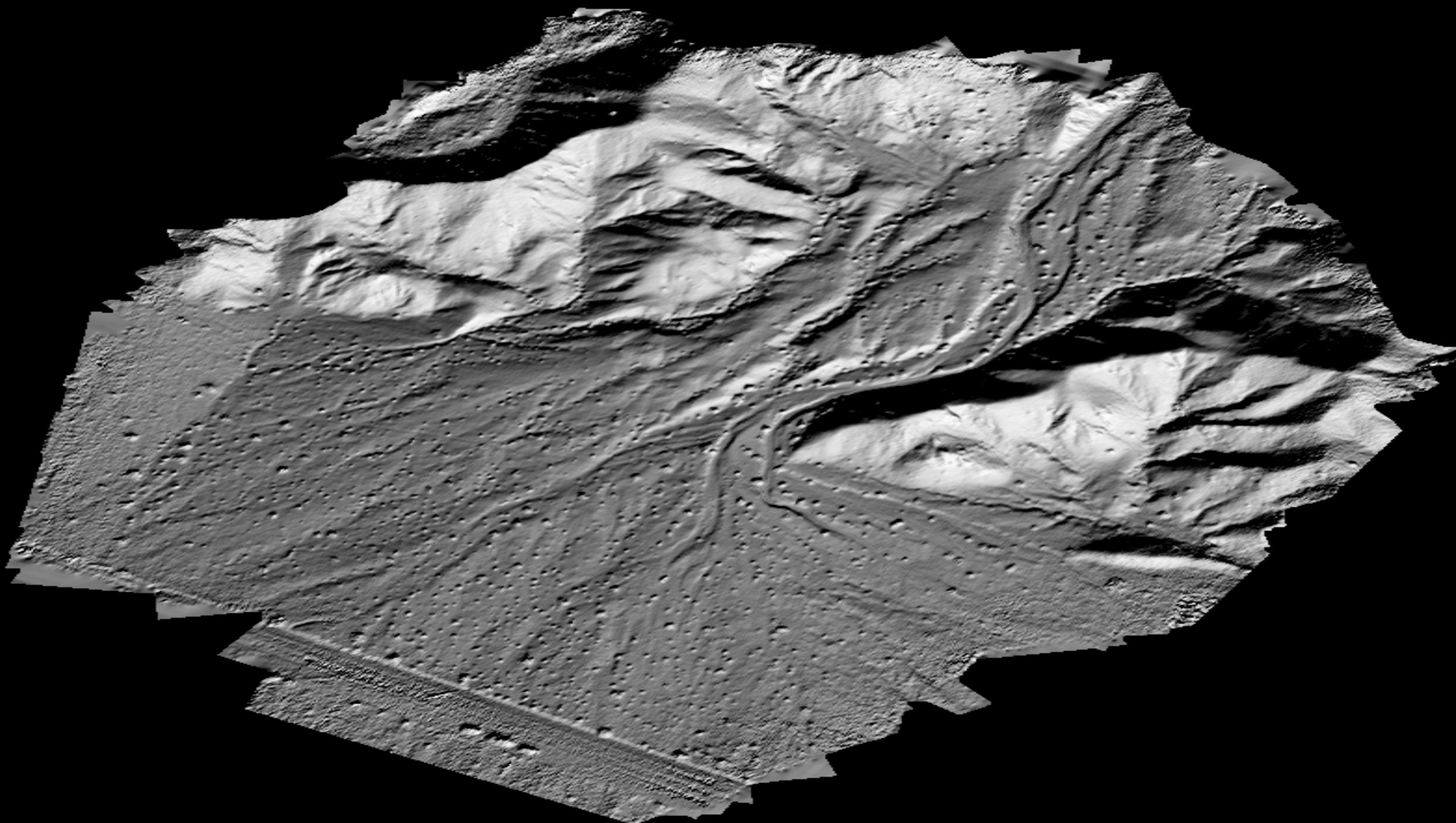
Structure from Motion



Workshop on Point Clouds and Applications in Science

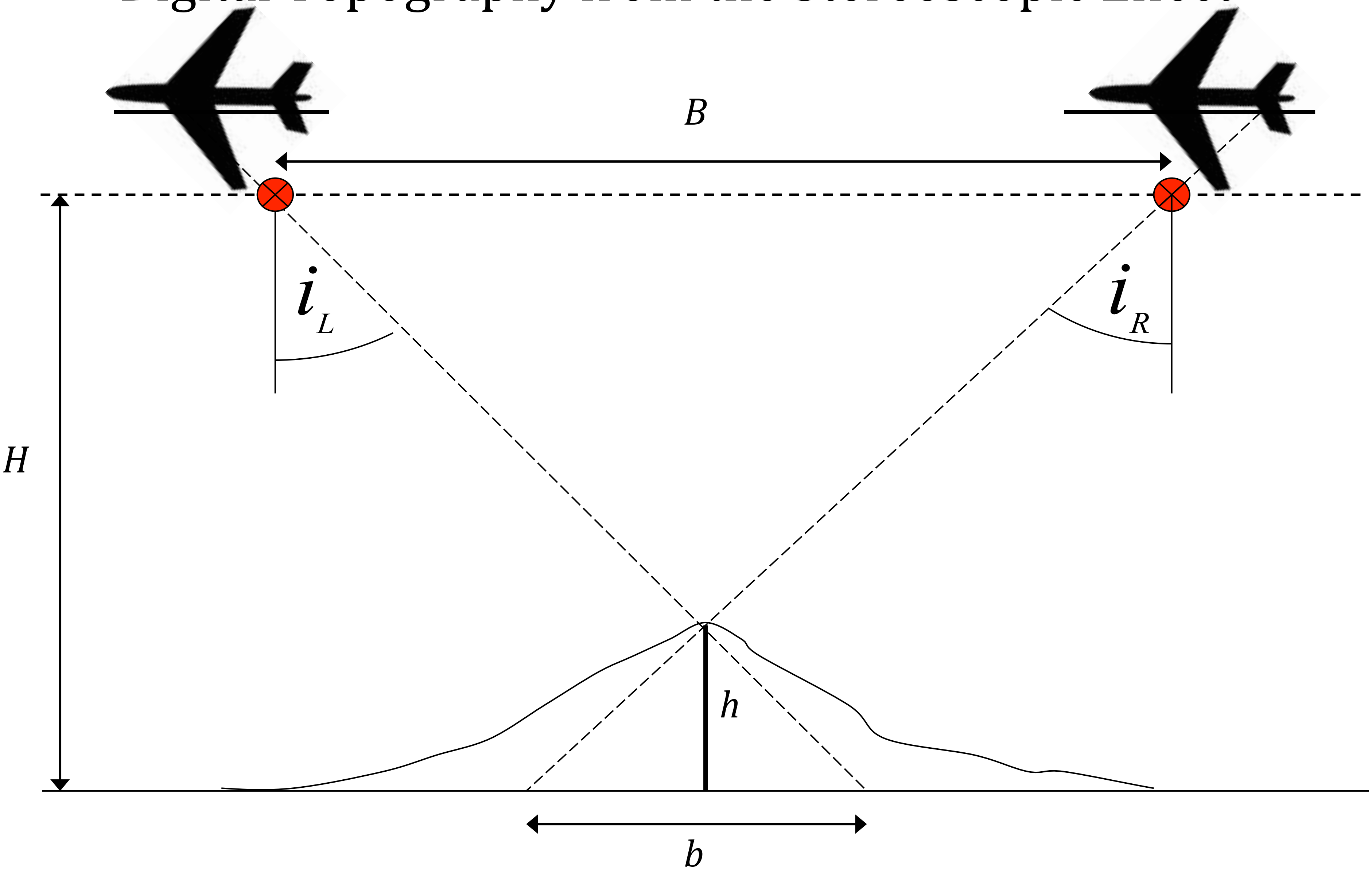
April 8-10, 2015, CICESE, Ensenada B.C.

Outline

Structure from Motion (SfM):

- How it works
- Our workflow
- Value of ground control points (GCPs)
- Potential with existing aerial photos
- Example multitemporal study

Digital Topography from the Stereoscopic Effect



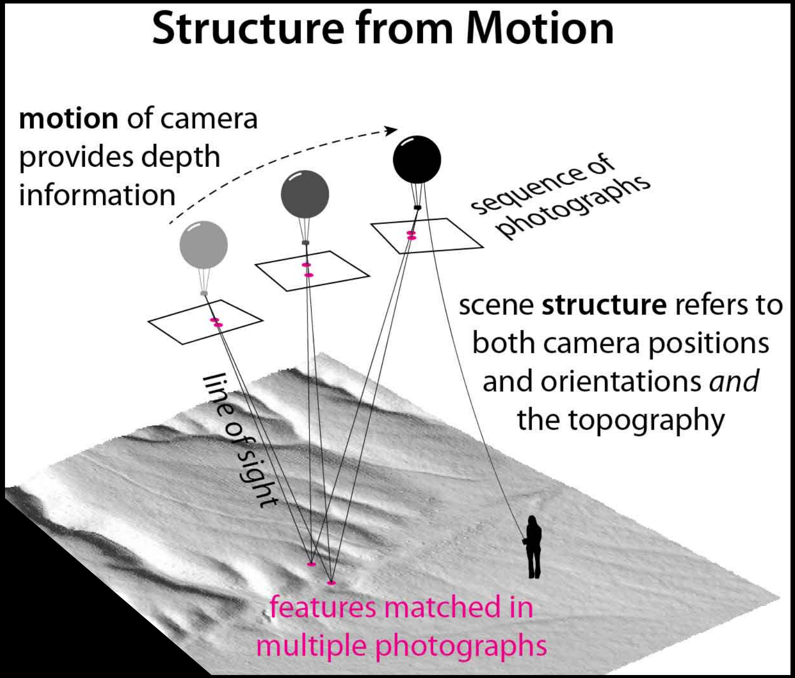
Structure from Motion vs. Stereophotogrammetry

- Traditional stereophotogrammetry requires that we know the precise locations of the photos, and a fairly simple photo geometry

- Structure from Motion simultaneously solves for the camera parameters and the scene geometry, and can support large changes in camera position

Structure from Motion (SfM)

- Reconstructs 3D model of a scene from photographs with overlapping coverage taken from changing perspectives
- Triangulates among features in different photos using Scale Invariant Feature Transform (Lowe, 2004; Snavely et al., 2008)



Johnson et al., 2014

- Incorporation of aerial platform improves camera perspective and increases coverage compared to ground-based surveys

Pros and Cons

Pros:

- Inexpensive
- User-friendly software and technology
- Very high-resolution data
- Colored point clouds

Cons:

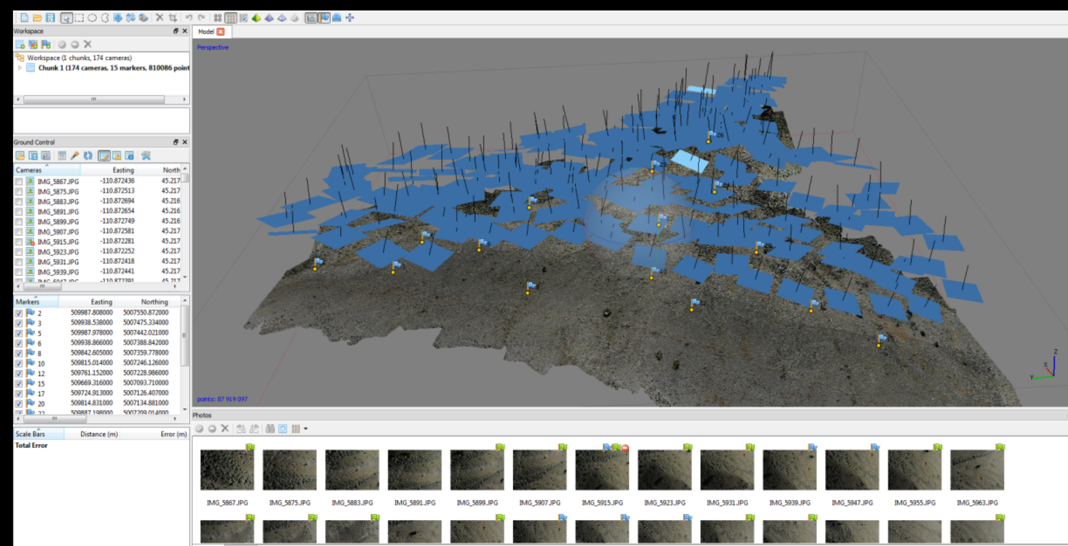
- Cannot “see through” vegetation
- Usually cover much smaller areas than LiDAR

SfM Workflow

Photo credit: Kate Scharer

Field work and data collection

Data processing



Field Work

Choose platform

Select camera

Deploy and survey ground control points

Collect photographs

Motorized glider

Helium balloon

Helikite

http://aeroquad.com/attachment.php?attachmentid=7091&d=1375885270

Considerations

- Site conditions
  - Weather – especially wind
  - Terrain – steep or sub-horizontal
- Regulations
  - In America, using a tether avoids most issues
- Desired resolution
  - Smaller distance between camera and target yields higher density point cloud but photo footprint is smaller

Photos: Emily Kleber

Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points

Collect photographs

Criteria:

- Time-lapse or remote-controlled triggering
- GPS tagging preferred

Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points (GCPs)

Collect photographs

GPS locations of prominent features are used during the processing phase to improve point cloud accuracy

Field Work

Choose aerial platform

Select camera

Deploy and survey ground control points

Collect photographs

Proper photo collection

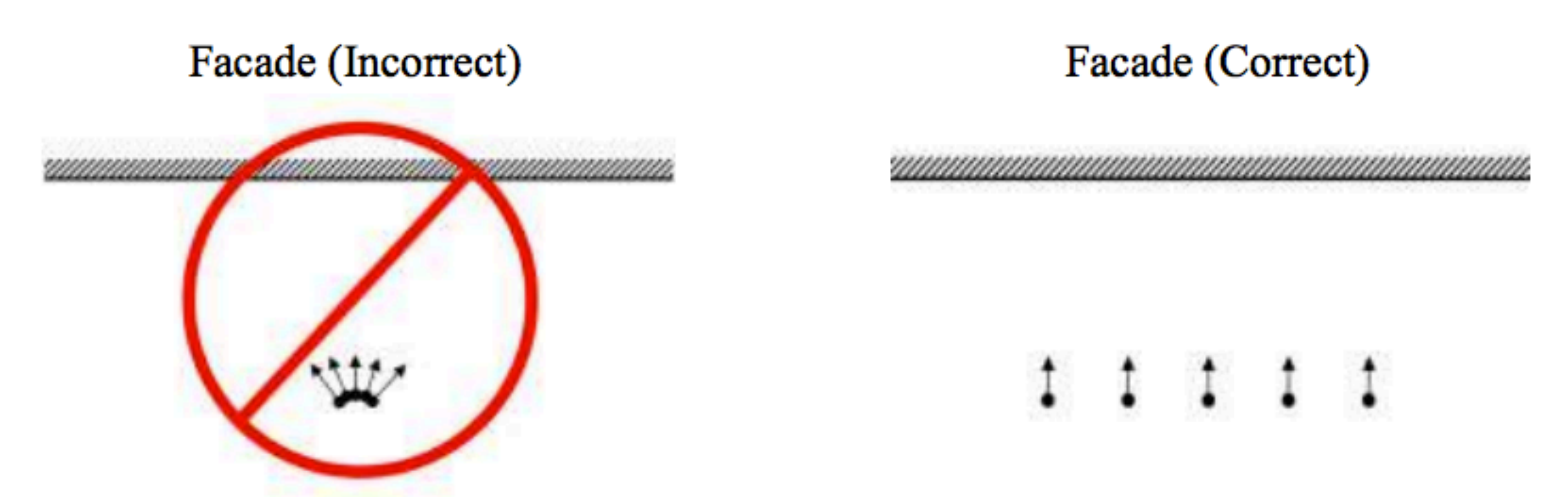
more detail provided by Agisoft:
http://www.agisoft.com/pdf/tips_and_tricks/Image%20Capture%20Tips%20-%20Equipment%20and%20Shooting%20Scenarios.pdf

-More photos are better than not enough

-Each photo should be maximally occupied by features of interest (but the full object does not need to be in every frame)

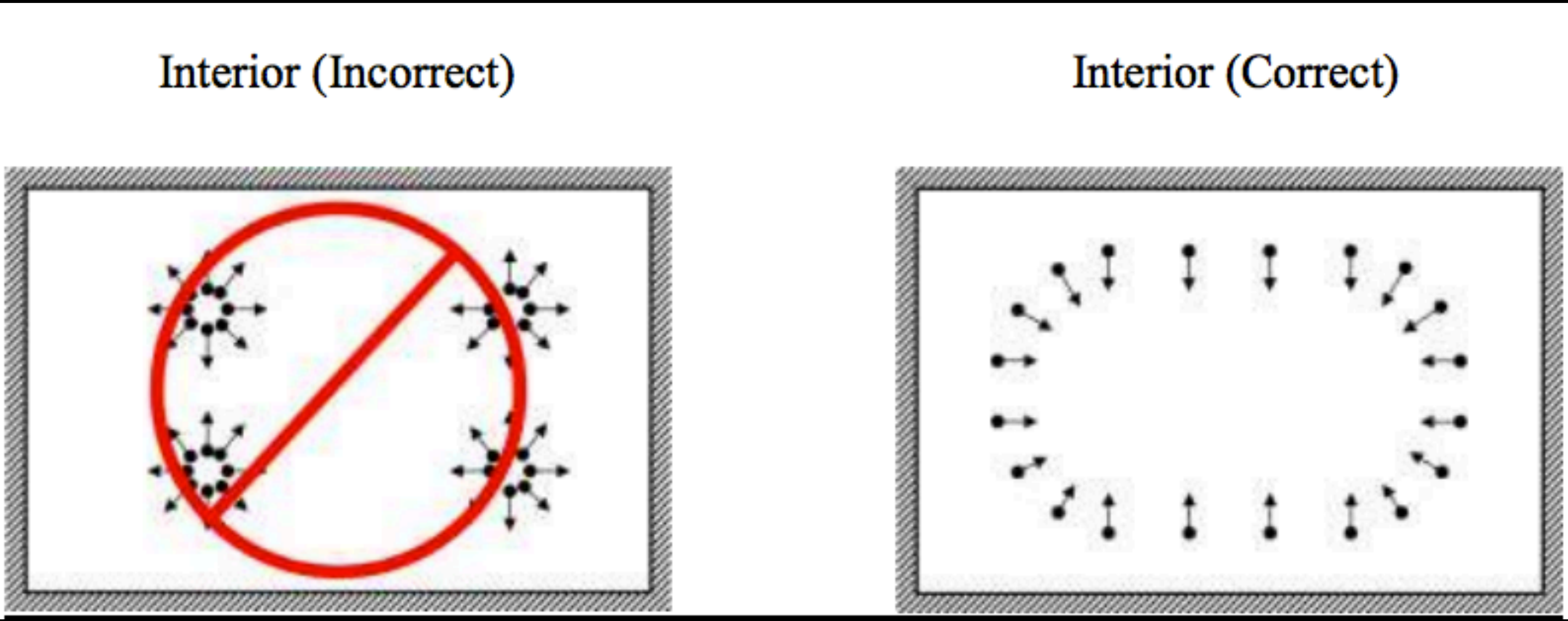
-For aerial data collection, aim for 80% forward overlap and 60% side overlap

Imaging a sub-planar feature



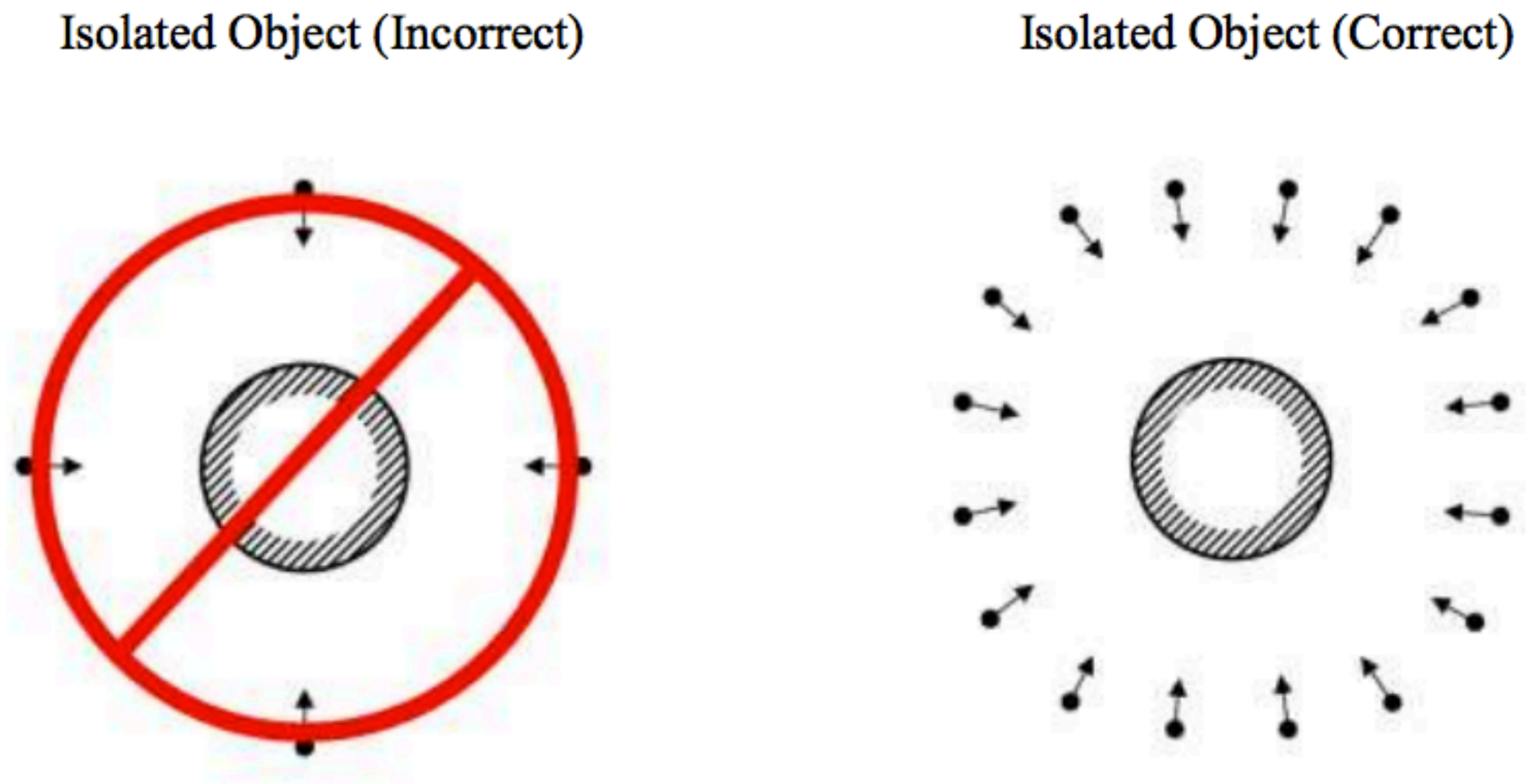
Collect photos from multiple locations but similar look angles

