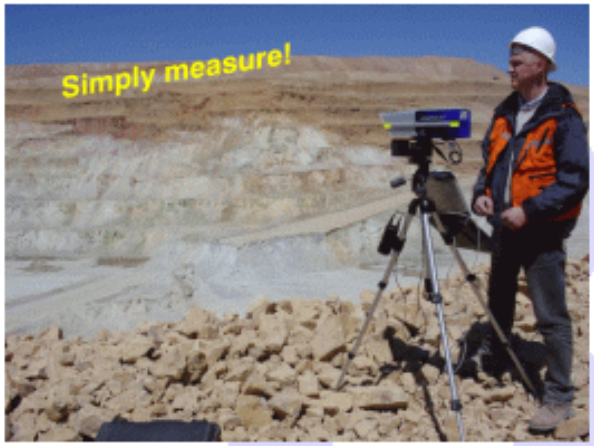
Contact free acquisition and assessment of rock and terrain surfaces by metric 3D images



1/25/2011

Visit us during the ISEE 2011 in San Diego, USA. more...

12/07/2010

New distributor in India more...

- 2011 exhibitions....
- BMX BlastPlanner Demo more...
- JMX Analyst Demo more...
- Free 3D image viewer more...

Complete systems:

JointMetriX3D

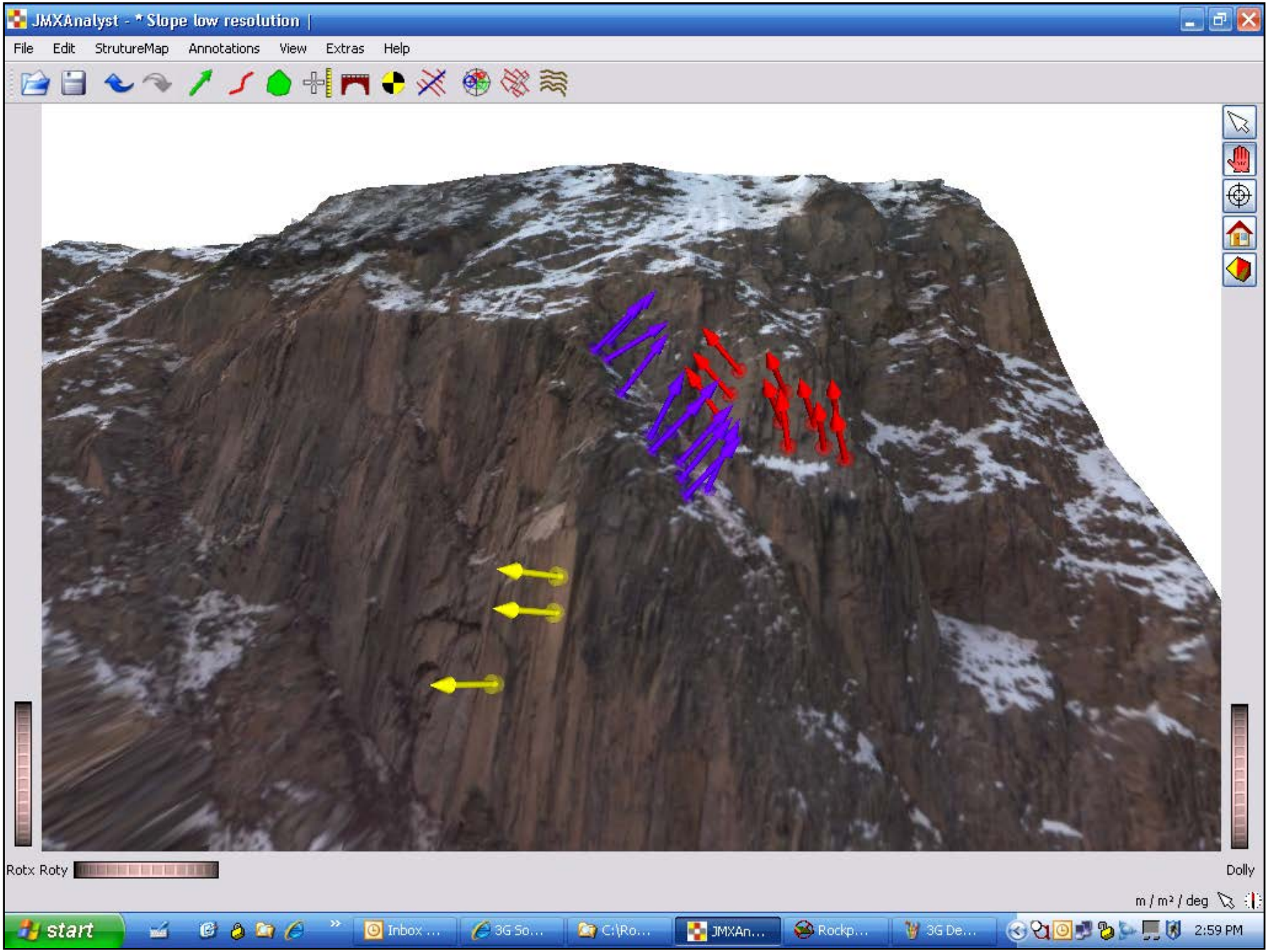
ShapeMetriX3D

BlastMetriX3D

Applications:

- Bench face surveying
- Tunnelling
- Mining
- Stability
- Monitoring
- Documentation

You need JavaScript for this site.


JMXAnalyst - * Slope low resolution |
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C:\Ro...
JMXAn...
Rockp...
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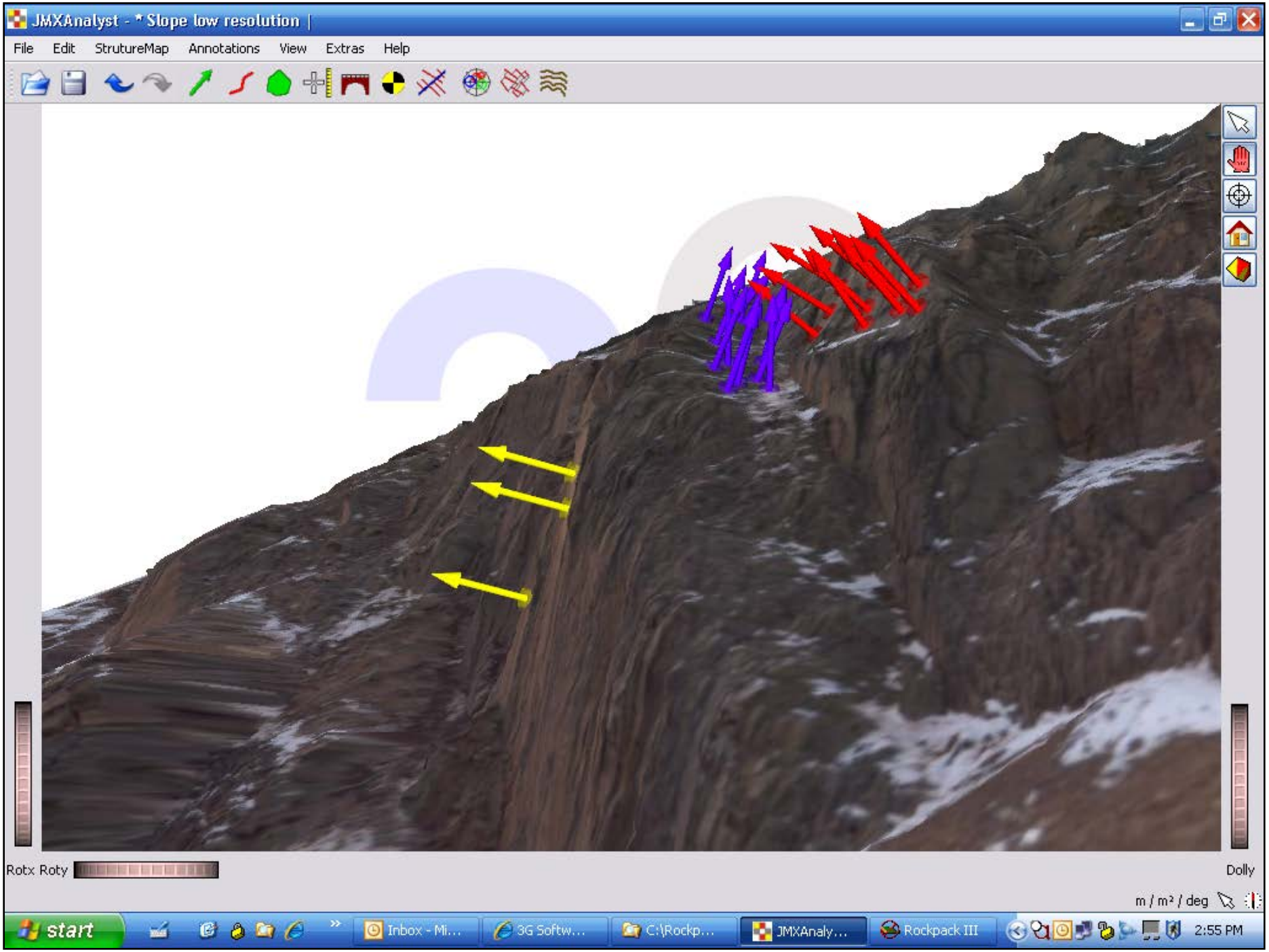
JMXAnalyst - * Slope low resolution |
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JMXAnaly...
Rockpack III
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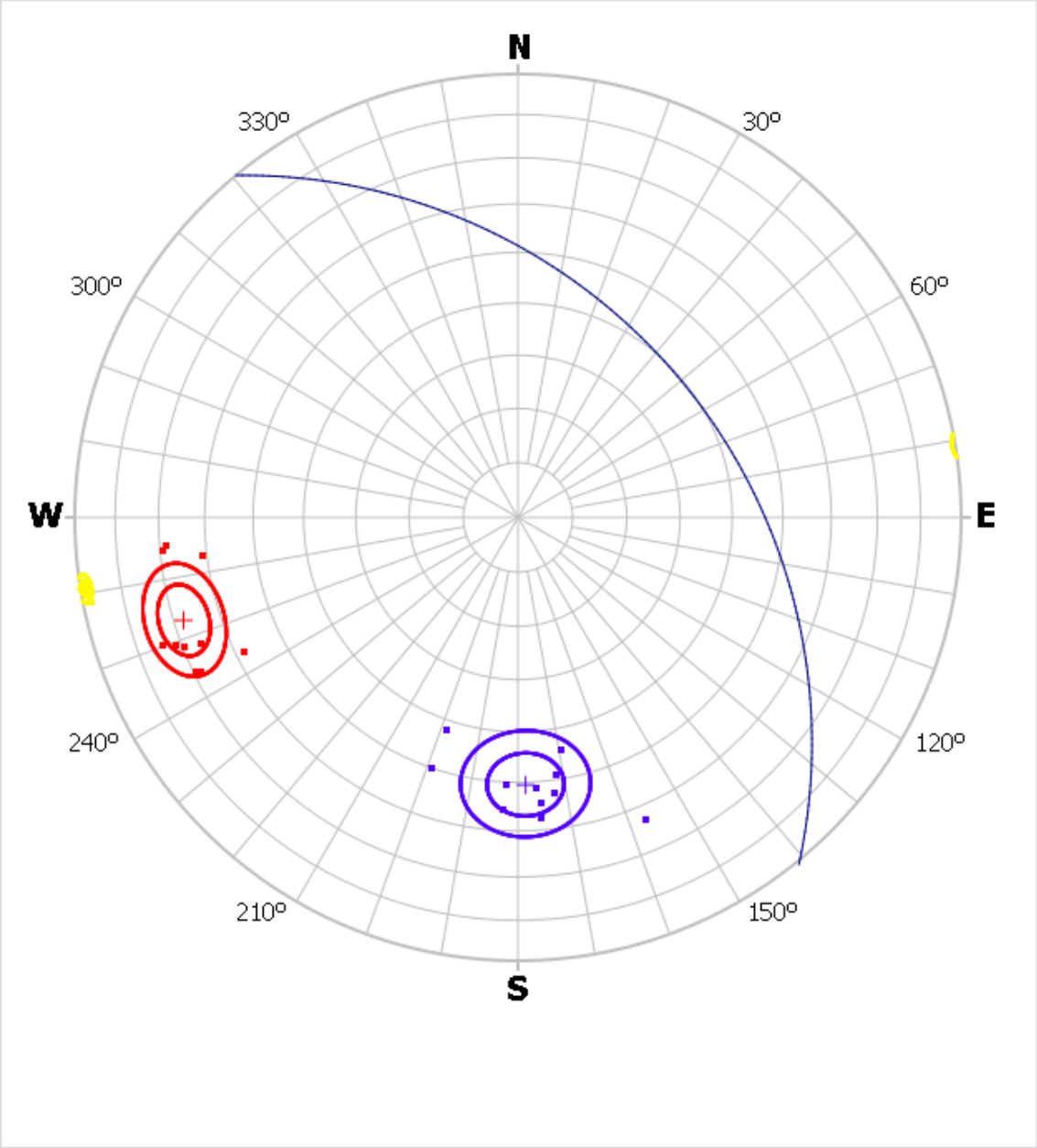
Lower Hemisphere

Close



Lambert Projection

StructureSet 01

Dip direction:	72.89	°
Dip angle:	67.88	°
Spherical aperture:	8.79	°
Concentration:	77.09	
Degree of orientation:	97.67	%
Cone of confidence:	5.54	°
Confidence:	95	%
Number of orientations:	10 / 10	

StructureSet 02

Dip direction:	358.37	°
Dip angle:	50.54	°
Spherical aperture:	10.76	°
Concentration:	52.16	
Degree of orientation:	96.51	%
Cone of confidence:	6.38	°
Confidence:	95	%
Number of orientations:	11 / 11	

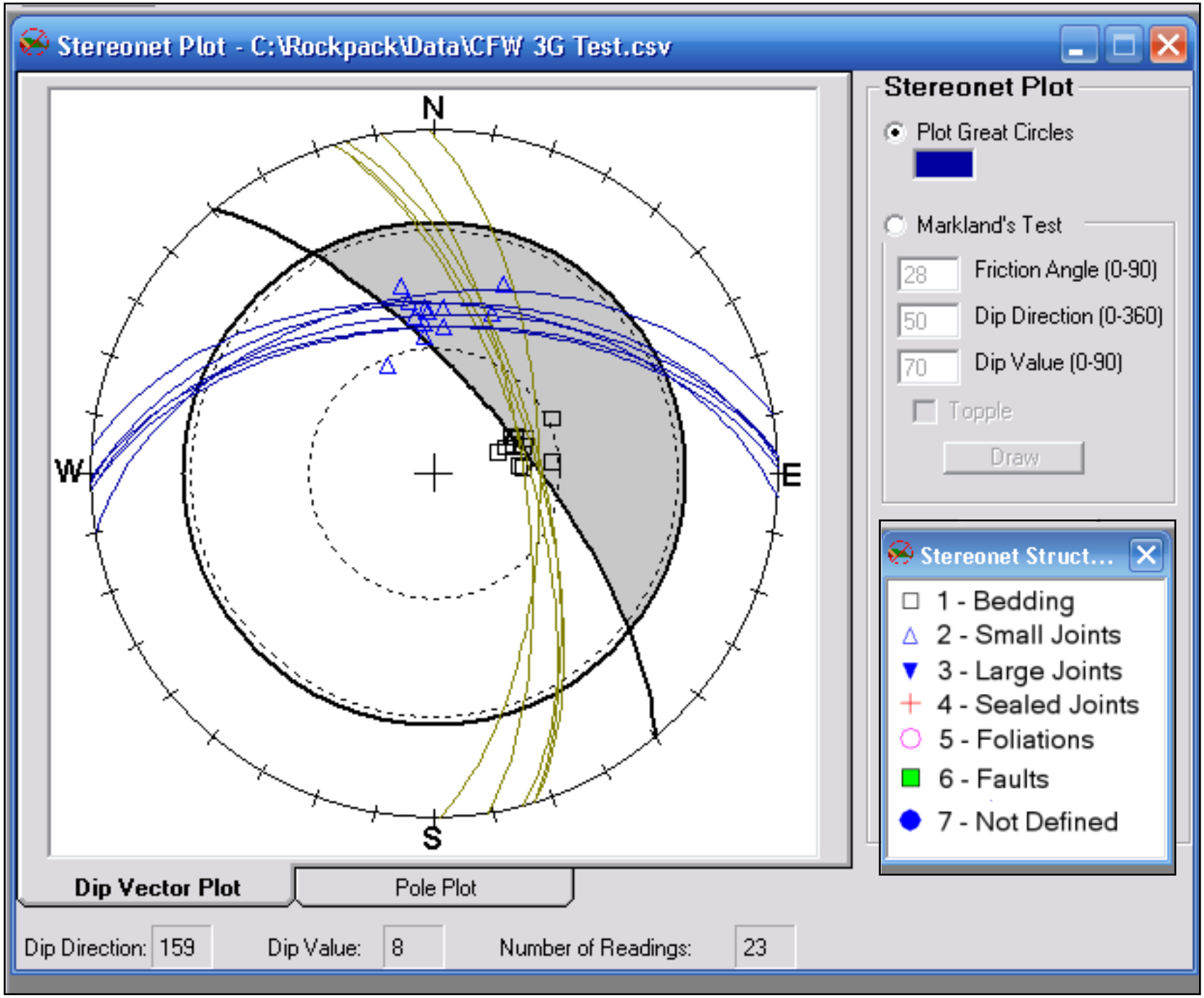
StructureSet 03

Dip direction:	80.66	°
Dip angle:	89.01	°
Spherical aperture:	0.98	°

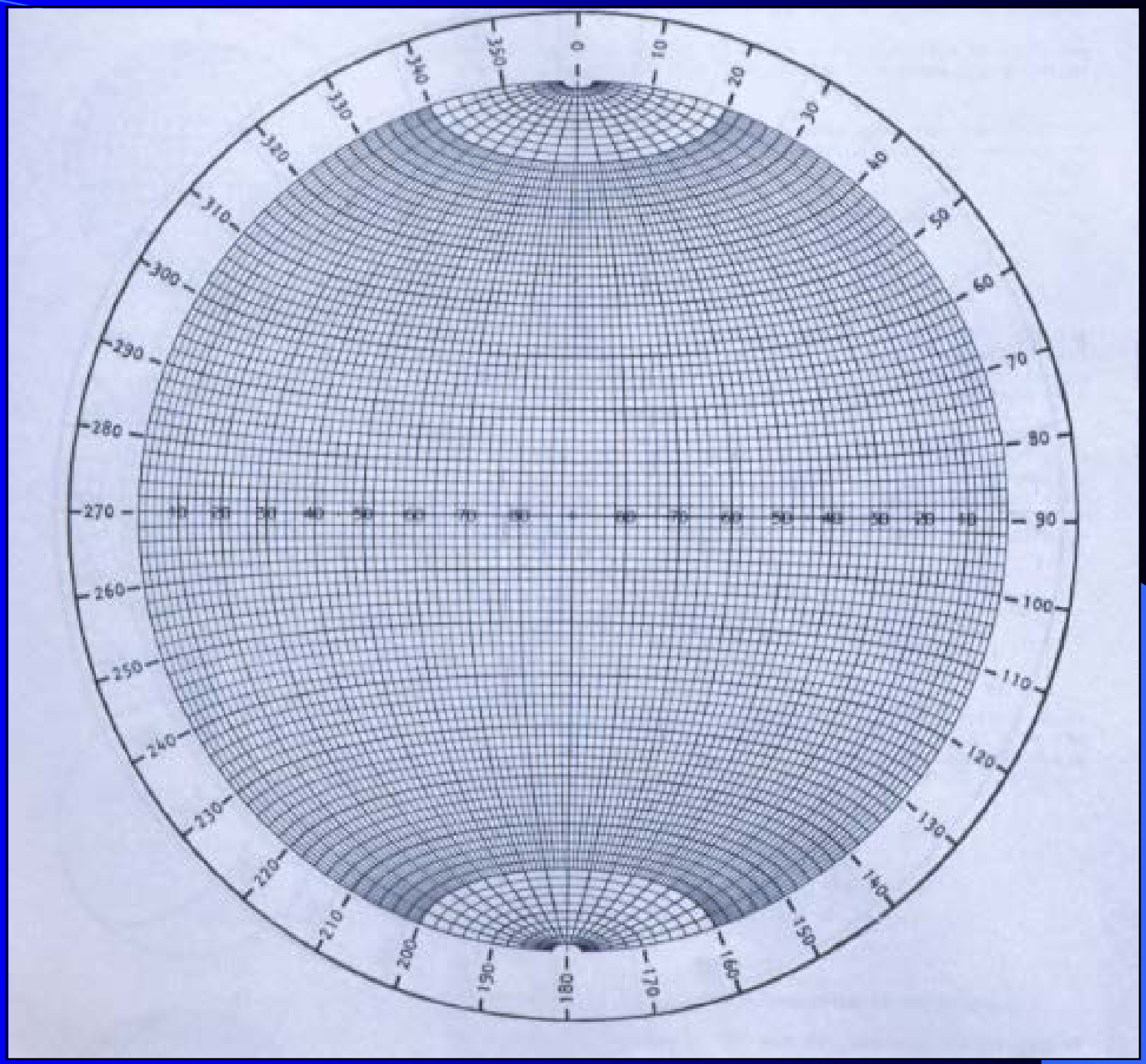
- [x] Enable pole orientations
- [x] Daw net
- [x] Draw rock face's great circle

