Lessons Learned from Application of Ground-Based Digital Photogrammetry to Small-scale Movement on Unstable Rock Slopes: A Case Study from Virginia's Valley and Ridge.

William L. Niemann[1]

1 – Marshall University Geology Department
Huntington, West Virginia 25701

Digital photogrammetry presented here is a supplemental part of a larger project:

"Sinkhole Detection and Bridge/Landslide Monitoring for Transportation Infrastructure by Automated Analysis of Interferometric Synthetic Aperture Radar Images (InSAR)"

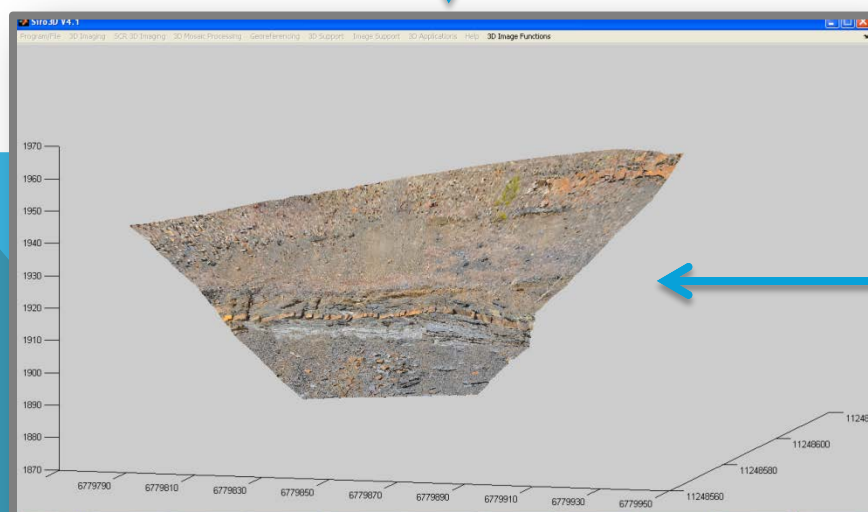
Scott Acton, *University of Virginia*
Edward Hoppe, *VTRC;* Brian Bruckno, *VDOT*
Adrian Bohane; Giacoma Farloni, TRE

Technologies Tested

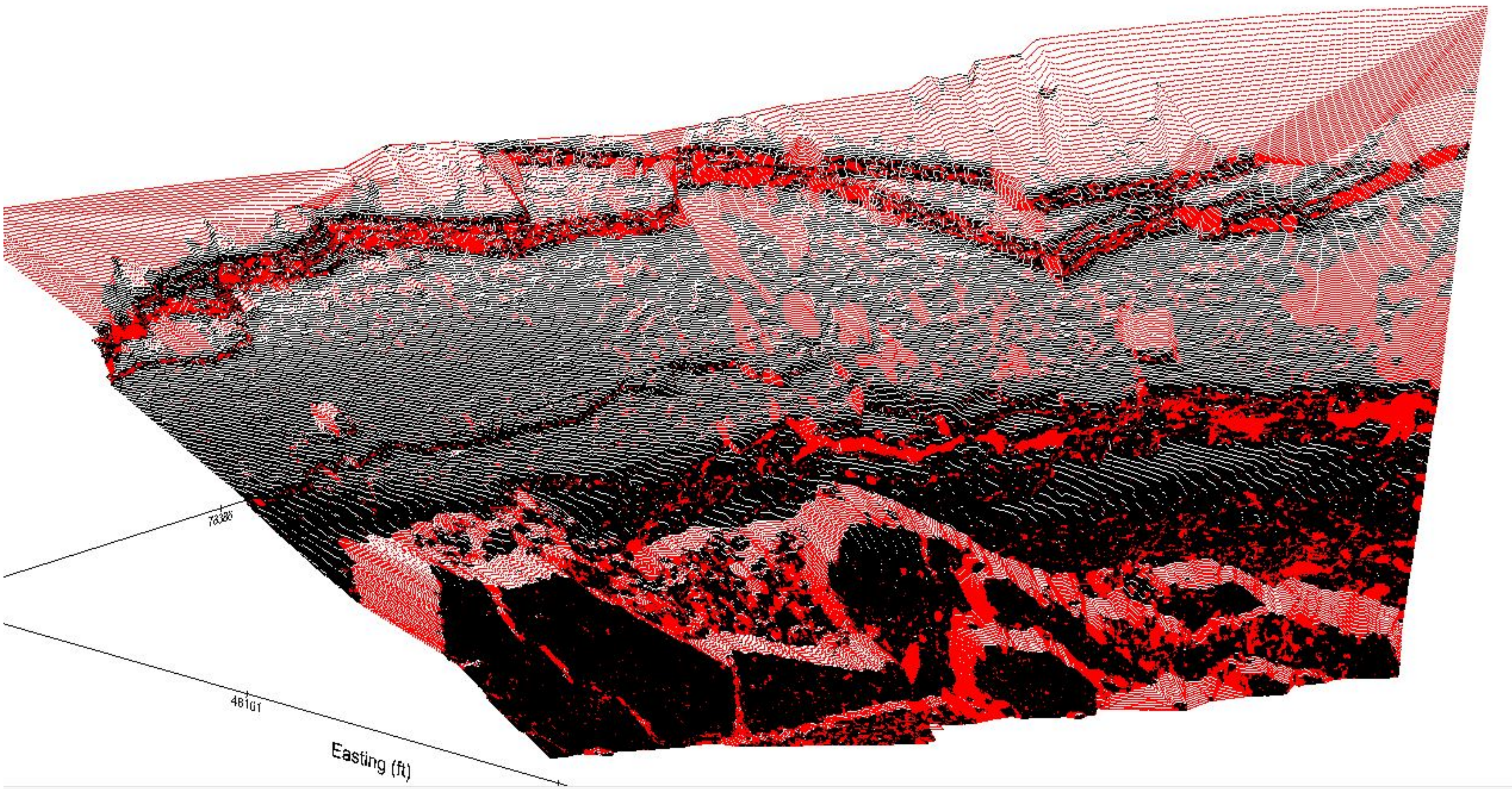
- Interferometric Synthetic Aperture Radar Images (InSAR)
- Light Detection and Ranging (LIDAR)
- Ground-based Digital photogrammetry (GBDPG)

- Digital Photogrammetry–Introduction
- Case Study
- Discussion
- Conclusions

Sirovision®



Built from 100,000+ XYZ points


48101
Easting (ft)

Uses of GBDPG:

- Developed specifically for mapping open-pit mine rock faces (Poropat, 2005, 2006)
  - Mine/quarry blasting strategies/effectiveness
  - Volume calculations

- Rock mass characterization (partial)

(e.g., roughness, wall strength, weathering, of joints should be confirmed manually)

  - Rock slope characterization/stability
  - Fracture flow
  - Underground applications: mining, tunneling, etc.

- Measuring small-scale displacement on active rock slopes (proactive monitoring)

Potential Benefits of GBDPG

- Maps large areas quickly, accurately.
- Low cost: inexpensive equipment, short field and processing times.
- Allows evaluations/measurements of inaccessible or unsafe areas.
- Permanent 3D record permits "virtual fieldwork."
- Robust 3D Model based on dense XYZ point coupled with photograph.

Limitations of DPG:

- Affected negatively by non-reflective surfaces:
  vegetation, horizon, shadow, irregularities,
  shallow slope angles, etc.
  (The above can also limit success of LIDAR)