Imaging an interior (e.g. of a room)



Collect photos from the opposite side of the interior

Imaging an isolated object

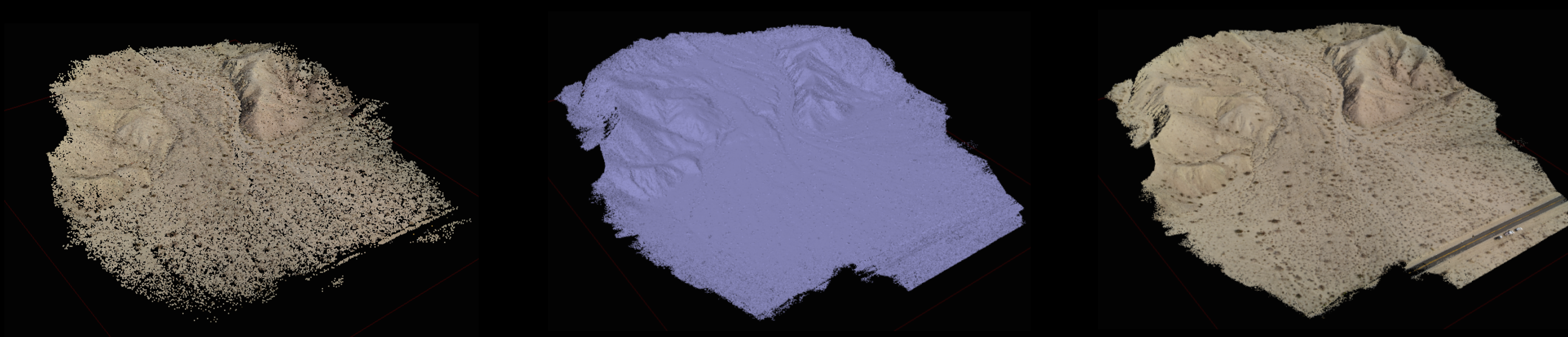


Collect photos many angles

Data Processing

*Agisoft Photoscan Pro

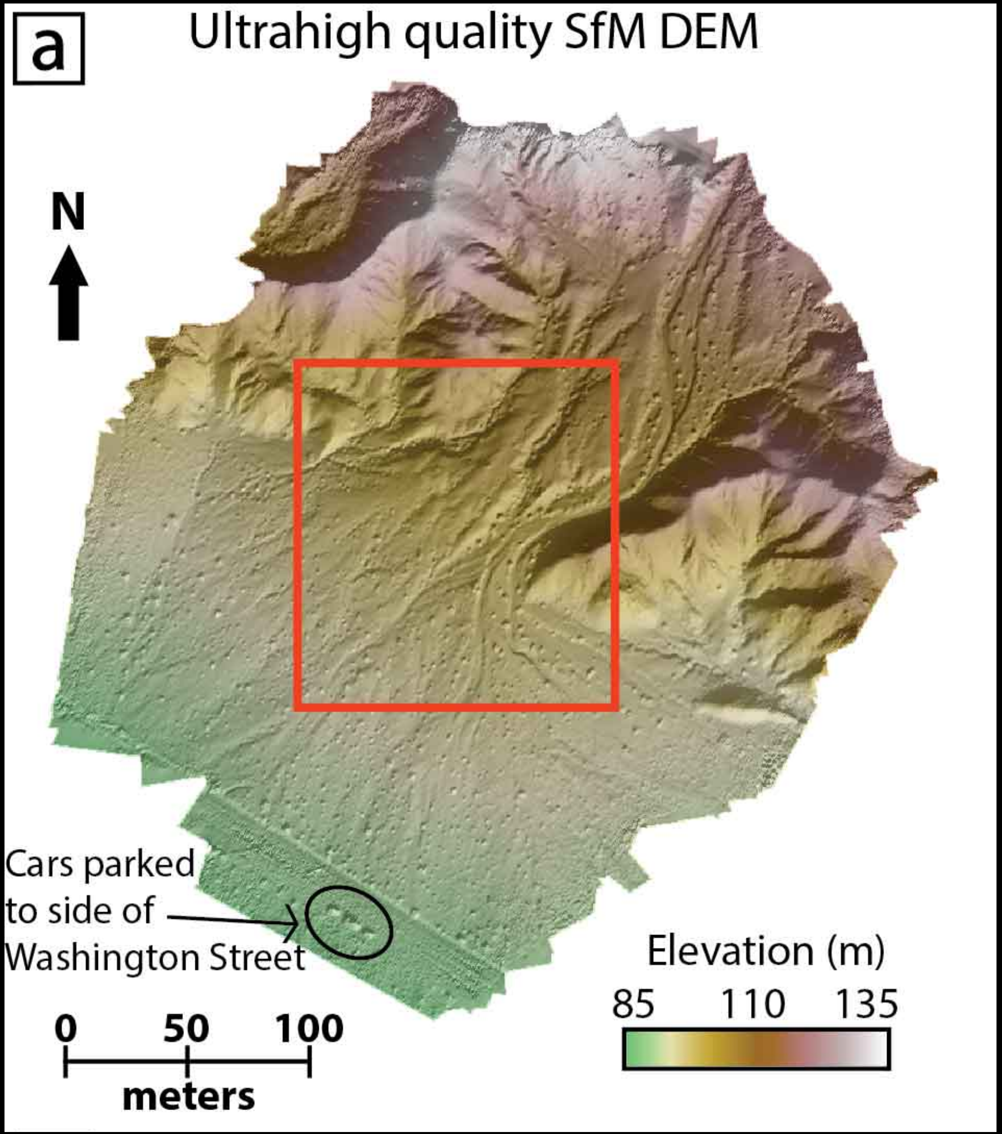
More details in Johnson et al., (2014).



*Alternative workflows presented in Westoby et al. (2012), James and Robson (2012), and Fonstad et al. (2013).

Ground Control Points (GCPs): a case study at the Washington Street Site

We compared our SfM DEM to an existing DEM to quantify the accuracy of structure from motion when GCPs are and are not used



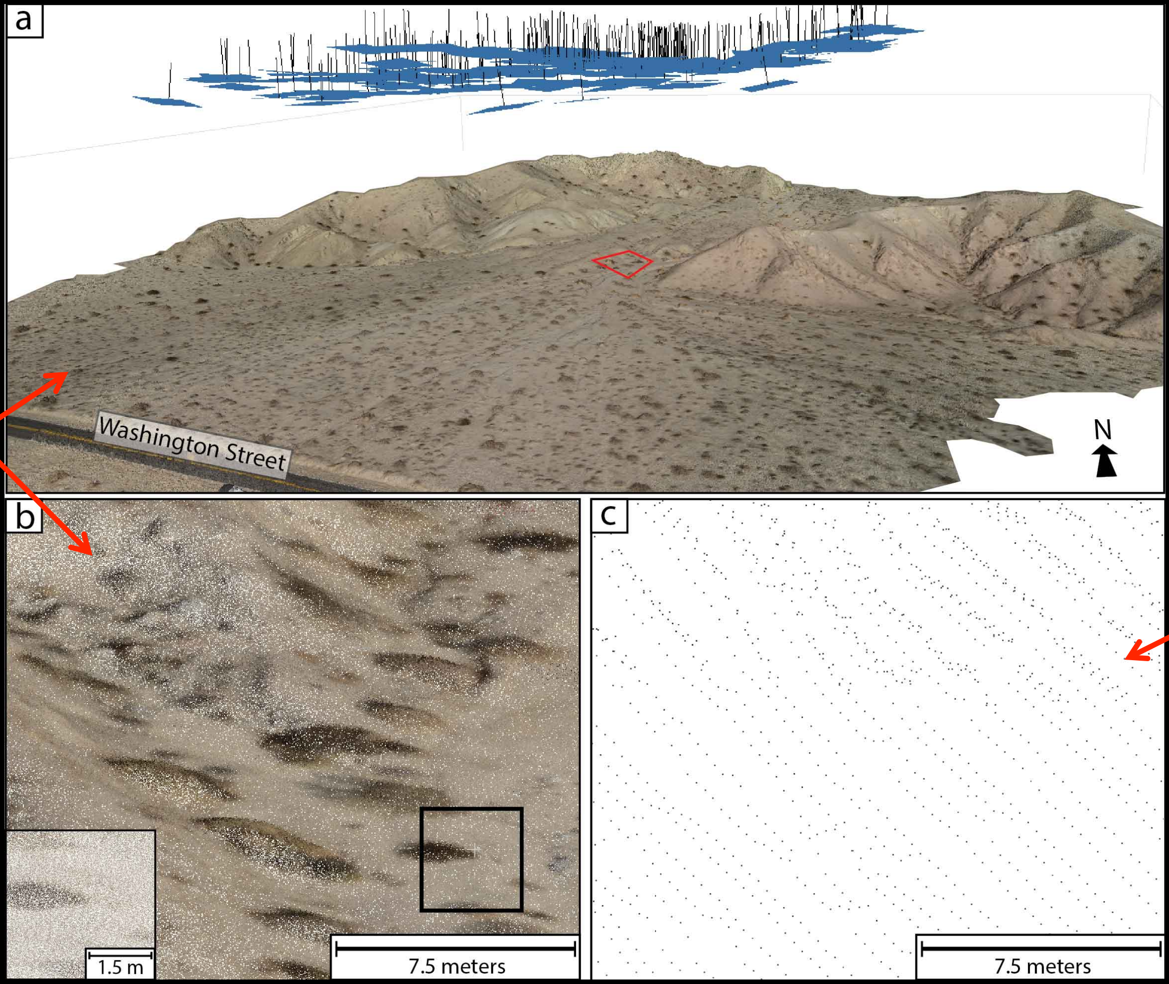
Washington Street Site

How does SfM point density compare to airborne LiDAR?

SfM point density (points/m^2):

90% > 60

50% > 700



LiDAR point density (points/m^2):

90% > 1

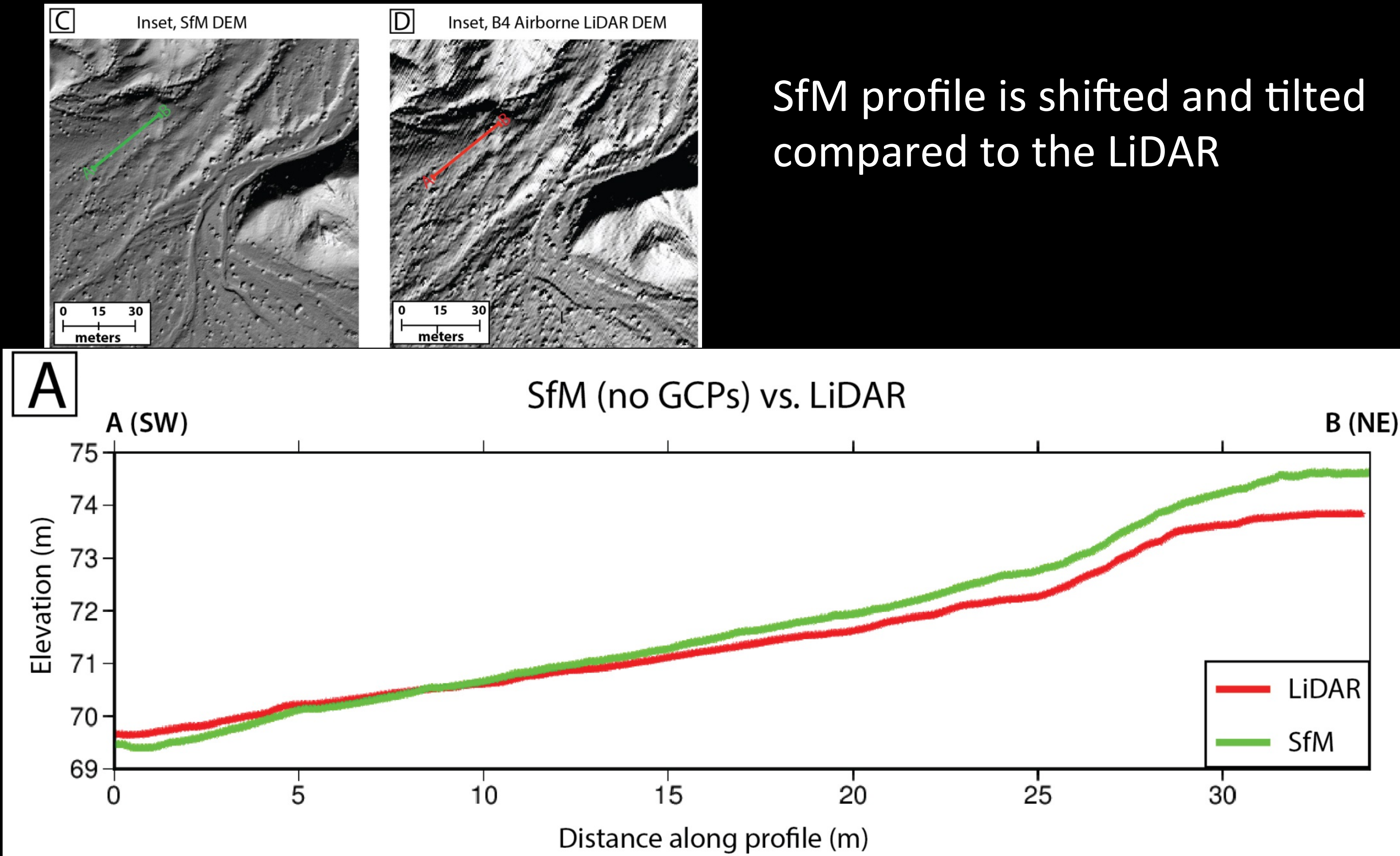
50% > 1.75

Johnson et al., 2014

‘B4’ LiDAR Project led by the USGS and Ohio State University and funded by the NSF. Data collected by NCALM.