Print Export Close

start Inb... 3G ... C:\... JMX... Roc... 3G ... Low... 3:03 PM

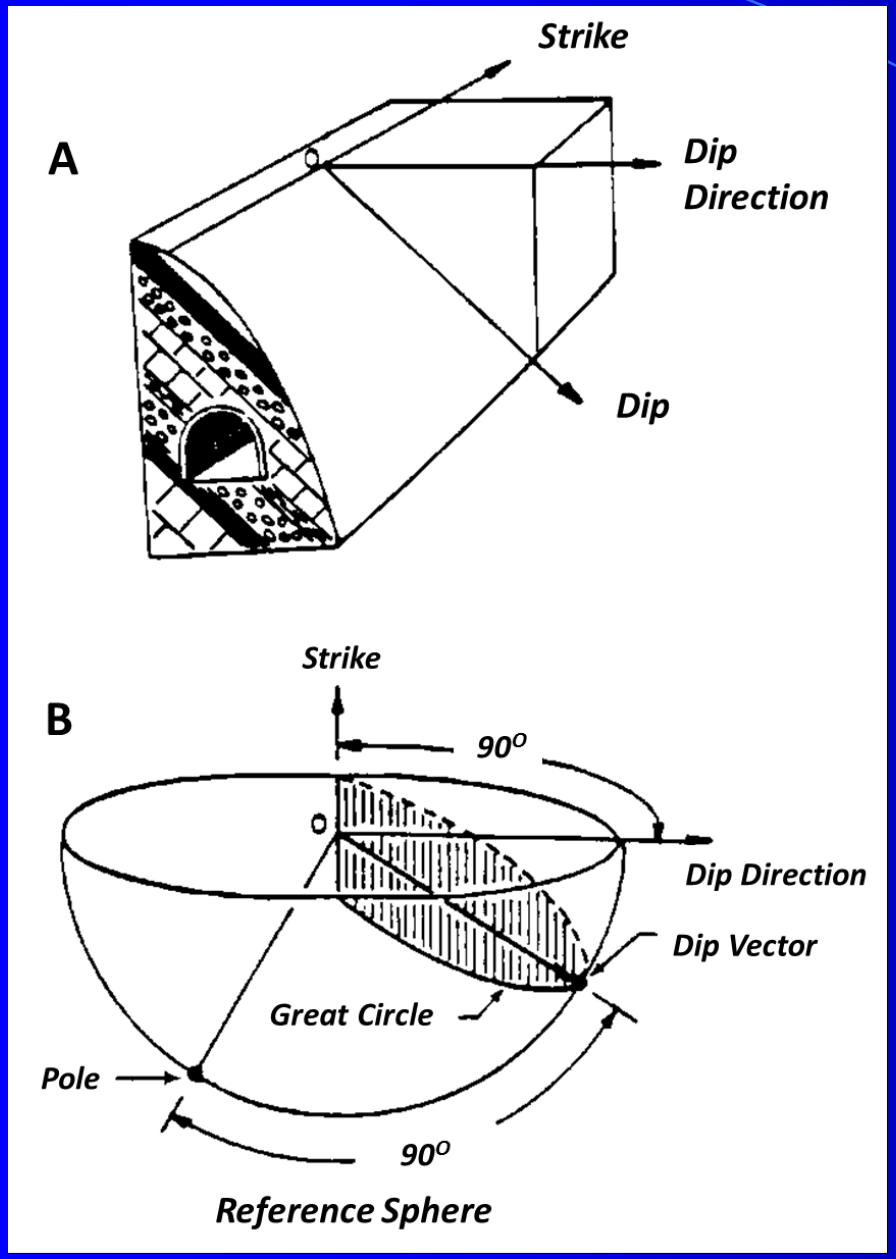

Stereonet Plot - C:\Rockpack\Data\CFW 3G Test.csv
N
W
E
S
Stereonet Plot
Plot Great Circles
Markland's Test
28
Friction Angle (0-90)
50
Dip Direction (0-360)
70
Dip Value (0-90)
Topple
Draw
Stereonet Struct...
1 - Bedding
2 - Small Joints
3 - Large Joints
4 - Sealed Joints
5 - Foliations
6 - Faults
7 - Not Defined
Dip Vector Plot
Pole Plot
Dip Direction: 159
Dip Value: 8
Number of Readings: 23

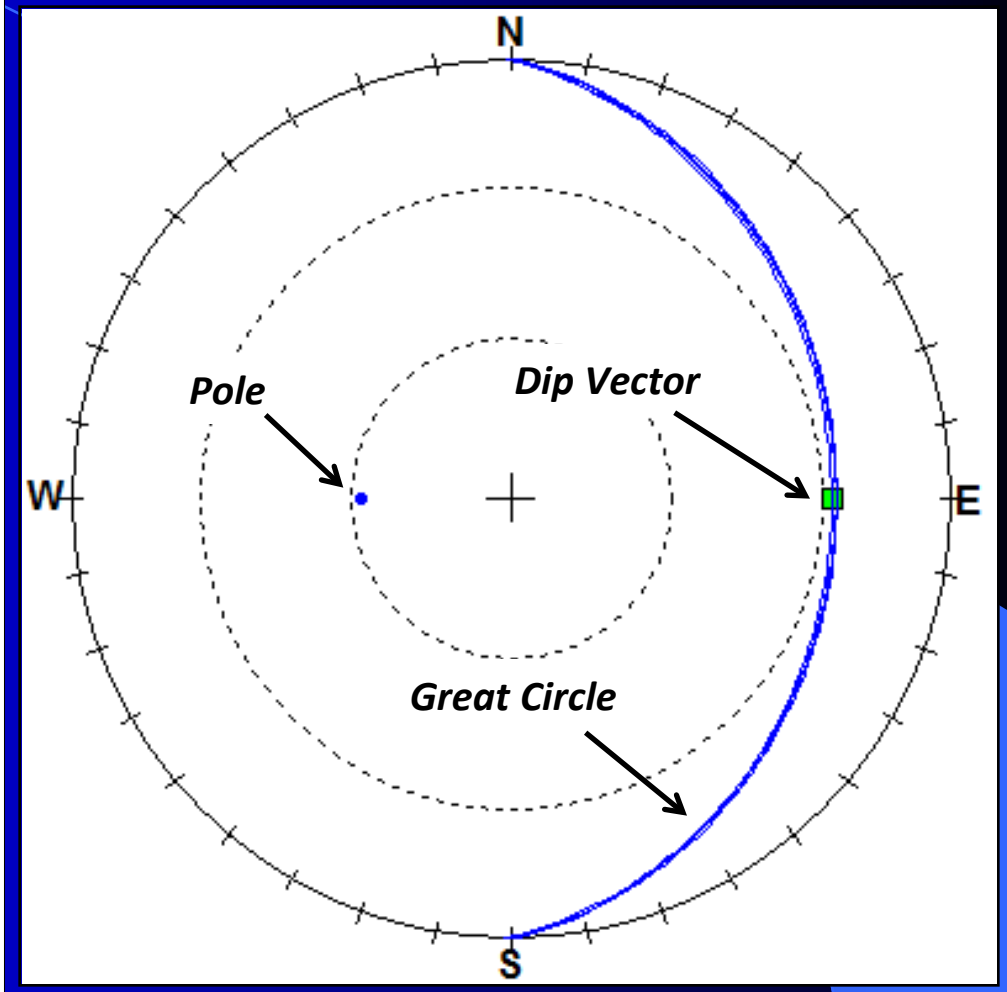
Equatorial stereonet projection



Orientations of planes in space

STEREONET ANALYSES

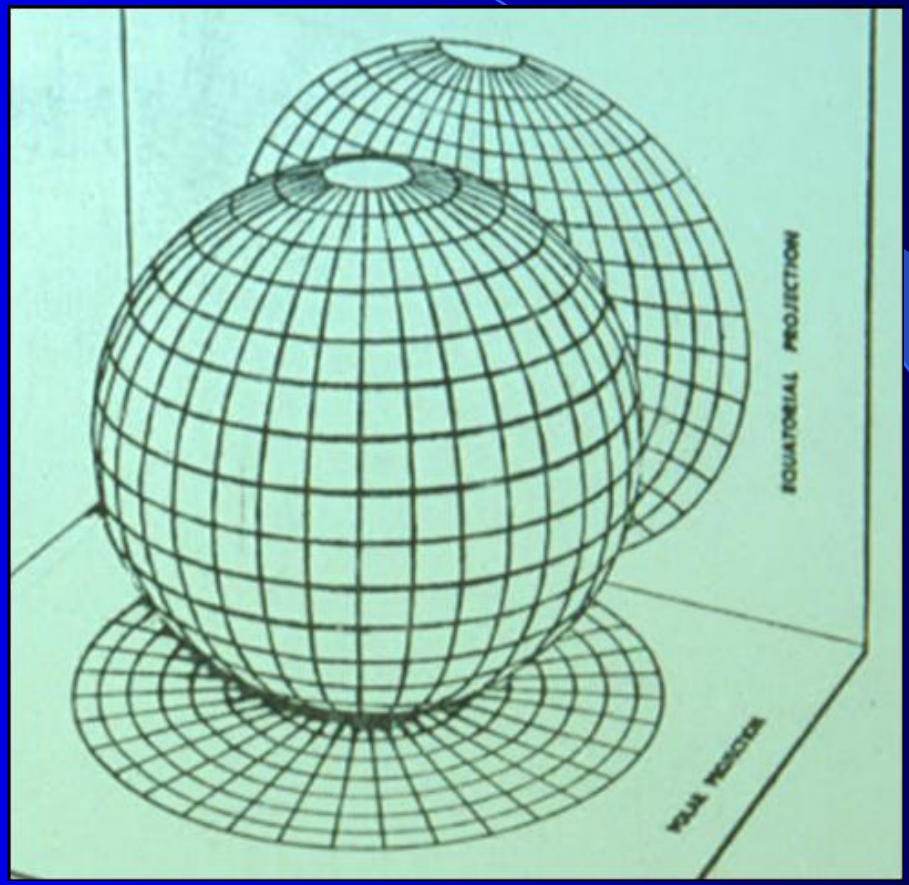




Stereonet representations of a plane having dip direction & dip of 090/28

STEREONET PROJECTION DIRECTIONS

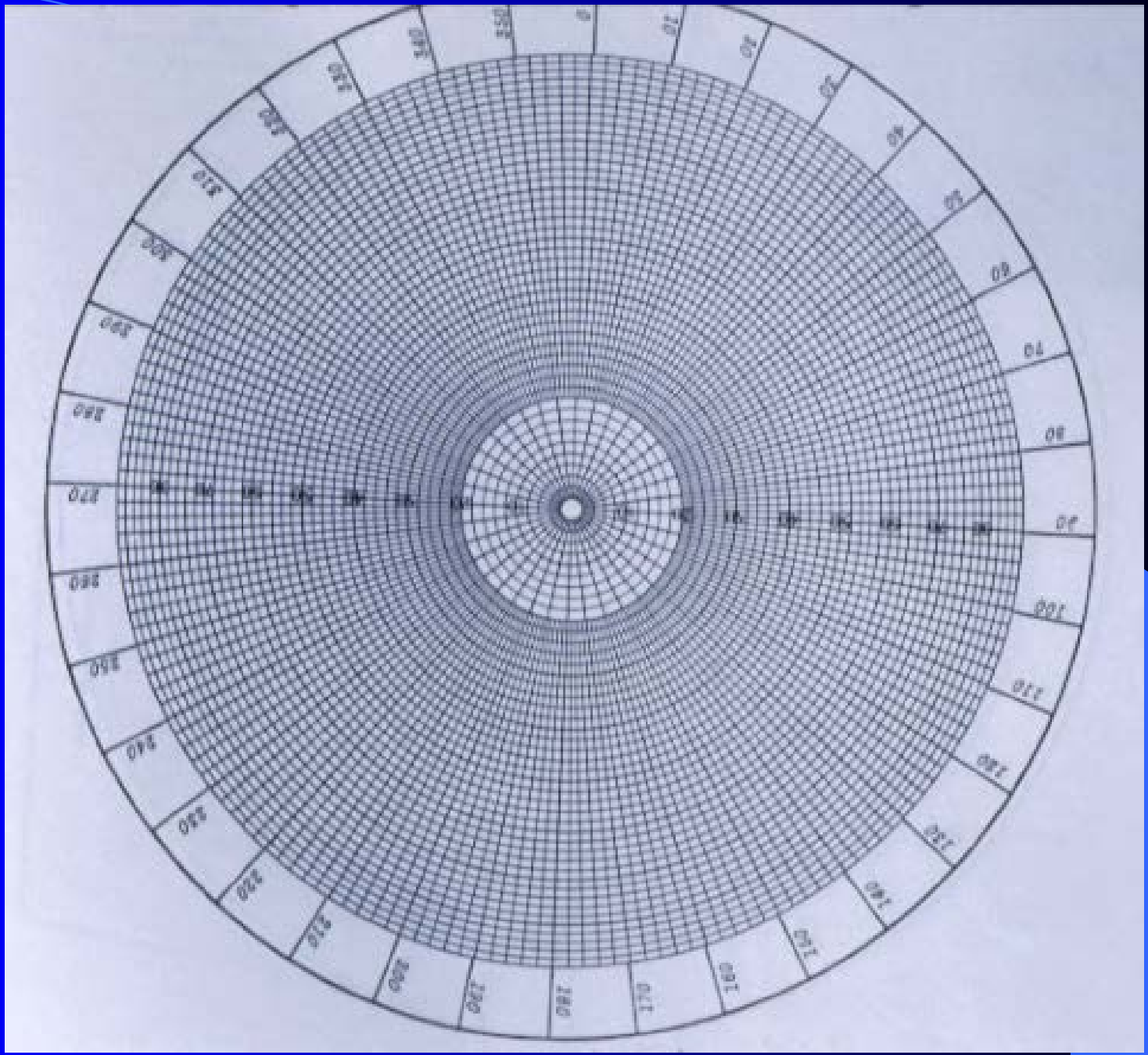
- Equatorial:
  - Dip Vectors
  - Poles
  - Great Circles
- Polar:
  - Dip Vectors
  - Poles