- Software issues

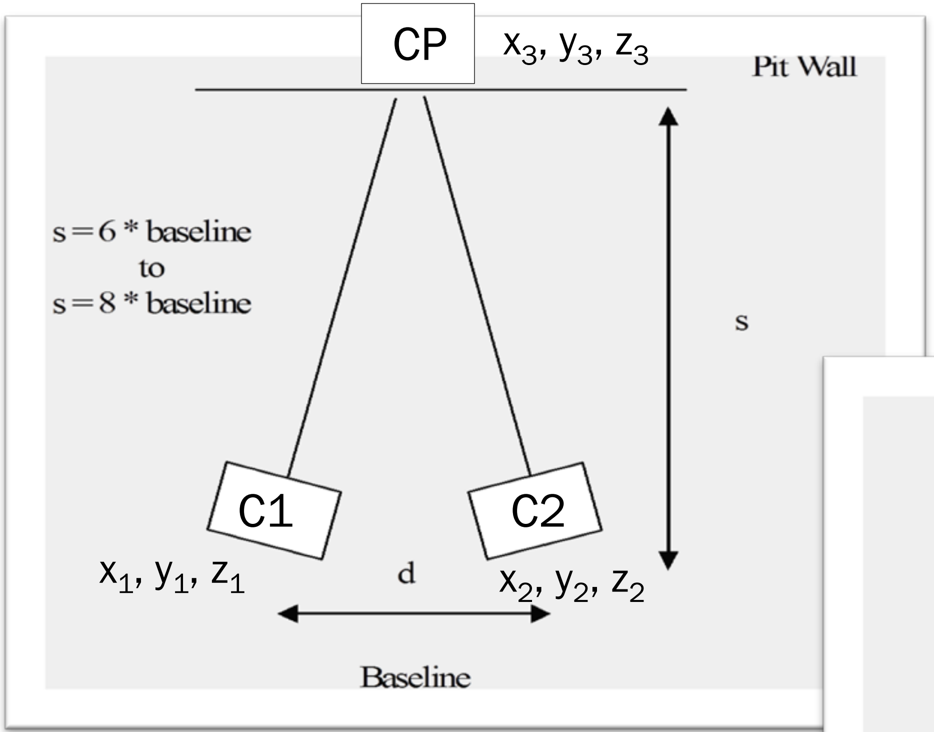
- Coordinate issues

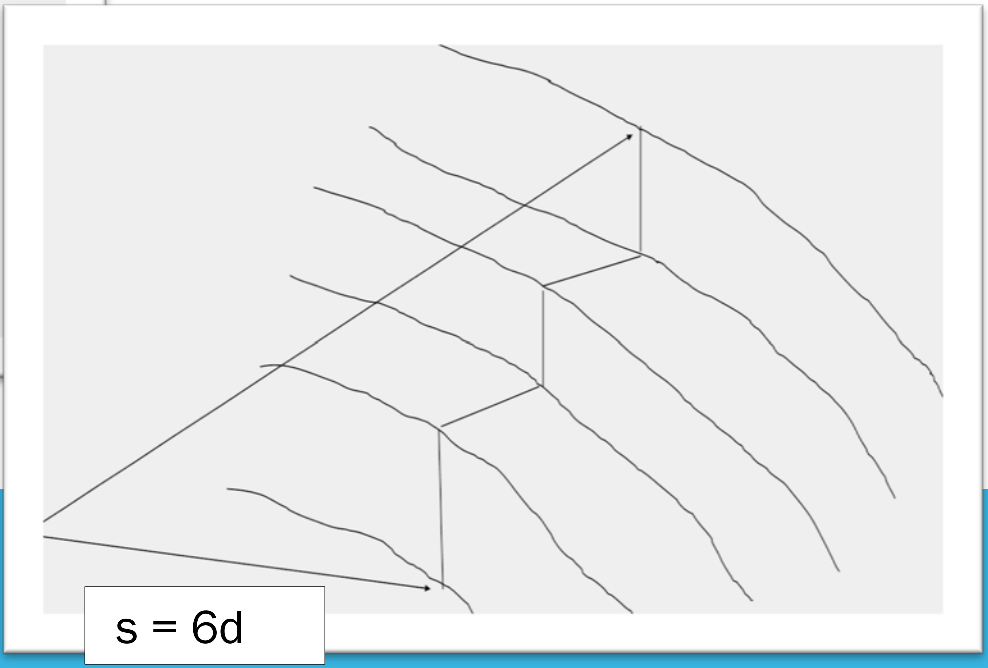
Required Resources

- DSLR Camera w/fixed-length lens(es)
  - Nikon D-90 (12.3 megapixel) w/24-mm lens
- Tripod with triaxial head and leveling plate
  - Manfrotto 460 magnesium head or equivalent
- DPG Software
  - *Sirovision®* (v. 4.1)
- Total cost ~$3,000
- +Cost of location control: surveying,

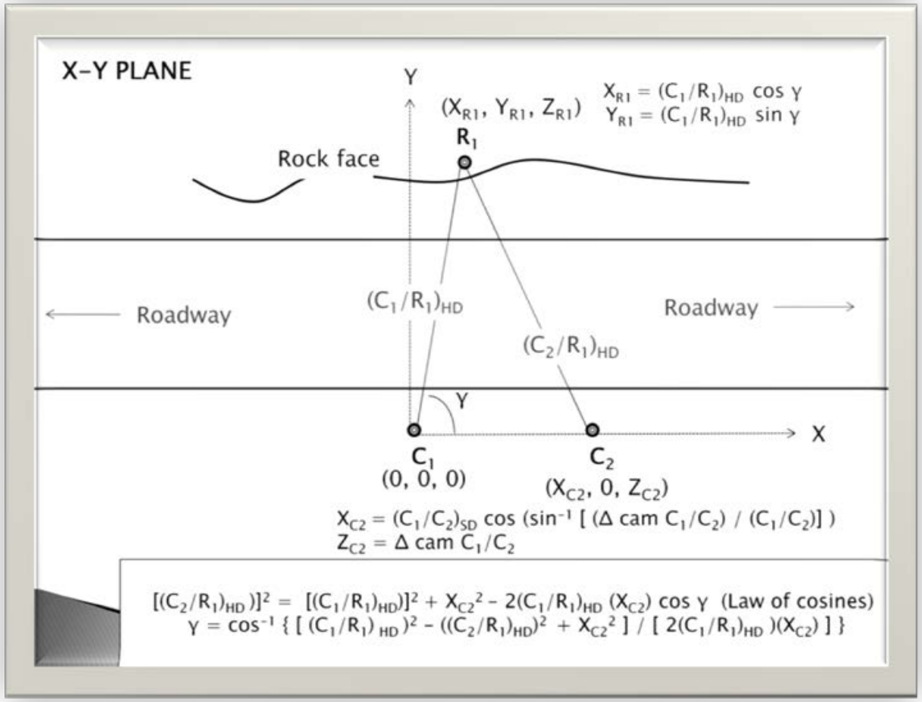
  range finder, GPS

Ground-based Digital Photogrammetry (GBDPG)



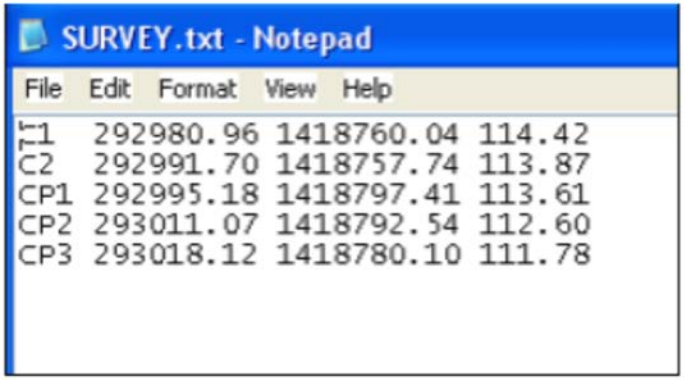


- Relative versus Absolute coordinates
- Semi-quantitative vs. Quantitative DPG



Latitude	Longitude	Northing	Easting	Elevation, ft	Code	Locality	Intuitive Name
38.18690463	-79.23869578	6751973.3930	11270600.0640	1757.771	C1	0042-001	Route 42 C1
38.18689732	-79.23866231	6751970.6540	11270609.6630	1757.602	C2	0042-001	Route 42 C2
38.18698469	-79.23851201	6752002.1230	11270653.1170	1769.104	RSF	0042-001	Route 42 Rock Slope Face
38.18684191	-79.23842806	6751949.9320	11270676.8290	1757.077	HDS1	0042-001	Route 42 HDS 1
38.18691234	-79.23896211	6751976.8150	11270523.5410	1760.525	HDS2	0042-001	Route 42 HDS 2
38.11643084	-79.44372383	6726850.7440	11211408.7510	1571.637	C1	0600-001	Route 600 C1
38.1164582	-79.44371343	6726860.6770	11211411.8450	1571.562	C2	0600-001	Route 600 C2
38.11652167	-79.44392219	6726884.4060	11211352.0260	1603.452	RSF	0600-001	Route 600 Rock Slope Face

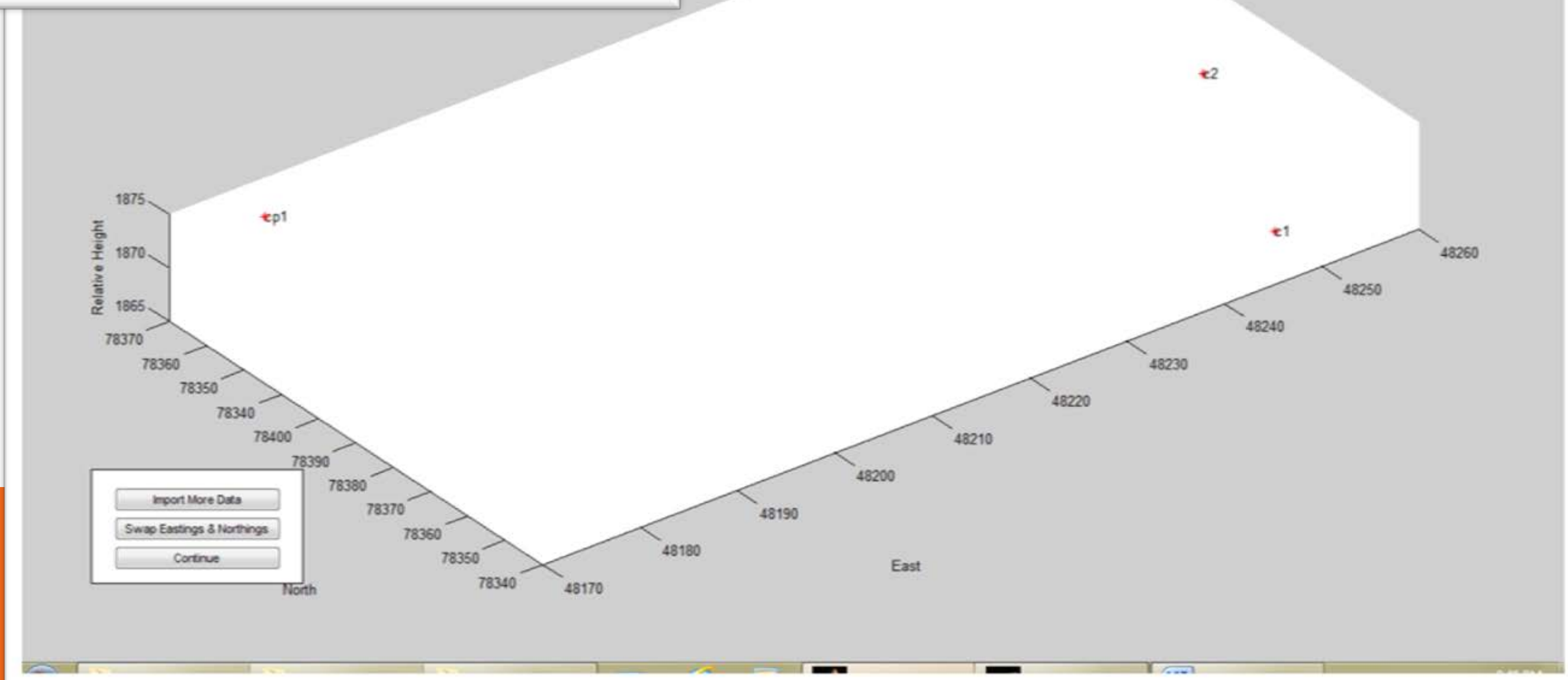
Example GBDPG Geometry



SURVEY.txt - Notepad

File Edit Format View Help

```
C1  292980.96 1418760.04 114.42
C2  292991.70 1418757.74 113.87
CP1 292995.18 1418797.41 113.61
CP2 293011.07 1418792.54 112.60
CP3 293018.12 1418780.10 111.78
```



GBDPG Geometry at Project Rock Slopes

Site	C1-C2 (ft)	C1-GCP (ft)	C2-GCP (ft)	C1 Height (ft)	C2 Height (ft)
629-001 (Lower)	26.02	83.13	83.61	5.54	5.50
629-001 (Upper)	26.02	177.02	176.11	5.54	5.50
629-002	15.97	109.46	108.29	5.42	5.29
629-003	8.75	57.50	57.04	5.04	5.29
064-001	19.54	127.15	130.10	5.21	5.13
600-001	10.41	73.21	71.98	5.00	4.96
042-001	10.02	60.93	54.36	5.08	5.17
Greenville Road	3.16	23.72	25.07	4.29	4.54

Accuracy of Method

- Point (Spatial) vs. Orientation accuracy

- How determined?
  - Theoretical
  - Controlled Environment
  - Field Environment

Published Accuracy of Method

(expressed as spatial error)