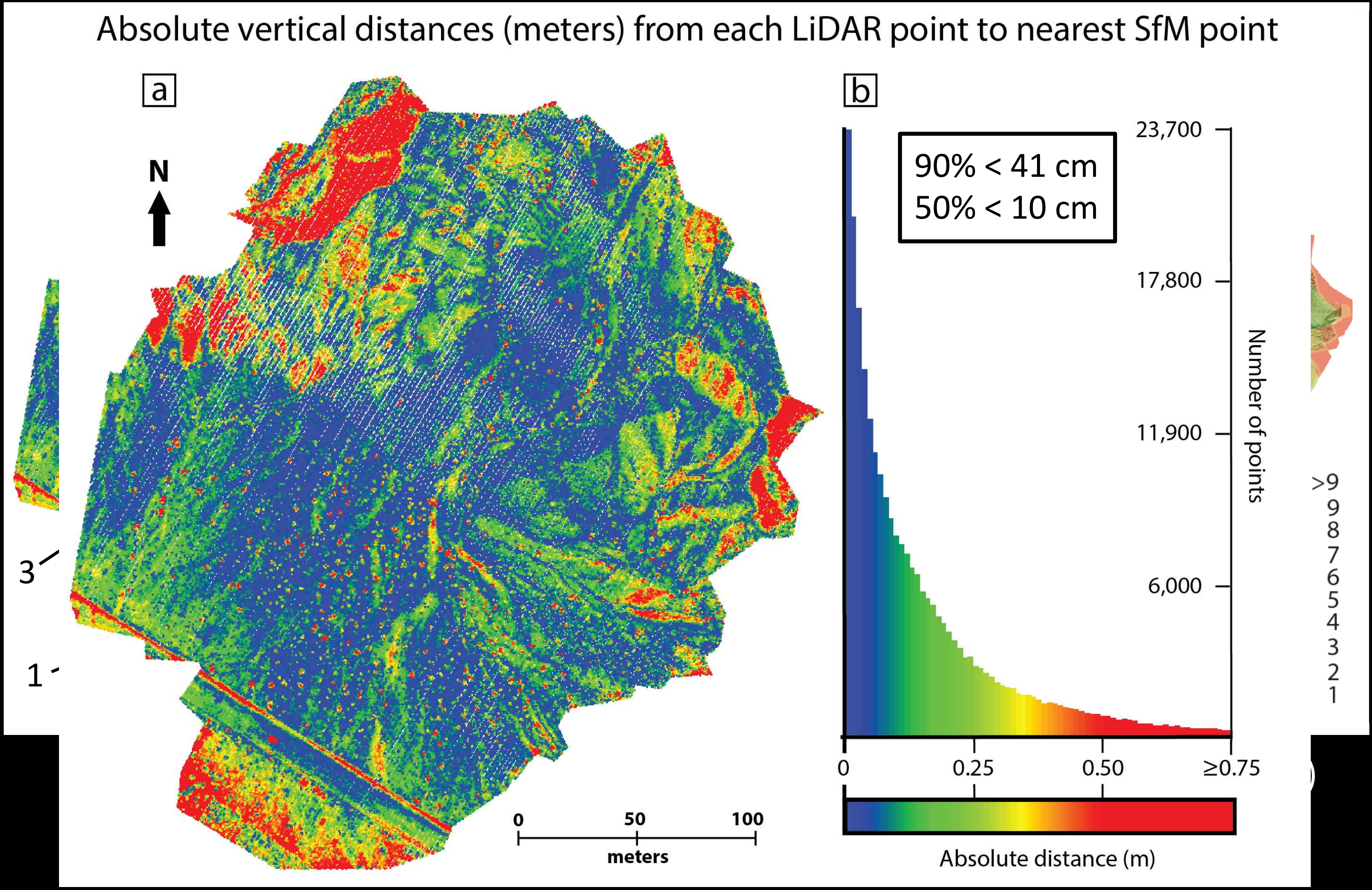
Washington Street Site: No GCPs

SfM profile is shifted and tilted compared to the LiDAR



Johnson et al., 2014

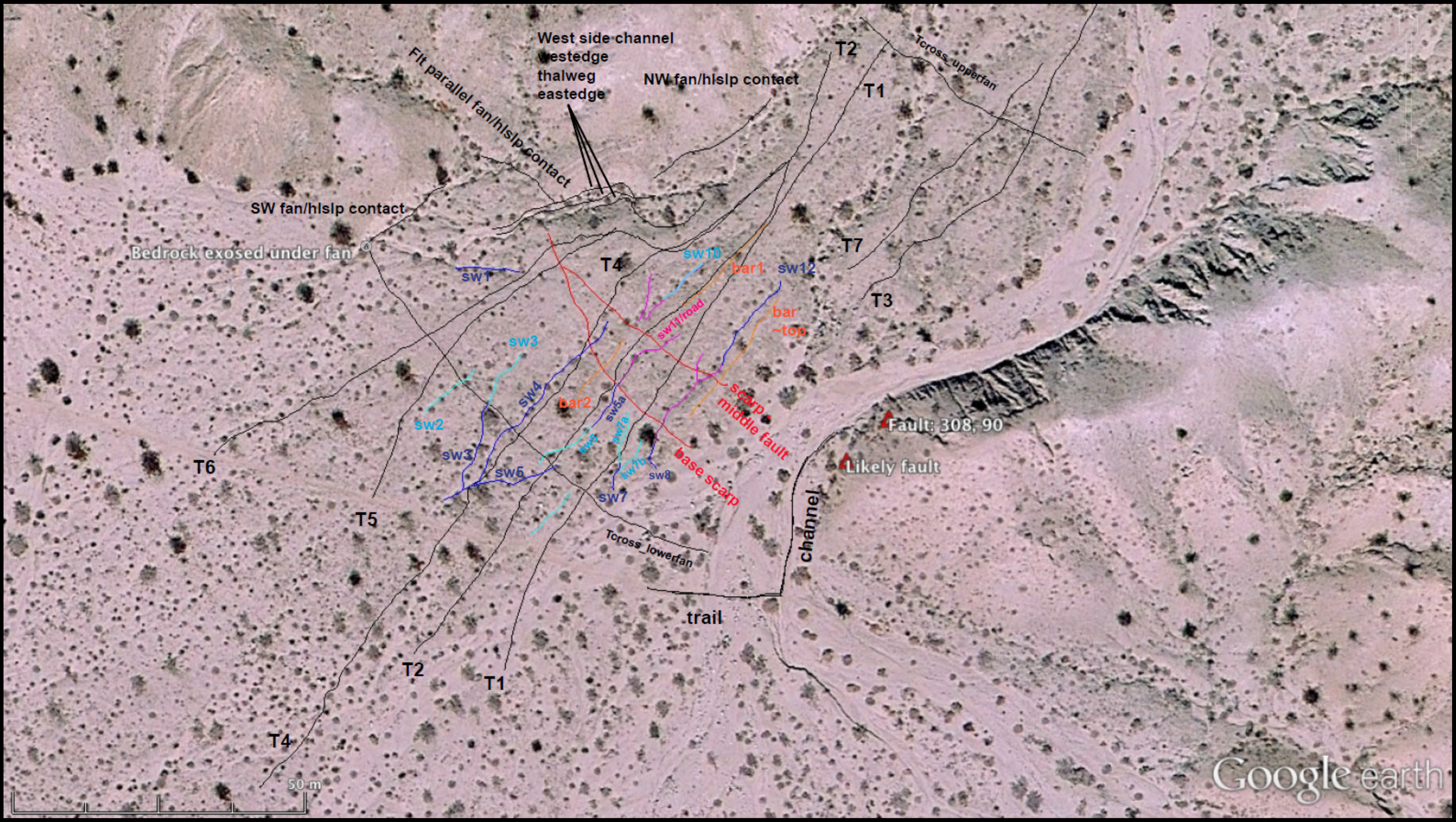
Washington Street Site: No GCPs



Johnson et al., 2014

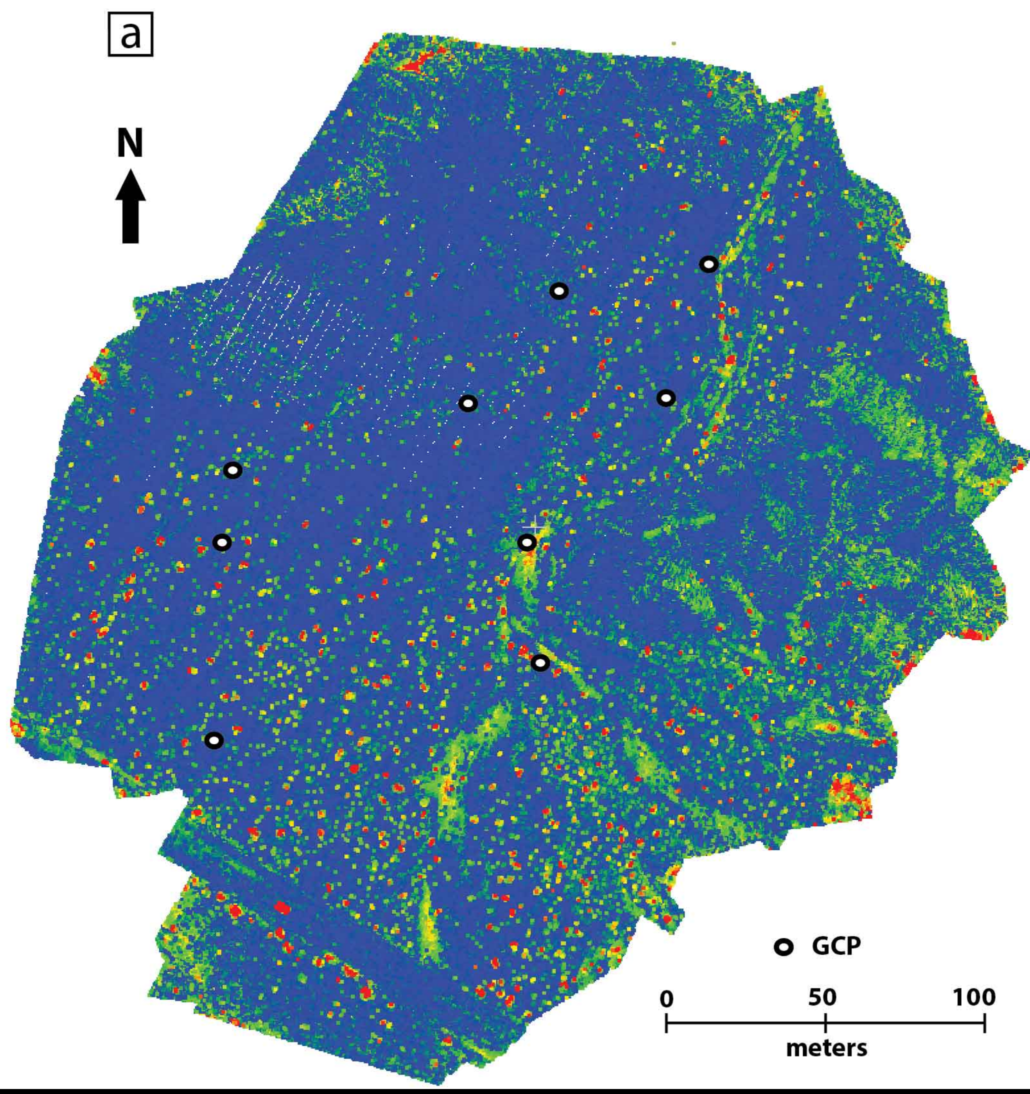
Washington Street Site: With GCPs

- Add GCPs from GeoXH GPS with 20 cm uncertainty



Washington Street Site: With GCPs

Absolute vertical distances (meters) from each LiDAR point to nearest SfM point

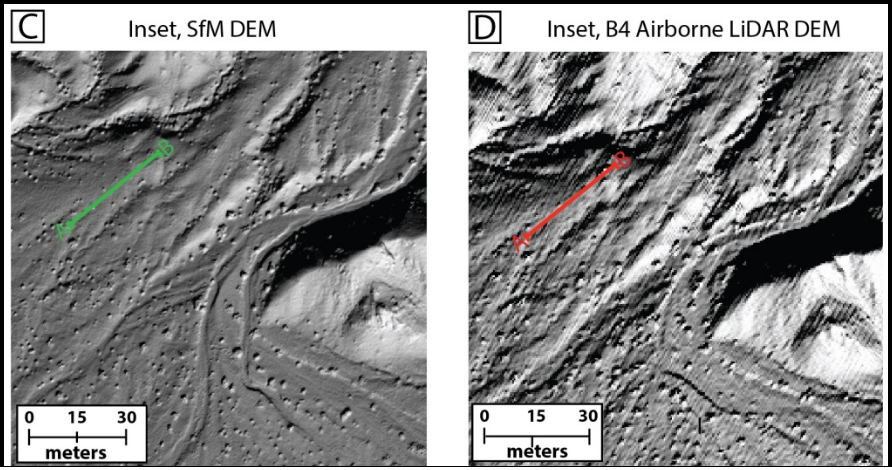


90% < 13 cm
50% < 3 cm

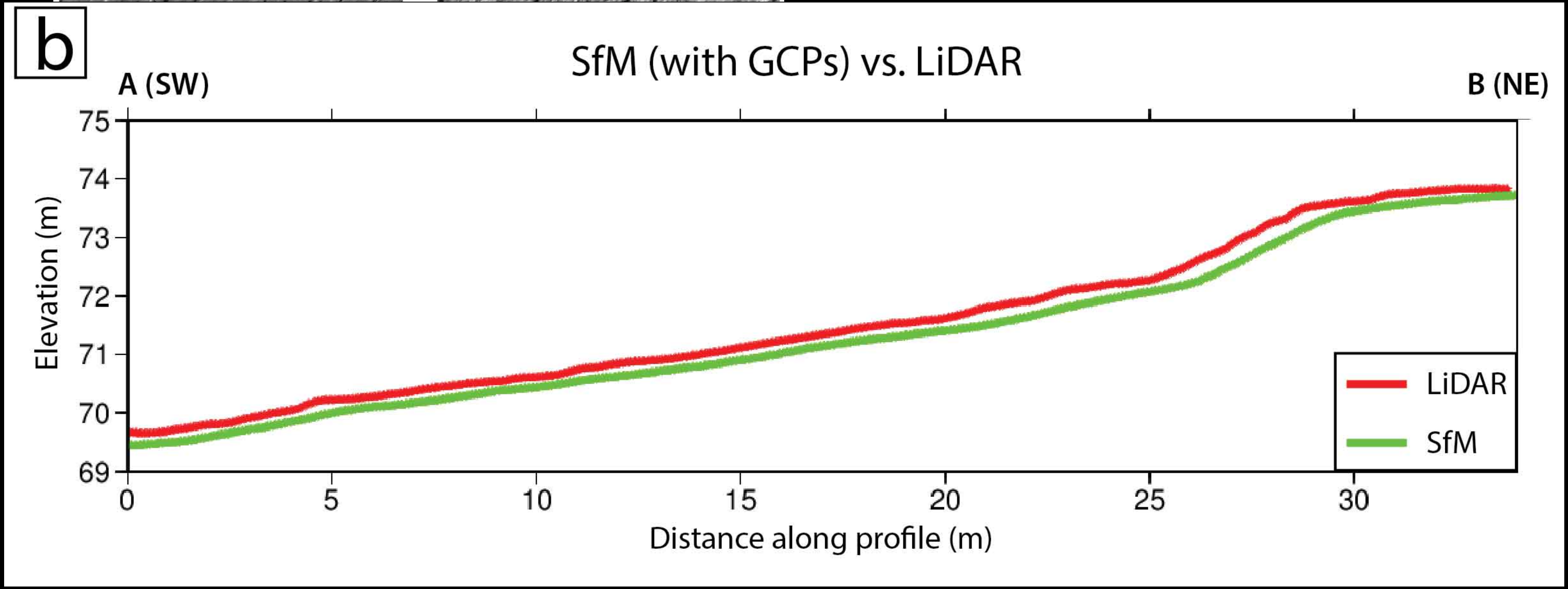
- Published LiDAR errors: 5-10 cm
- Bushes (and cars) have largest errors
- Steep slopes have larger errors in LiDAR data
- Geomorphic changes now stand out

Johnson et al., 2014

Washington Street Site: With GCPs



- SfM profile now mimics the shape of the LiDAR profile
- Slight remaining shift due to systematic error in the GPS base station

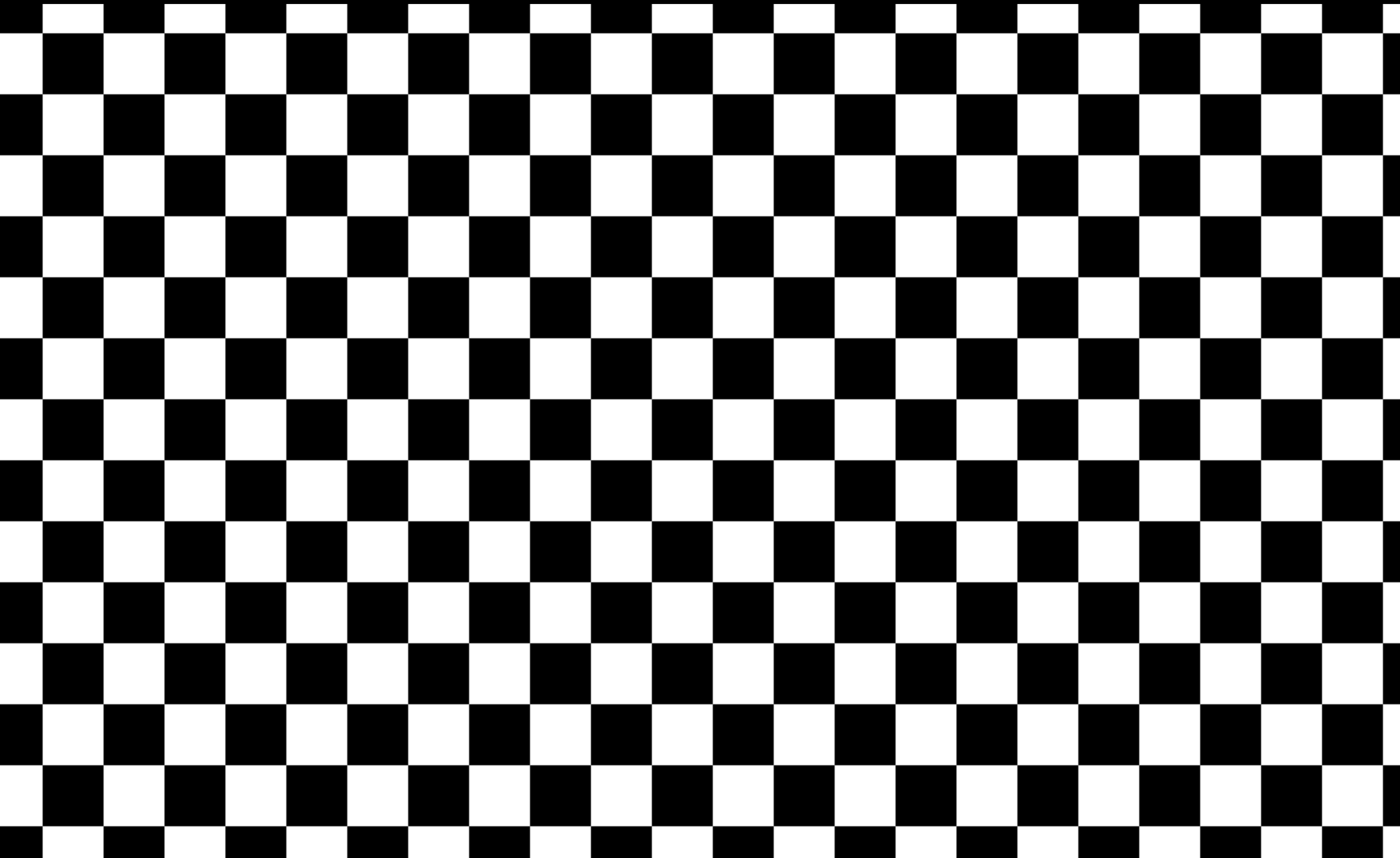


Johnson et al., 2014

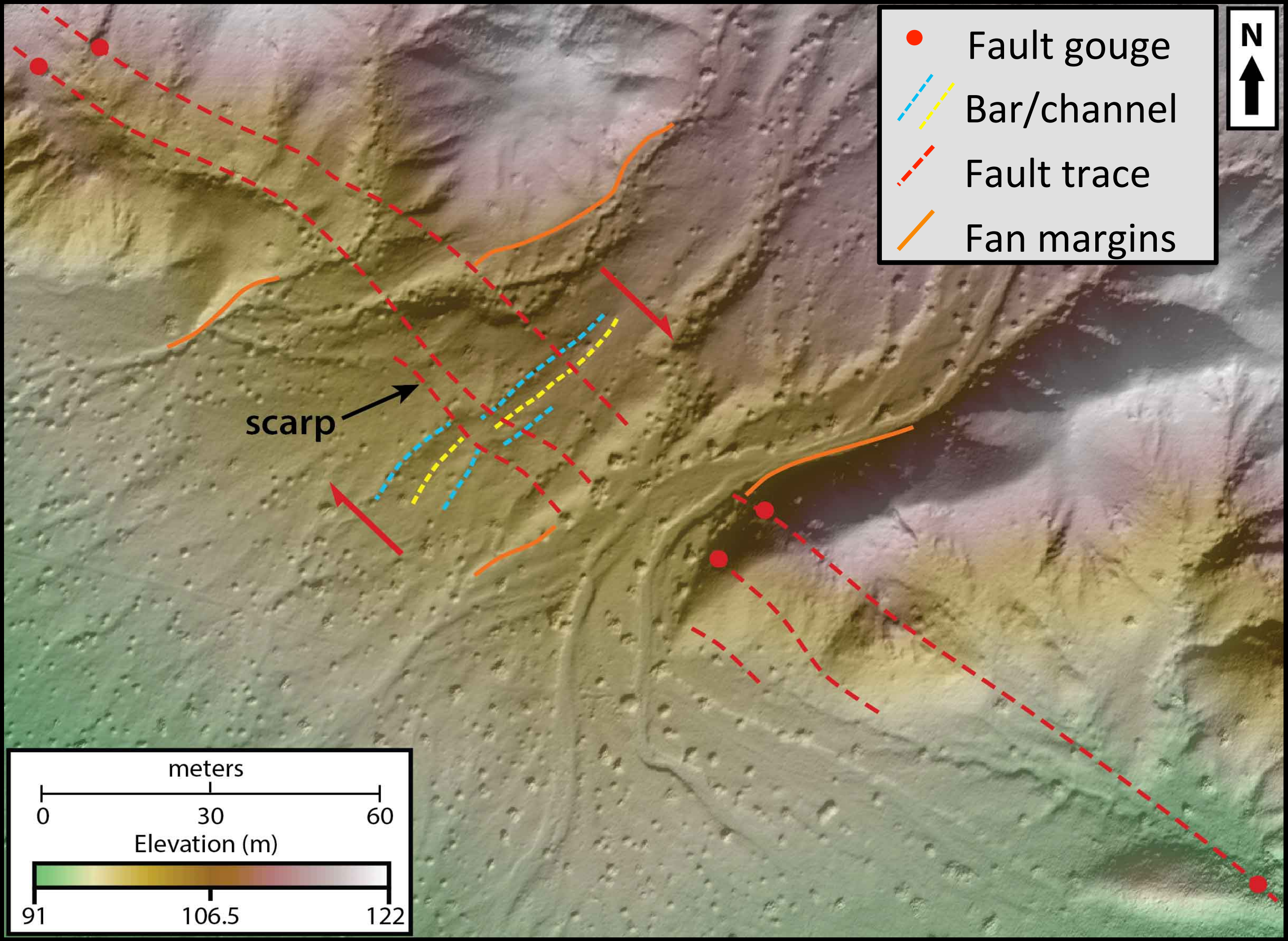
Conclusion: although SfM is able to work out the rough 3D structure of the scene without any GCPs, there may be warping and tilting → **we always use GCPs!**

If images are collected from a camera that does not have GPS, GCPs must be used to create a spatial/geospatial reference frame.

Agisoft Lens



Washington Street Site Interpretation



Channel/bar offset:
3 m*

Scarp height:
0.8 m

Fan margin offset:
20-25 m

Johnson et al., 2014

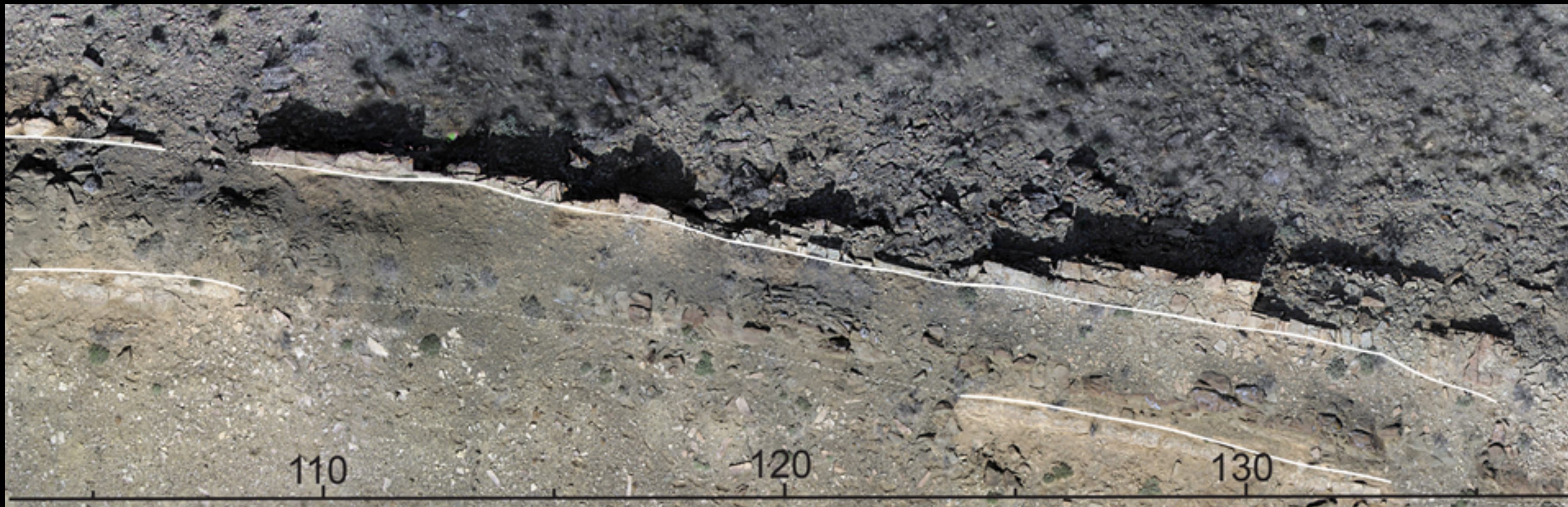
*Corresponds with slip estimates for ca. 1690 earthquake

Example: Jointing and magmatic dikes as a precursor to the development of volcanic plugs

Townsend et al. (in press)

Use geologic evidence to test flow localization theories

Characterize systematic set of dike-perpendicular joints in sedimentary host rock



Used orthophoto (5 mm resolution) to measure the length and orientation of the joints

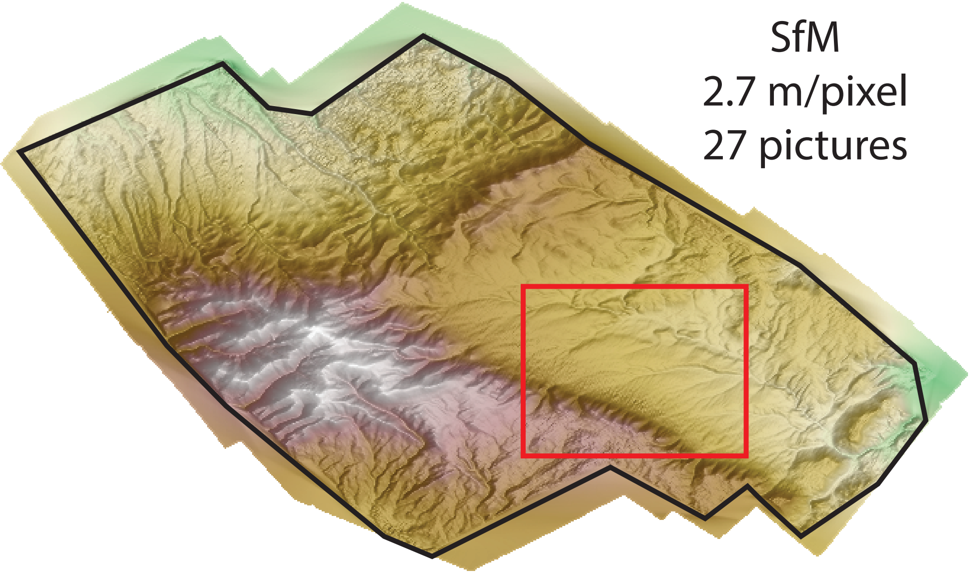
Showed that perpendicular joints are associated with magma emplacement and thermal pressurization in host rock → fracturing is precursor to host rock erosion and sustained flow

SfM from existing aerial photos

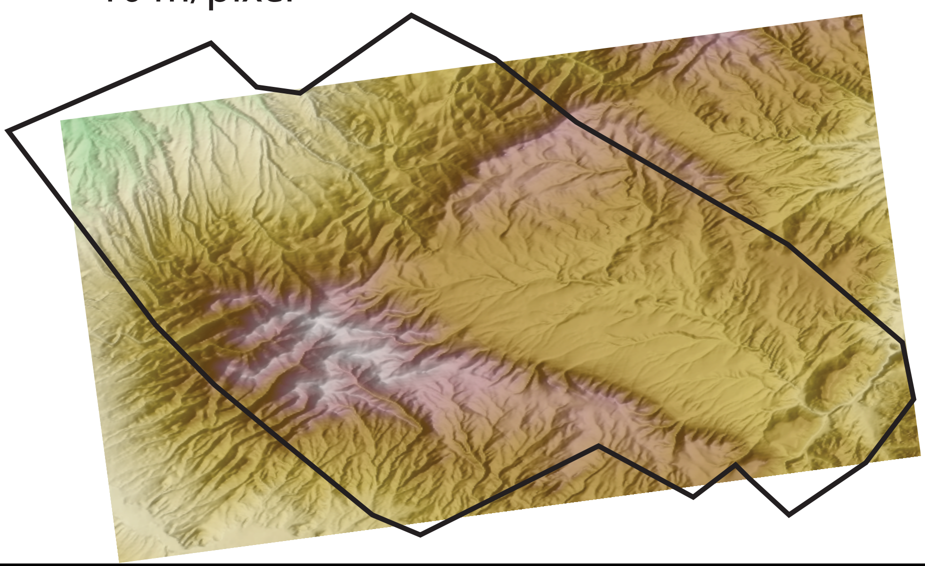
Because rigid photo geometry and camera position/orientation details are not important in SfM, we can extract elevation data from any set of aerial photos – provided they have sufficient overlap.