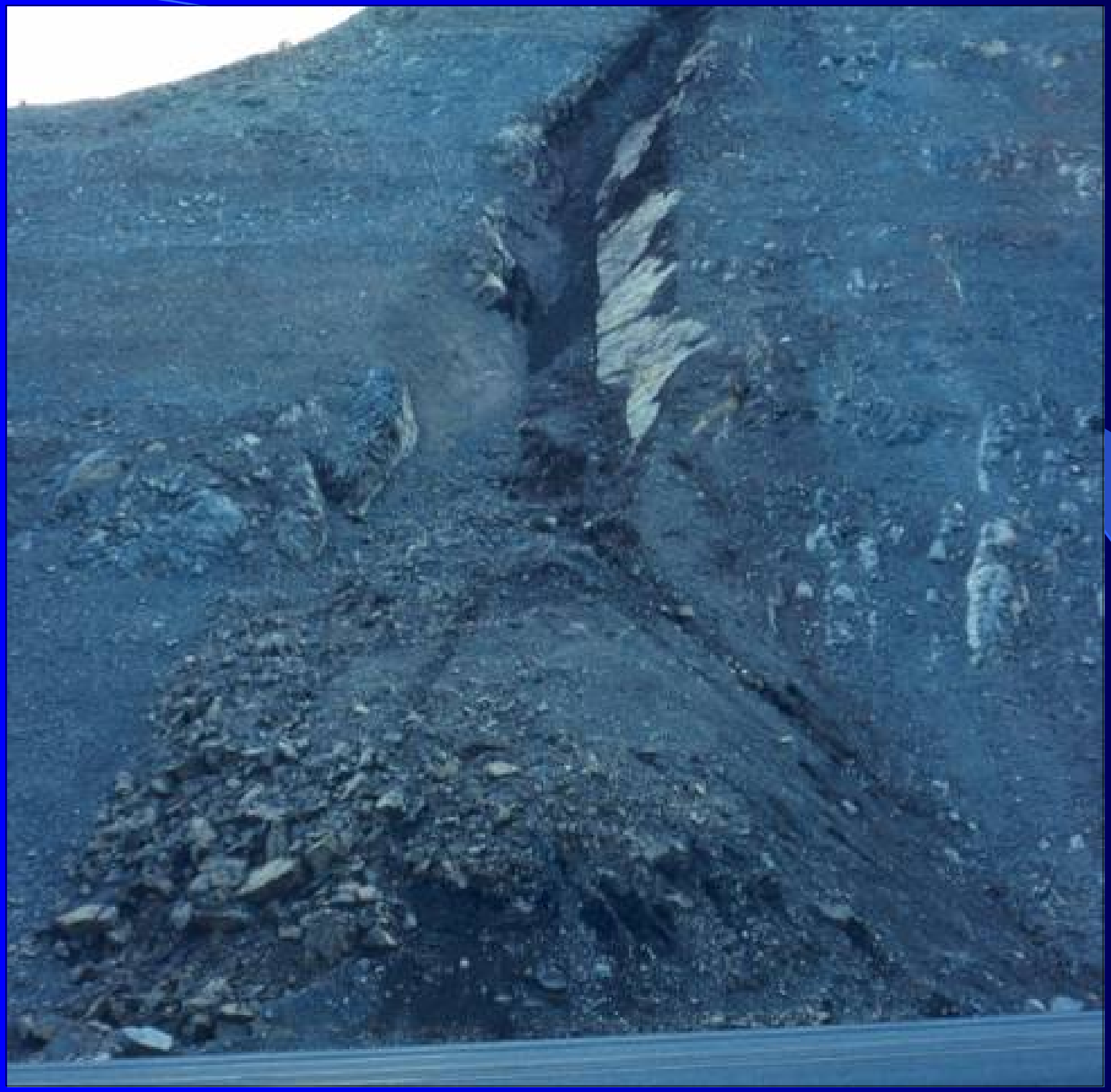
Equatorial projection

Polar projection

Polar stereonet projection

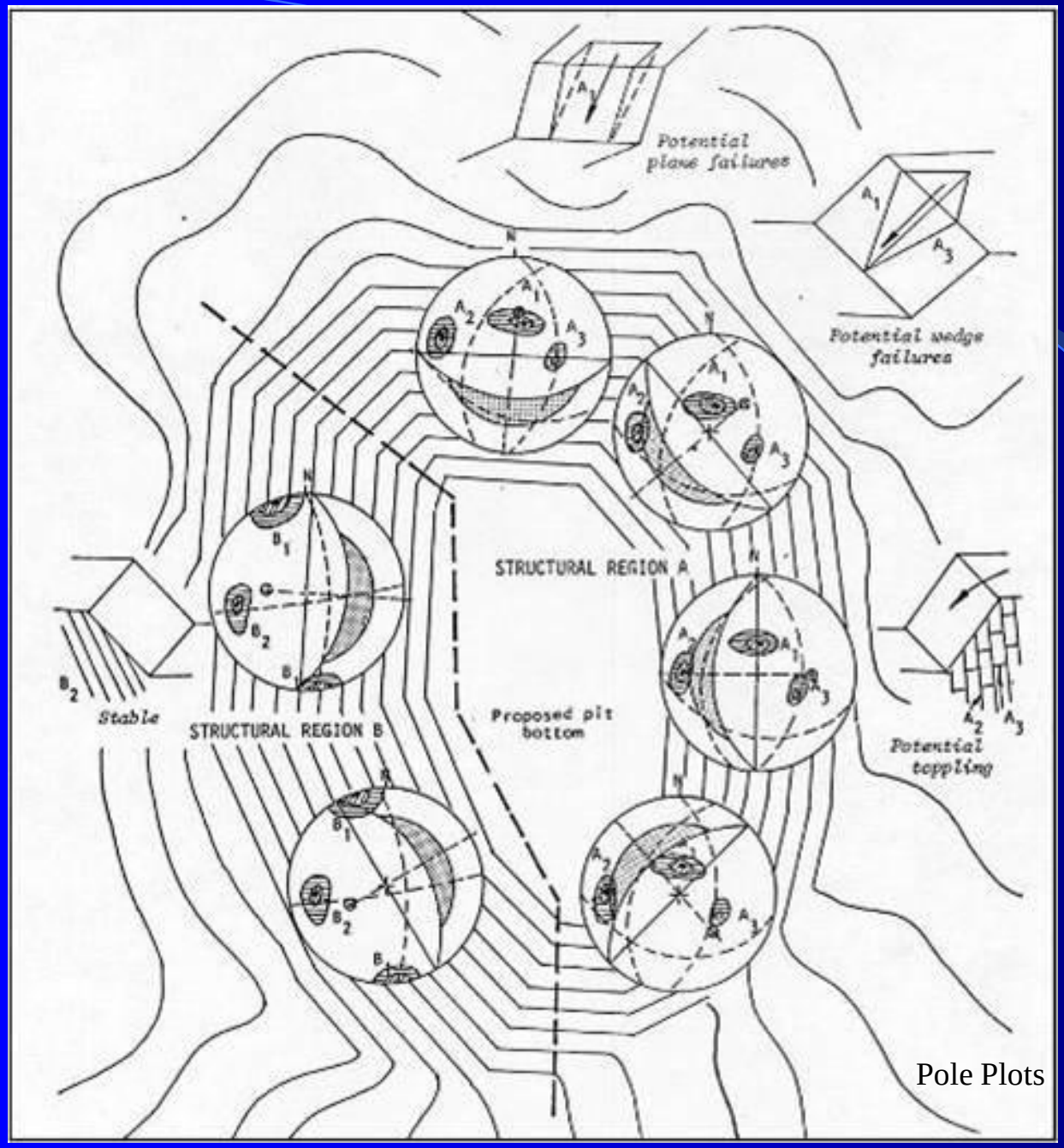



I-77 southwest
Virginia



Utah

Montana



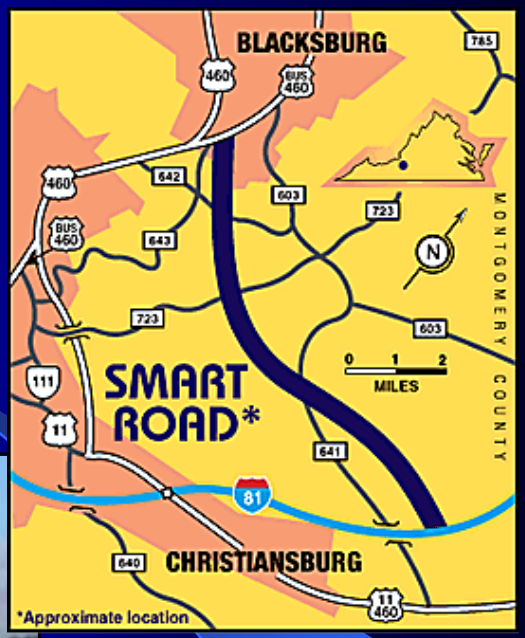
Two structural domains, three failure modes

VDOT We Keep Virginia Moving

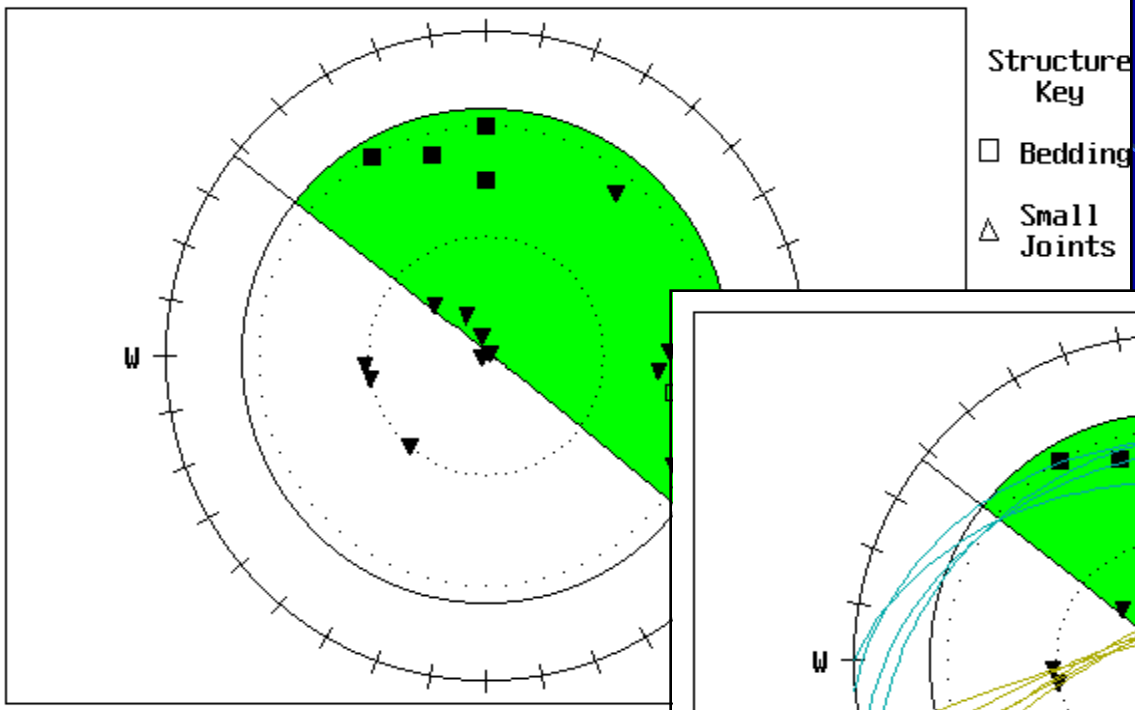
1997-98

The Smart Road

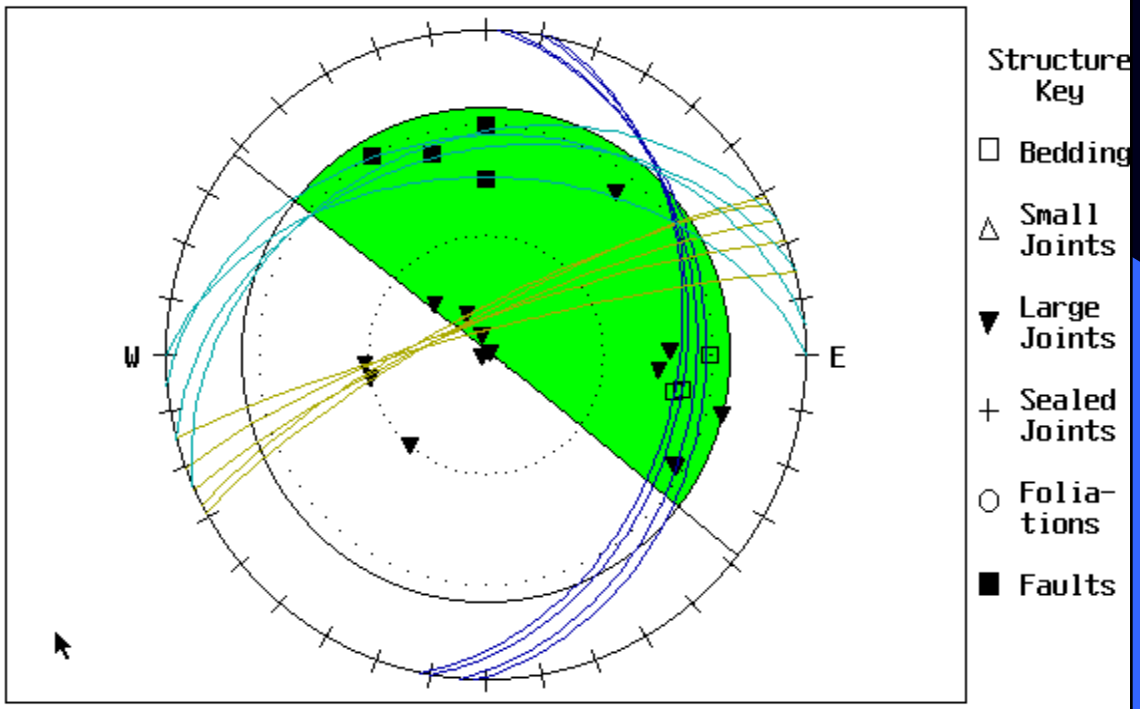
An excellent example of structural control of stability



VDOT We Keep Virginia Moving



MARKLAND TEST PLOT: c:\rkpk2-04\data\a207
Friction Angle = 25 degrees
Slope dip direction = 38 degrees, Dip =
Number of Stations = 21

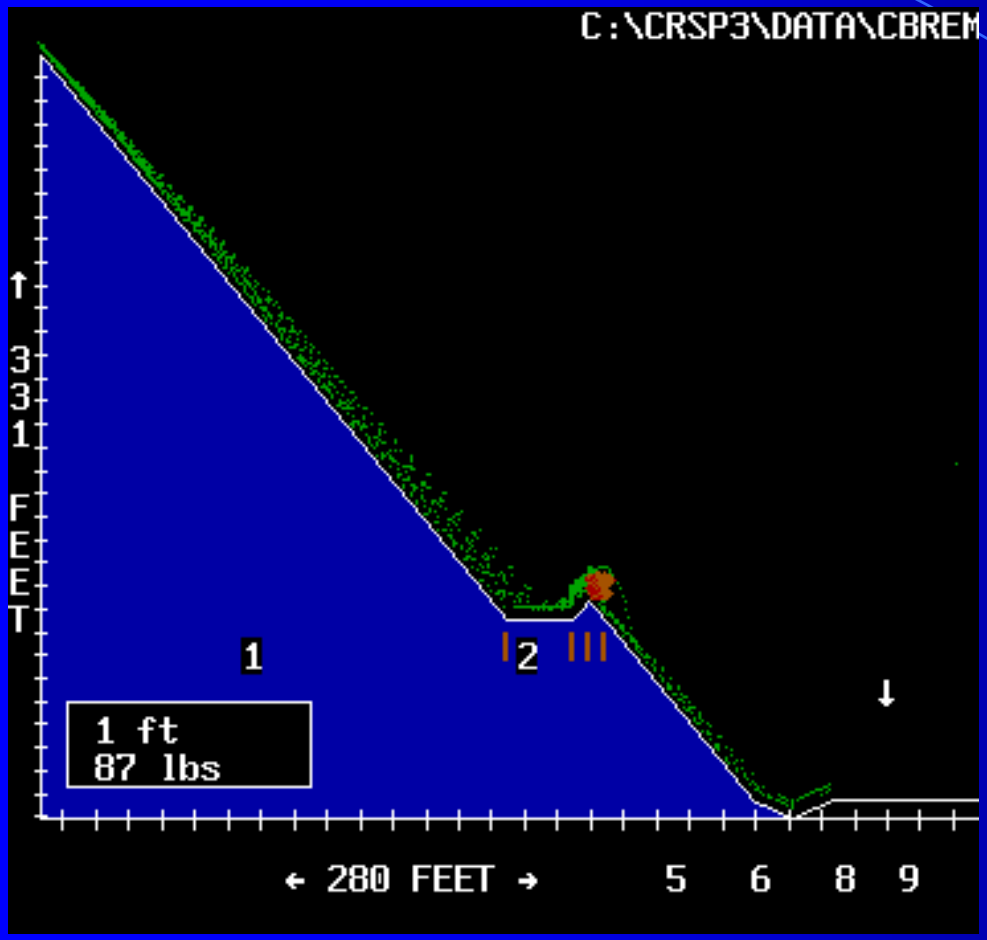


MARKLAND TEST PLOT: c:\rkpk2-04\data\a20714.DAT
Friction Angle = 25 degrees
Slope dip direction = 38 degrees, Dip = 90 degrees
Number of Stations = 21

Graduate research by Robin Reed


KOBELCO

Rockslides vs rockfalls...



Colorado Rockfall Simulation Program CRSP

The design dilemma:

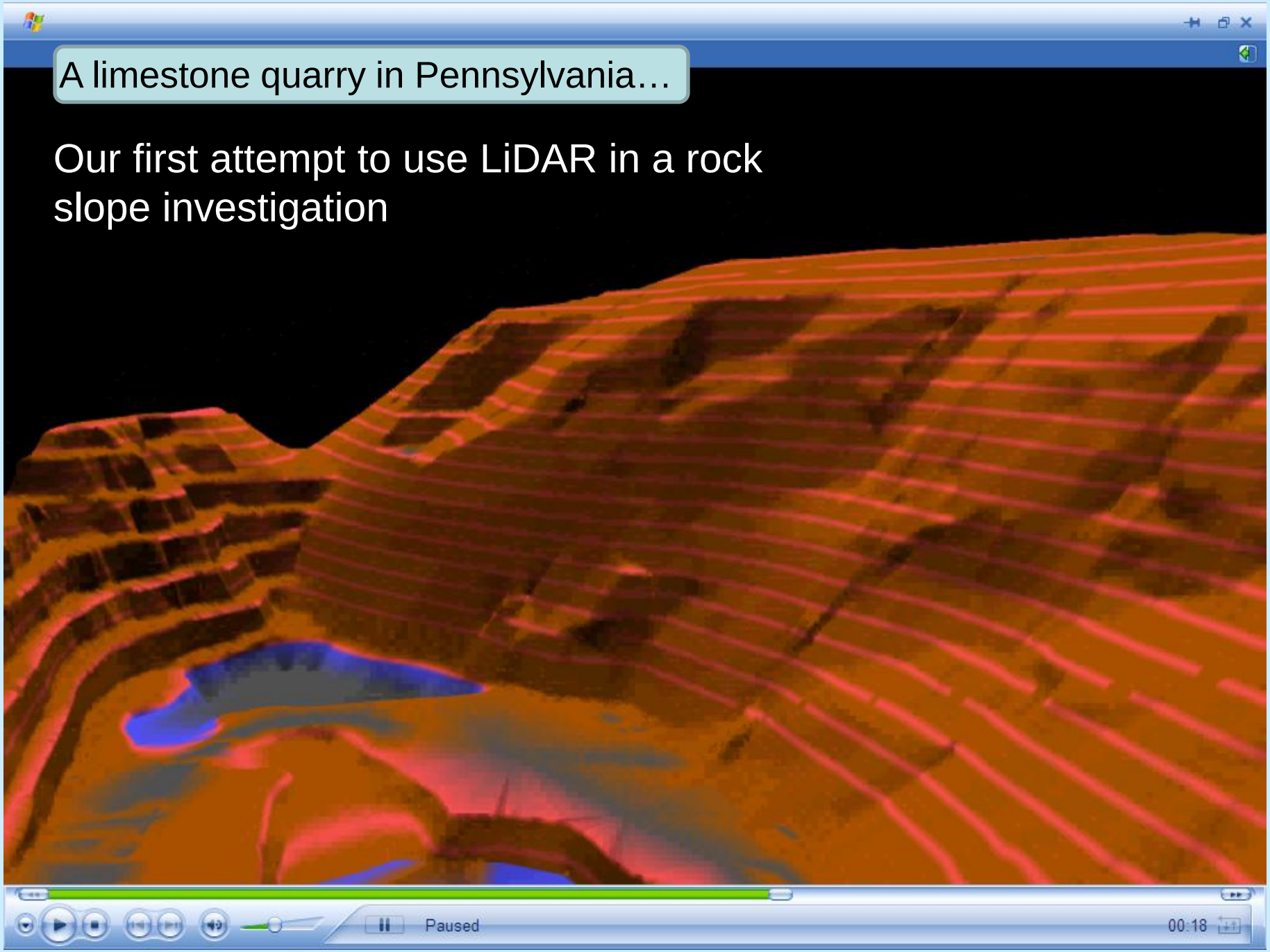
- vertical slopes are <u>not</u> usually the best, thanks to discontinuities