Theoretical

- 1/10,000 = 0.01%, (Shaffner et al.,2004)

Controlled environment

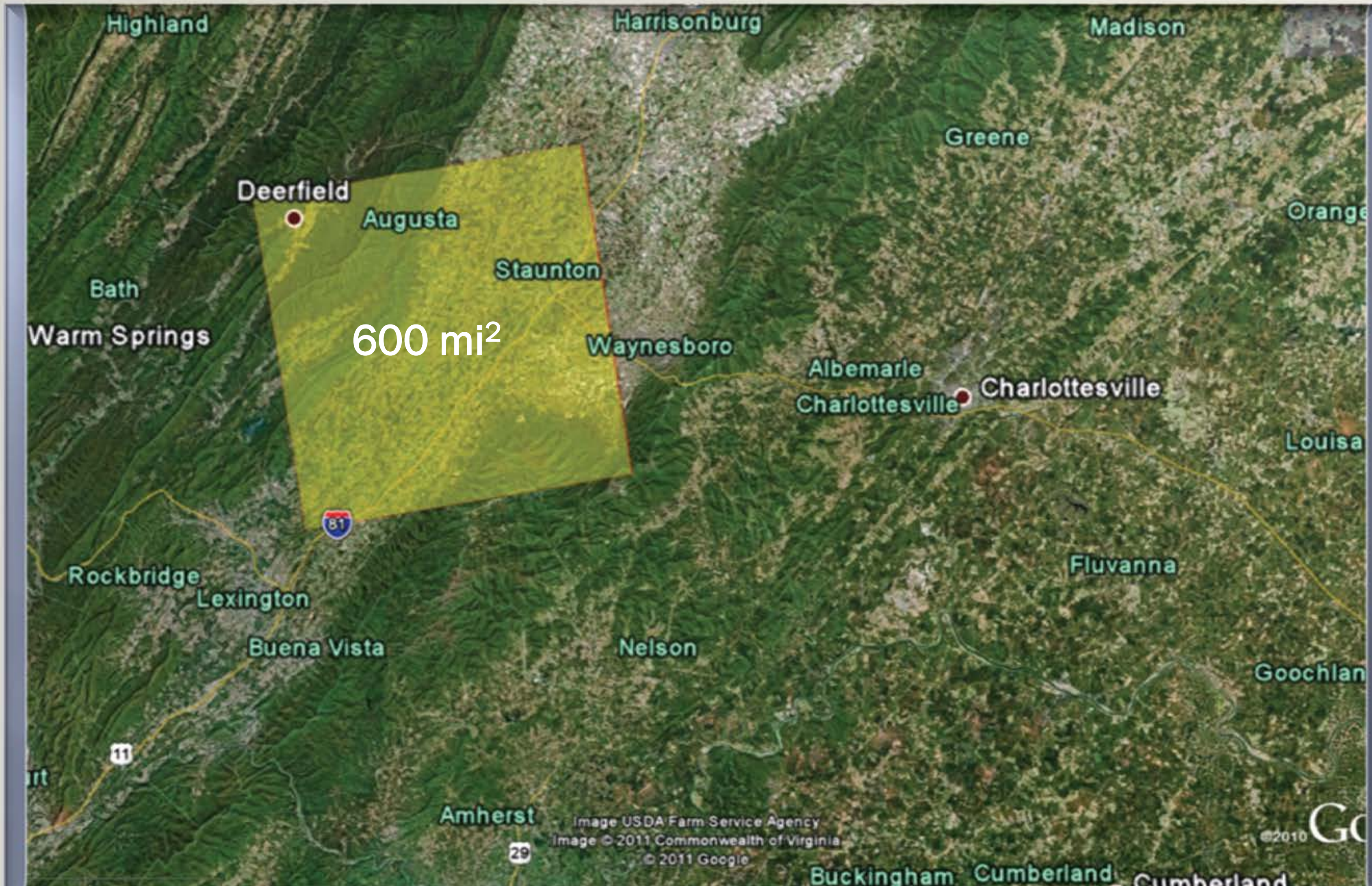
- ±5 mm/95 m (relative to theodolite) = 0.005%

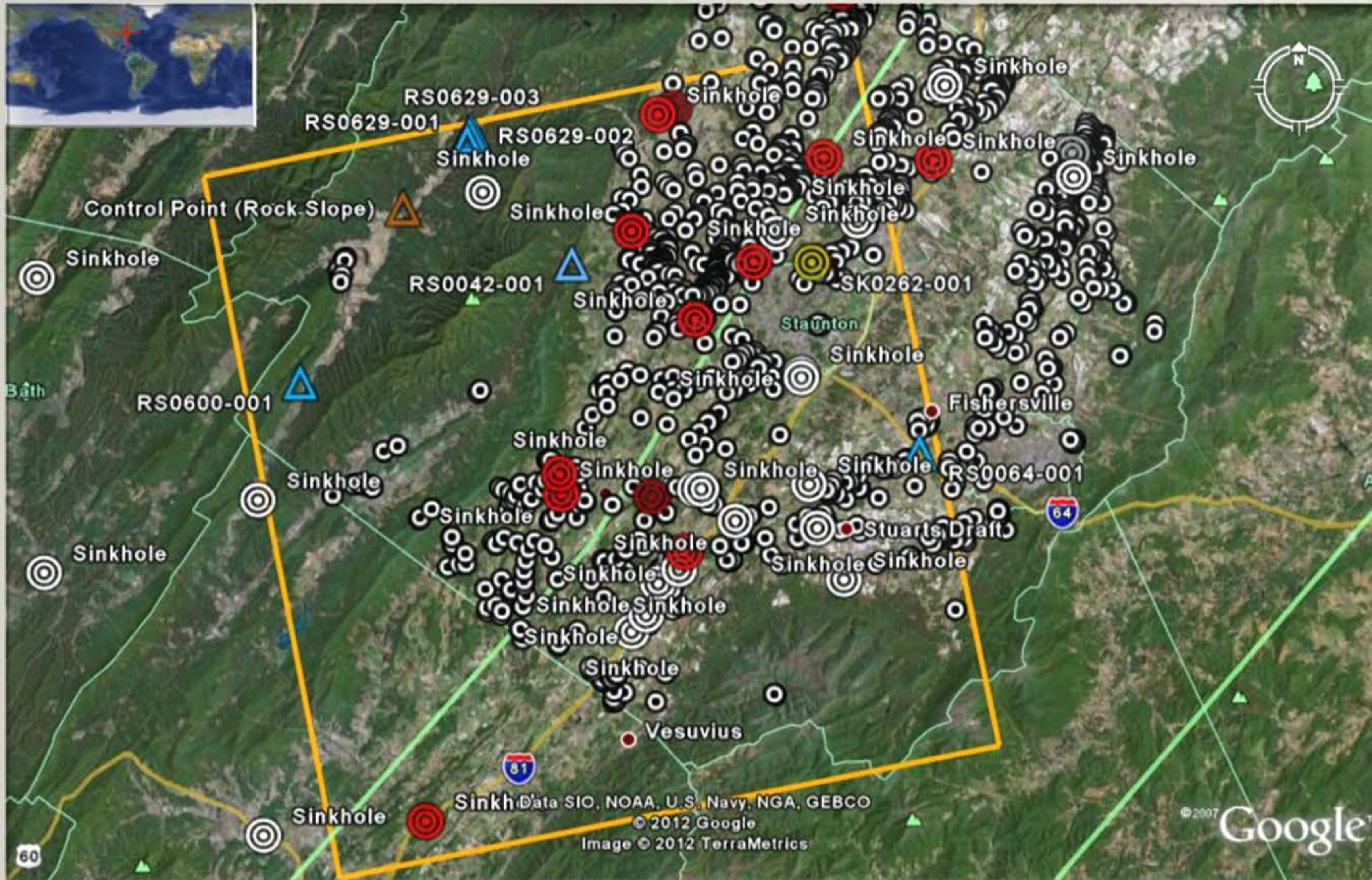
(Poropat,2005, 2006)

Field environment

- 0.7 to 4.7 in/~50 ft (relative to theodolite) = ~0.1% to ~0.8%
  - (Shaffner et al.,2004)
- 1.7 ft/500 ft (relative to theodolite) = ~0.3%
  - (Stohr et al., 2011)

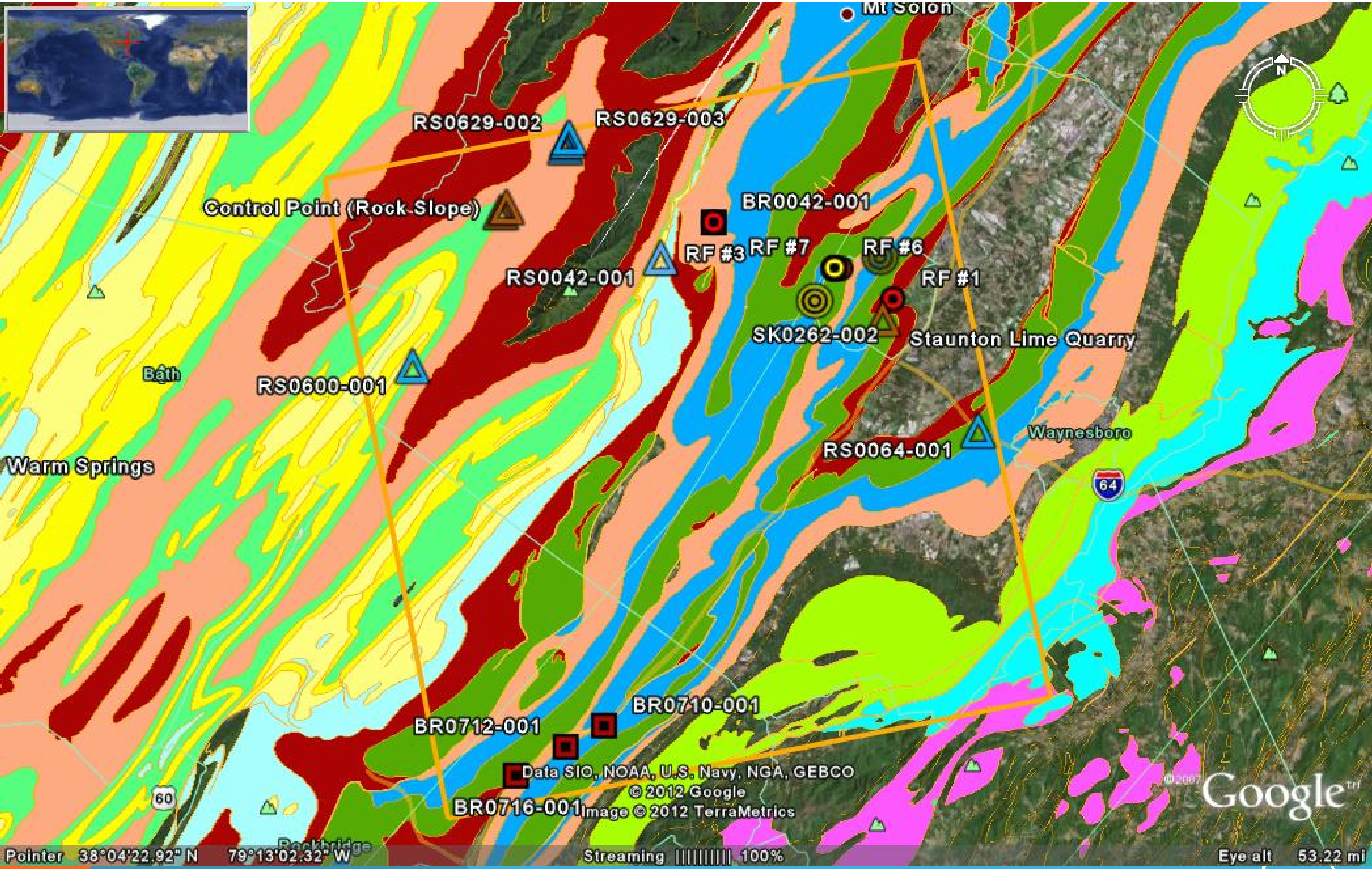
Case Study: application of GBDPG to small-scale movement on six rock slopes in Virginia’s Valley & Ridge