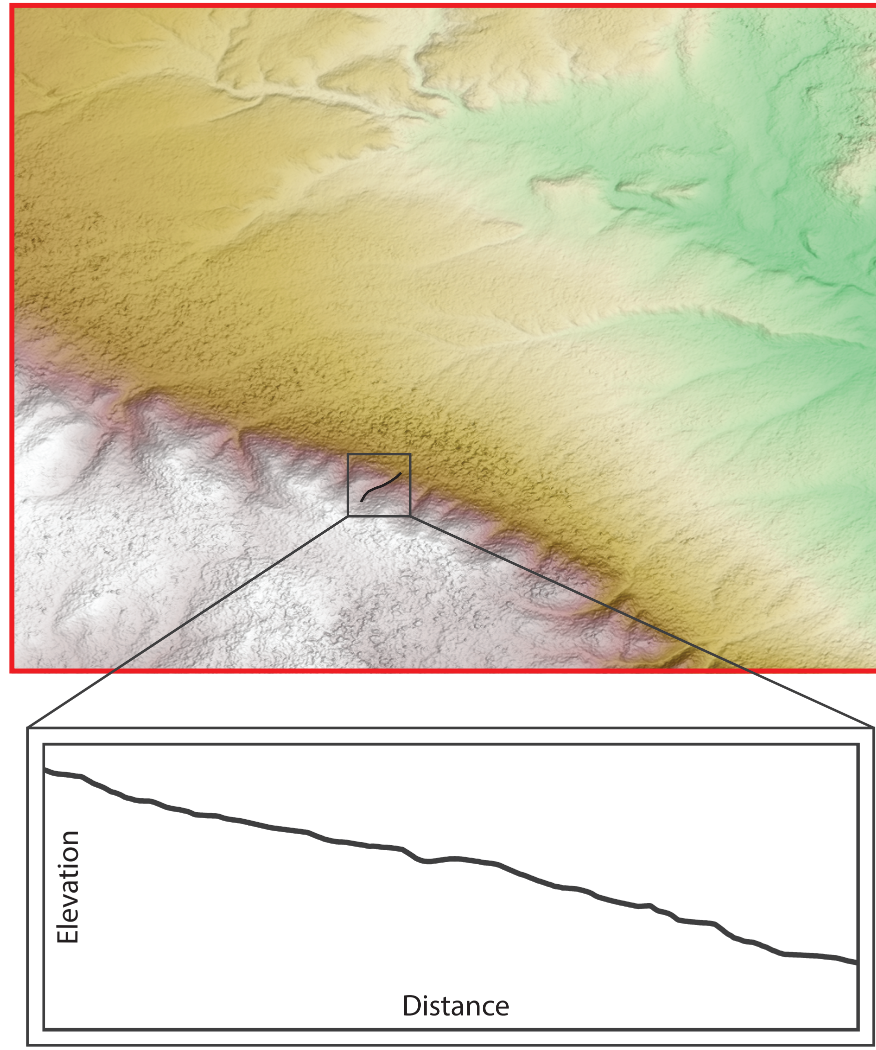
Example: Stream profile analysis in Montana

SfM
2.7 m/pixel
27 pictures

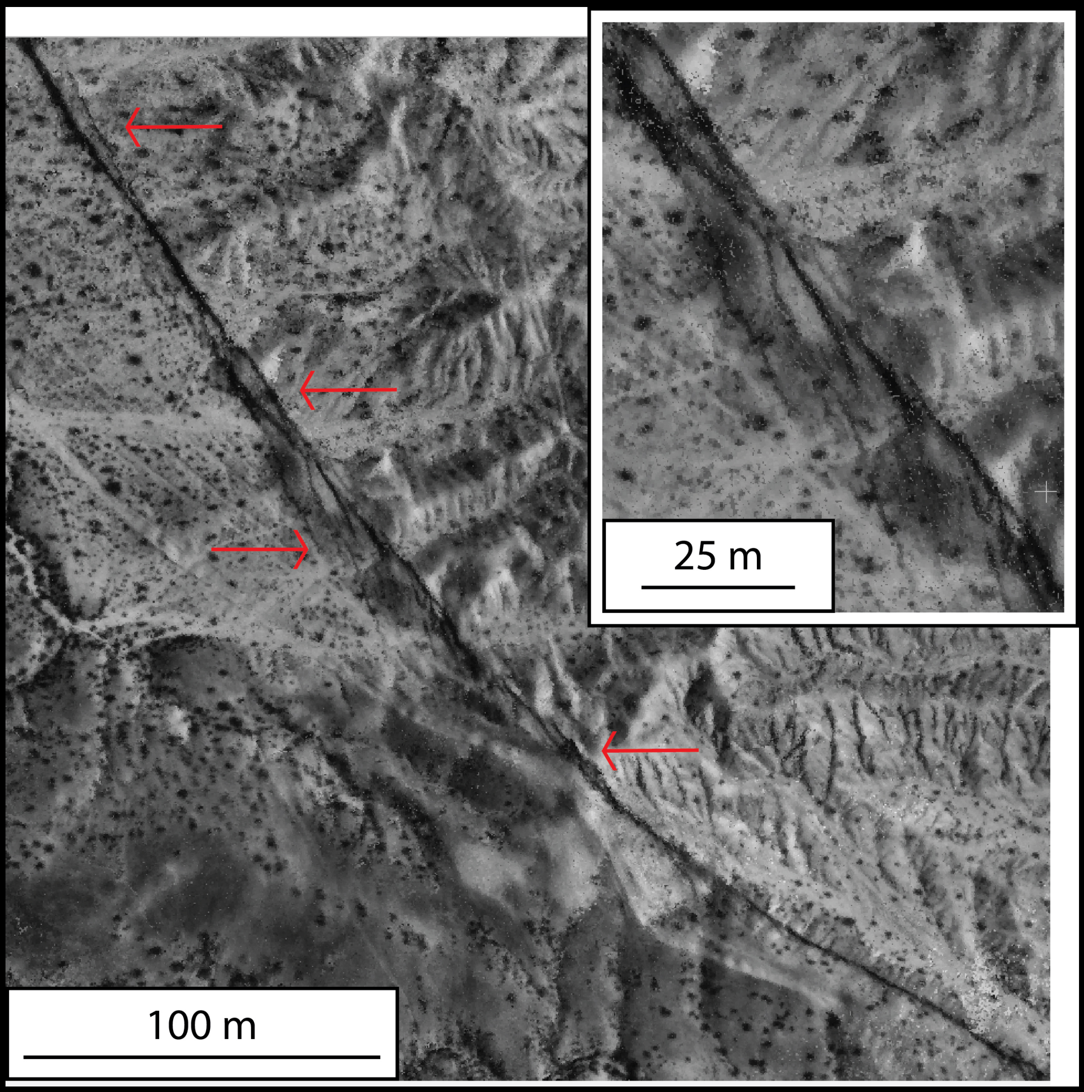


NED
10 m/pixel





Example: Assessment of the 1992 Lander's earthquake rupture zone width and complexity



Does rupture width and complexity depend more on lithology and surface cover thickness, or structural maturity of the causative fault?

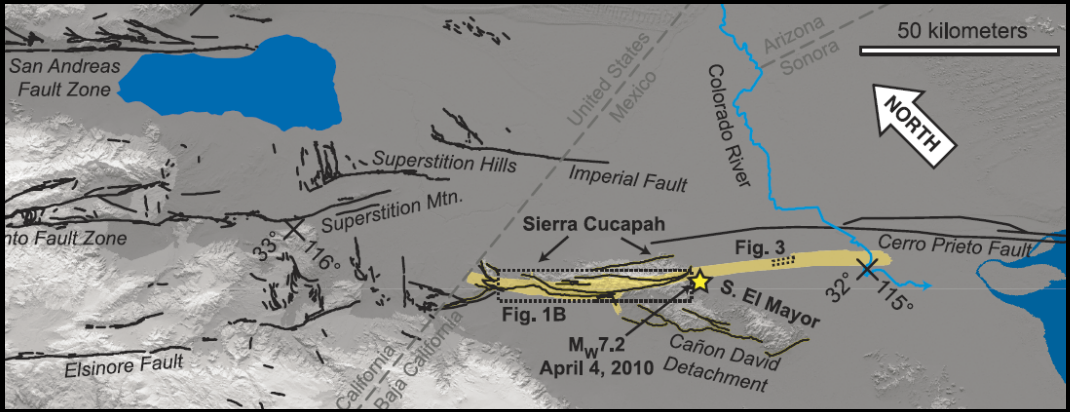
Point cloud generated using aerial photos from just after the earthquake

Use in multitemporal studies

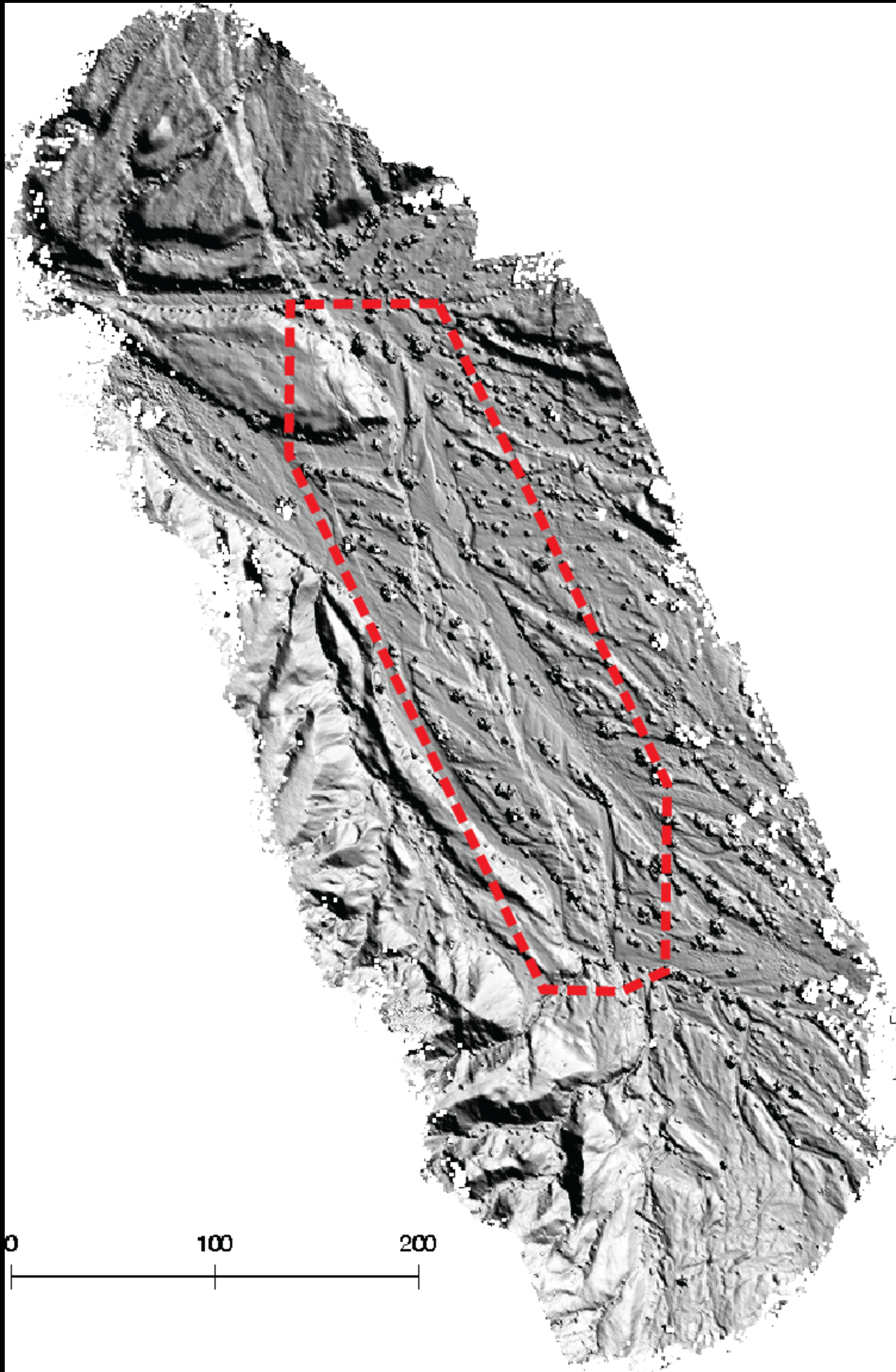
Suitable for repeat surveys if:

- Satellite methods do not provide sufficient resolution (time and/or space)
- Alternative methods (e.g. laser scanning) are too costly or logistically complicated