- work with the geologic structures first to eliminate rockslides

- then mitigate falling and rolling rock with barriers & mesh

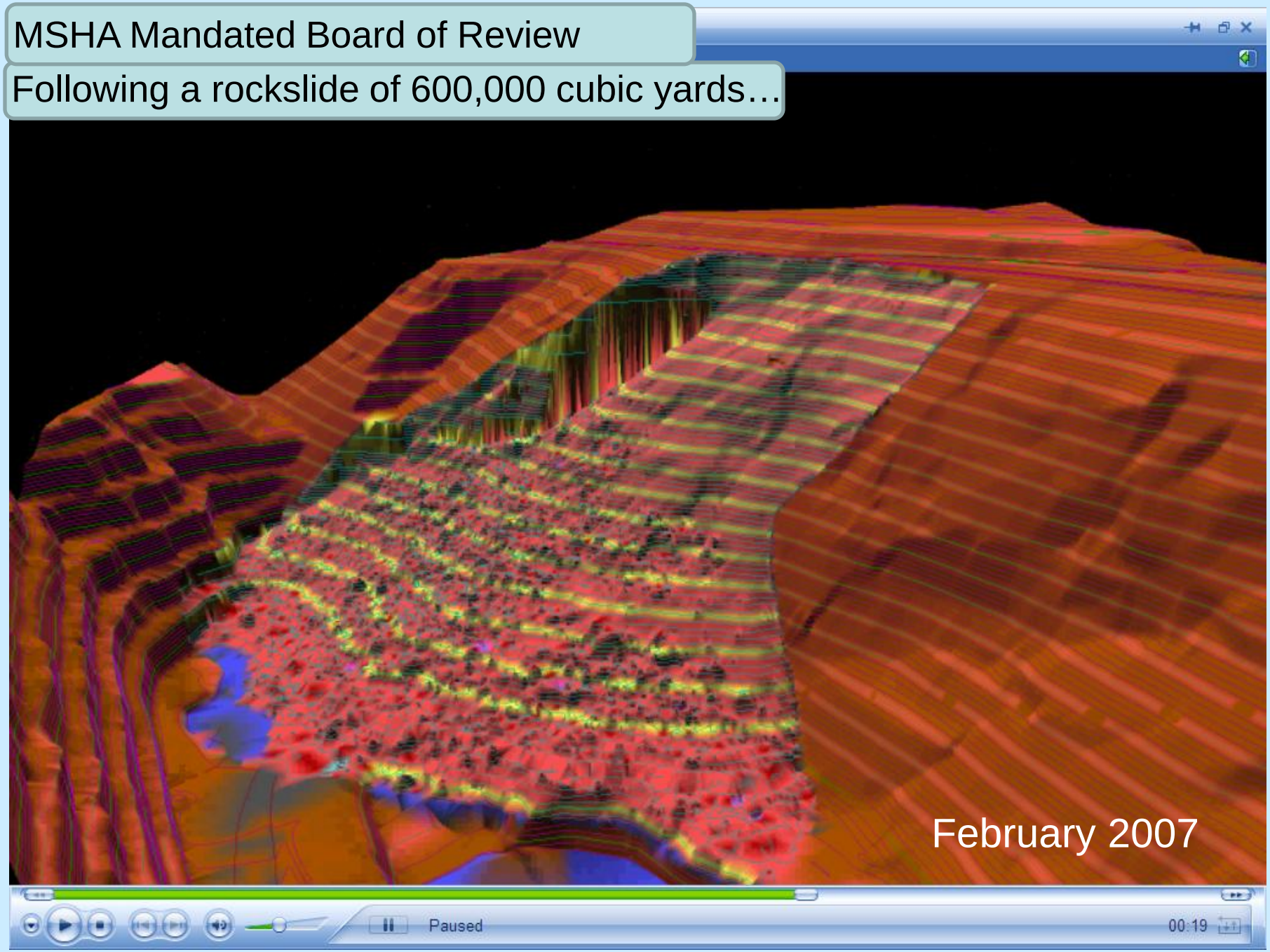
A limestone quarry in Pennsylvania…

Our first attempt to use LiDAR in a rock slope investigation



MSHA Mandated Board of Review

Following a rockslide of 600,000 cubic yards…



Pre-slide Geometry

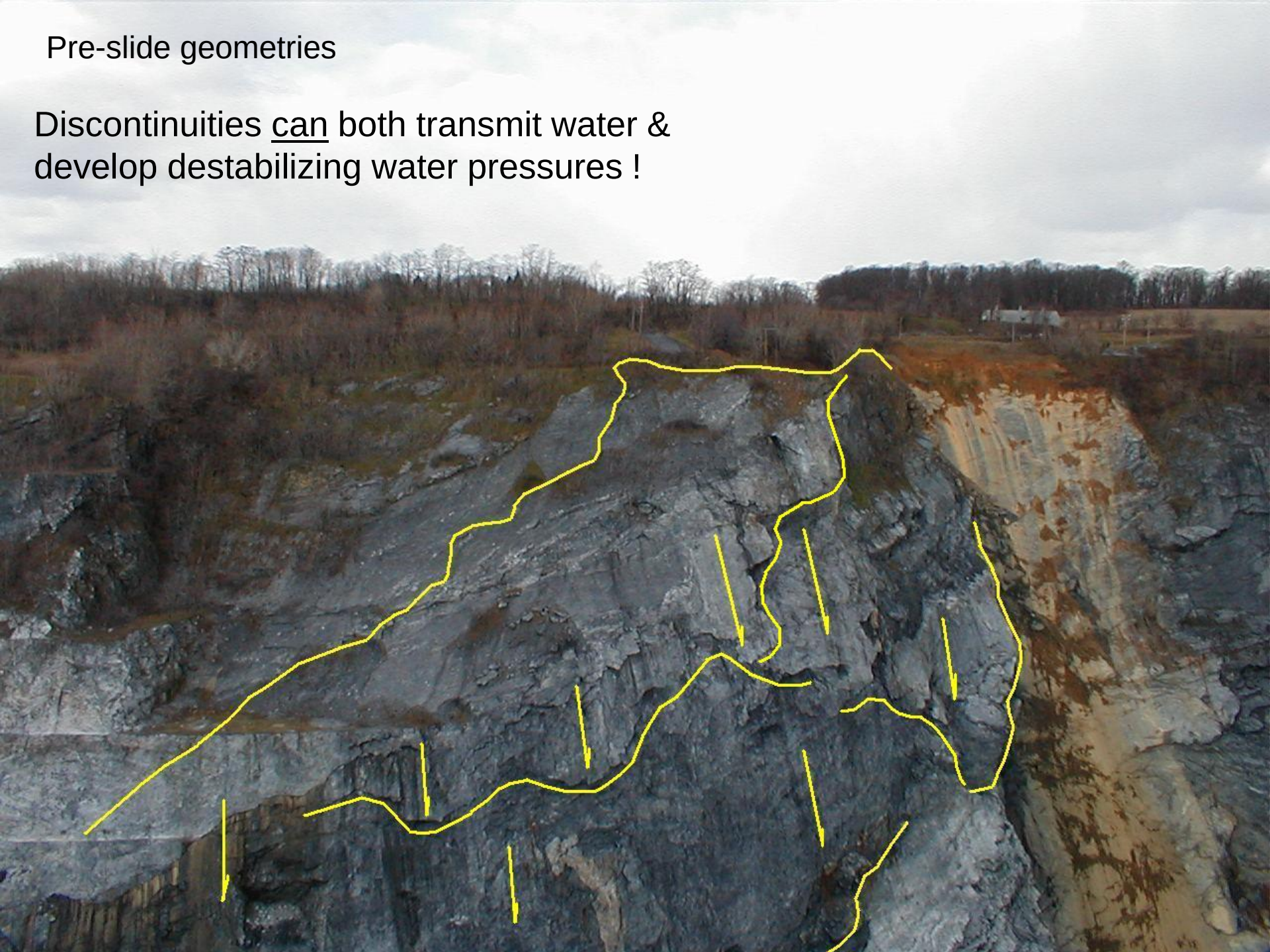
Interpretation by CFW

Geometries for back calculations

Interpretation by CFW

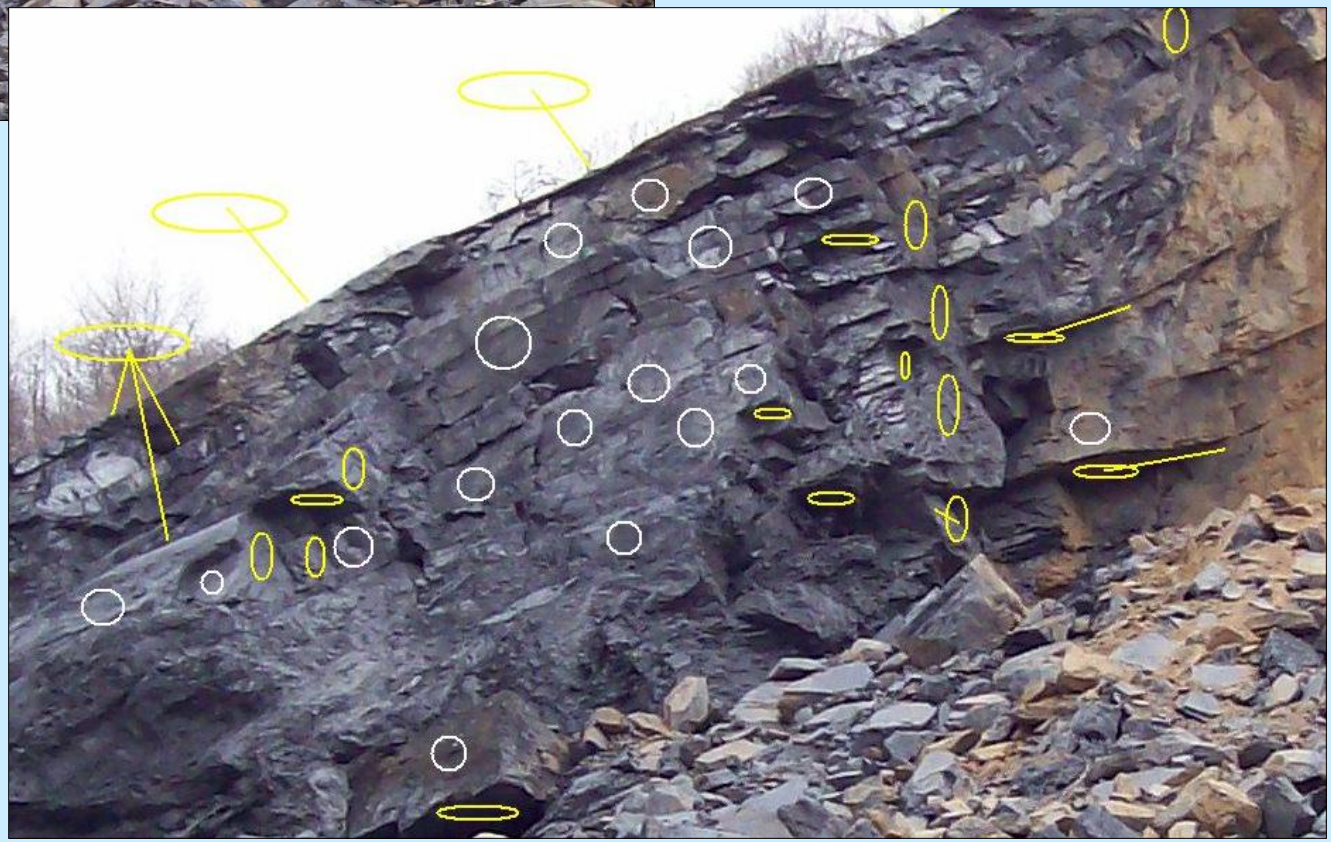
Pre-slide geometries

Discontinuities <u>can</u> both transmit water & develop destabilizing water pressures !



Post-slide Geometry

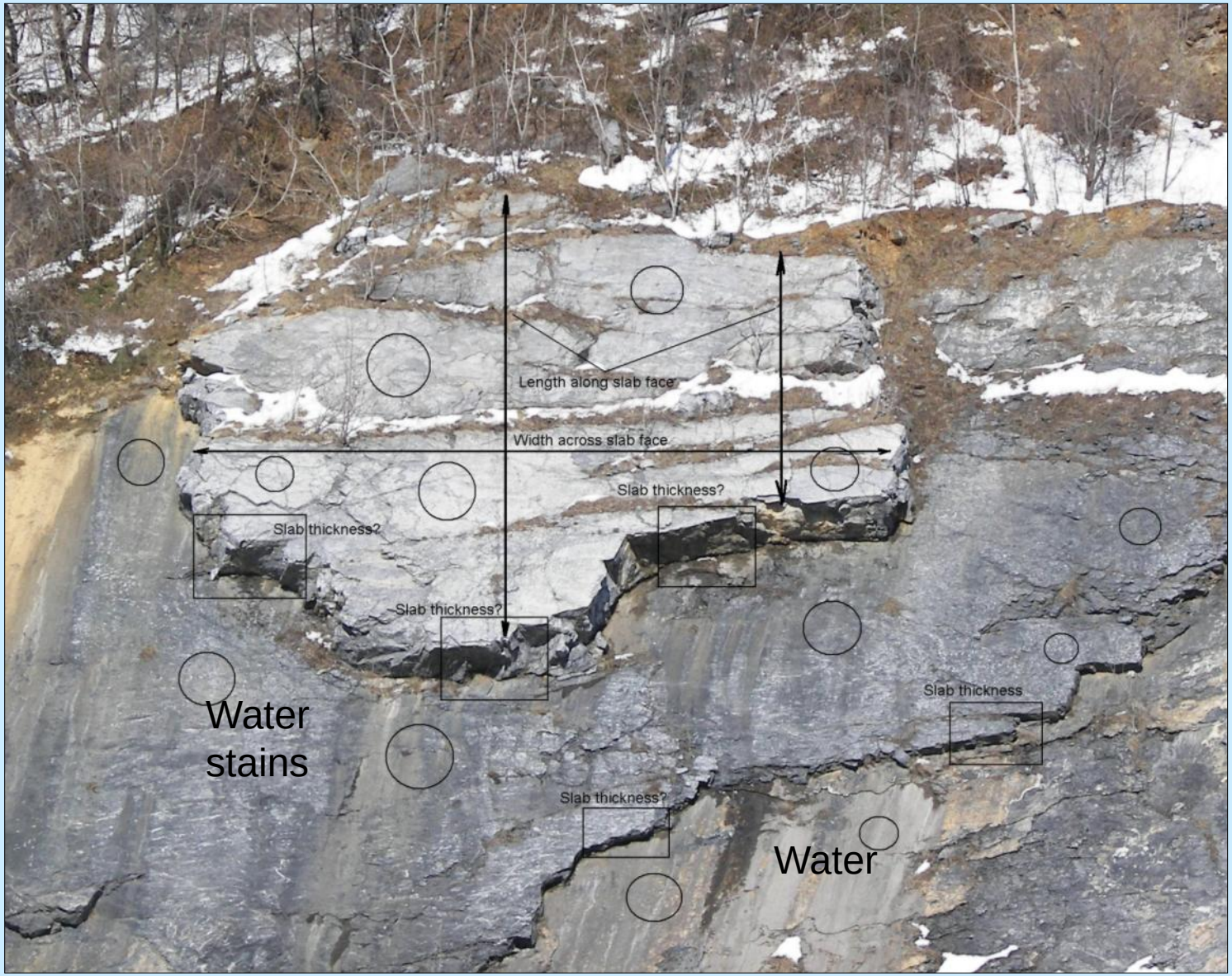
Remaining pinnacle
a safety concern?



LIDAR points of interest in remaining rock mass


Drilled & blasted by
Janod

Remaining adjacent slab - Safety Concern? – Role of Water?



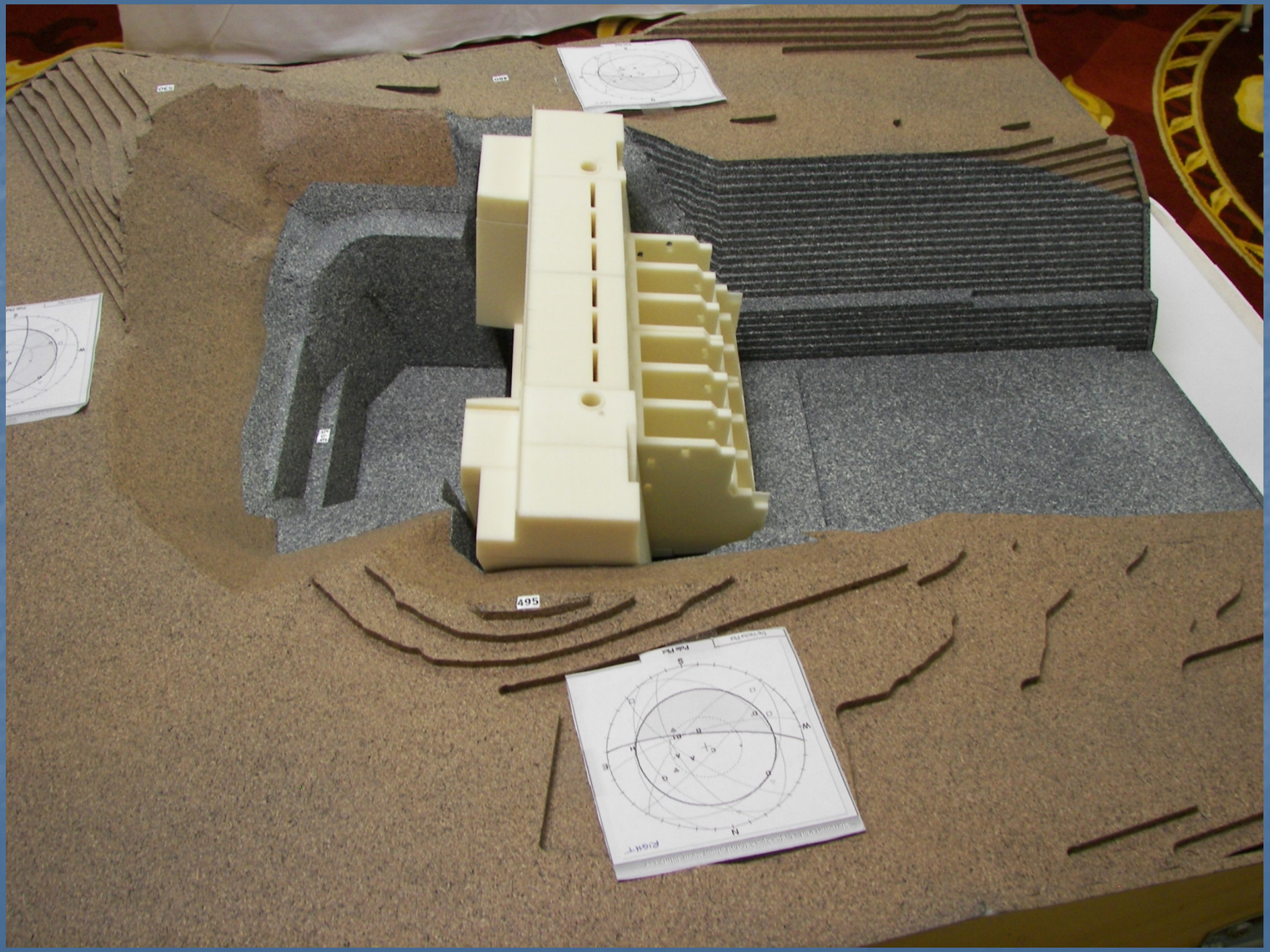
Folsom Dam

Auxiliary Spillway – Joint Federal Project

U.S. Army Corps of Engineers
& Bureau of Reclamation

3d Rendering of the Auxiliary Spillway and Folsom Bridge Road

Model and Animation



Structure exposed during construction of spillway

2011 - 2012

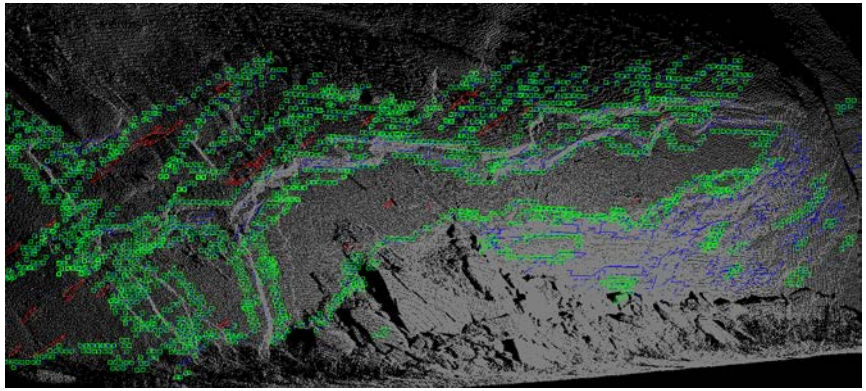
Skip Watts &
Dick Goodman

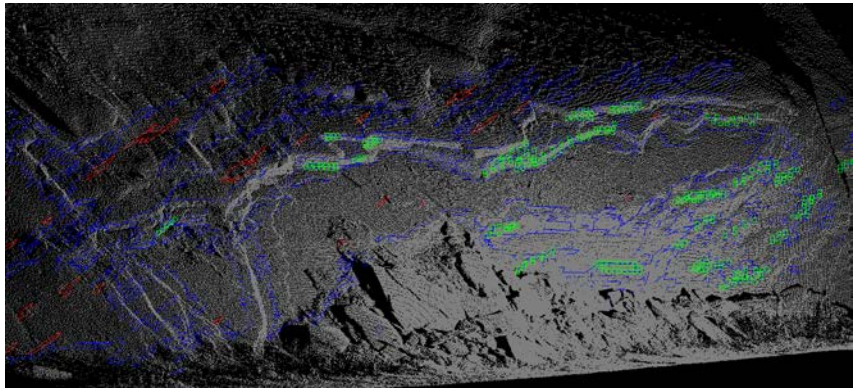
Structure exposed during construction of spillway

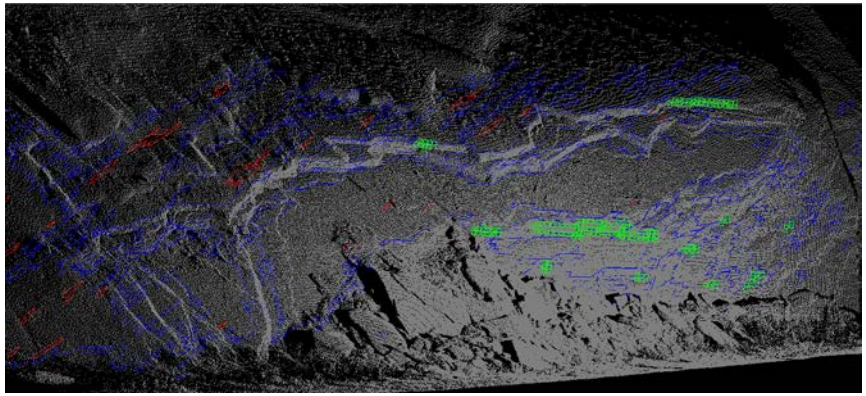

Field Trip Site
Rt 629, Deerfield, VA
before failure

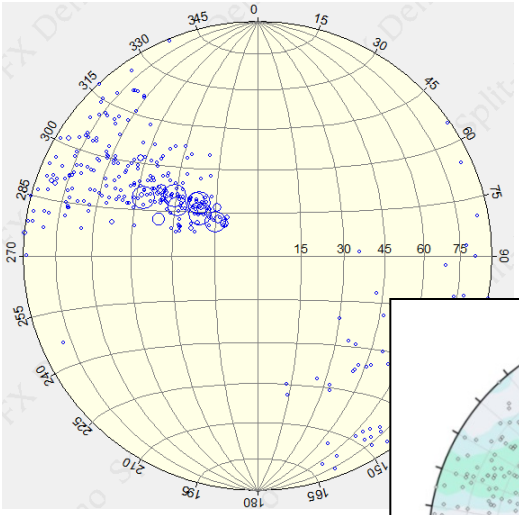
VDOT's Brian Bruckno tells all

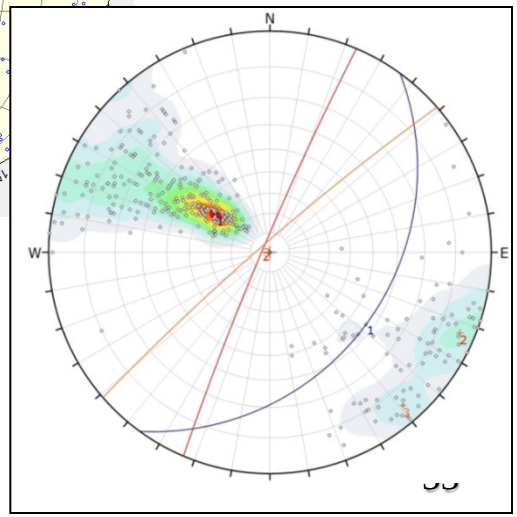
Dr. Andrew Foy & George Stephenson of Radford University, Leica C10