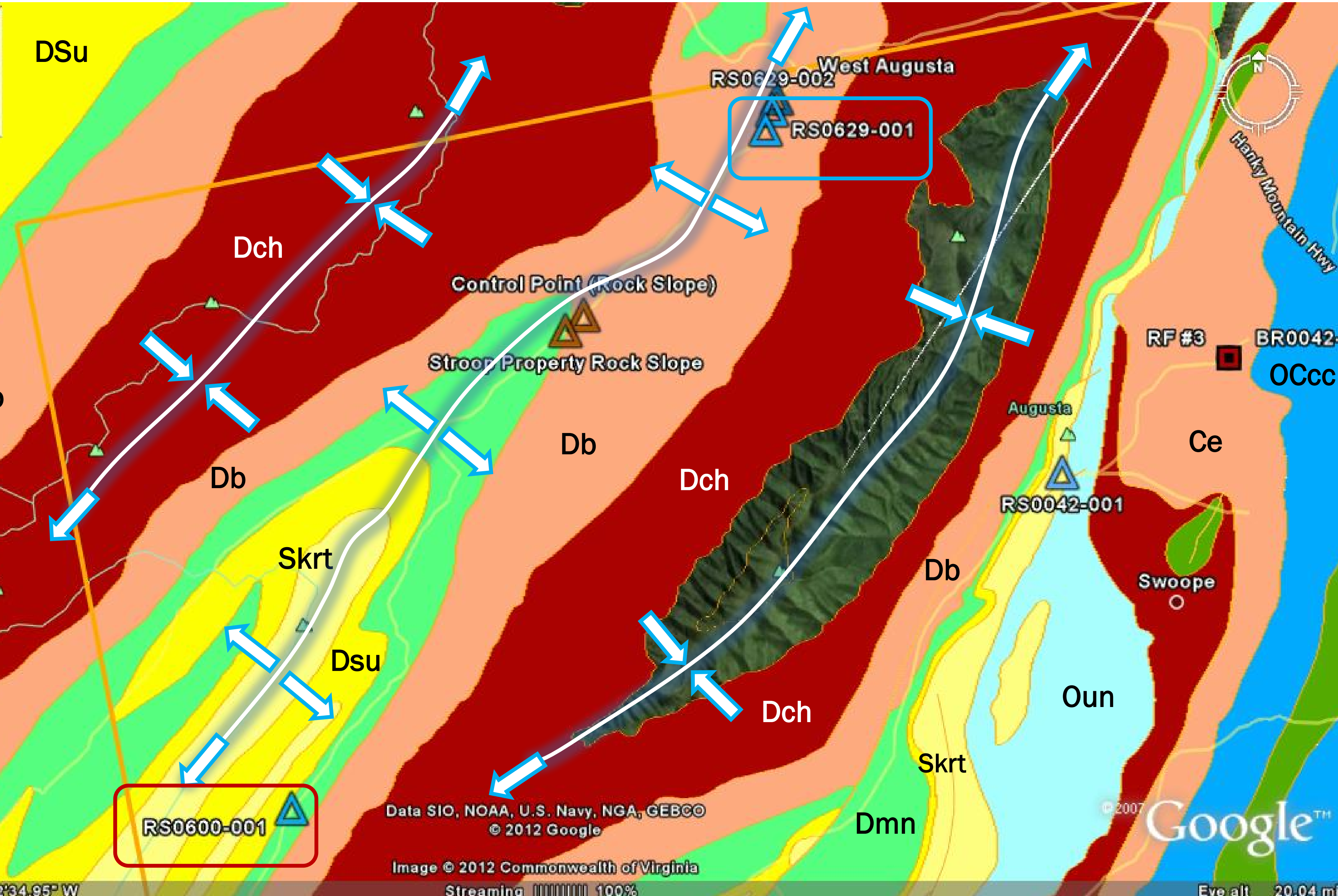

Highland
Harrisonburg
Madison
Greene
Deerfield
Augusta
Staunton
Orange
Bath
Warm Springs
600 mi²
Waynesboro
Albemarle
Charlottesville
Charlottesville
Louisa
81
Fluvanna
Rockbridge
Lexington
Buena Vista
Nelson
Goochlan
11
Amherst
Image USDA Farm Service Agency
Image © 2011 Commonwealth of Virginia
© 2011 Google
29
Buckingham
Cumberland
Cumberland
©2010


RS0629-003
RS0629-001
RS0629-002
Sinkhole
Control Point (Rock Slope)
RS0042-001
SK0262-001
Staunton
Bath
RS0600-001
Fishersville
RS0064-001
Stuarts Draft
Vesuvius
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Google
Image © 2012 TerraMetrics
Google

Stratigraphy of project rock slopes

ERA	PERIOD	STRATIGRAPHIC UNIT	SITE	LITHOLOGY
Paleozoic	Devonian			
		Brallier Fm.	RS-629-001, 002, 003	**Shale, slate, sandstone**
	Silurian	Licking Creek Fm.	RS-600-001	**Cherty limestone**
		Keyser Fm.	RS-042-001	**Limestone, dolomite, "marble"**
	Cambrian	Beekmantown Gp.	RS-064-001	**Cherty limestone**


Mt Solon
RS0629-002
RS0629-003
Control Point (Rock Slope)
BR0042-001
RF #3
RF #7
RF #6
RF #1
RS0042-001
SK0262-002
Staunton Lime Quarry
Bath
RS0600-001
Waynesboro
RS0064-001
Warm Springs
64
BR0710-001
BR0712-001
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Google
BR0716-001
Image © 2012 TerraMetrics
60
Google
Pointer 38°04'22.92" N 79°13'02.32" W
Streaming 100%
Eye alt 53.22 mi


DSu
West Augusta
RS0629-002
RS0629-001
Dch
Control Point (Rock Slope)
Stroop Property Rock Slope
Db
Dch
Db
Skrt
Dsu
RF #3
OCcc
Augusta
Ce
RS0042-001
Db
Swoope
Oun
Dch
Skrt
Dmn
RS0600-001
Hanky Mountain Hwy
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
© 2012 Google
Image © 2012 Commonwealth of Virginia
Google
Streaming 100%
Eye alt 20.04 mi

RS-629-001

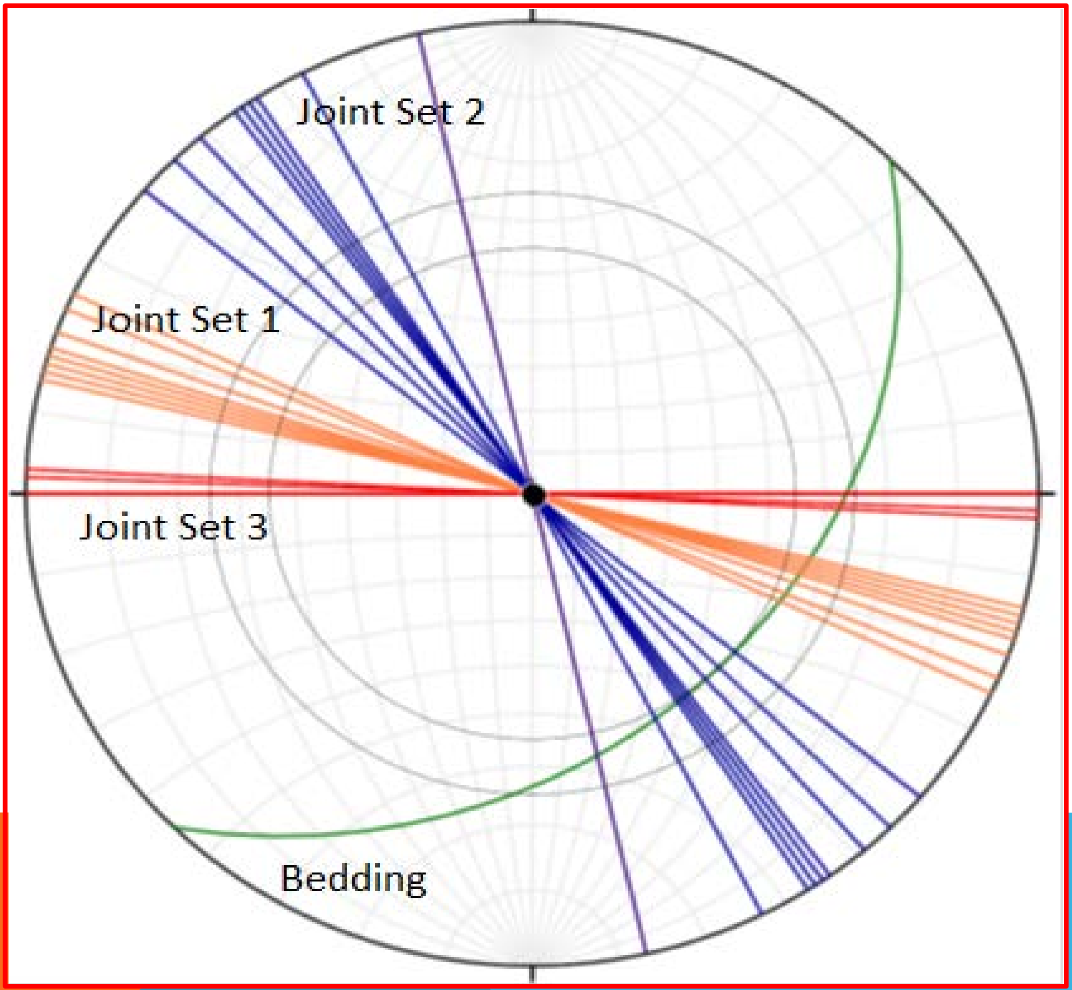
- Catastrophic slope failure in 2009 (10K yds^3).
- Folded and jointed beds.
- Clastic metasediments of Brallier Formation (Devonian).
- Dip slope (35 deg.) on lower cut.
- Upper and lower slopes imaged separately.