Example: Degradation of the El Mayor-Cucapah earthquake scarp

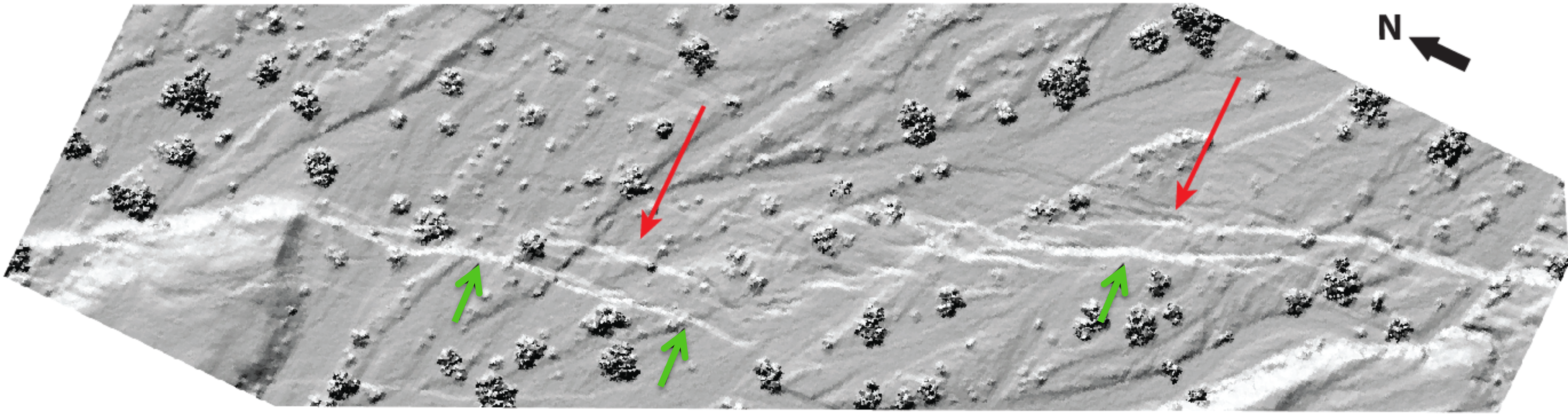


Degradation of the 2010 El Mayor-Cucapah earthquake scarp

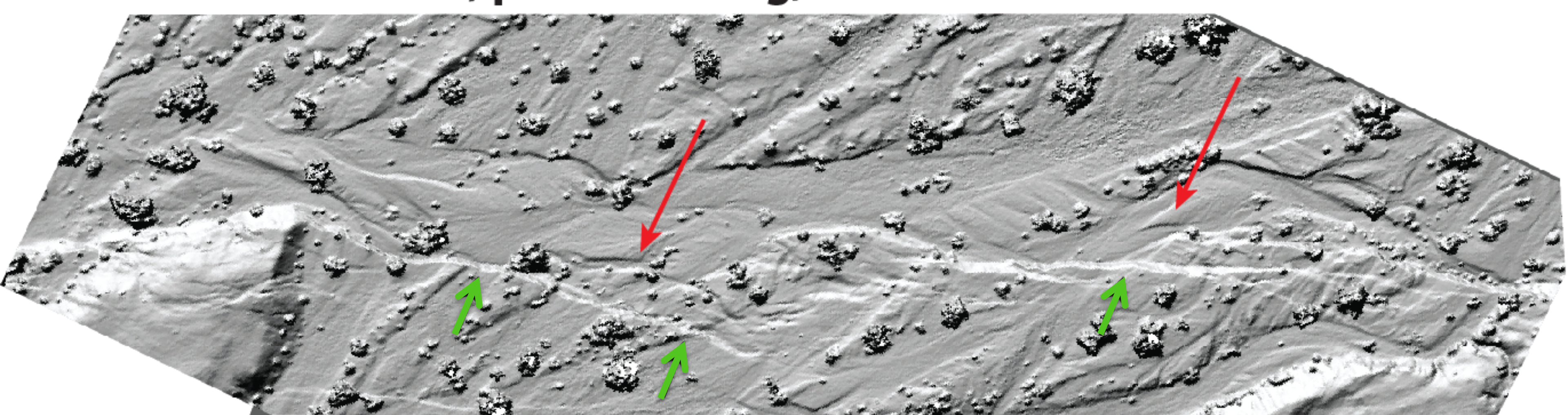


Degradation due to flooding

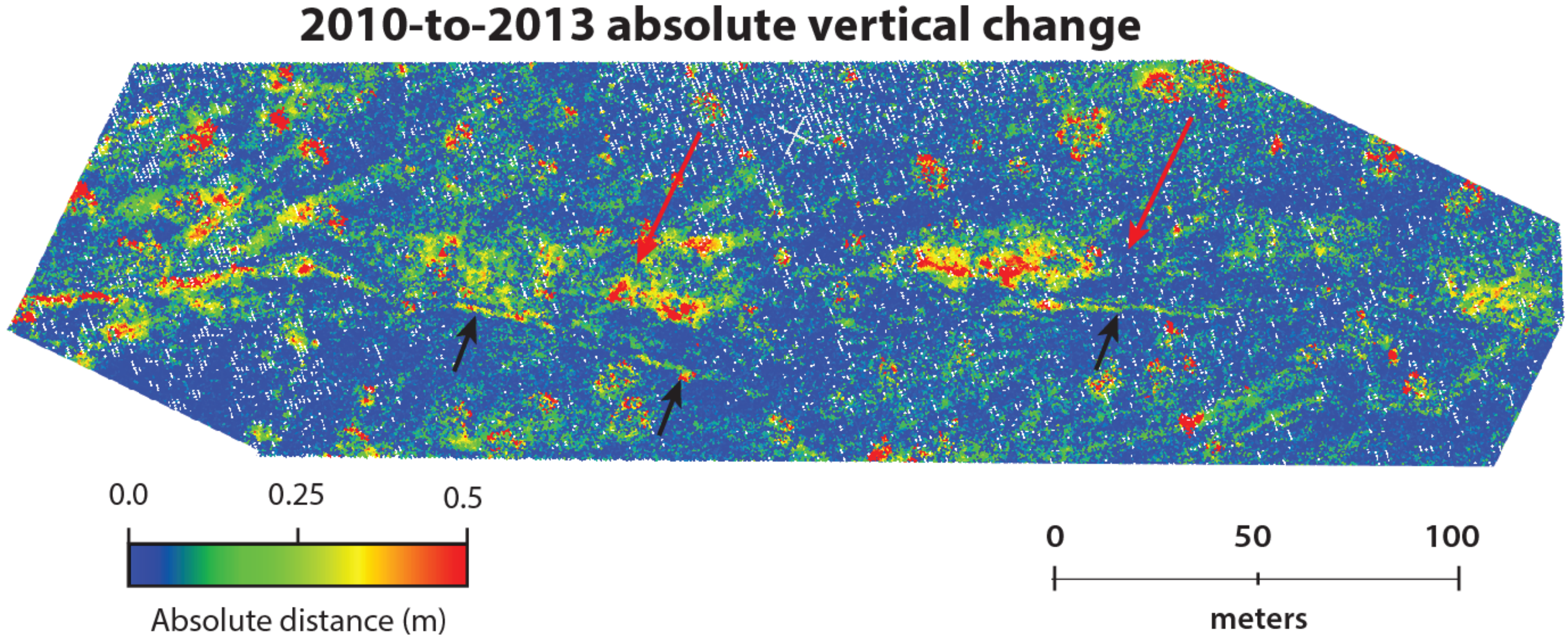
LiDAR; post-earthquake, August 2010



SfM; post-flooding, November 2013



Quantitative comparison



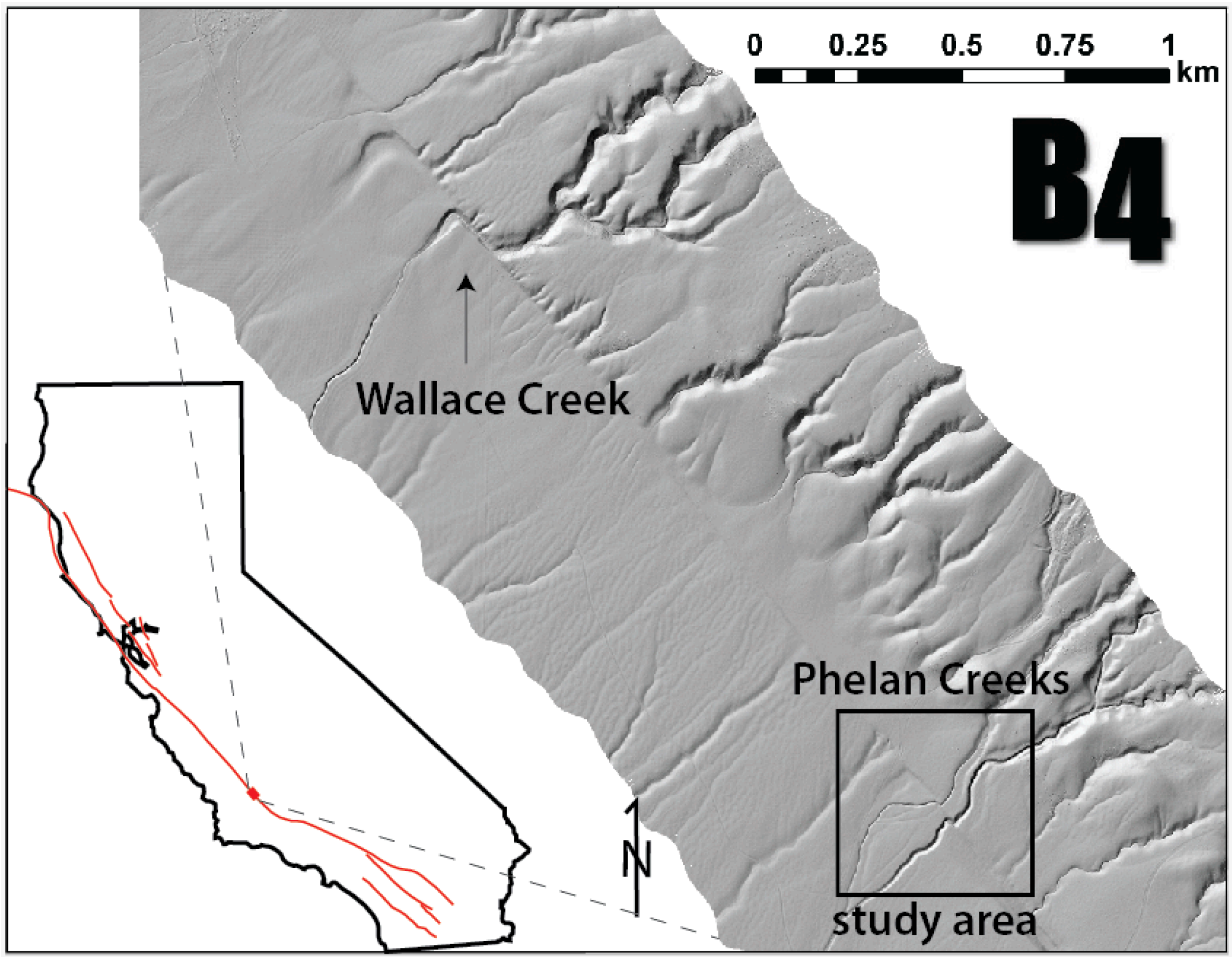
General Applications in Active Tectonics

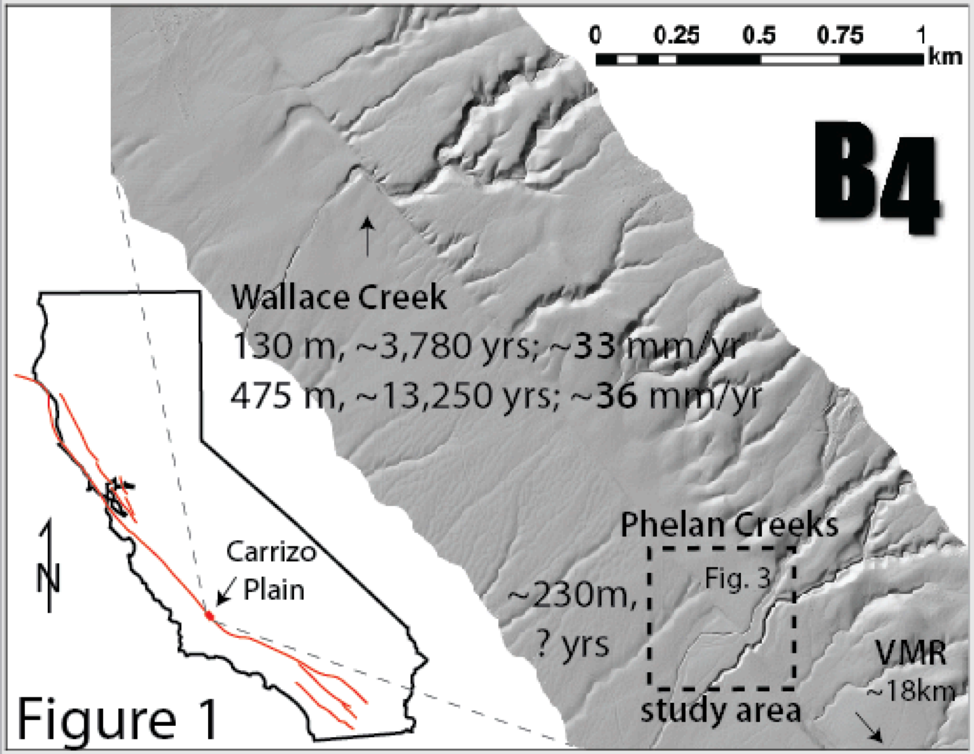
CICESE, April 2015
Barrett Salisbury
Arizona State University

Outline

- southern San Andreas, ballooning
- central (creeping) San Andreas, UAV
- Preliminary Pre- and Post-event comparison, Napa, CA
- Fun outcrop modeling, Antarctic Peninsula
- Examples of closed objects

southern San Andreas




0 0.25 0.5 0.75 1 km
B4
Wallace Creek
130 m, ~3,780 yrs; ~33 mm/yr
475 m, ~13,250 yrs; ~36 mm/yr
Carrizo Plain
N
Phelan Creeks
Fig. 3
~230m, ? yrs
study area
VMR ~18km
Figure 1

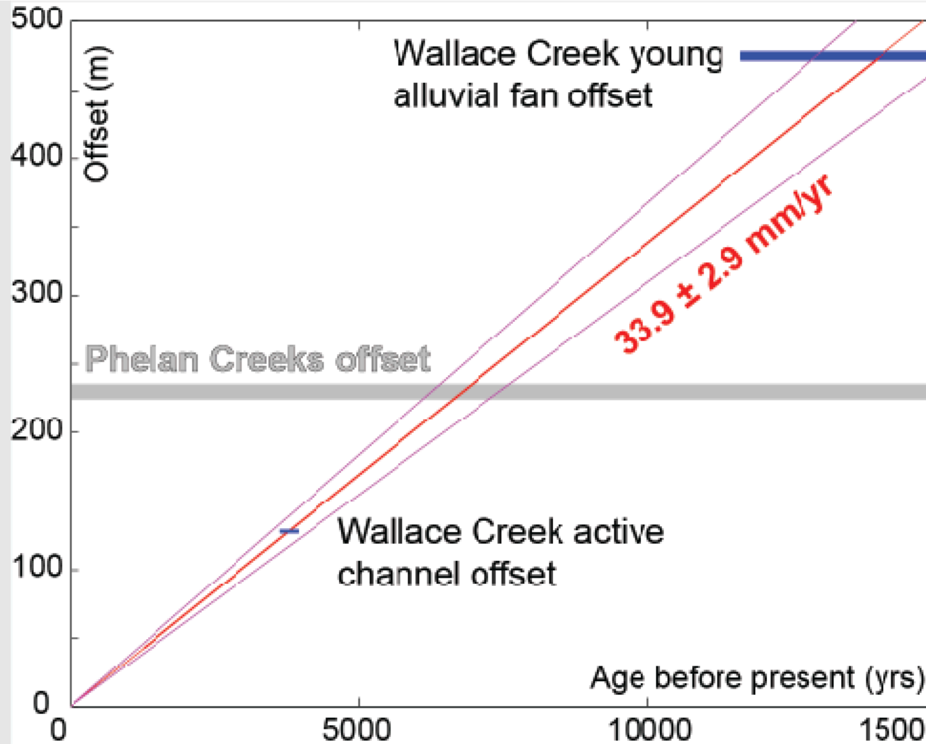
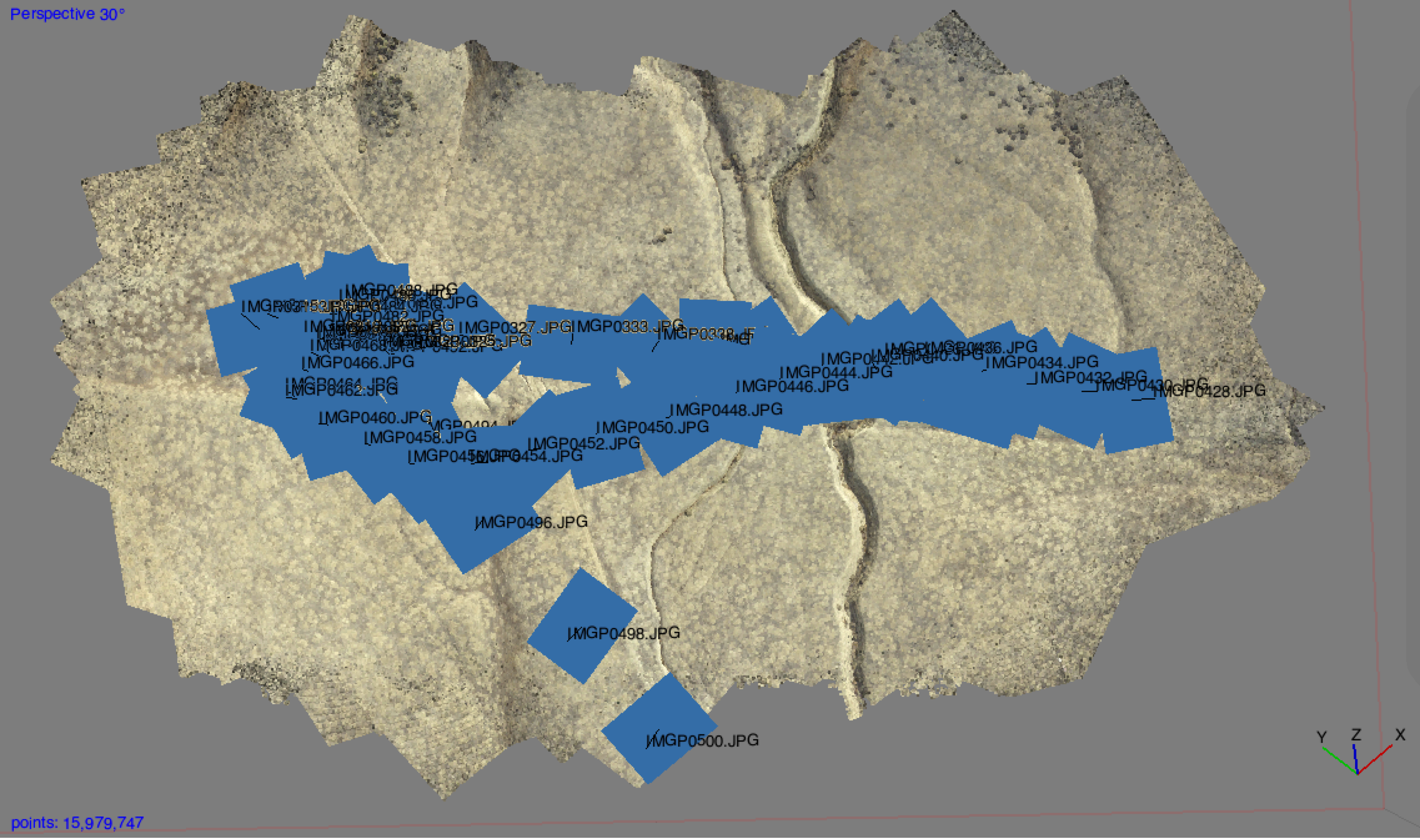
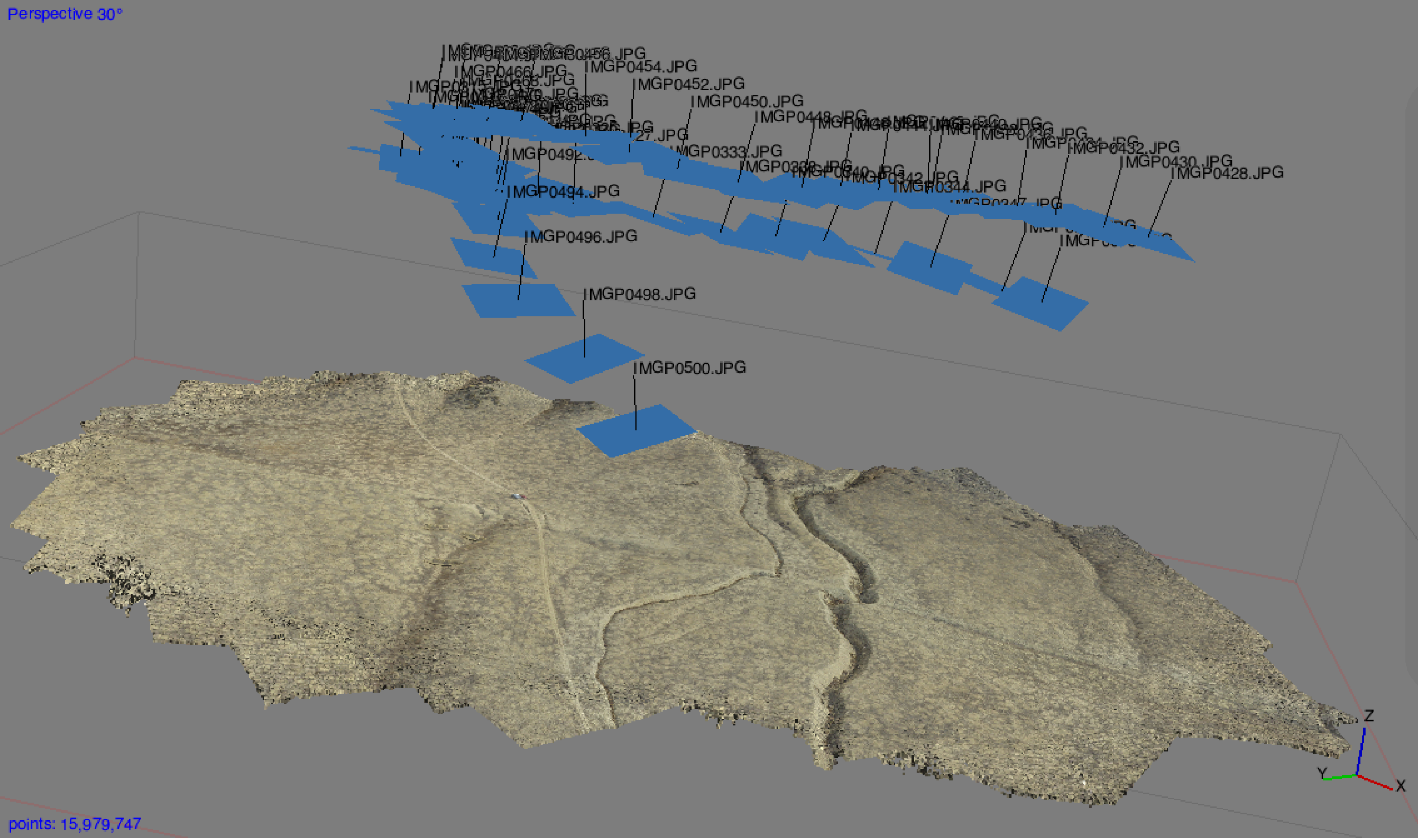
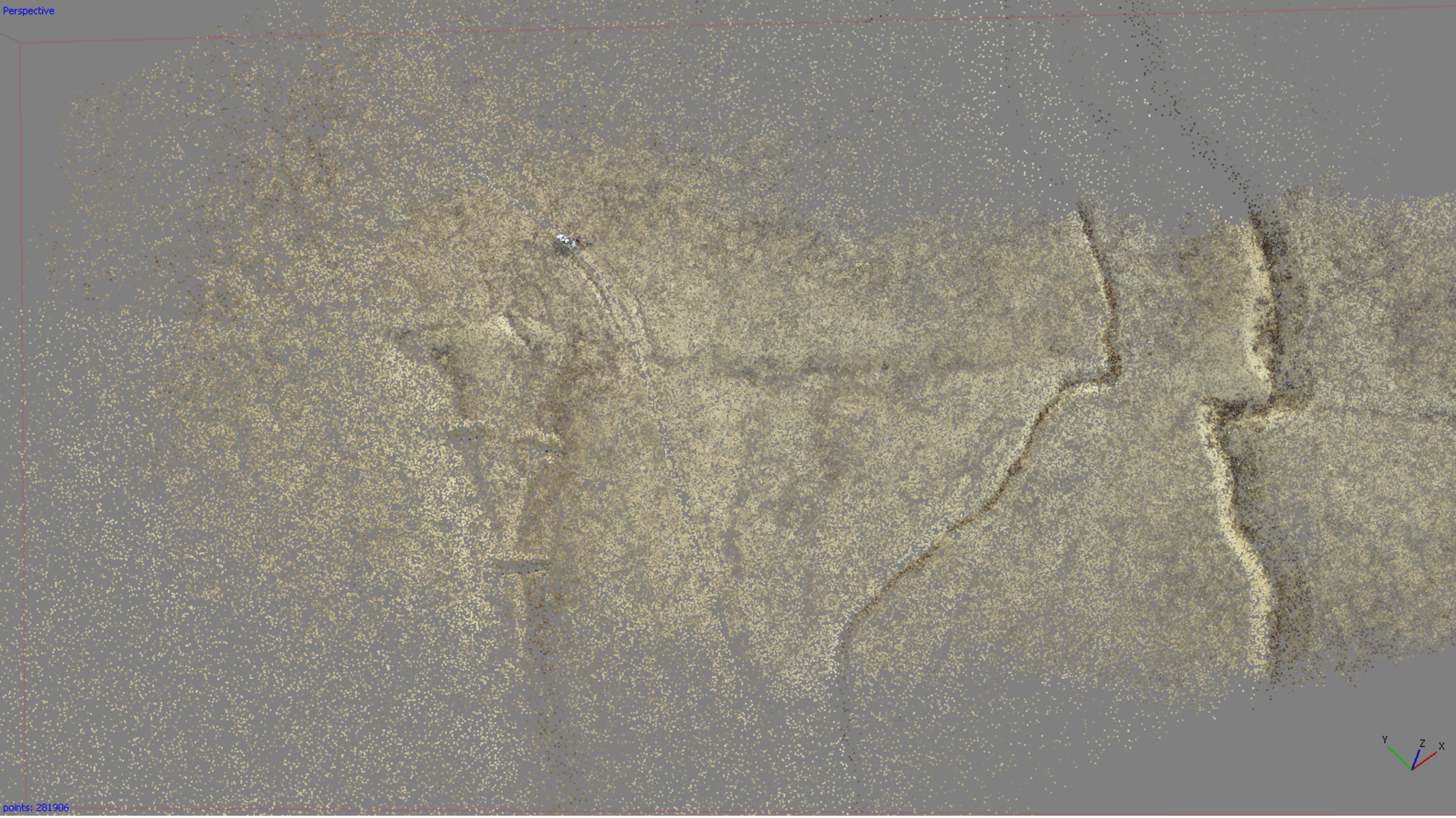

Offset (m)
Wallace Creek young alluvial fan offset
33.9 ± 2.9 mm/yr
Phelan Creeks offset
Wallace Creek active channel offset
Age before present (yrs)
0 100 200 300 400 500
0 5000 10000 15000