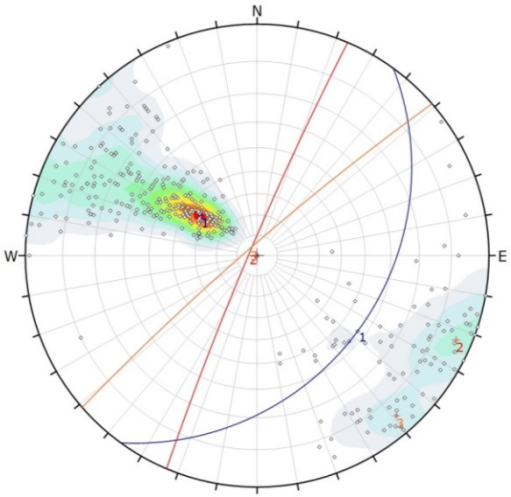


Various steps in the processing of the LiDAR data to obtain stereonets

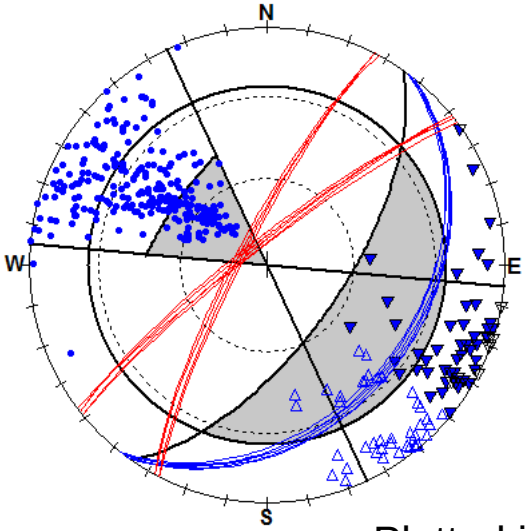
FISHER&STRICKLER
ROCK ENGINEERING, LLC

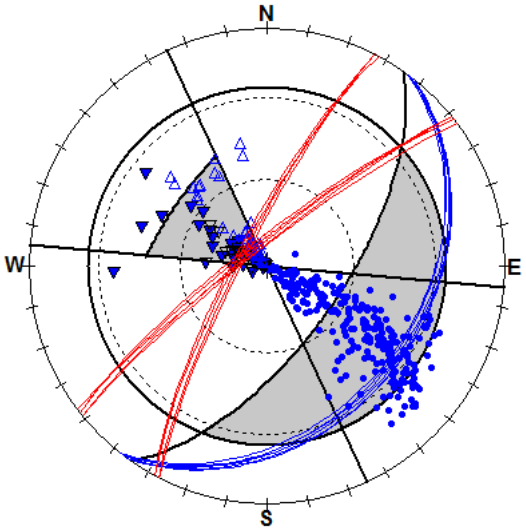
LiDAR Point Cloud - Stereonet stability analyses

Rt 629 Deerfield, VA



Plotted in *Dips*



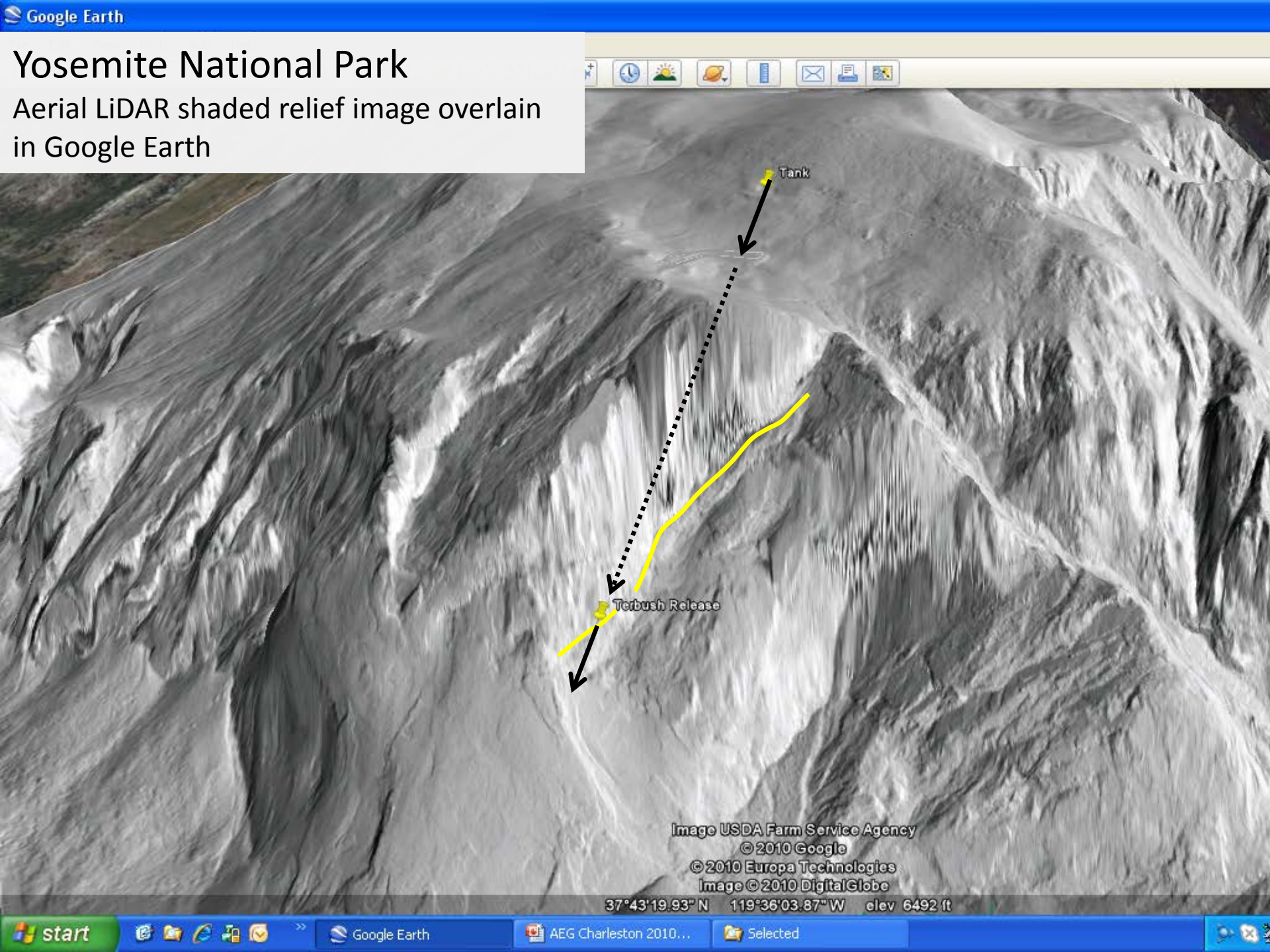


Plotted in *RockPack III*

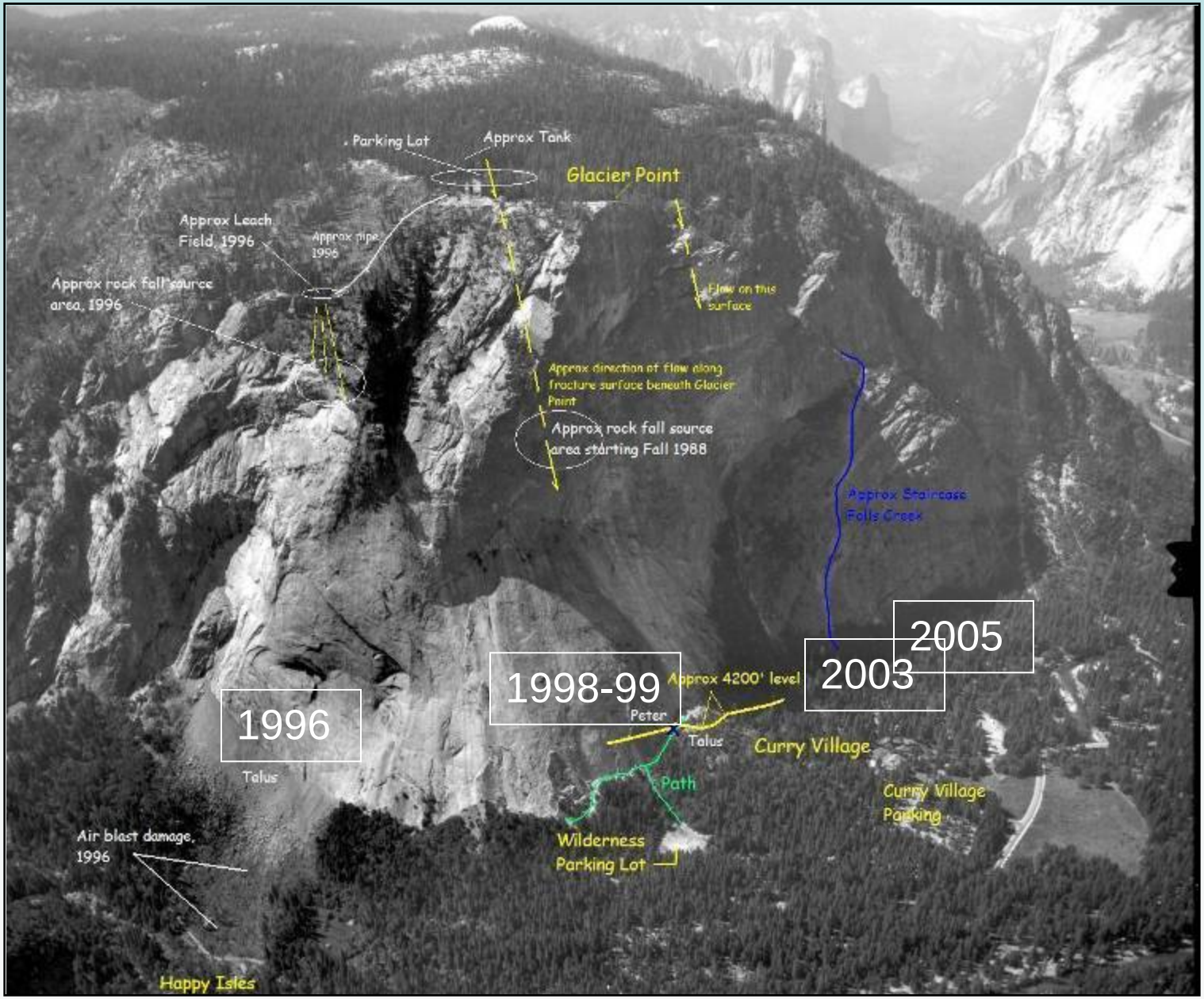
FISHER&STRICKLER
ROCK ENGINEERING, LLC

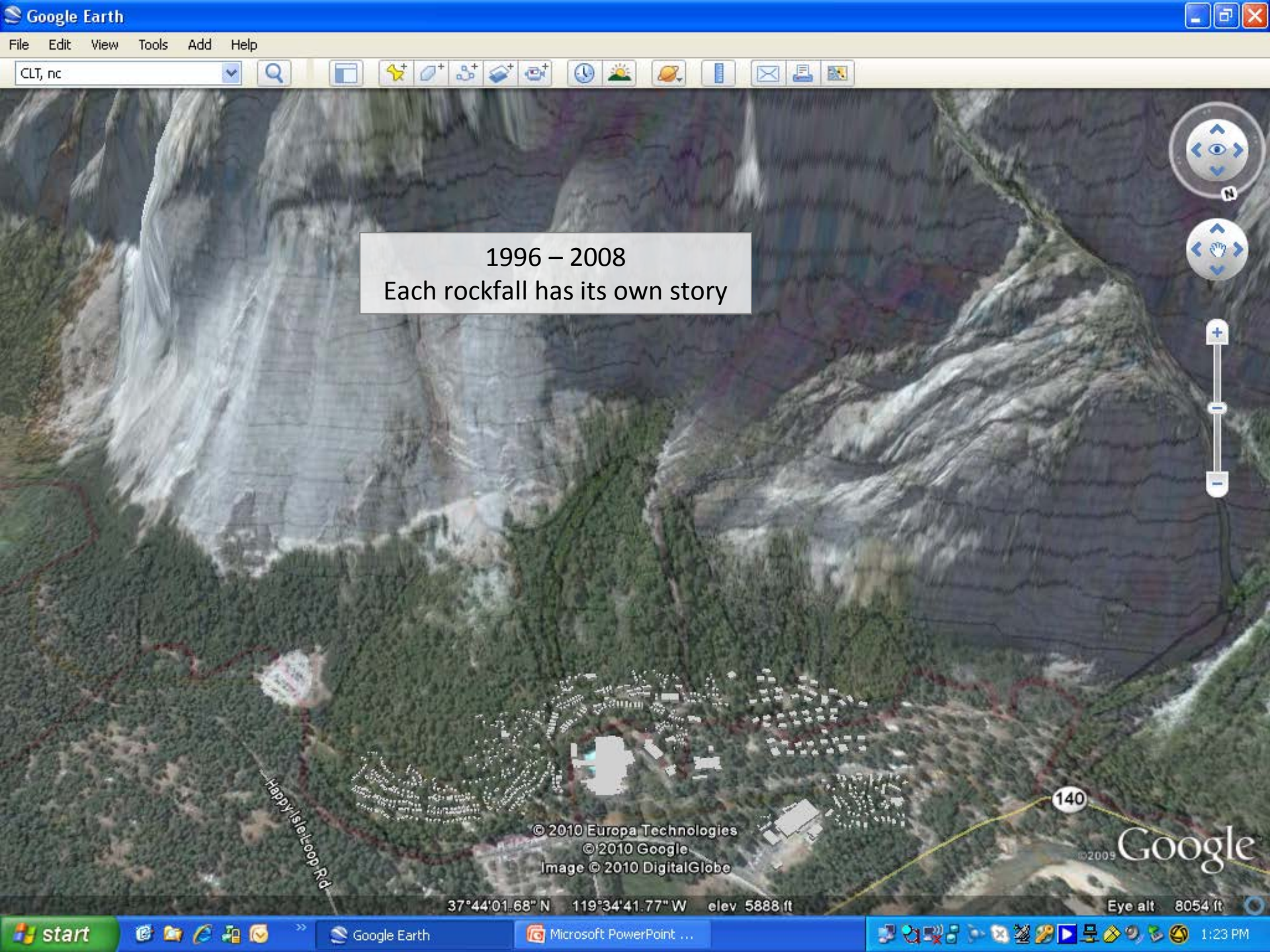
Yosemite National Park

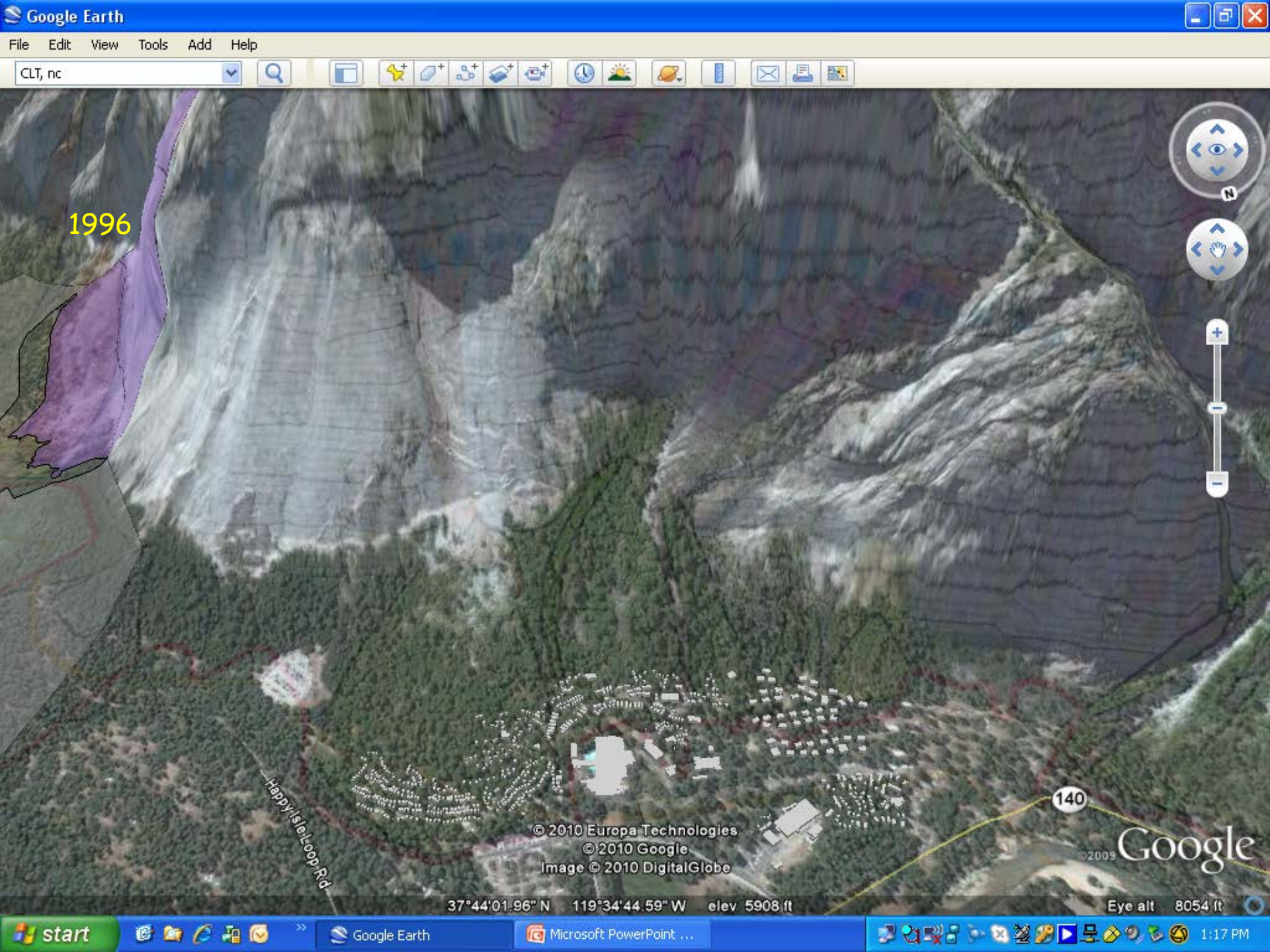
Aerial LiDAR shaded relief image overlain in Google Earth