March 2012

RS 629-001

Catastrophic slope failure in 2009 (10K yds^3)

RS 629-001

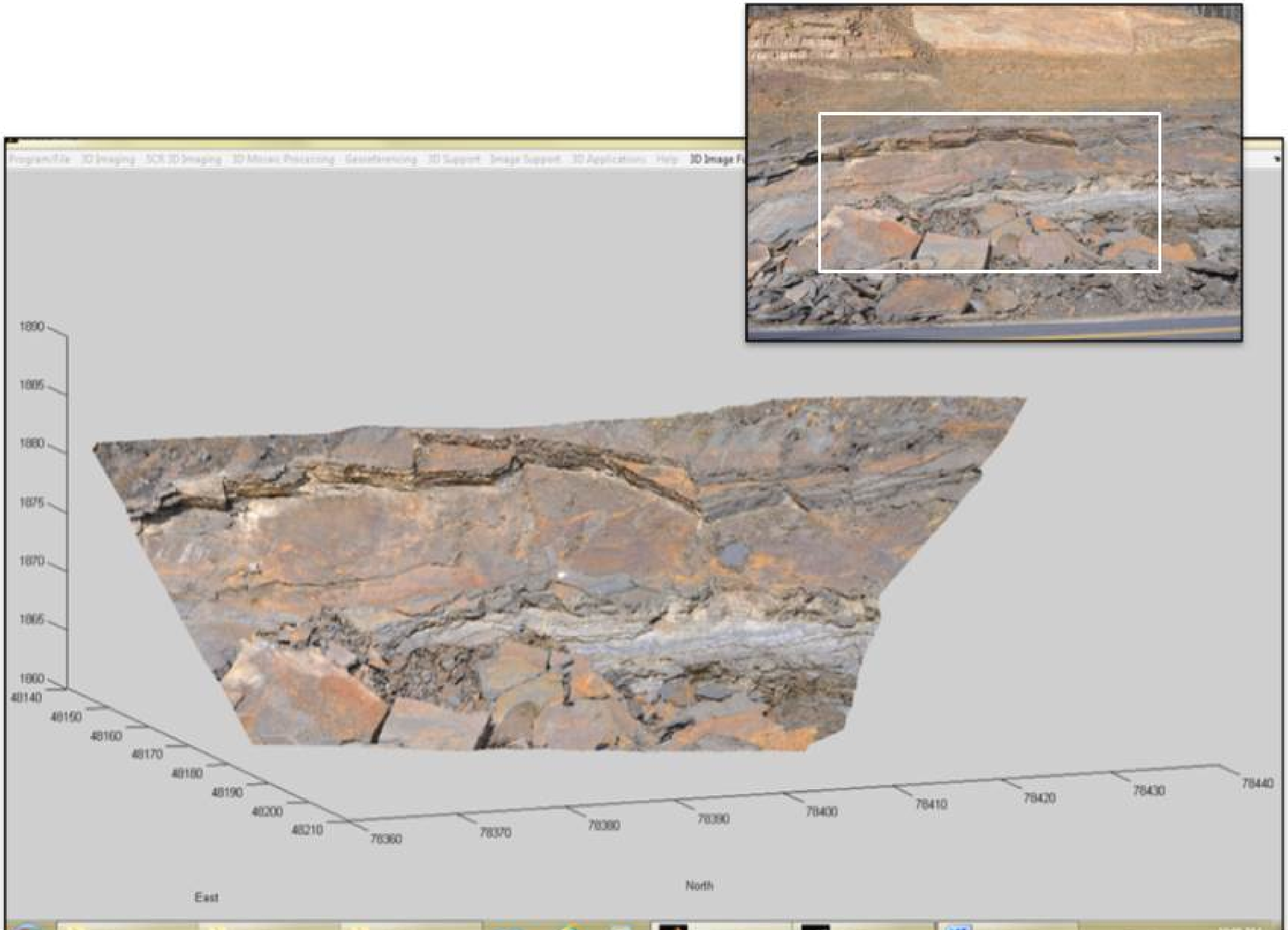


Line survey of discontinuities measured with Brunton compass (Morris, 2012)

Monitoring Schedule

- Six rock slopes
- Photographed quarterly
  - First event: November 2011
  - Final event: November 2012

RS 629-001


1890
1885
1880
1875
1870
1865
1860
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48150
48160
48170
48180
48190
48200
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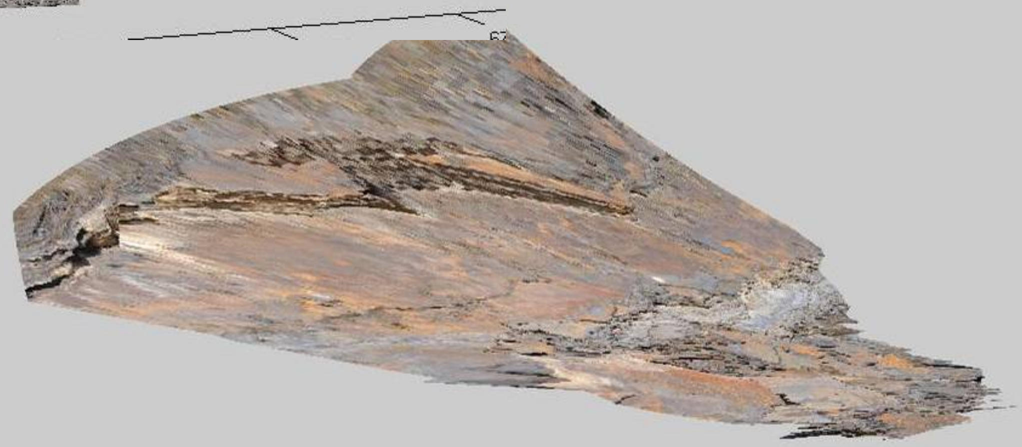
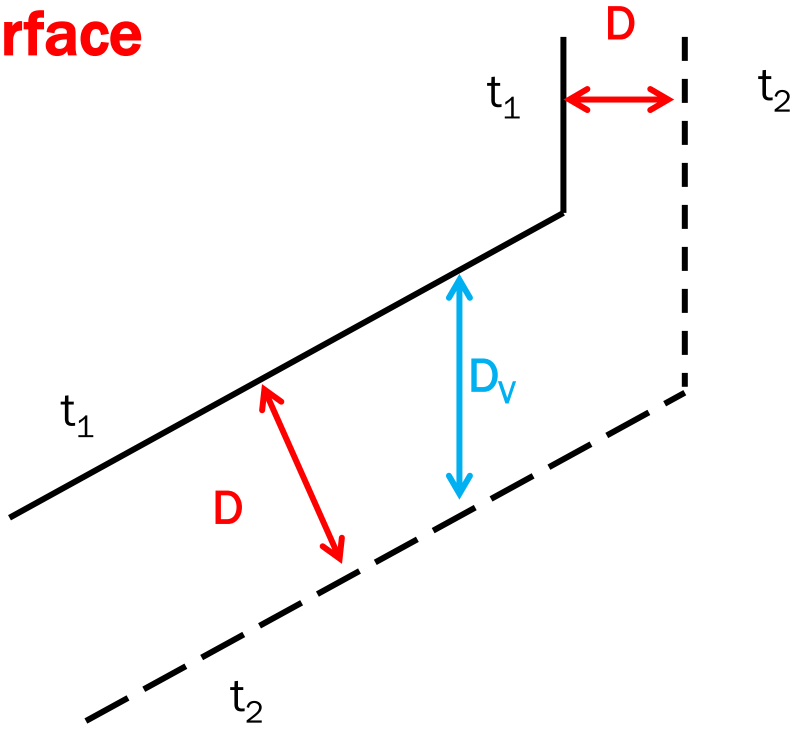
78360
78370
78380
78390
78400
78410
78420
78430
78440
East
North