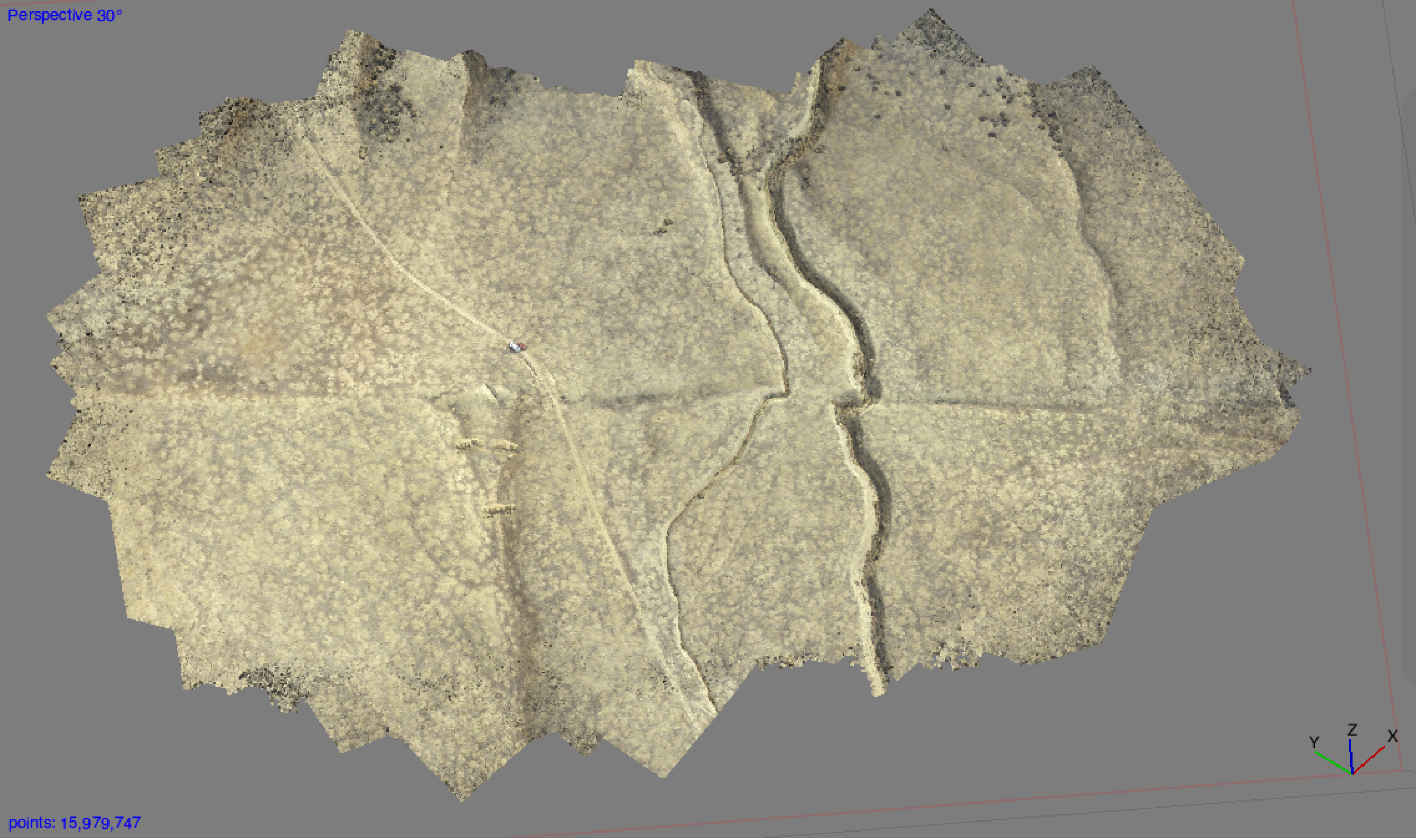
Figure 2


POSTED
NO TRESPASSING
KEEP OUT

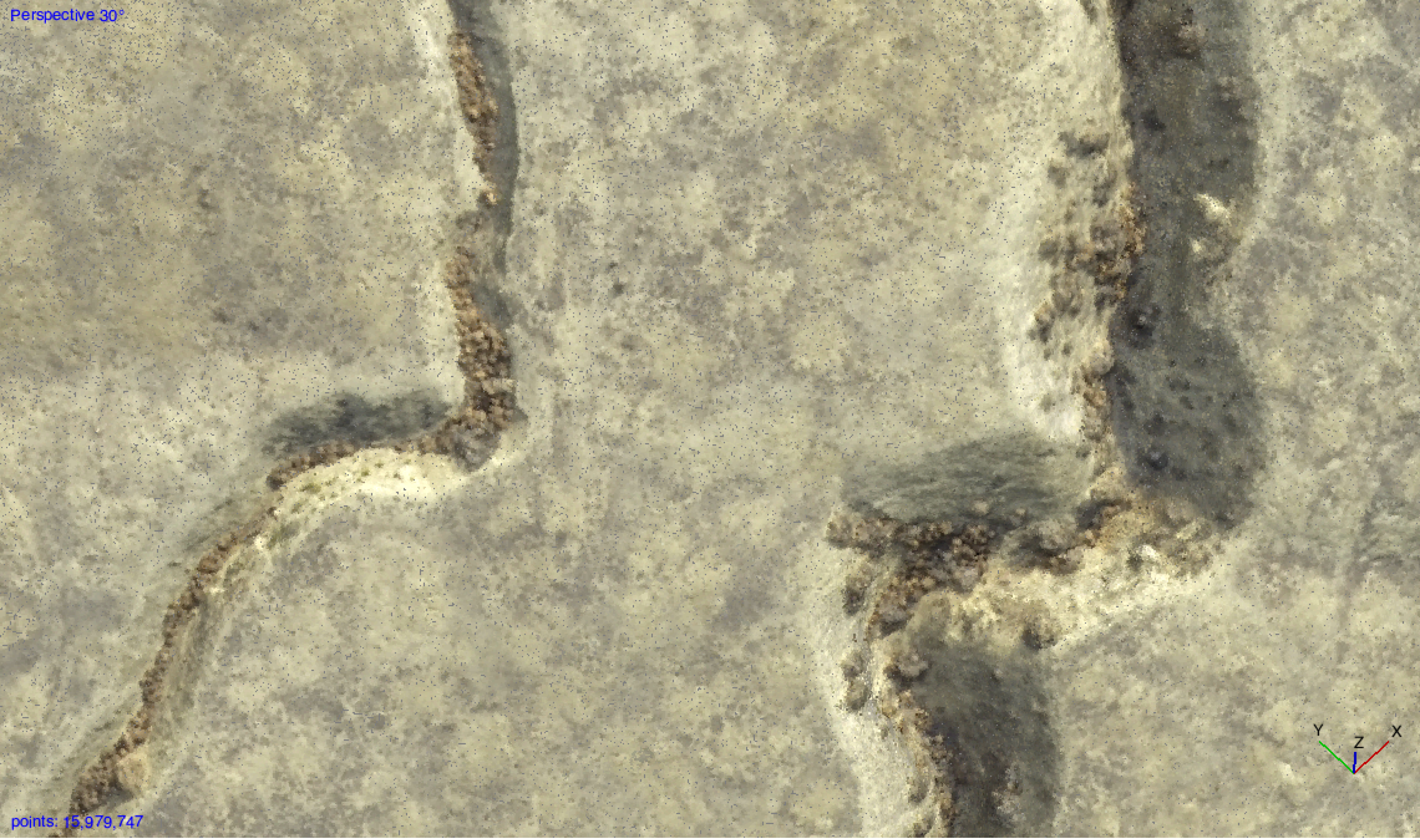

Perspective 30°
IMGP0327.JPG
IMGP0333.JPG
IMGP0466.JPG
IMGP0462.JPG
IMGP0460.JPG
IMGP0458.JPG
IMGP0454.JPG
IMGP0452.JPG
IMGP0450.JPG
IMGP0448.JPG
IMGP0446.JPG
IMGP0444.JPG
IMGP0434.JPG
IMGP0428.JPG
IMGP0496.JPG
IMGP0498.JPG
IMGP0500.JPG
Y
Z
X
points: 15,979,747

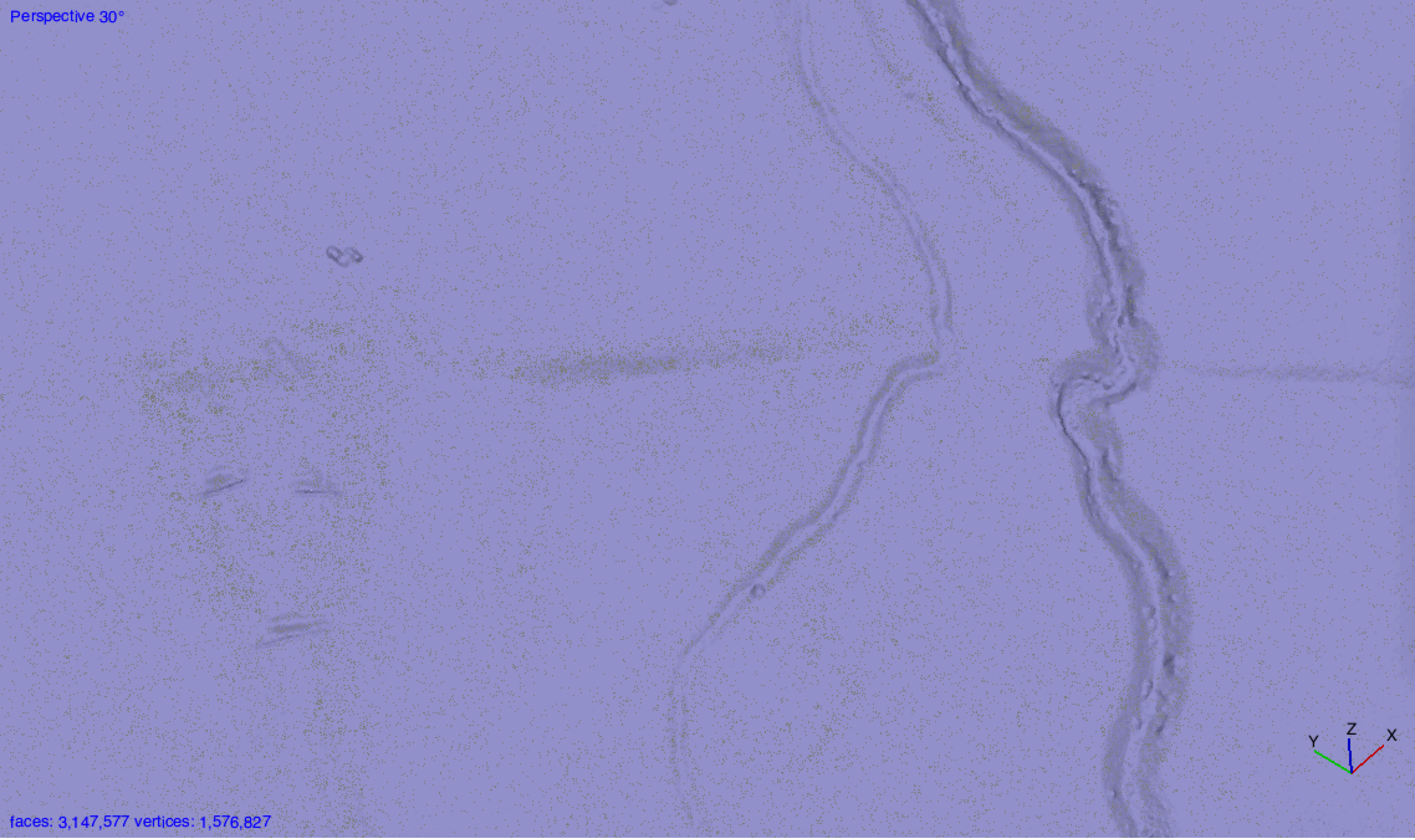

Perspective 30°
IMGP0466.JPG
IMGP0454.JPG
IMGP0452.JPG
IMGP0450.JPG
IMGP0333.JPG
IMGP0432.JPG
IMGP0430.JPG
IMGP0428.JPG
IMGP0494.JPG
IMGP0496.JPG
IMGP0498.JPG
IMGP0500.JPG
points: 15,979,747
Z
Y
X


Perspective
points: 281906
Y
Z
X

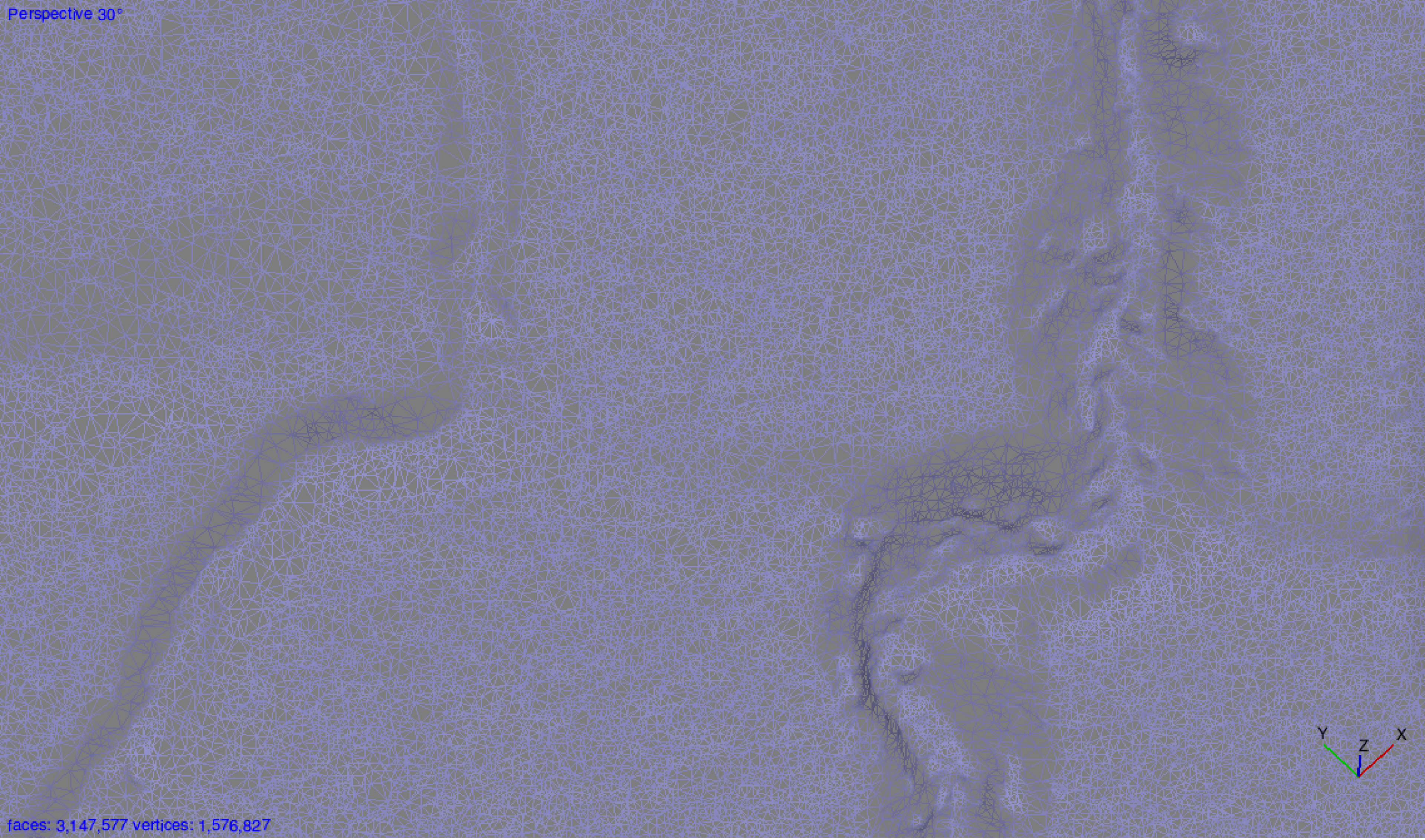

Perspective 30°
points: 15,979,747
Y
Z
X


Perspective 30°
points: 15,979,747
Y
Z
X

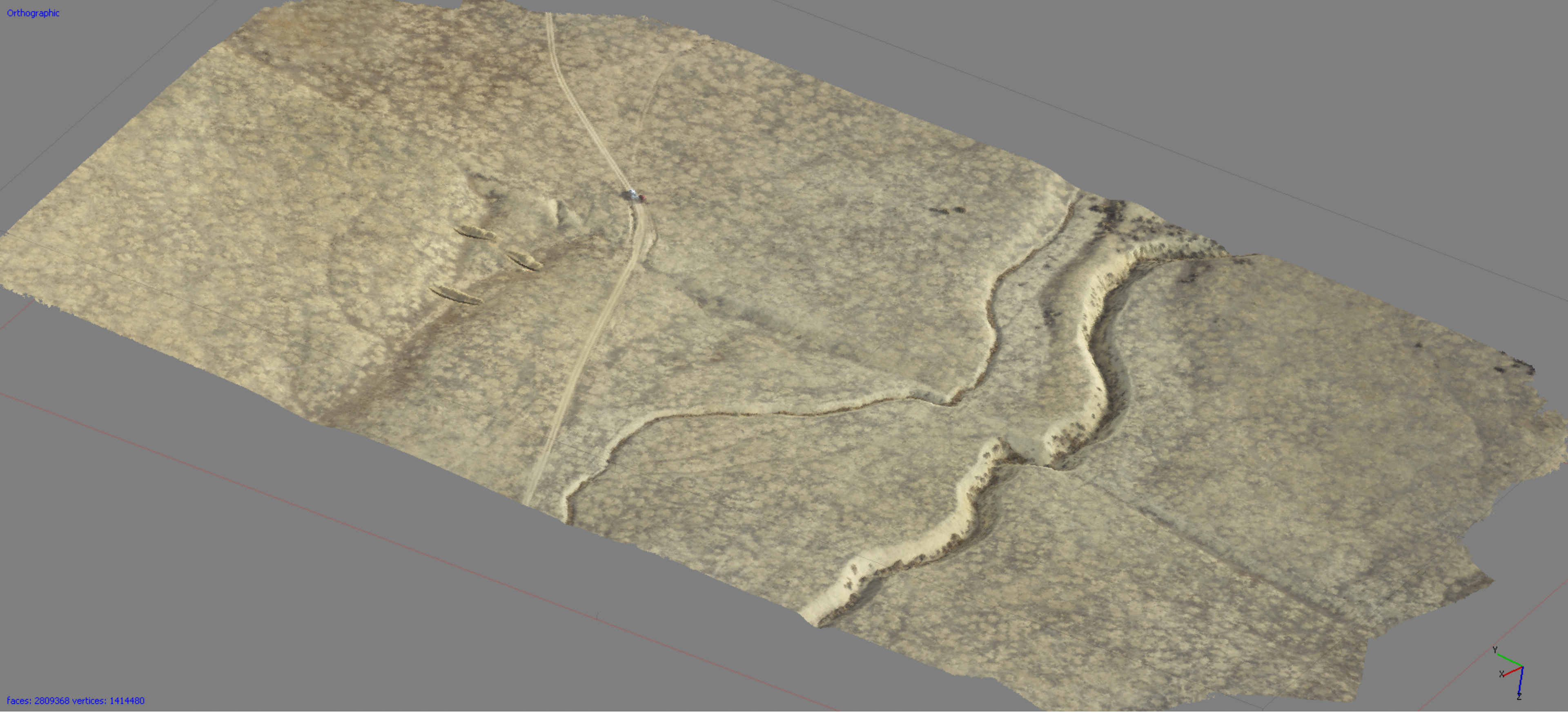

Perspective 30°
points: 15,979,747
Y
Z
X



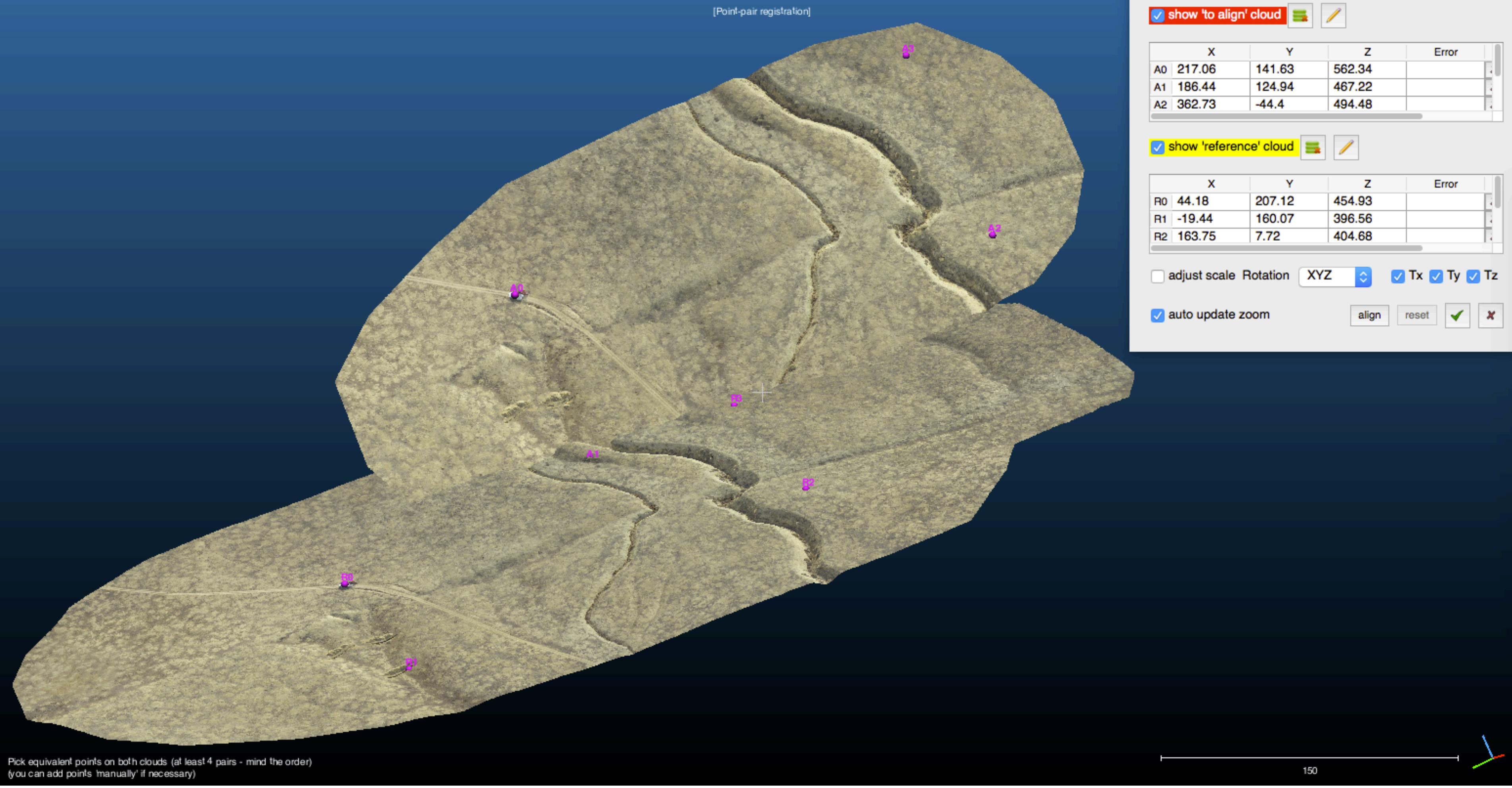
Perspective 30°
faces: 3,147,577 vertices: 1,576,827
Y
Z
X