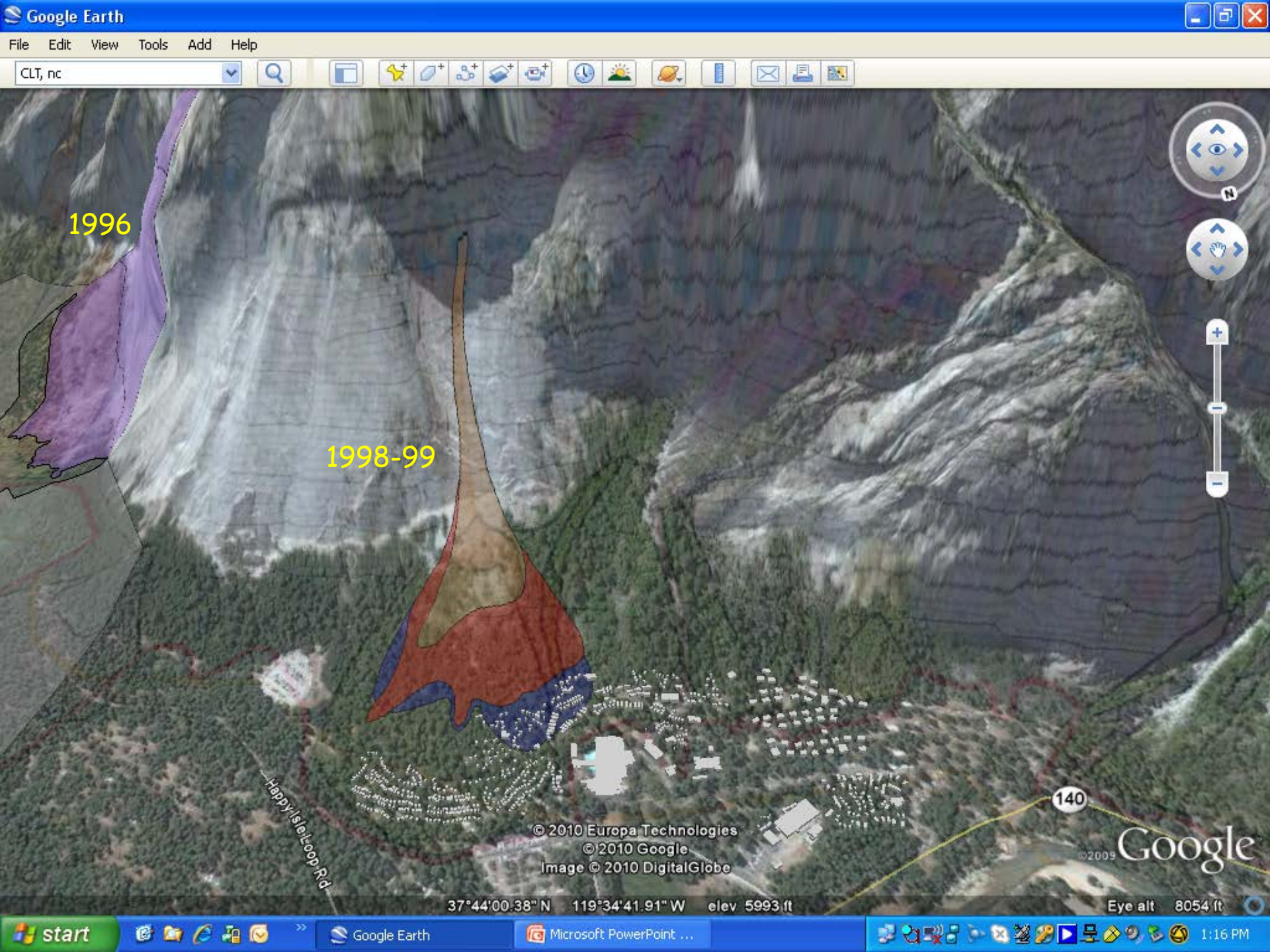


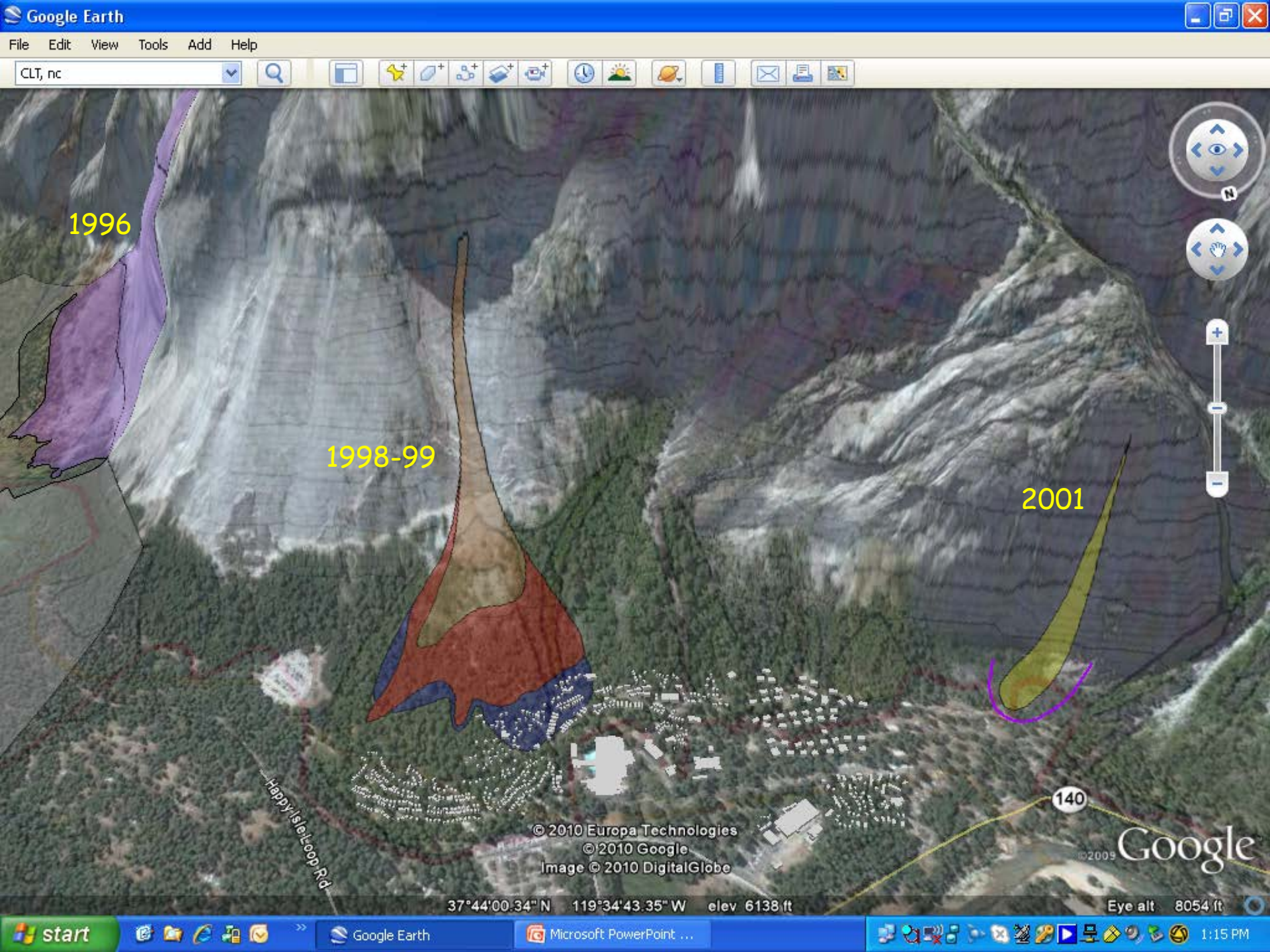
Rockfall damage & injuries in Yosemite Valley below Glacier Point 1996 - 2008

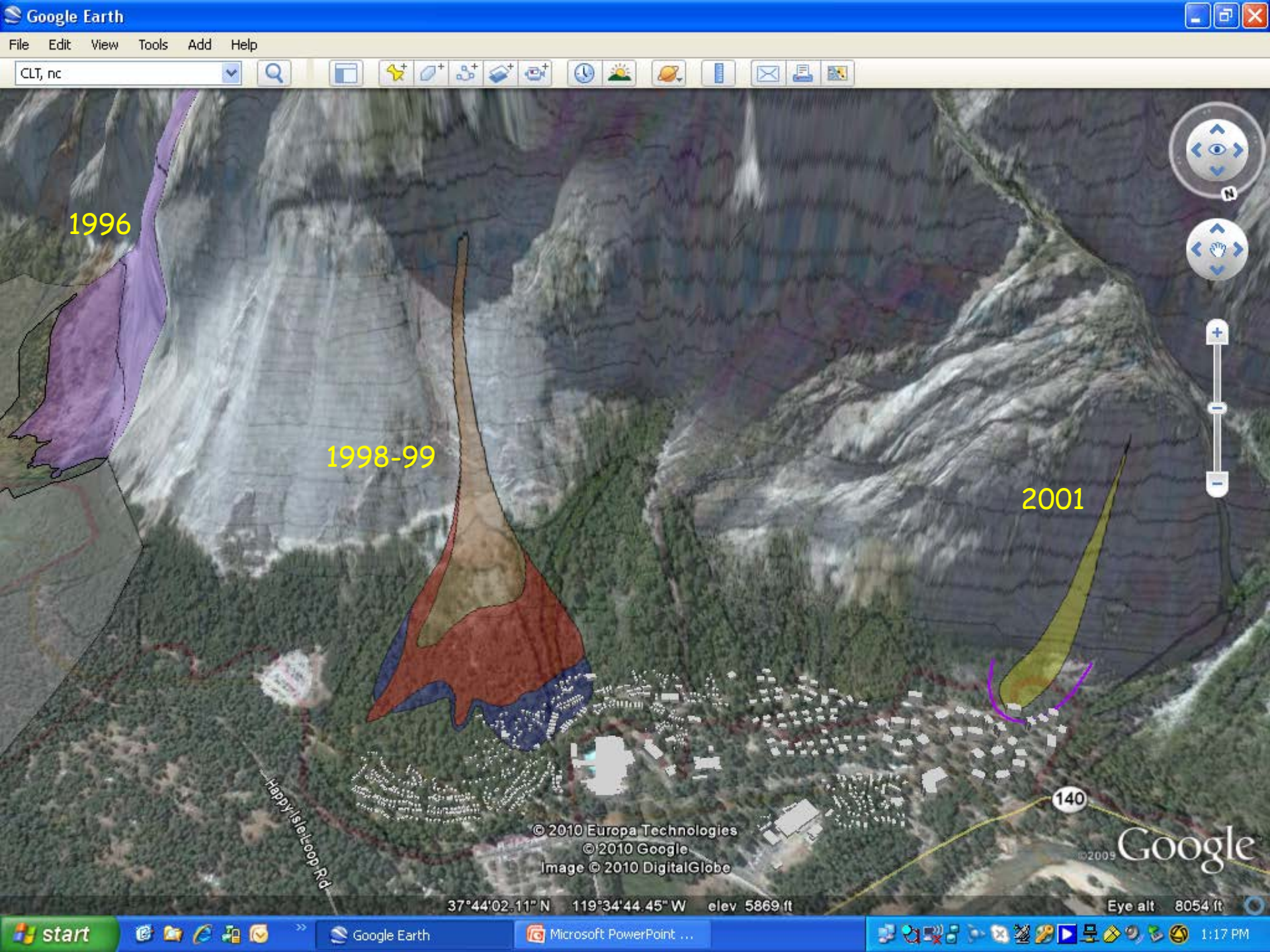


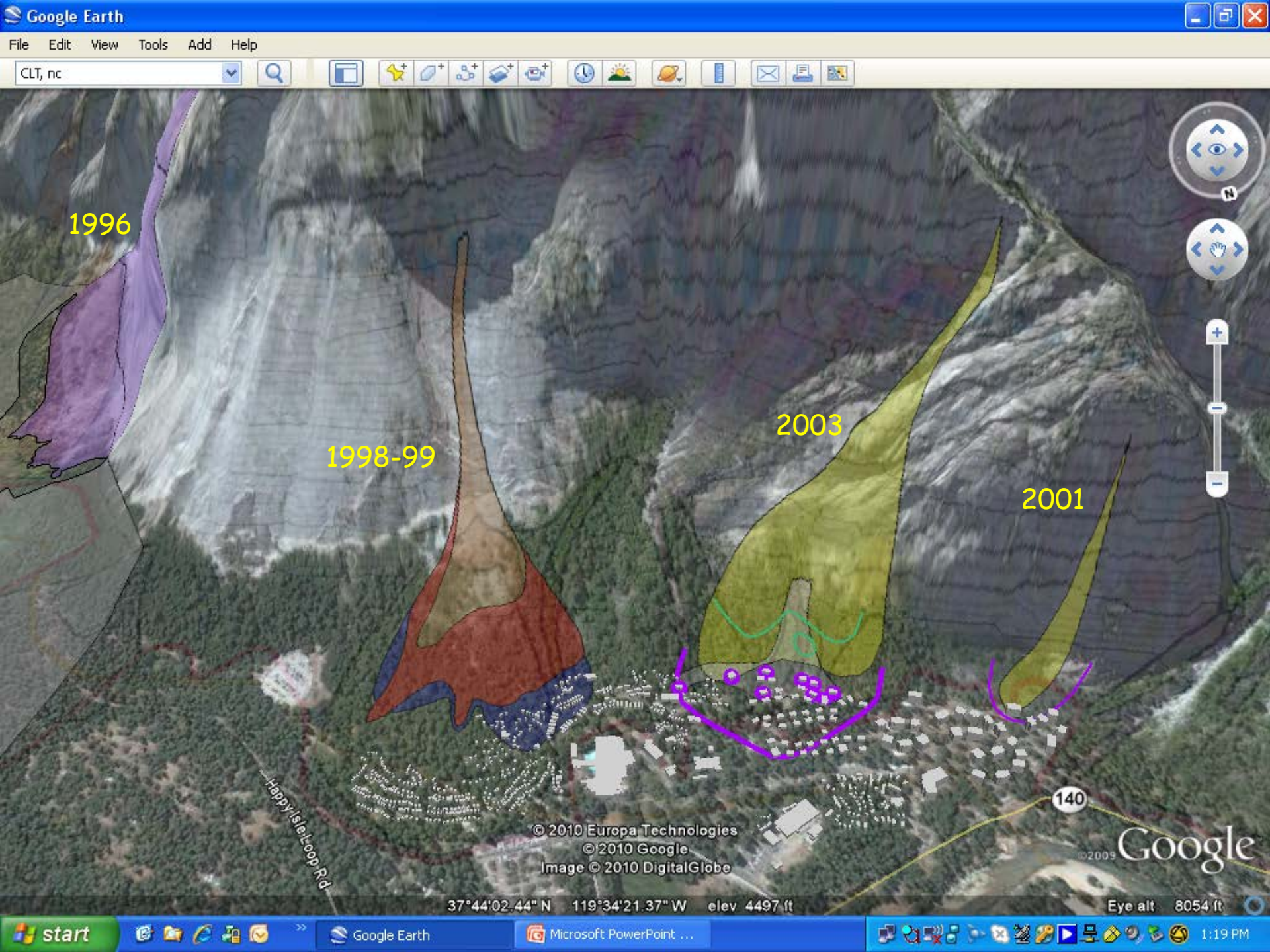

Google Earth
File Edit View Tools Add Help
CLT, nc
1996 – 2008
Each rockfall has its own story
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'01.68" N 119°34'41.77" W elev 5888 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:23 PM

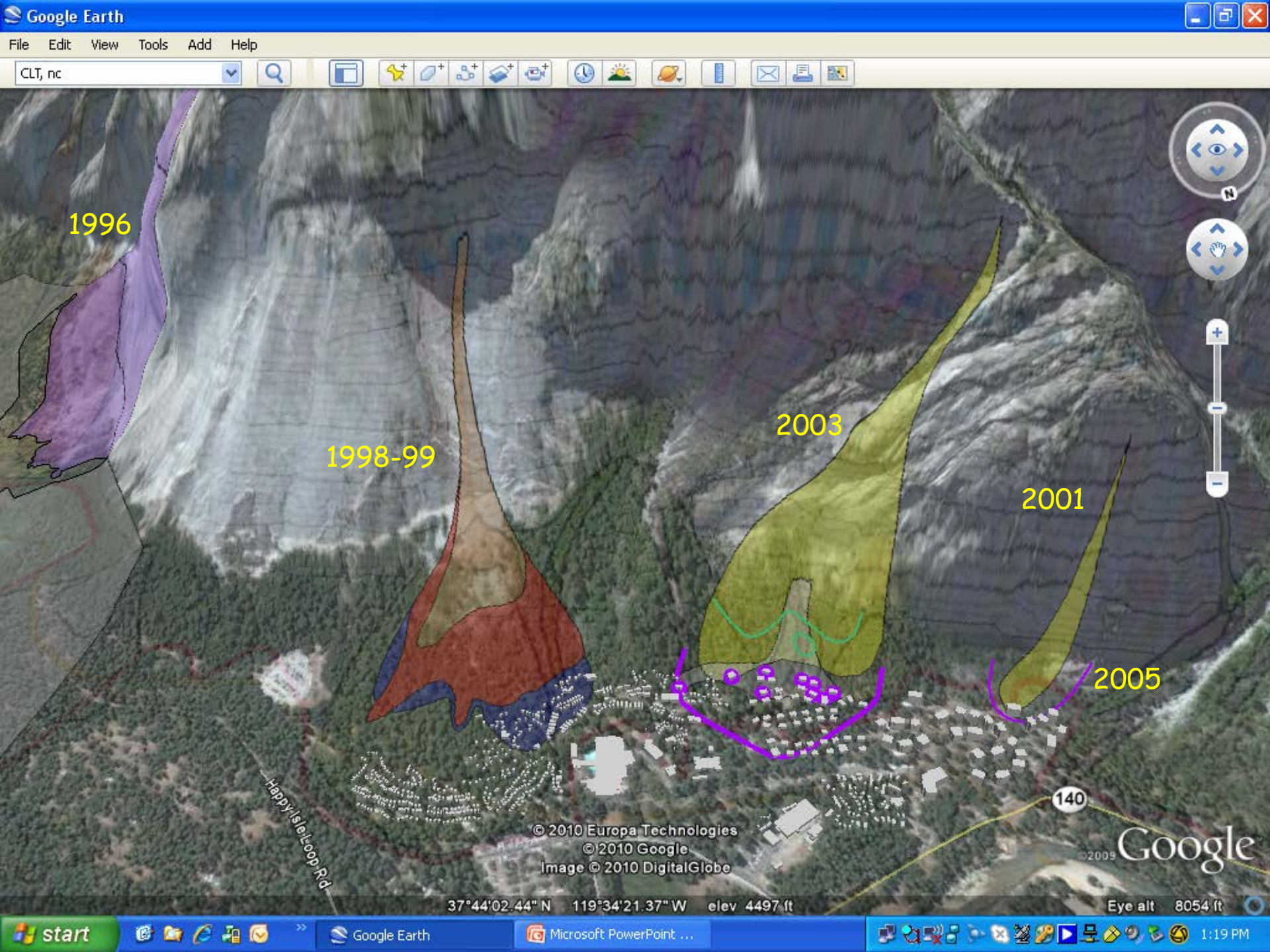

Google Earth
File Edit View Tools Add Help
CLT, nc
1996
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'01.96" N 119°34'44.59" W elev 5908 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:17 PM

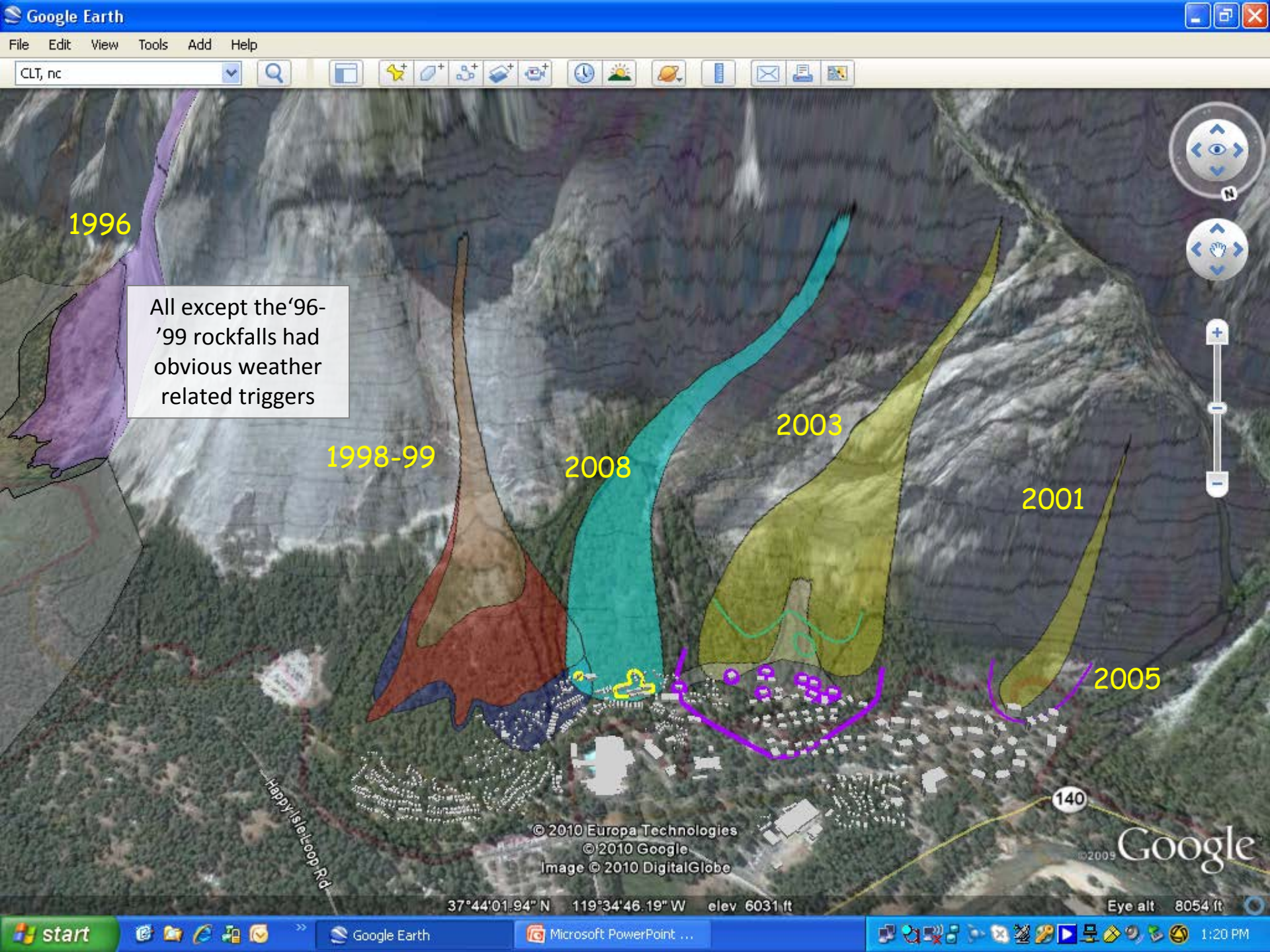

Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'00.38" N 119°34'41.91" W elev 5993 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:16 PM