RS 629-001

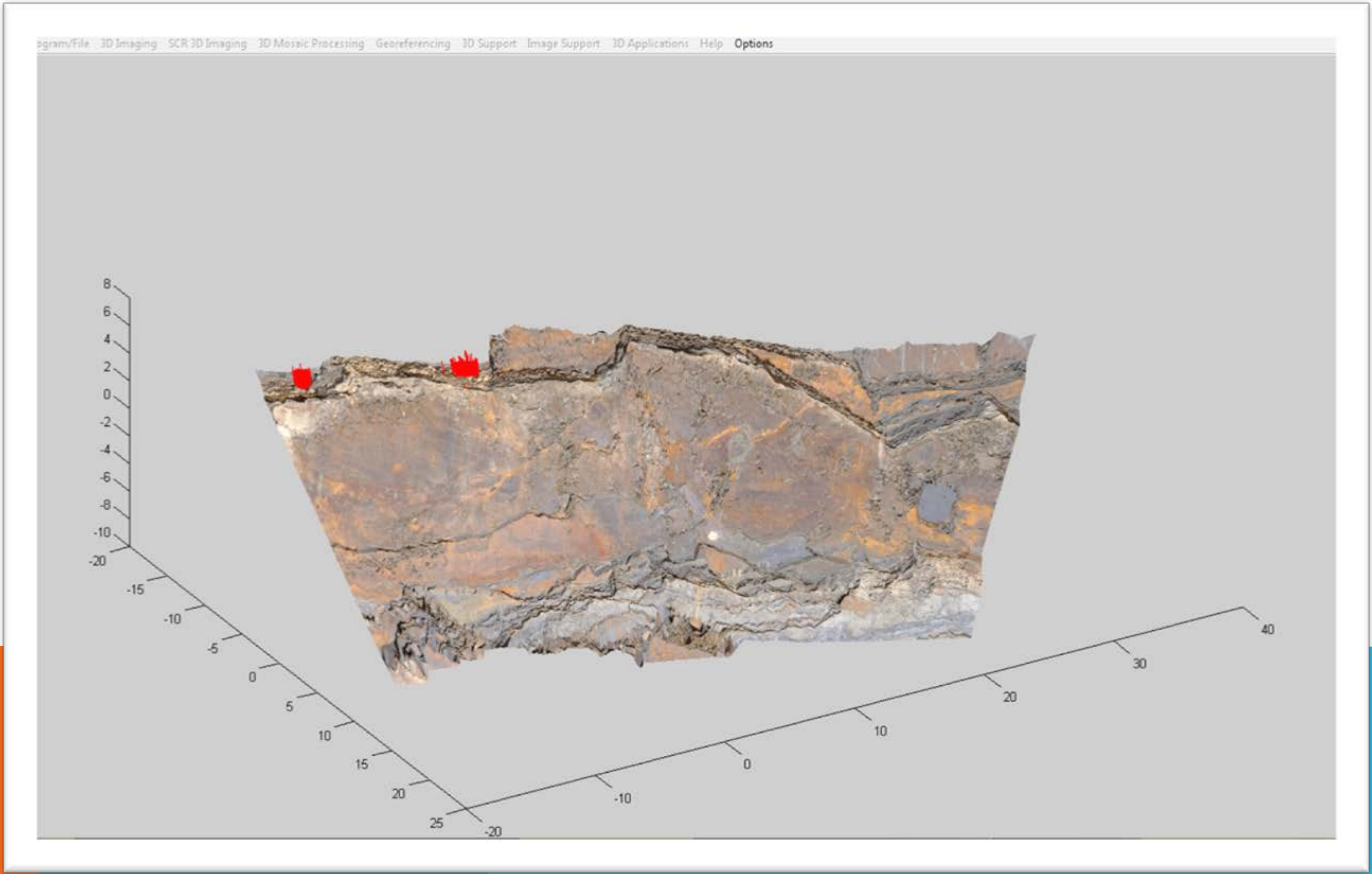


Displacement Calculations

- **Normal to Surface**
  - **Vertical**



RS-629-001 maximum displacement vectors, March 2012 versus November 2012



Displacement Calculations from Sirovision®

Site	Area (ft^2)	Average (ft)	Average Depth (ft)	Maximum (ft)	Maximum Depth (ft)	Volume (ft^3)
629-001 (Lower)	334	**-0.98**	**-1.19**	-2.07	-2.53	-326.1
629-001 (Upper)	189	**-0.15**	**-0.18**	-0.70	-0.85	-28.5
629-002	107	**1.58**	**1.95**	2.85	3.52	169.2
629-003	23	**-1.47**	**-4.30**	-3.55	-10.38	-33.2
064-001	281	**2.49**	**9.63**	9.63	15.76	701.2
600-001	73	**0.09**	**0.12**	0.46	0.60	6.4
042-001	11	**-0.20**	**-0.45**	-2.00	-4.48	-2.2
Greenville Road	4	**-0.08**	**-0.10**	-0.38	-0.32	-0.3

Check on field point accuracy

Check on field point accuracy

= acceptable

= not acceptable

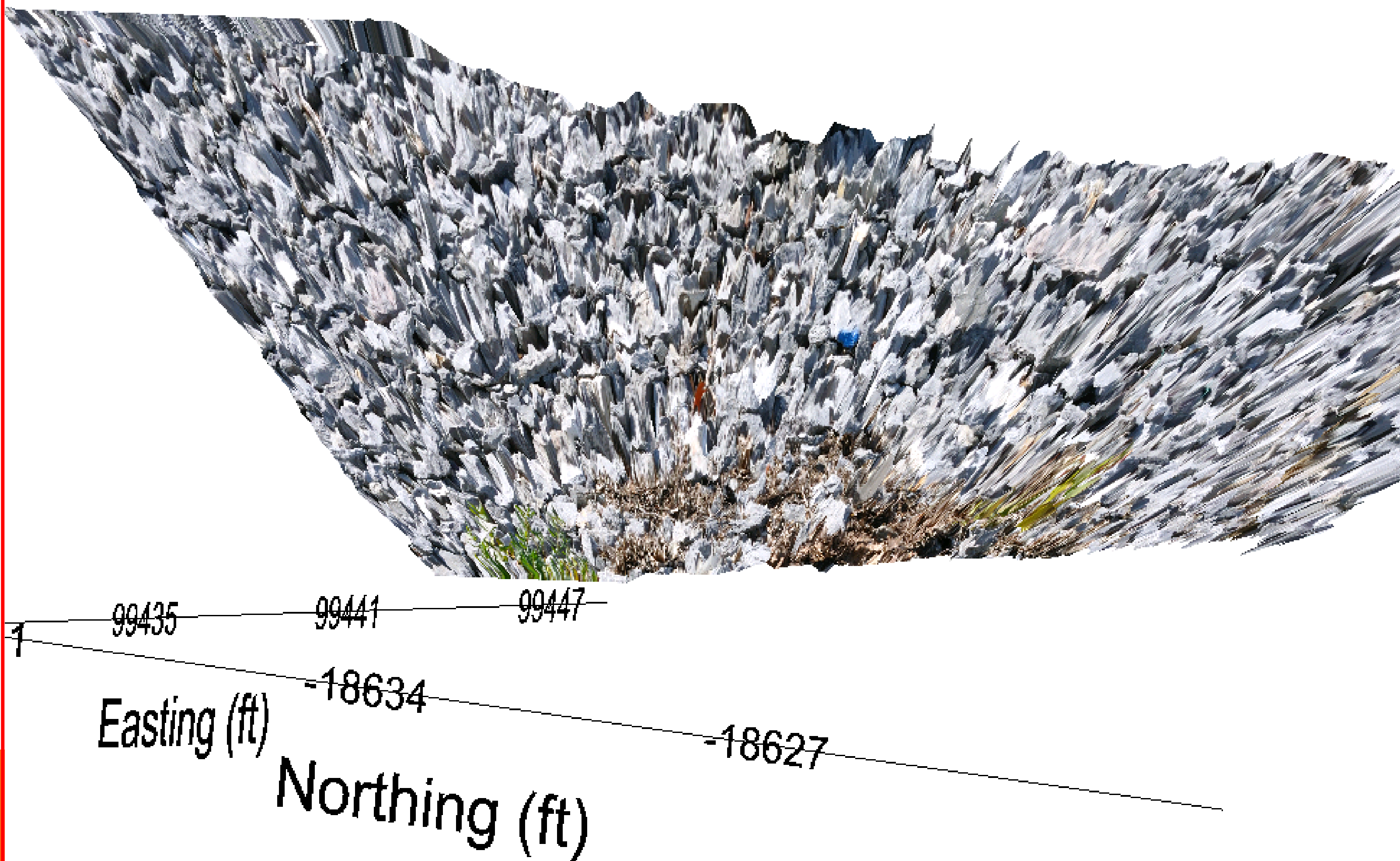
Site	S (ft)	Z - Error (ft)	Z - % Error
629-001 (Lower)	83.5	0.042	0.050
629-001 (Upper)	176.5	0.213	0.121
629-002	109.0	0.305	0.280
629-003	57.3	0.058	0.100
064-001	128.0	0.030	0.023
600-001	72.5	1.688	2.328
042-001	57.0	0.023	0.040
Greenville Road	24.5	0.272	1.110

>> 0.8%

>> 0.8%

Assessment of Possible Error in Displacement Calculations

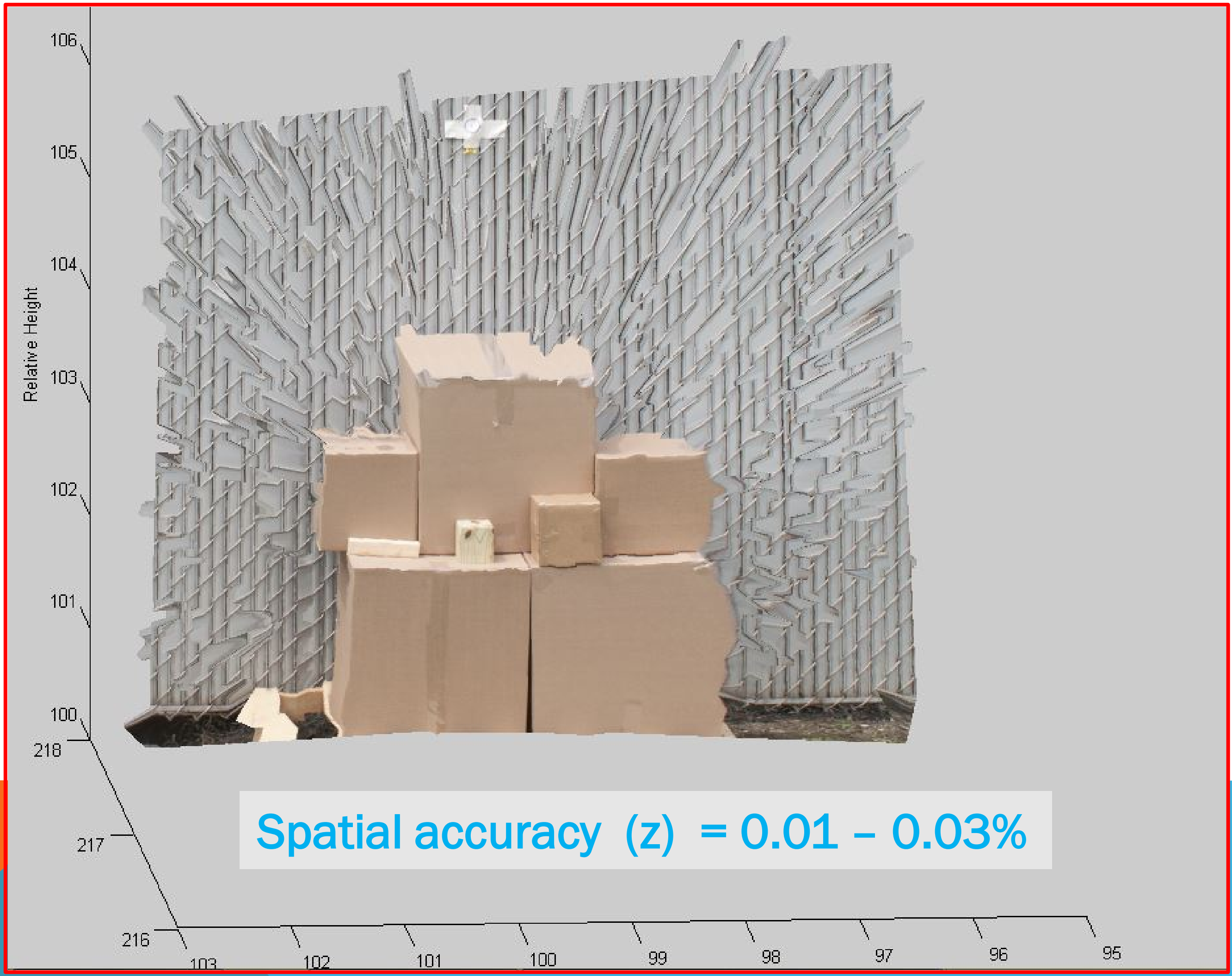
- Site Conditions
- Software flaws
- Inaccurate coordinates