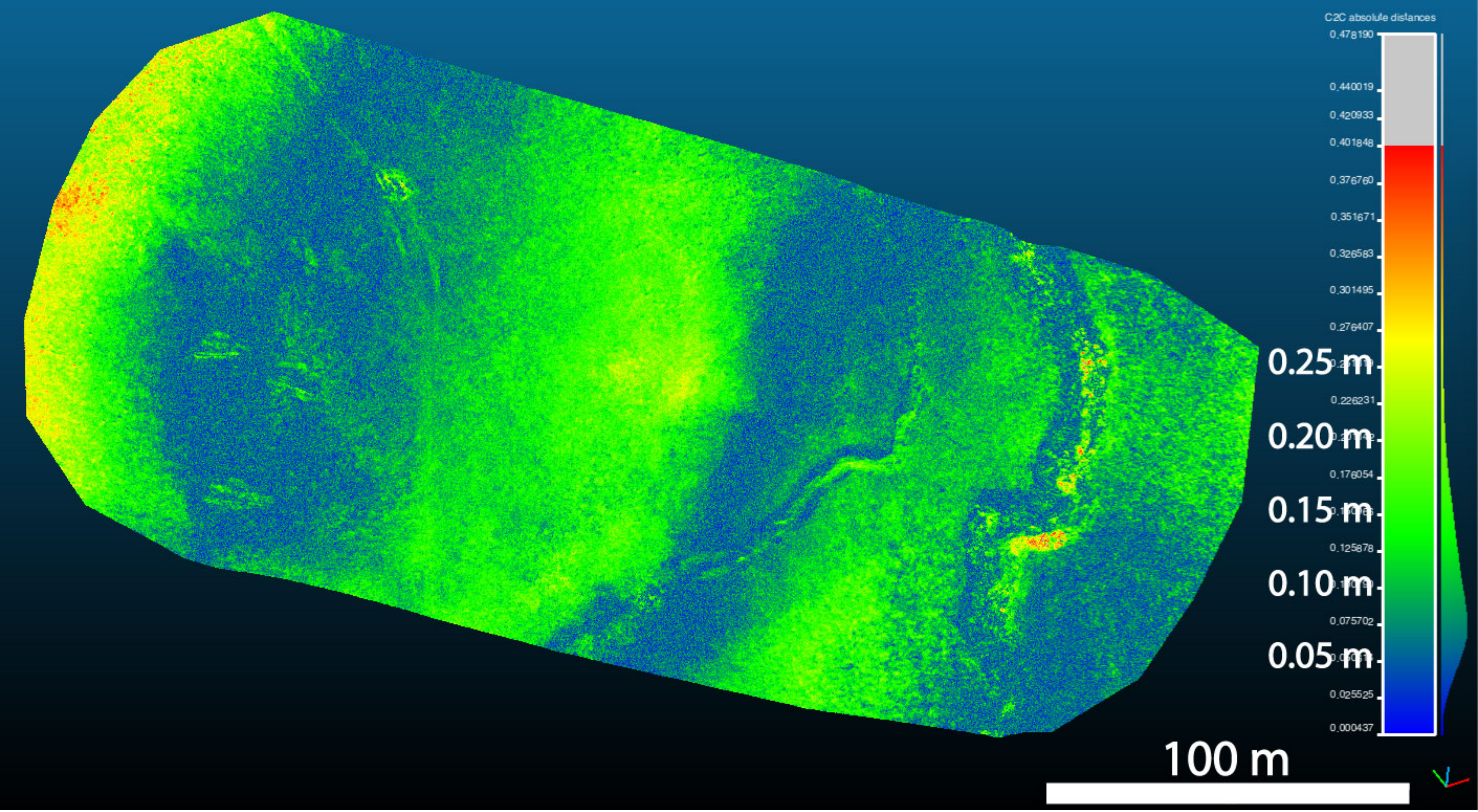


Perspective 30°
faces: 3,147,577 vertices: 1,576,827
Y
Z
X



Orthographic
faces: 2809368 vertices: 1414480
Y
X
Z


[Point-pair registration]
show 'to align' cloud
X Y Z Error
A0 217.06 141.63 562.34
A1 186.44 124.94 467.22
A2 362.73 -44.4 494.48
show 'reference' cloud
X Y Z Error
R0 44.18 207.12 454.93
R1 -19.44 160.07 396.56
R2 163.75 7.72 404.68
adjust scale Rotation XYZ Tx Ty Tz
auto update zoom align reset
Pick equivalent points on both clouds (at least 4 pairs - mind the order)
(you can add points 'manually' if necessary)
150



C2C absolute distances
0,478190
0,440019
0,420933
0,401848
0,376760
0,351671
0,326583
0,301495
0,276407
0.25 m
0,226231
0.20 m
0,176054
0.15 m
0,125878
0.10 m
0,075702
0.05 m
0,025525
0,000437
100 m


UNIT 23
UNIT 2
SCEC
UNIT 24
UNIT 3

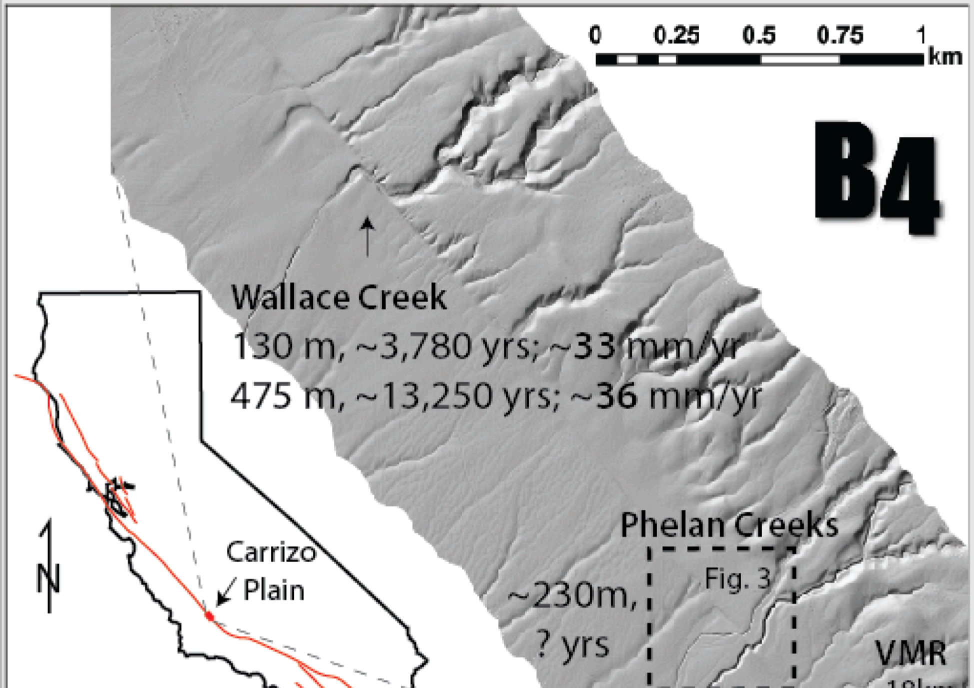


Figure 1

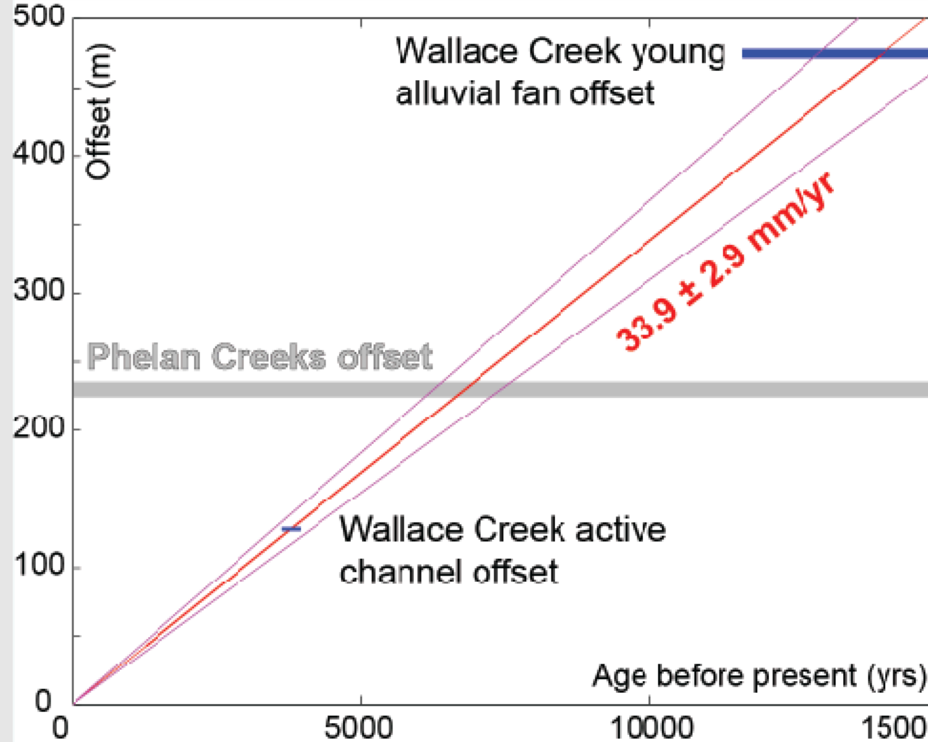
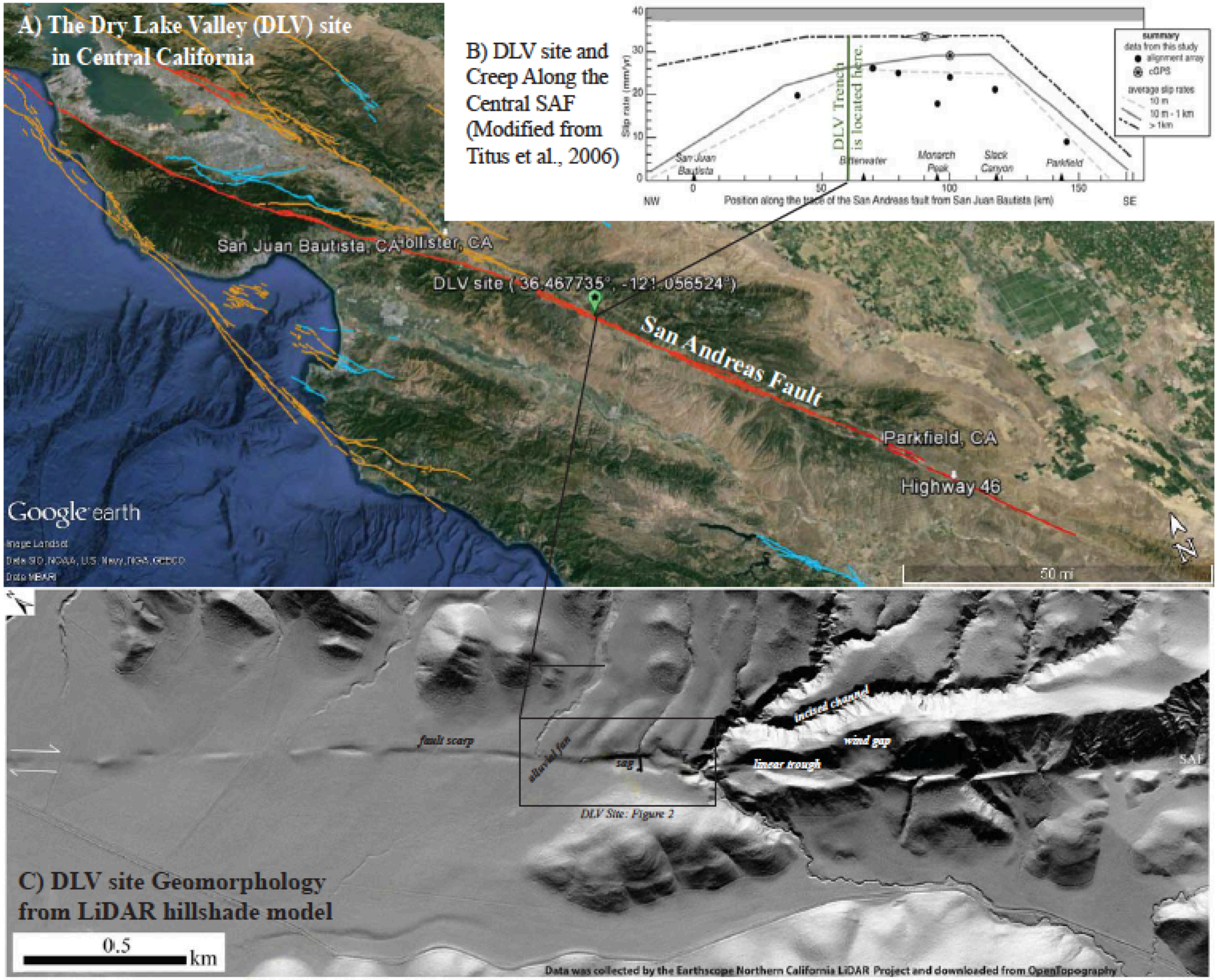


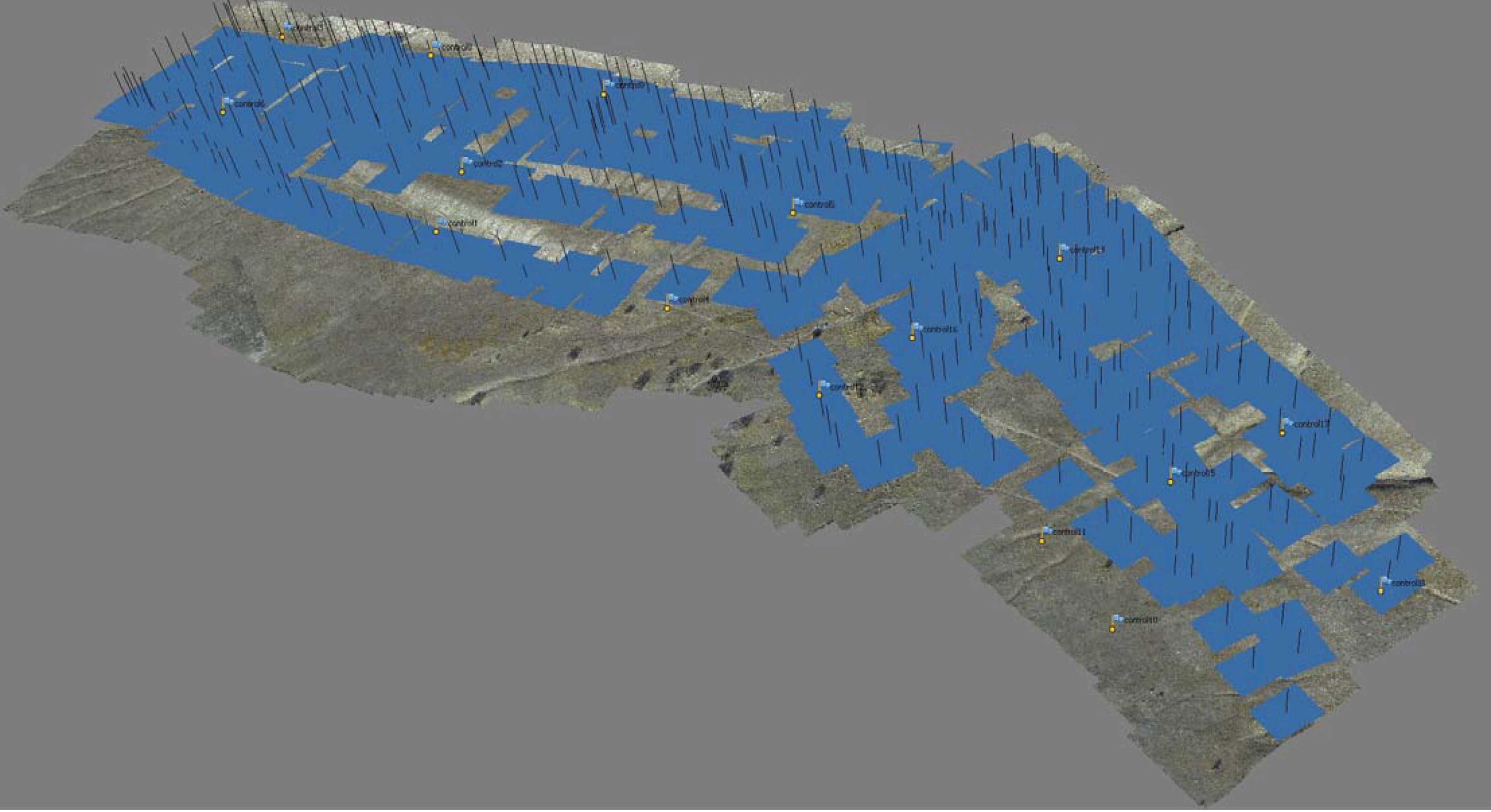
Figure 2

Central Creeping San Andreas

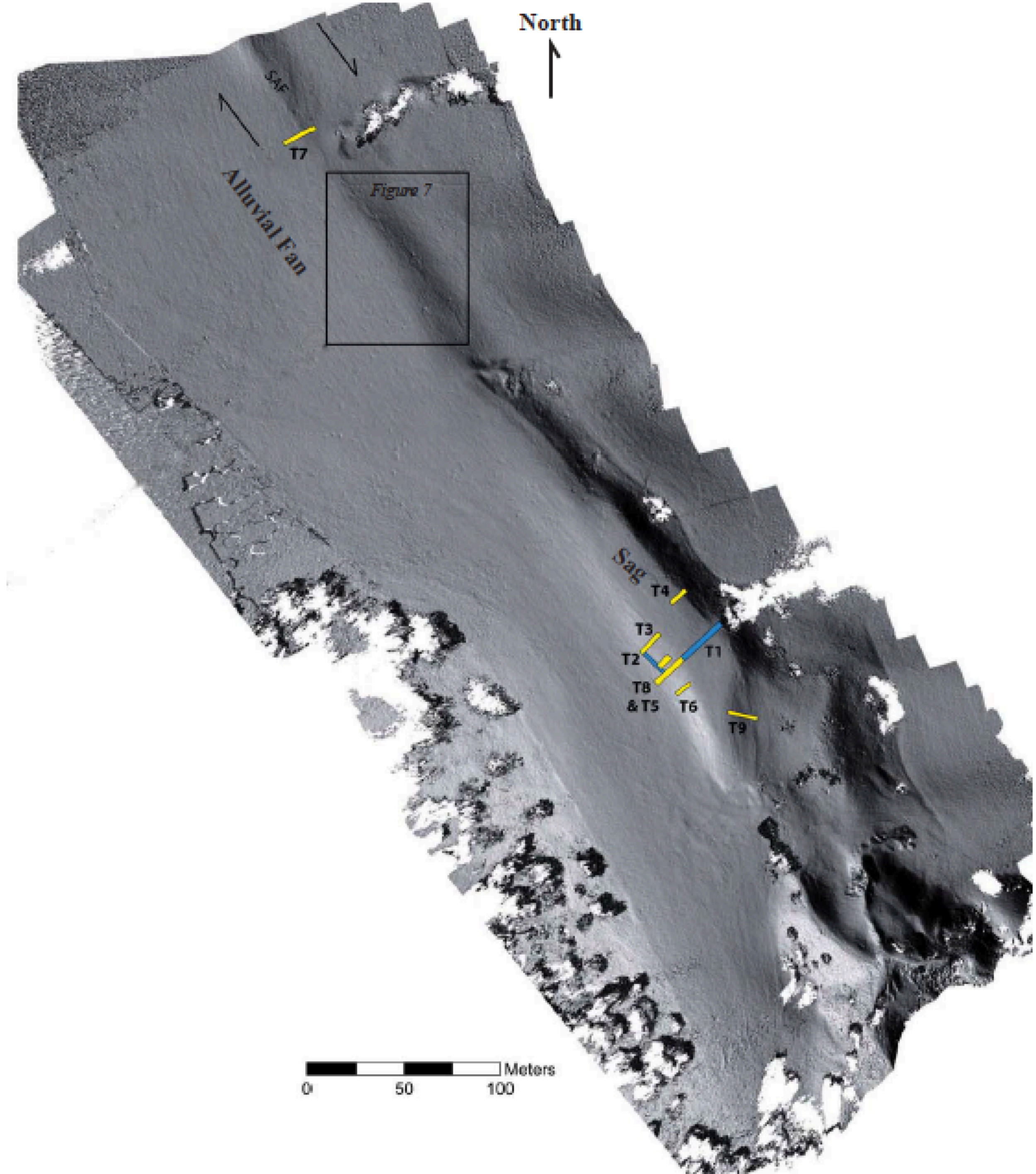


Toke and Arrowsmith, 2013 SCEC Annual Report


HERO3
20
30
40
50
60
70

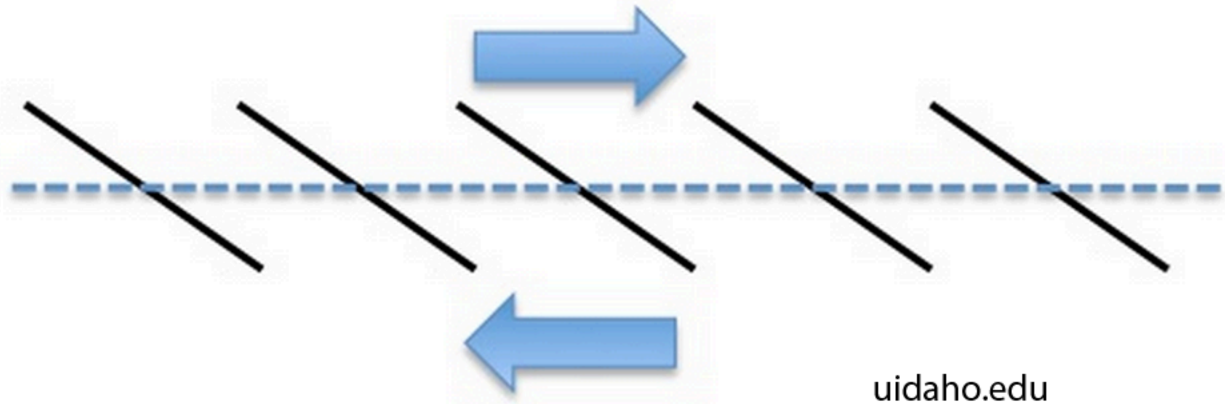


Bunds, M., N. Toke, S. Walker, A. Fletcher, and M. Arnoff, Dept. of Earth Sciences, Utah Valley University