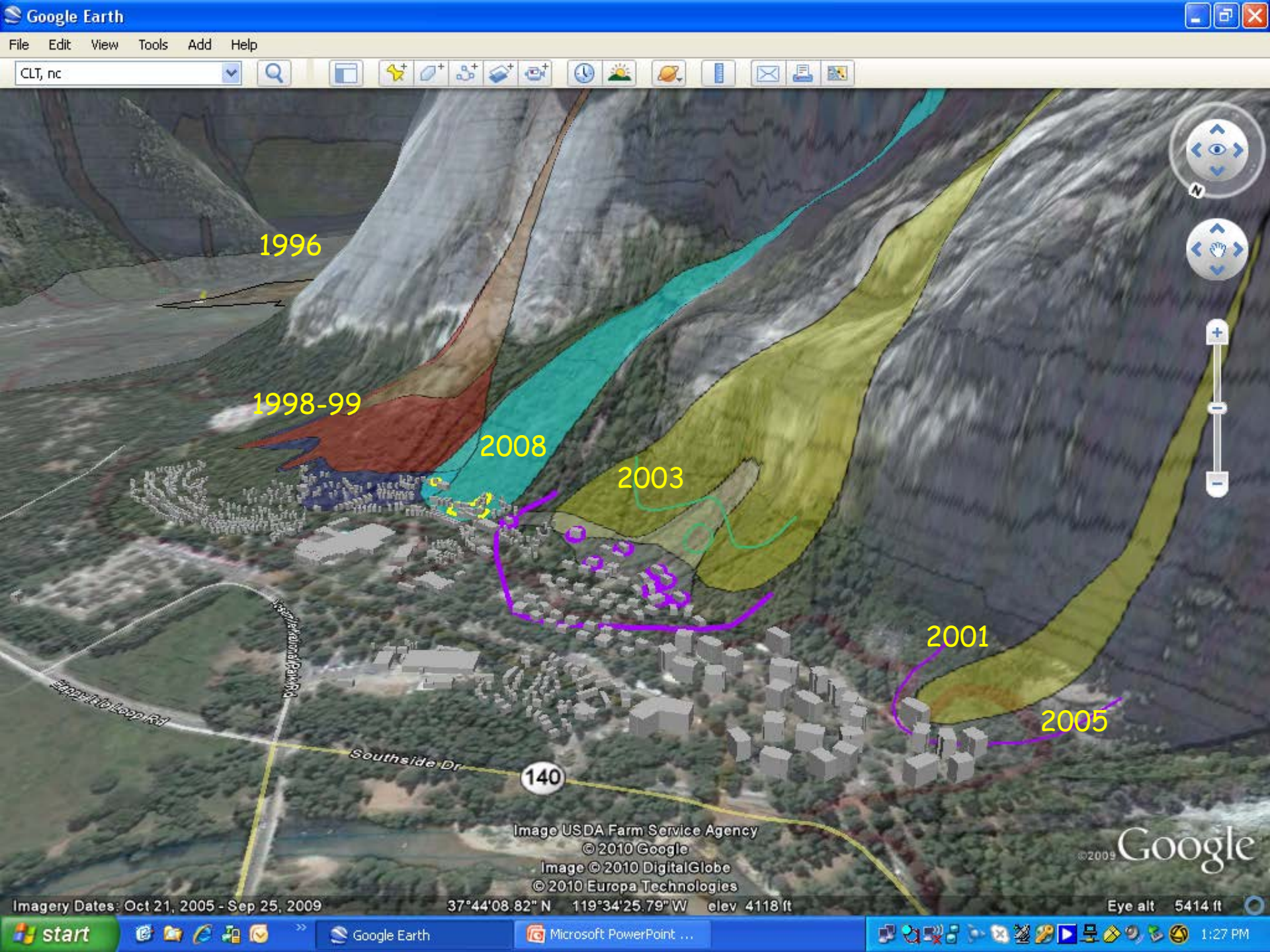

Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
2001
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'00.34" N 119°34'43.35" W elev 6138 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:15 PM


Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
2001
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'02.11" N 119°34'44.45" W elev 5869 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:17 PM

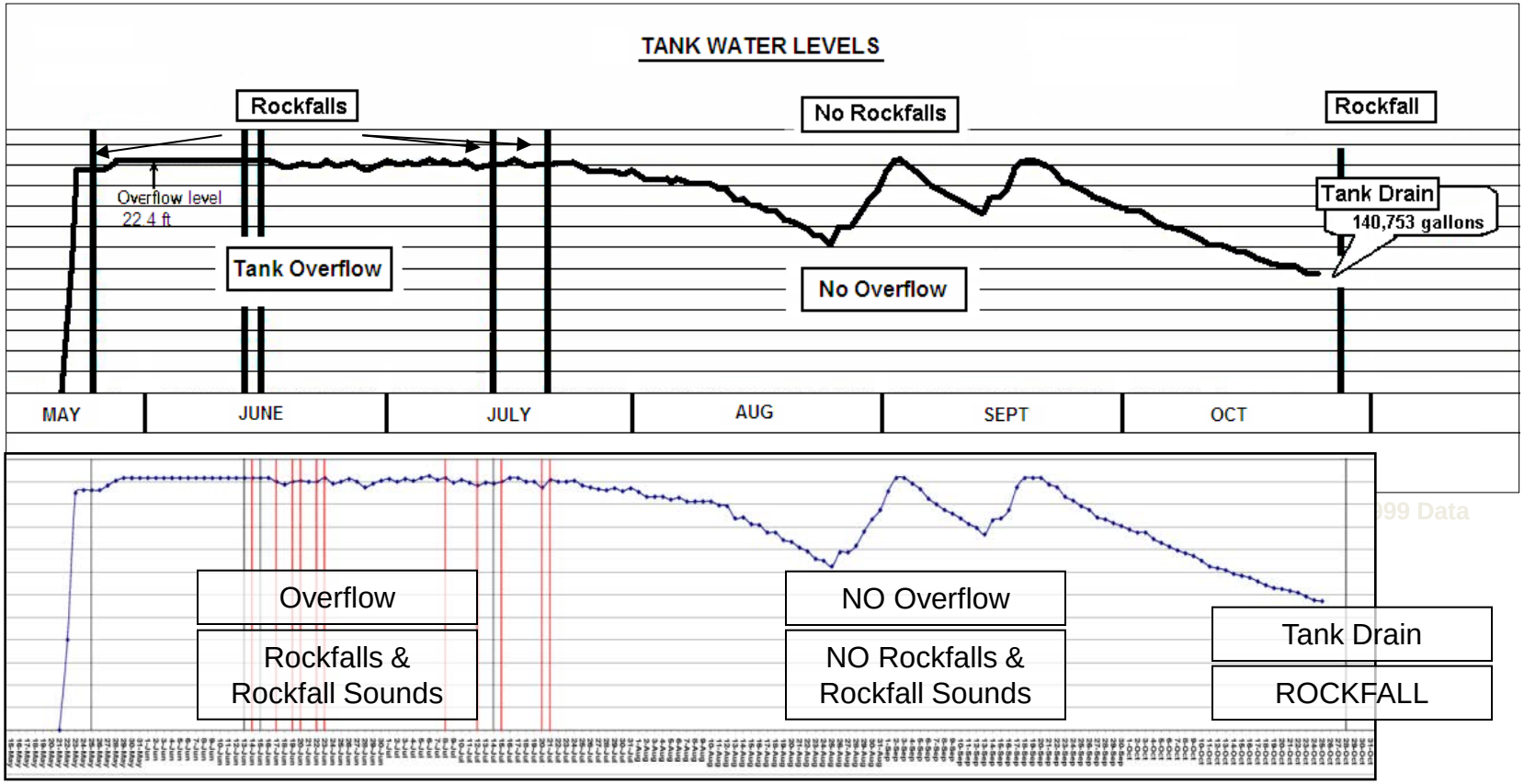

Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
2003
2001
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'02.44" N 119°34'21.37" W elev 4497 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:19 PM


Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
2003
2001
2005
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'02.44" N 119°34'21.37" W elev 4497 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:19 PM


Google Earth
File Edit View Tools Add Help
CLT, nc
1996
All except the'96-'99 rockfalls had obvious weather related triggers
1998-99
2008
2003
2001
2005
Happy Isle Loop Rd
140
© 2010 Europa Technologies
© 2010 Google
Image © 2010 DigitalGlobe
Google
37°44'01.94" N 119°34'46.19" W elev 6031 ft
Eye alt 8054 ft
start
Google Earth
Microsoft PowerPoint ...
1:20 PM


Google Earth
File Edit View Tools Add Help
CLT, nc
1996
1998-99
2008
2003
2001
2005
Southside Dr
140
Image USDA Farm Service Agency
© 2010 Google
Image © 2010 DigitalGlobe
© 2010 Europa Technologies
Google
Imagery Dates: Oct 21, 2005 - Sep 25, 2009
37°44'08.82" N 119°34'25.79" W elev 4118 ft
Eye alt 5414 ft
start
Google Earth
Microsoft PowerPoint ...
1:27 PM

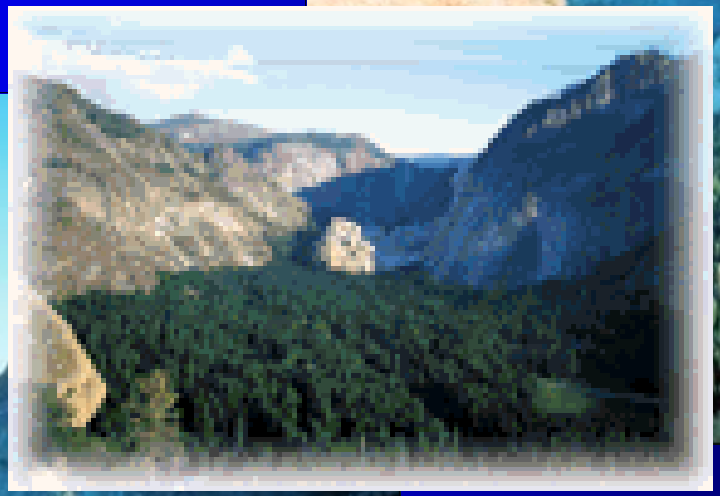
Unfortunately, the rockfall timing in 1996, 1998-1999 matched periods of wastewater discharge from visitors' facilities on top of Glacier Point



Rockfall events compared to tank overflow (top). Rockfalls & rockfall sounds compared to tank overflow, event data from Snyder 1999, Report to Chief Ranger Andrew (bottom)

Yosemite rockslides:

The July 10, 1996
Happy Isles event



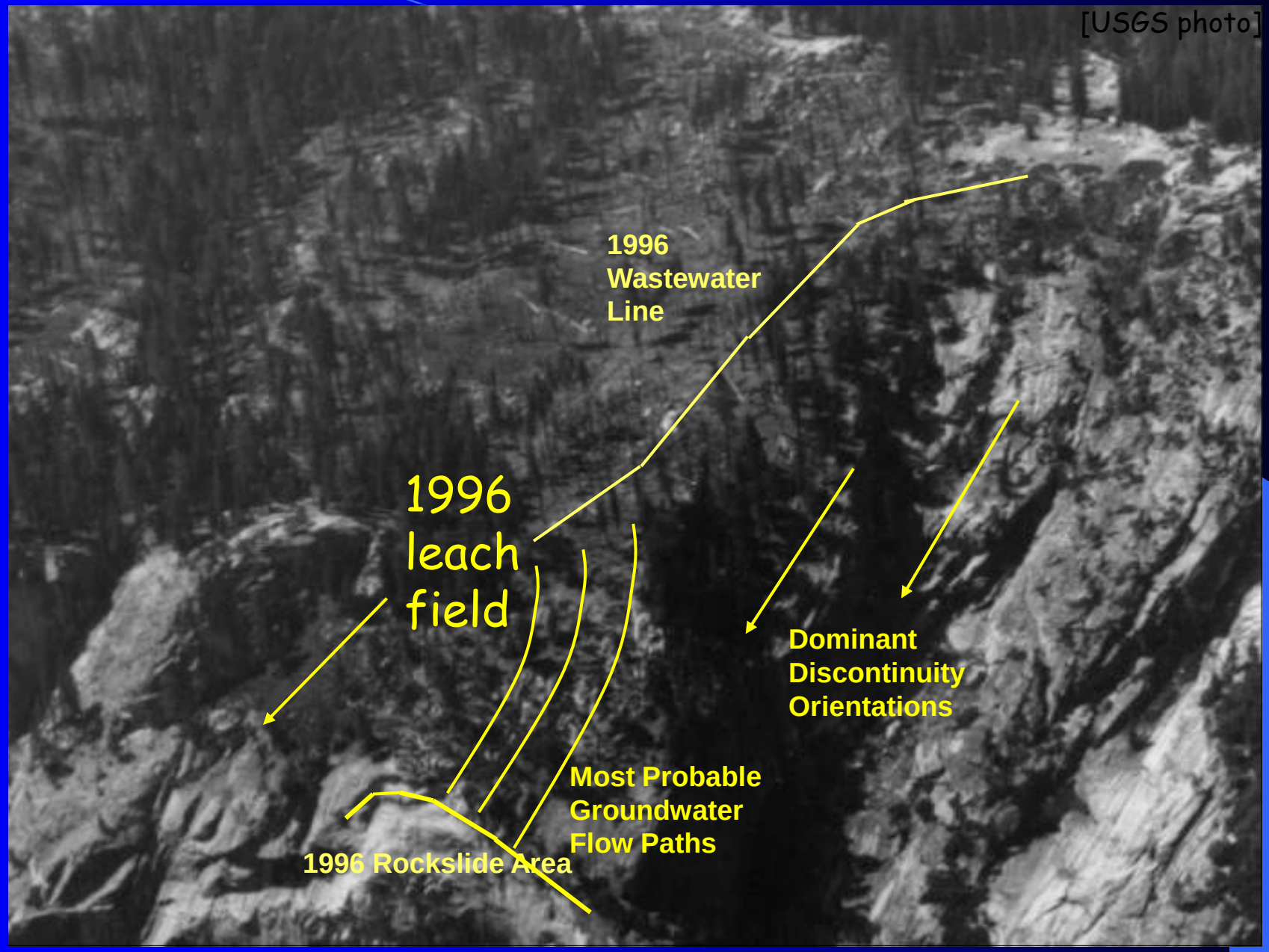
[photos by David F. Walter]

Happy Isles effects…

USGS photos

Wastewater management above the slide area…

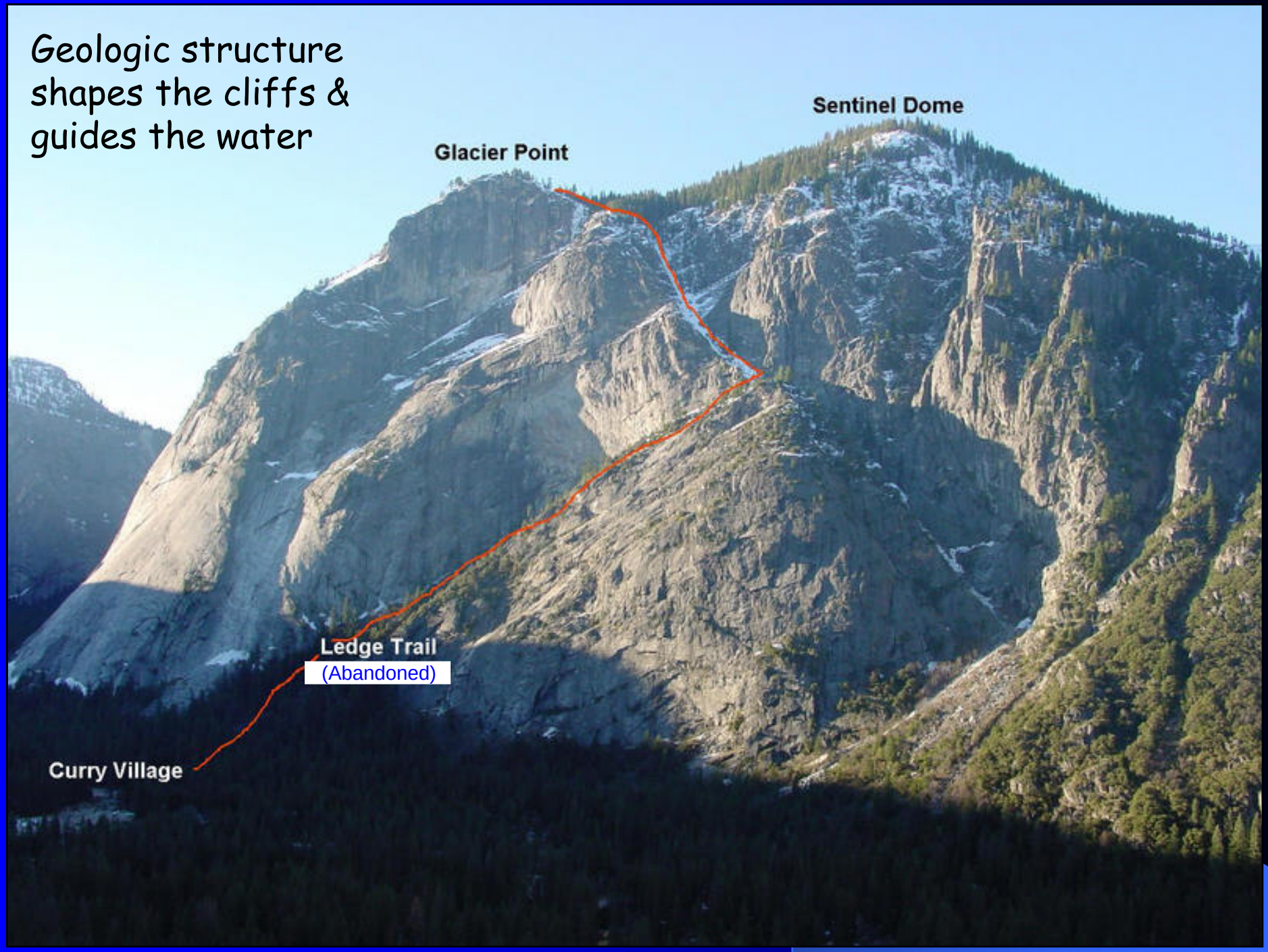
1996 leach field area (in August 1997)


[USGS photo]
1996
Wastewater
Line
1996
leach
field
Dominant
Discontinuity
Orientations
Most Probable
Groundwater
Flow Paths
1996 Rockslide Area

Seepage points at the release area, 1996

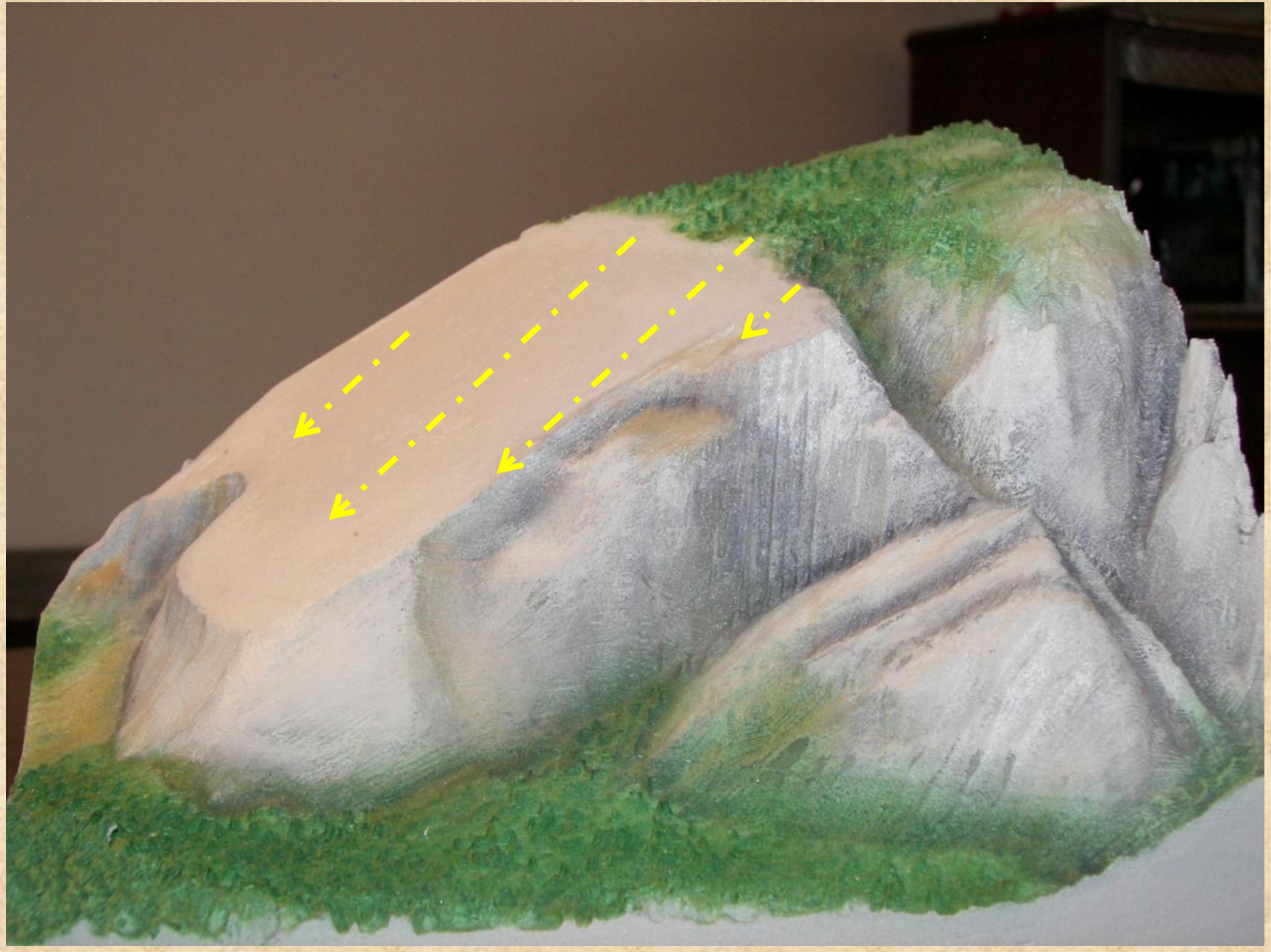
[USGS photo]