99435
99441
99447
1
-18634
-18627
Easting (ft)
Northing (ft)

Controlled Simulation

Controlled Simulation



Assessment of Possible Error in Displacement Calculations

- Site Conditions
  - Not a factor at most sites

- Software
  - Insignificant

- Coordinates
  - Residual error

Displacement adjusted for error

= acceptable

= not acceptable

Site	Z-Displmt. (ft)	Z - Error (ft)	Adjusted Displmt. (ft)
629-001 (Lower)	-1.19	0.042	- 1.15
629-001 (Upper)	-0.18	0.213	0.00
629-002	1.95	0.305	1.64
629-003	-4.30	0.058	-4.24
064-001	9.63	0.030	9.60
600-001	0.12	1.688	0.00
042-001	-0.45	0.023	-0.43
Greenville Road	-0.10	0.272	0.00

Displacement adjusted for error

= acceptable

= not acceptable

Site	Z-Displmt. (ft)	Z - Error (ft)	Adjusted Displmt. (ft)
629-001 (Lower)	-1.19	0.042	- 1.15
629-001 (Upper)	-0.18	0.213	0.00
629-002	1.95	0.305	1.64
629-003	-4.30	0.058	-4.24
064-001	9.63	0.030	9.60
600-001	0.12	1.688	0.00
042-001	-0.45	0.023	-0.43
Greenville Road	-0.10	0.272	0.00

Displacement adjusted for error

= acceptable

= not acceptable

Site	Z-Displmt. (ft)	Z - Error (ft)	Adjusted Displmt. (ft)	
629-001 (Lower)	-1.19	0.042	- 1.15	
629-001 (Upper)	-0.18	0.213	0.00	
629-002	1.95	0.305	1.64	SE
629-003	-4.30	0.058	-4.24	
064-001	9.63	0.030	9.60	SE
600-001	0.12	1.688	0.00	SE/SC
042-001	-0.45	0.023	-0.43	
Greenville Road	-0.10	0.272	0.00	SC

Conclusions

- Displacement calculations are a function of point (spatial) accuracy.

- Spatial accuracy of ~0.1% can be expected from GBDPG when site conditions permit high quality photographic images and reference coordinates are accurately determined. Software error is ~0.01% and does not limit accuracy.

Conclusions

- For large majority of rock slopes (6/7) spatial accuracy is comparable to published field applications of GBDPG (~0.1%).

- For smaller majority of rock slopes (4/7) displacement (or lack thereof) adjusted for spatial accuracy is considered both “real” and reasonable.

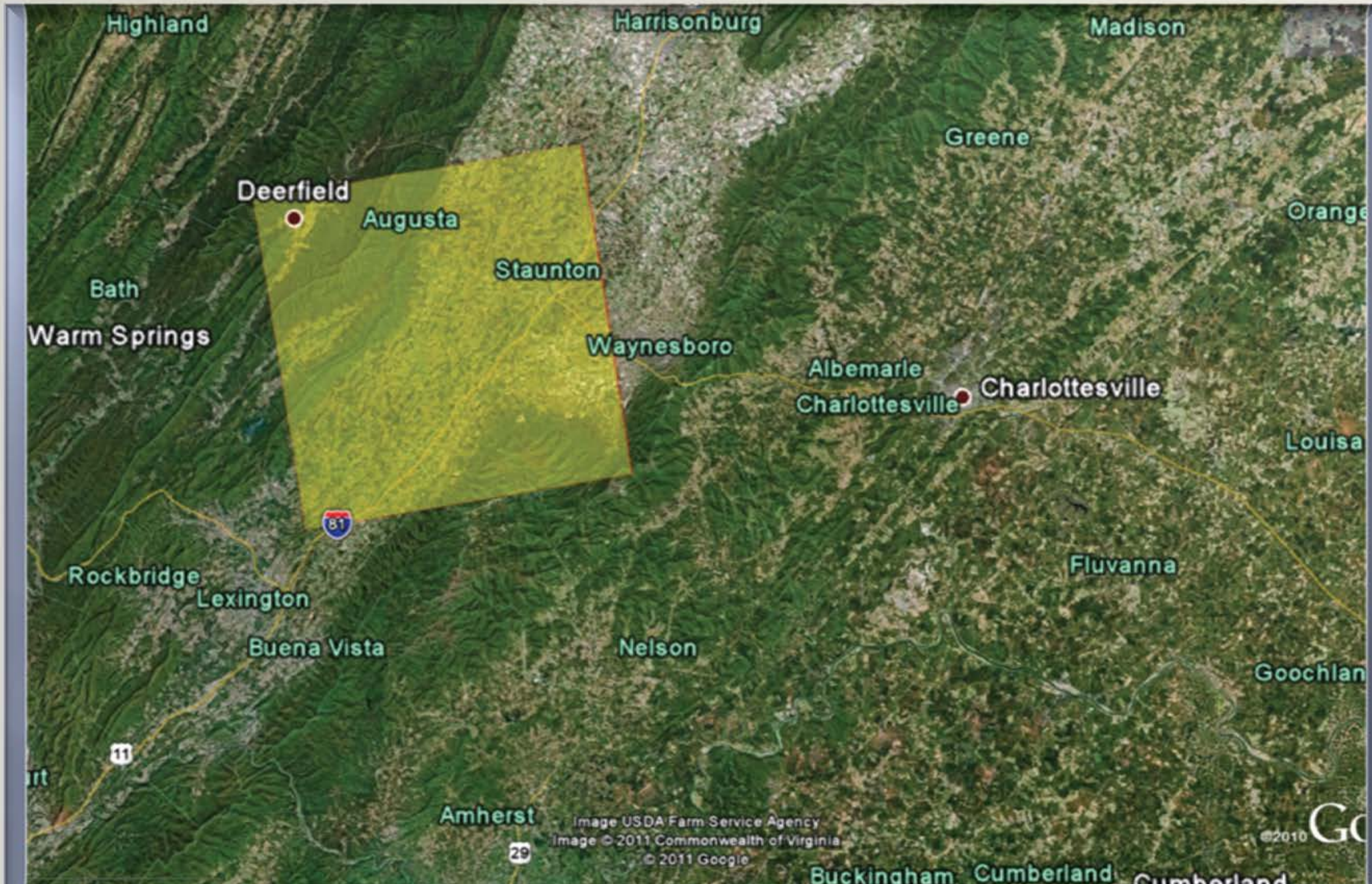
- Unacceptable error for minority of slopes (3/7) attributed to:
  - Poor quality images influenced by site conditions
  - Survey error

- “Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the processes of recording, measuring, and interpreting photographic images…” (ASPRS, 2004)

- Ground-based (i.e., “close range terrestrial”) digital photogrammetry (GBDPG) is a remote sensing tool that uses paired 2D photographs (stereoscopy) obtained and processed digitally to produce 3D models of comparable quality to those derived from manually acquired field data.

Goals of DPG and LIDAR:

- Provide ground-truthing of InSAR results on rock slopes (GBDPG and LIDAR) and bridge displacements (LIDAR).
- Direct comparison of results (GBDPG vs. LIDAR).

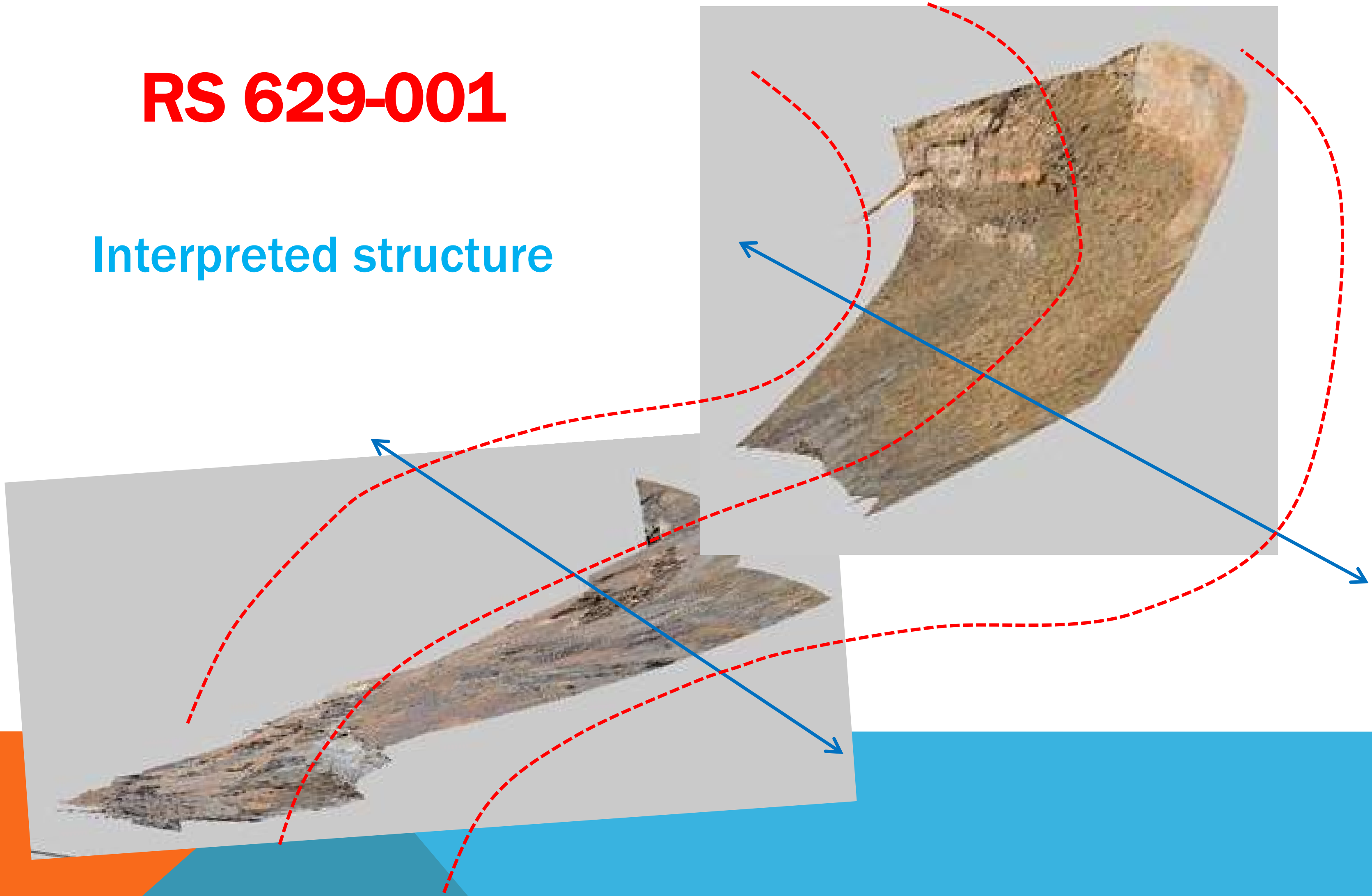

Highland
Harrisonburg
Madison
Greene
Deerfield
Augusta
Staunton
Bath
Warm Springs
Waynesboro
Albemarle
Charlottesville
Charlottesville
Louisa
81
Fluvanna
Rockbridge
Lexington
Buena Vista
Nelson
11
Amherst
29
Image USDA Farm Service Agency
Image © 2011 Commonwealth of Virginia
© 2011 Google
Buckingham
Cumberland
Cumberland