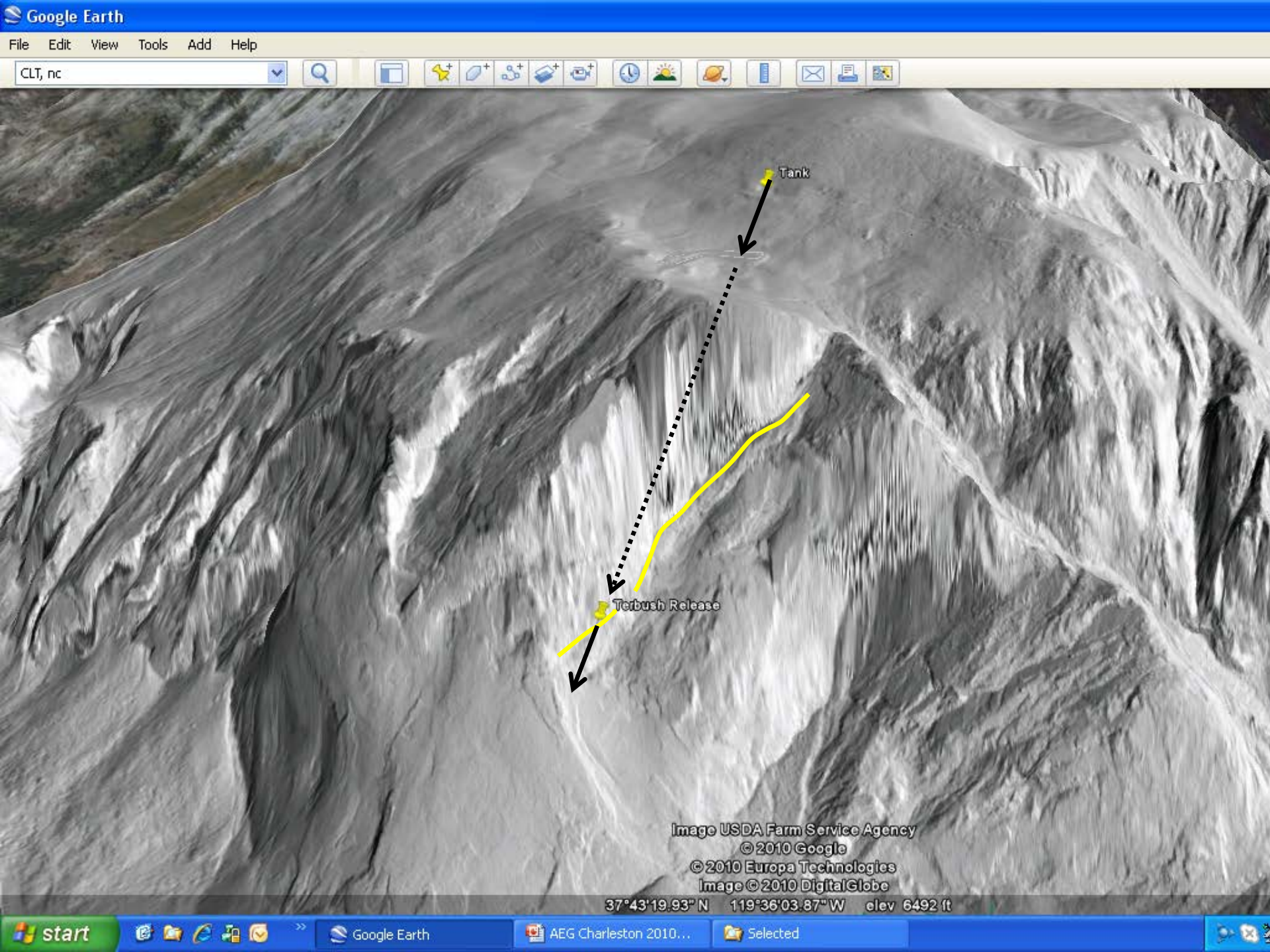
Geologic structure shapes the cliffs & guides the water

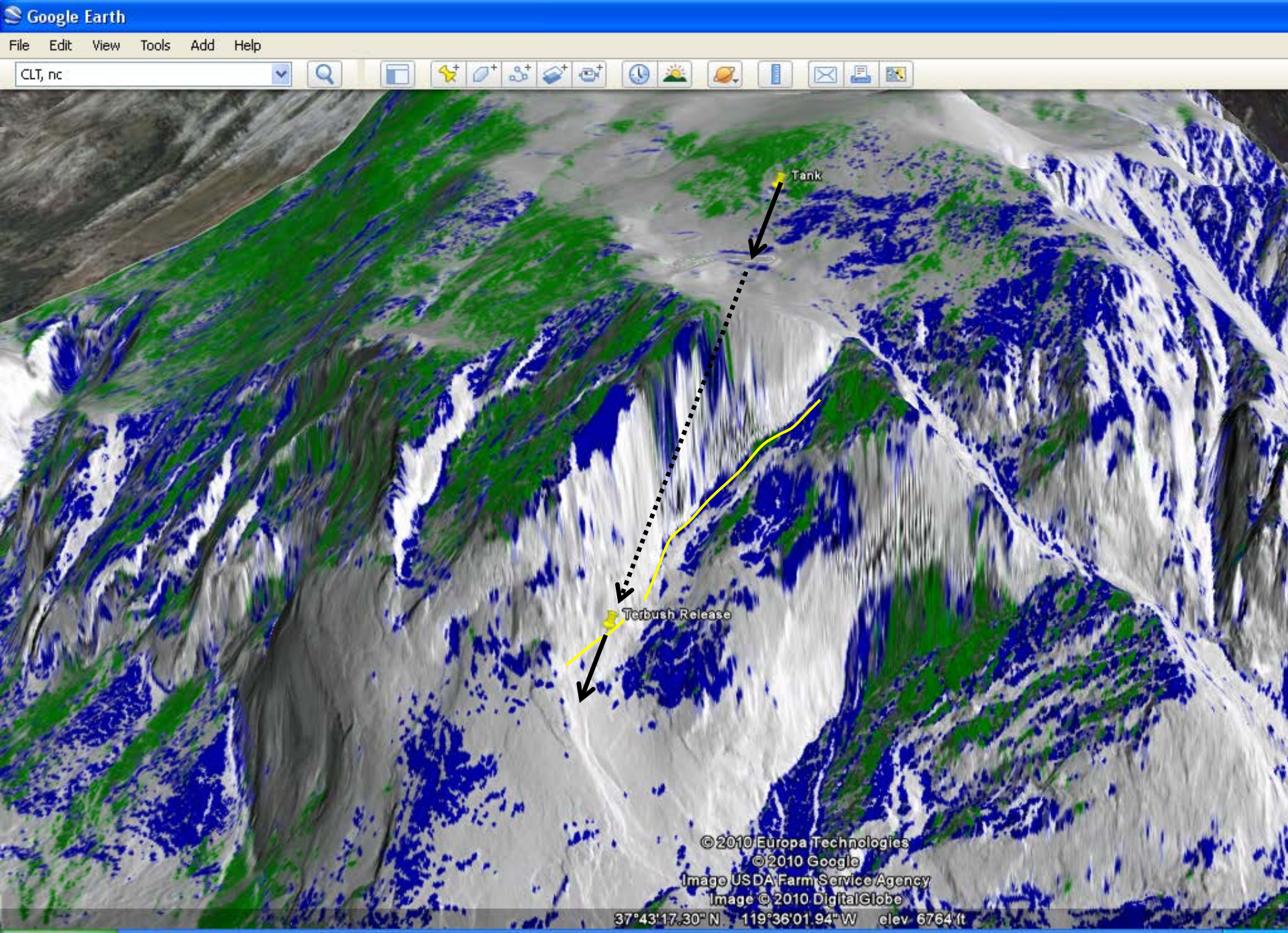



Glacier Point, Yosemite National Park
(modified from USGS Photo)
Drainage area
Apparent dips, not true dips
Groundwater Flow Paths
J2 fractures
1998-99
Release Area


1998-99 rockfall source
Terbush Discontinuity




Google Earth
File Edit View Tools Add Help
CLT, nc
Tank
Terbush Release
Image USDA Farm Service Agency
© 2010 Google
© 2010 Europa Technologies
Image © 2010 DigitalGlobe
37°43'19.93" N 119°36'03.87" W elev 6492 ft
start
Google Earth
AEG Charleston 2010...
Selected


Google Earth
File Edit View Tools Add Help
CLT, nc
Tank
Terbush Release
© 2010 Europa Technologies
© 2010 Google
Image USDA Farm Service Agency
Image © 2010 DigitalGlobe
37°43'17.30" N 119°36'01.94" W elev 6764 ft
start
Google Earth
AEG Charleston 2010...
Selected

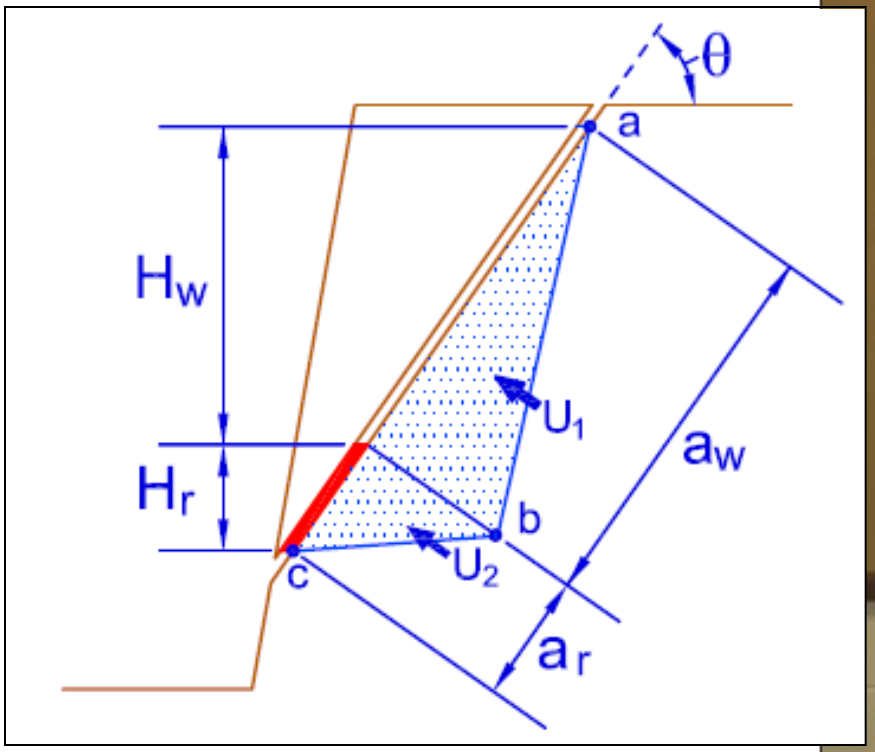
CONCLUSION

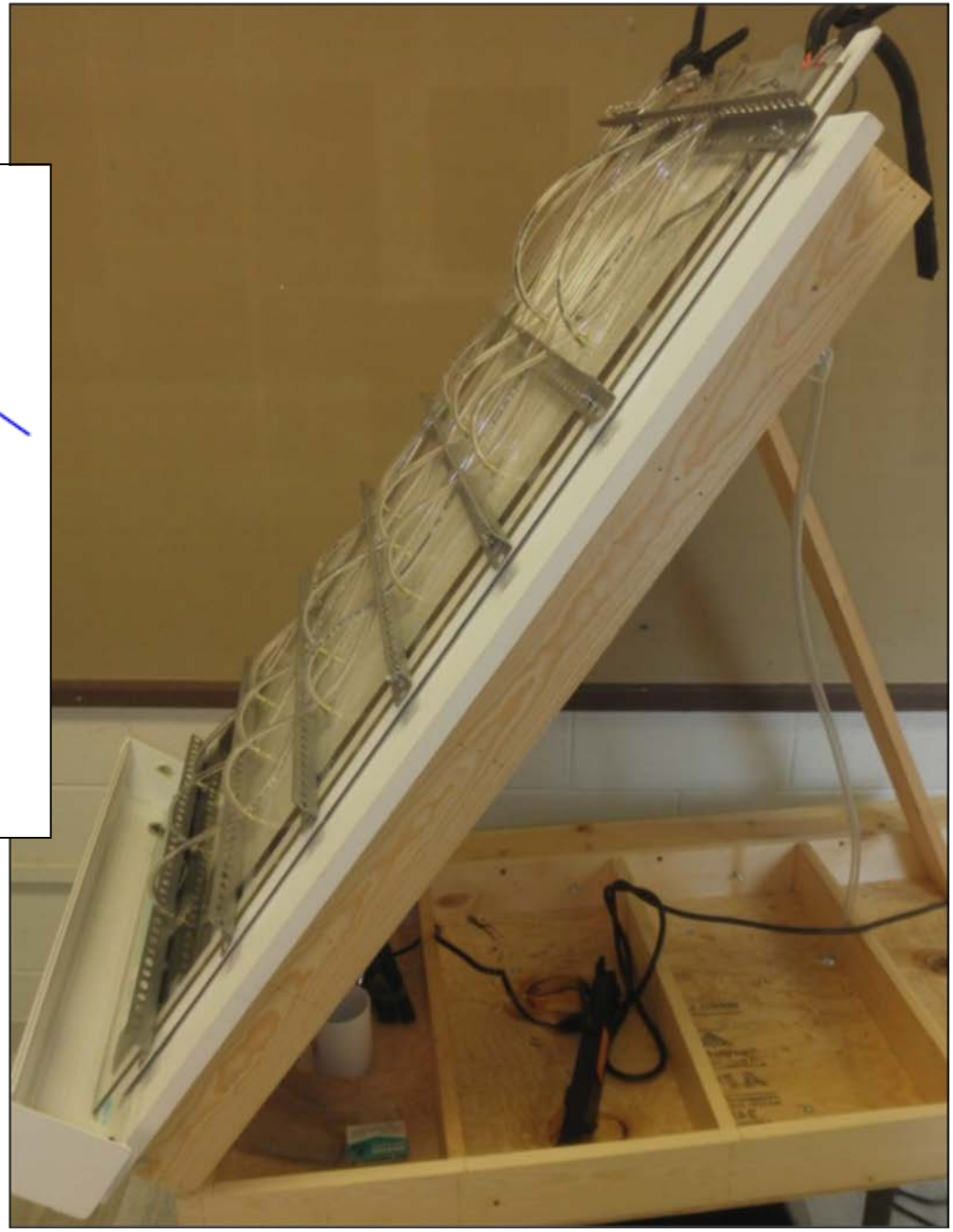
LiDAR is one of several tools that can be extremely useful under the right circumstances for obtaining geologic structure orientation data useful for evaluating the safety and stability of rock slopes

QUESTIONS ?


END OF TRAIL
DANGER
FALLING ROCKS
DO NOT GO BEYOND
THIS POINT

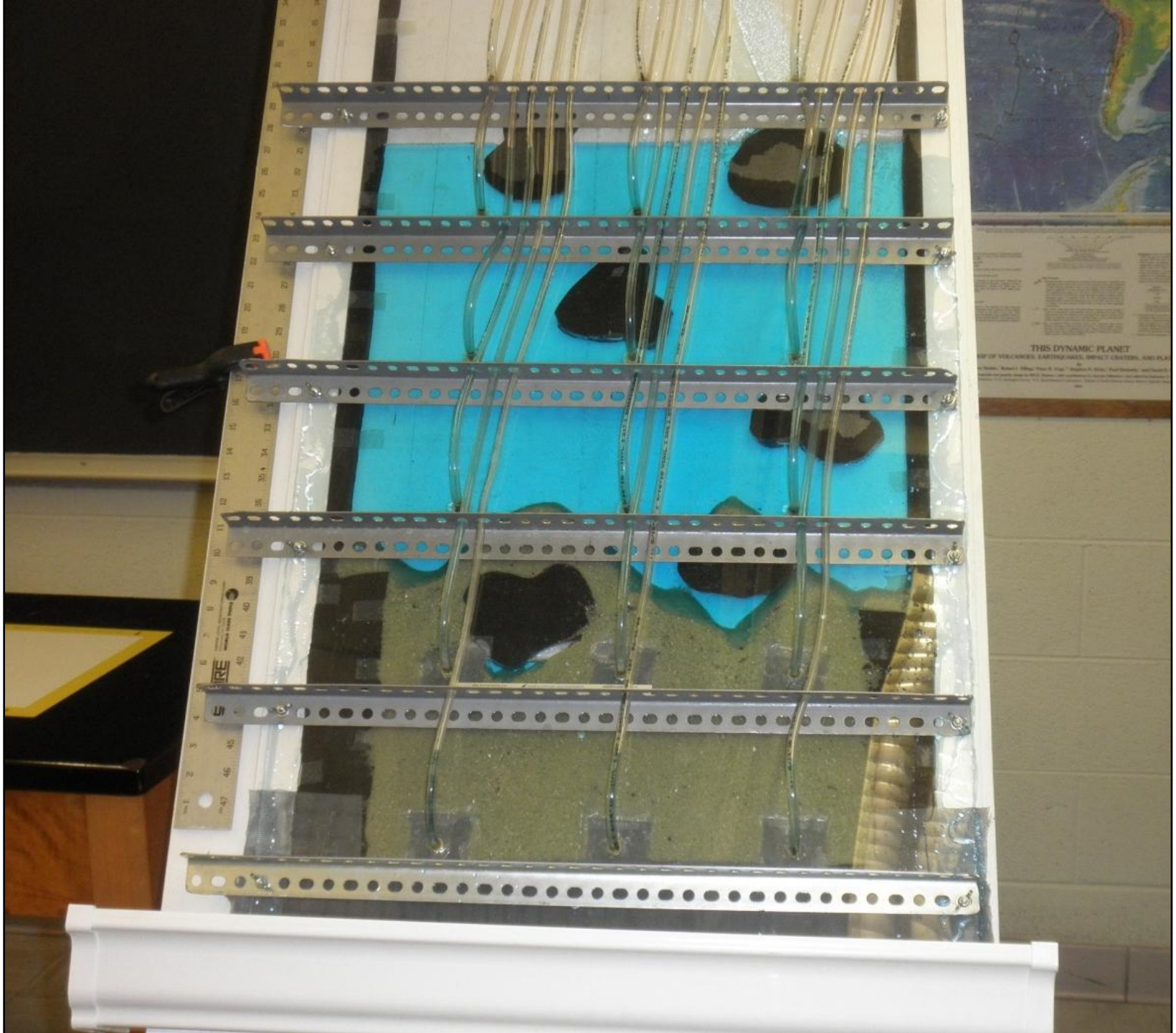
Fracture Permeameter





Parallel plates of Plexiglas

- Variable aperture & dip angle
- Variable head
- Variable infilling materials
- Piezometer tube array in top plate for measuring pressure distribution


THIS DYNAMIC PLANET