Rock Slope Descriptions

- RS-00629-001
- RS-00600-001

RS 629-001

Interpreted structure



RS-00600-001

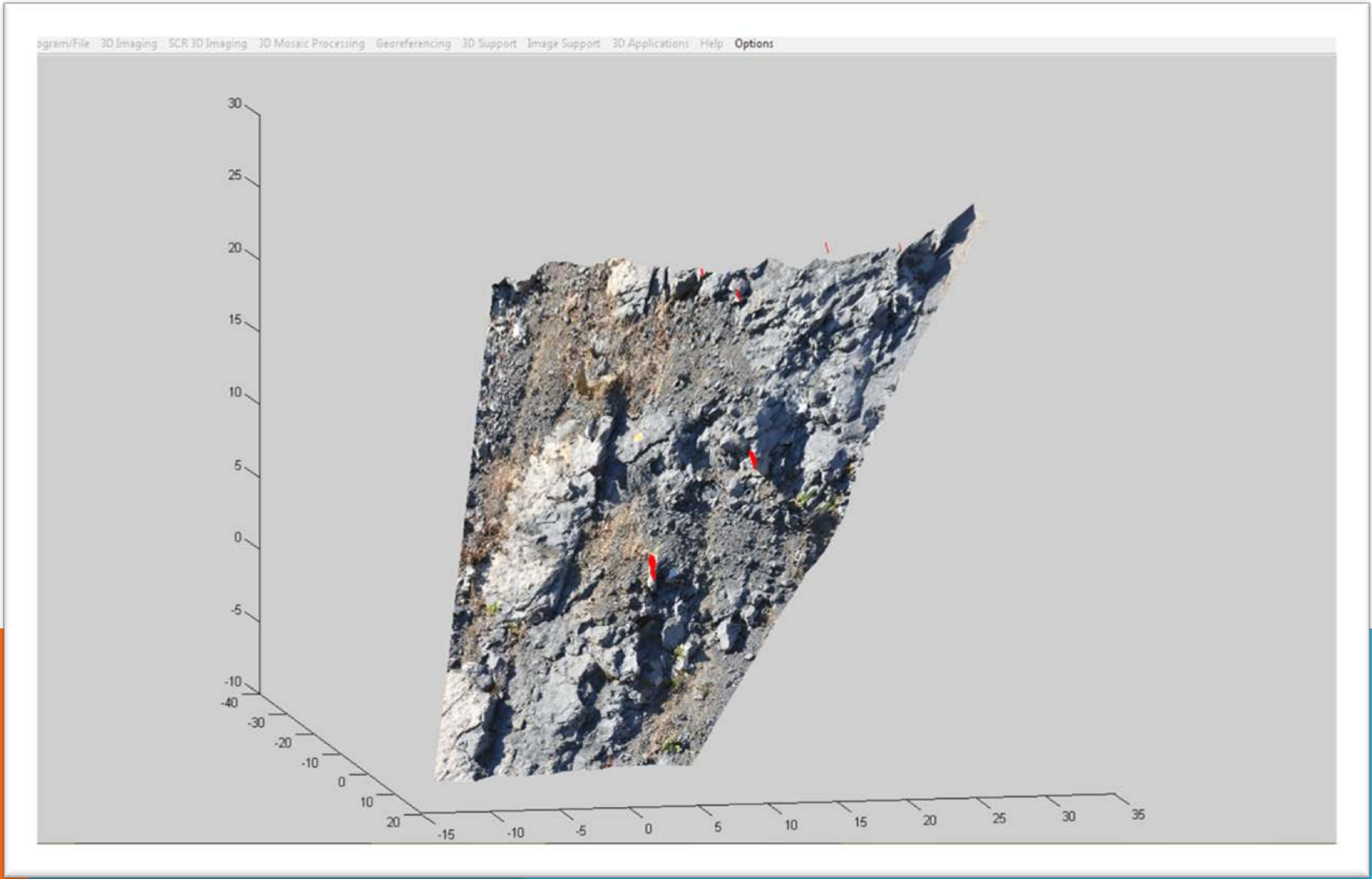
- Dip slopes (40 deg.) of cherty, wavy-bedded limestone.
- Helderberg Group (Devonian-Silurian).
- High-angle joints intersect bedding and slope, form blocks.

Displacement Calculations from Sirovision®

- Numerical displacement
  - Normal to surface
  - Negative versus positive
  - Average and maximum

- Areas of calculated maximum displacement potentially useful for qualitative assessment

RS-600-001 maximum displacement vectors, November 2011 versus November 2012



Conclusions

PARAMETER ▶ / METHOD ▼	AREA	SINK-HOLES	INFRA-STRUCTURE	ROCK SLOPES	COST
InSAR	Broad	Maybe	Yes	No	$$$
LIDAR	Focused	No	Maybe	Yes	$$
DPG	Focused	NA	NA	Yes	$

Preliminary Results

- +InSAR: Covers broad area, shows infrastructure well under right conditions, potentially useful for karst.

- - InSAR: Did not resolve rock slopes well.

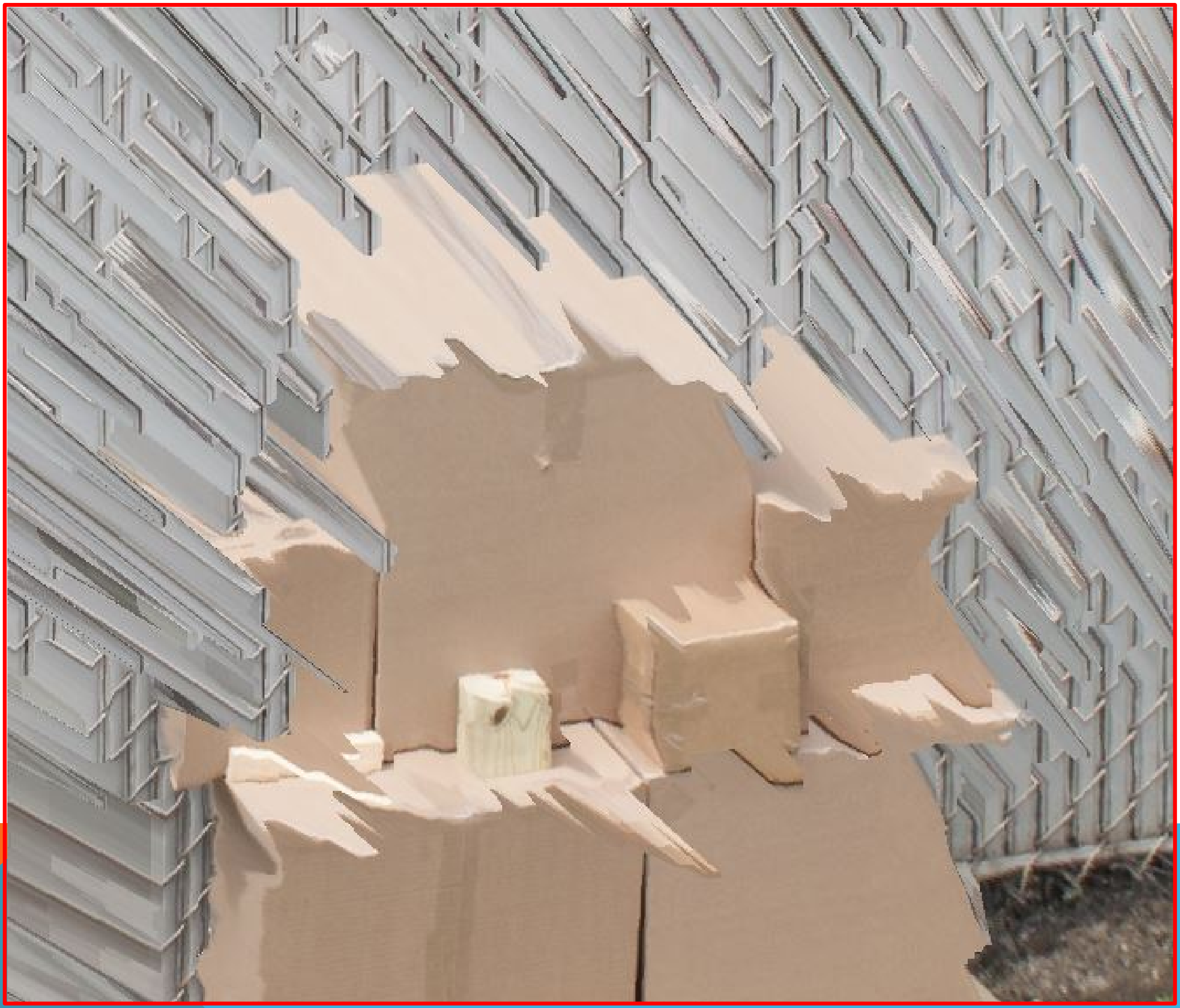
- +LIDAR: Covers focused area, shows slopes well, potentially useful for bridges.

- -LIDAR: Poor results for karst, expensive, kinematic analysis difficult.

Check on point accuracy

1. Check using field data
2. Check using data from controlled environment

Displacement Simulation



Conclusions

- Covers focused area, shows slopes well, moderate cost, amenable to kinematic analysis.
- Ability to yield reliable quantitative results for displacement on rock slopes is promising.