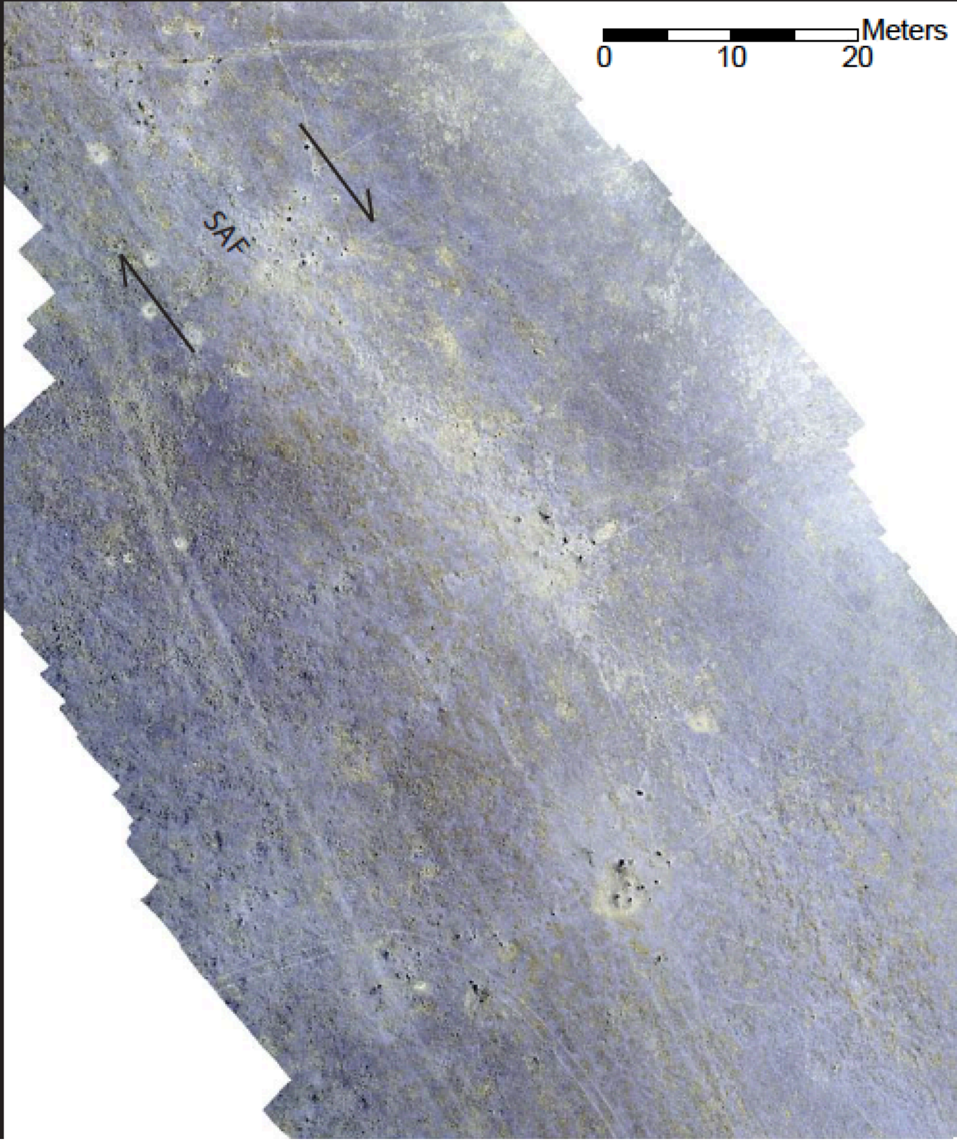

North
SAF
T7
Alluvial Fan
Figure 7
Sag
T4
T3
T1
T2
T8
& T5
T6
T9
Meters
0
50
100

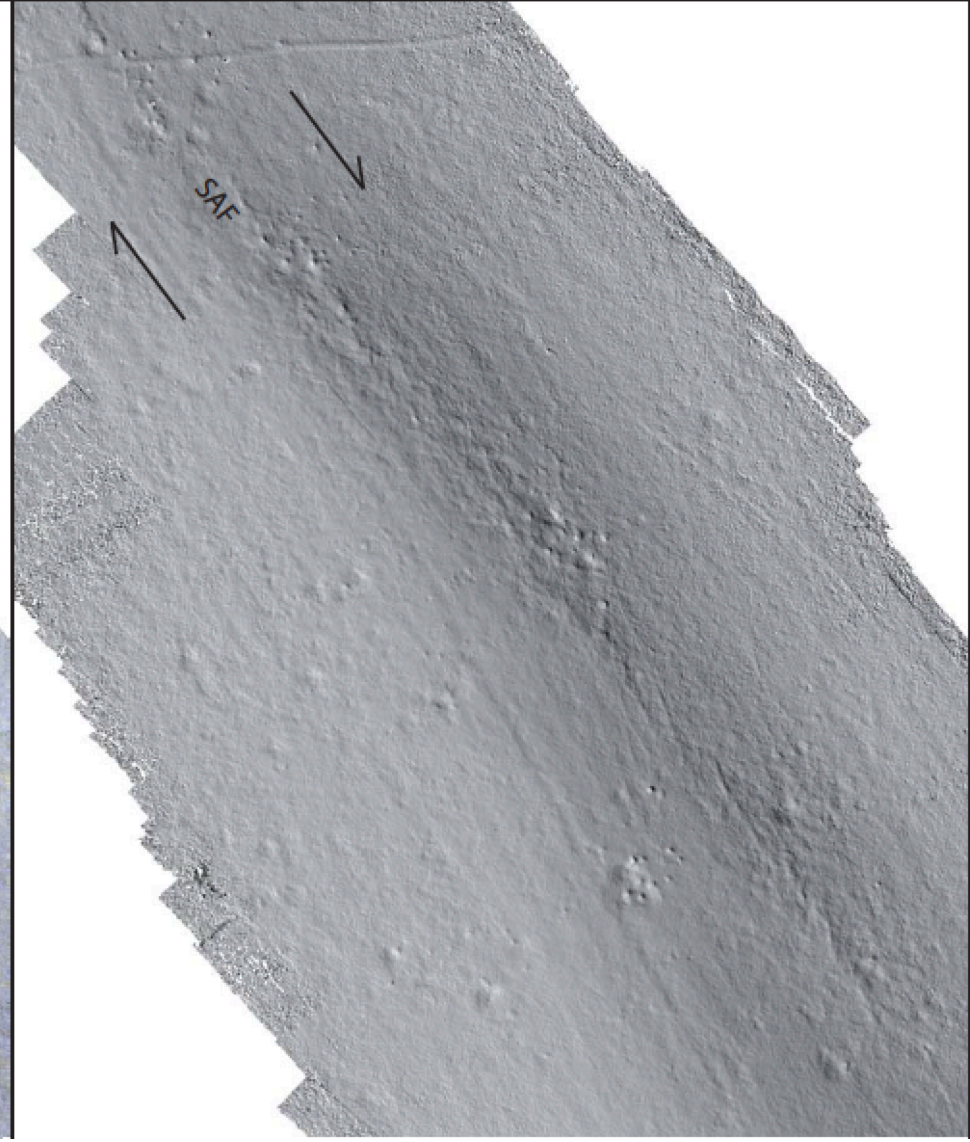
Bunds et al.

LEFT-STEPPING (RIGHT-LATERAL)



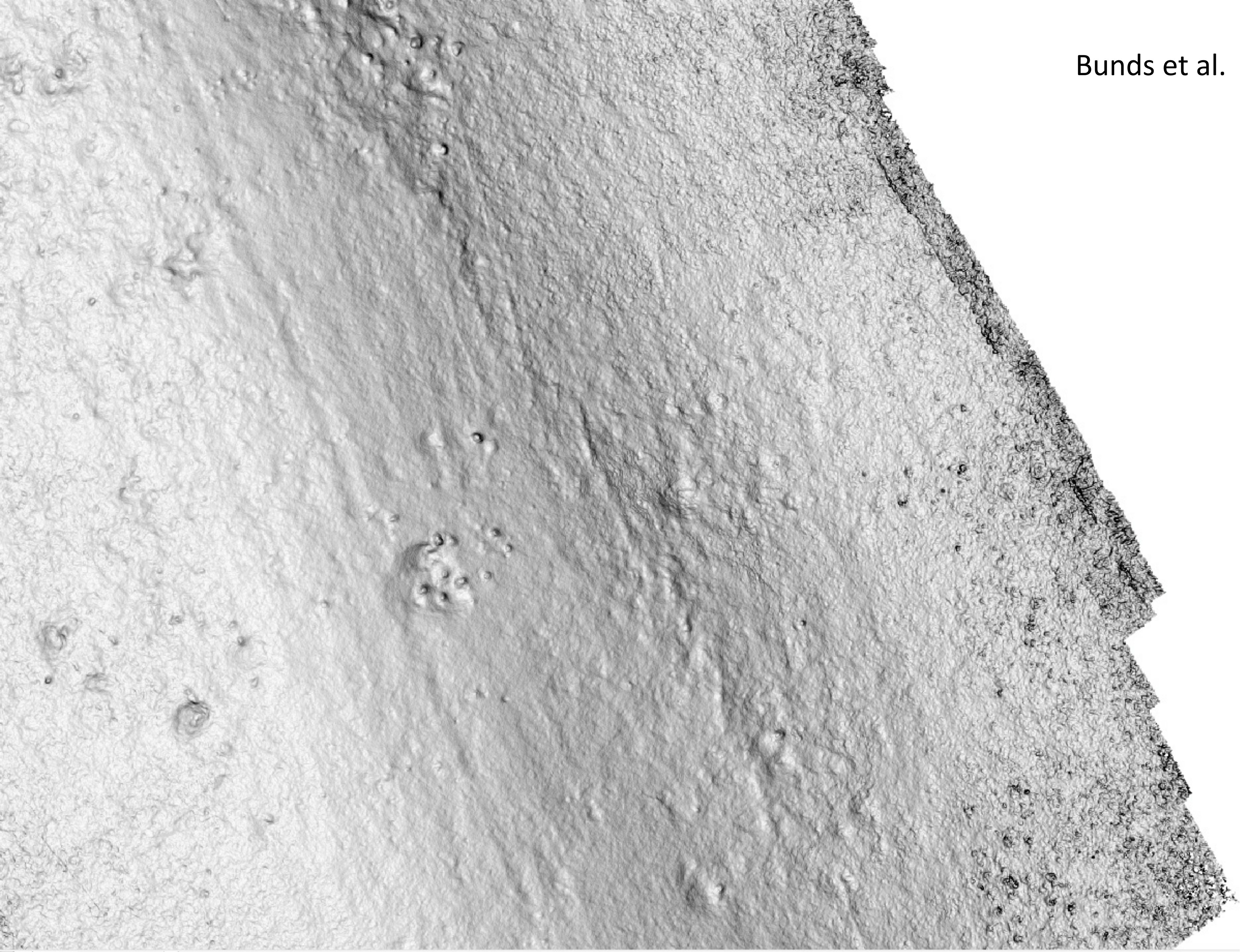
uidaho.edu



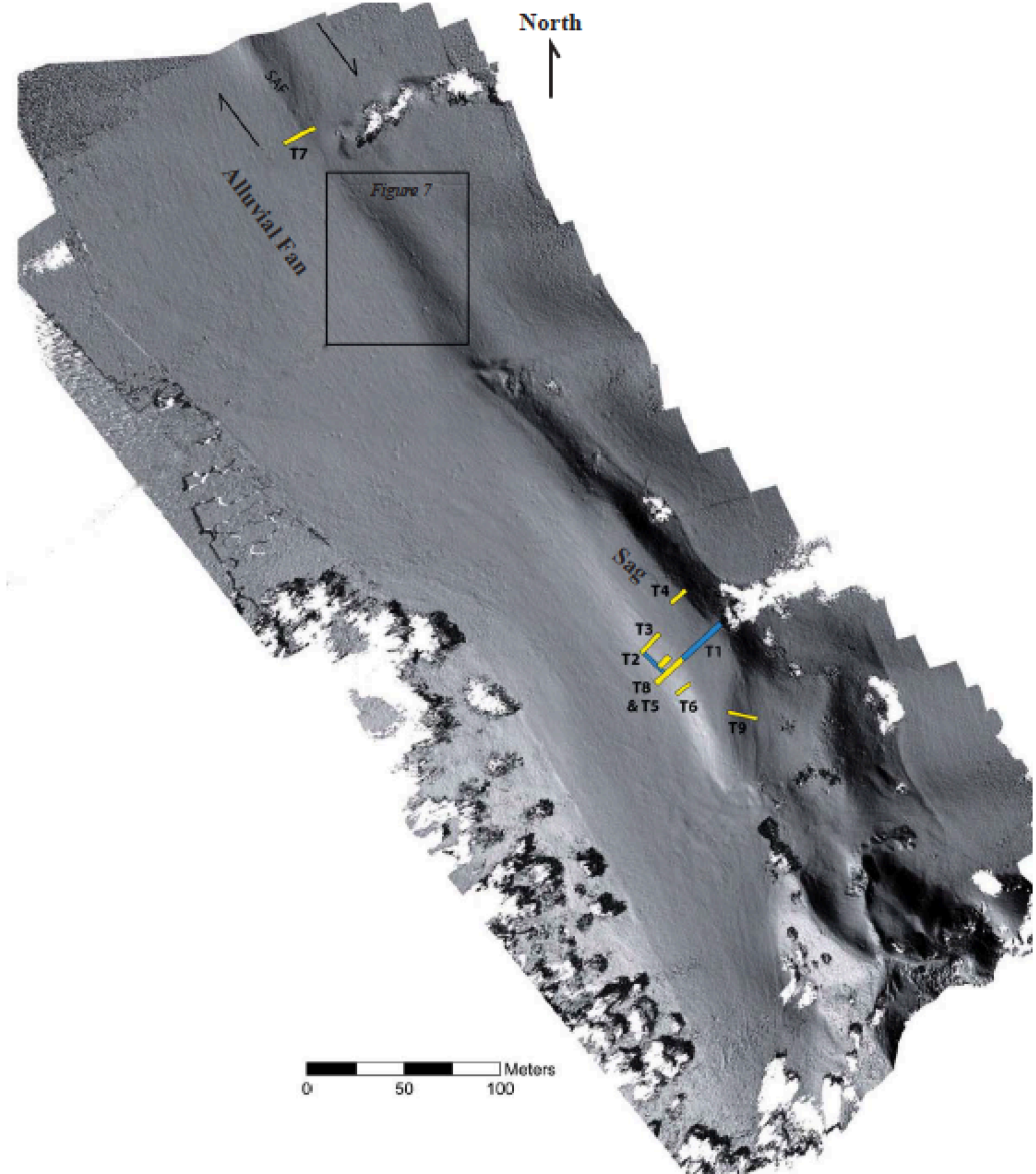


Bunds et al.

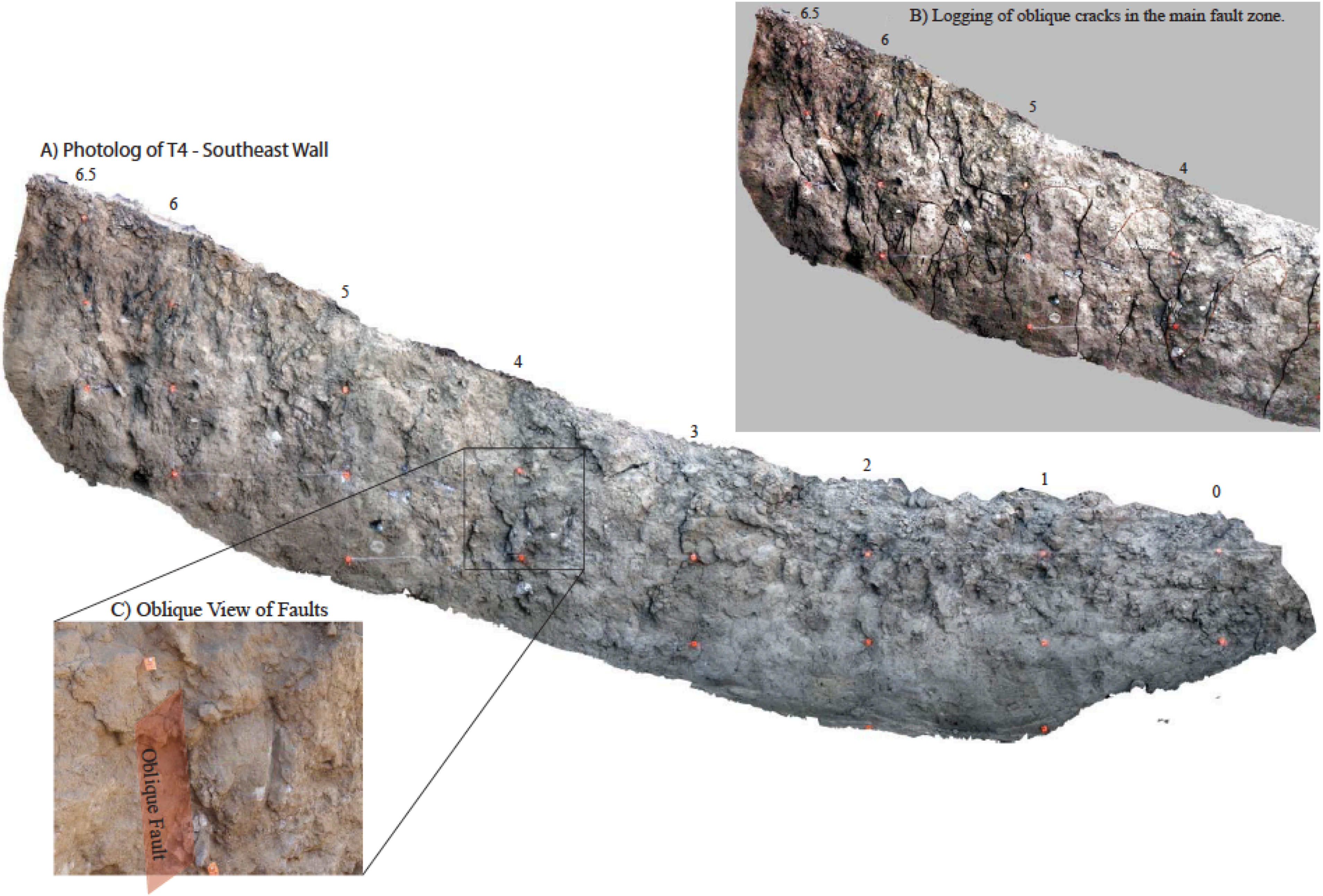
Bunds et al.



Toke and Arrowsmith, 2013 SCEC Annual Report

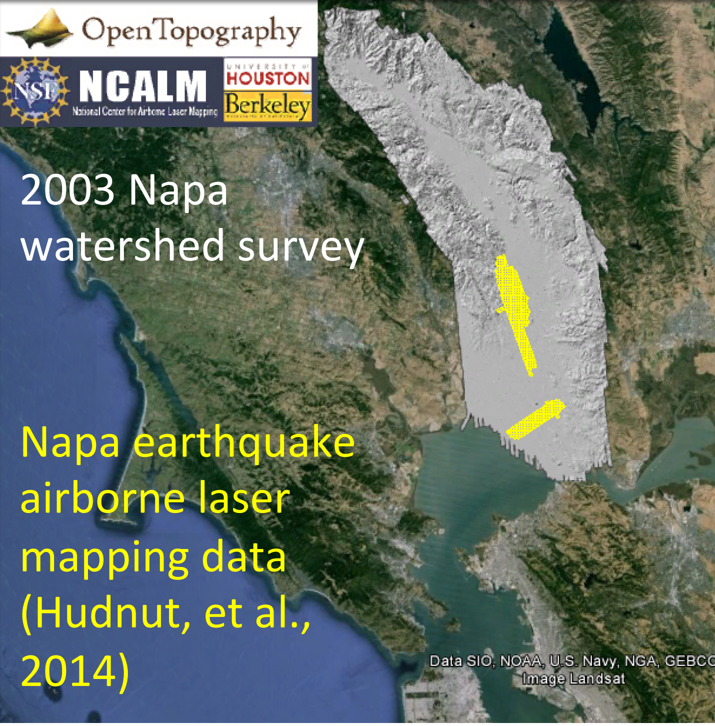

North
SAF
T7
Alluvial Fan
Figure 7
Sag
T4
T3
T1
T2
T8
& T5
T6
T9
Meters
0
50
100

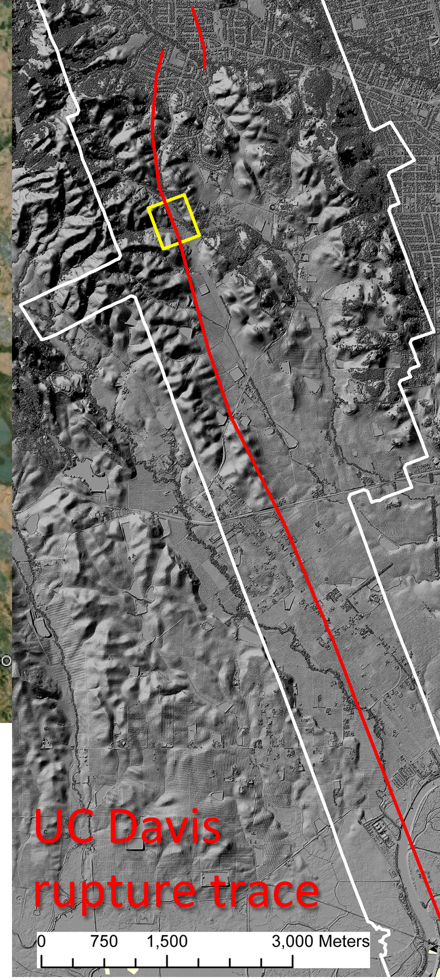
Bunds et al.



Toke and Arrowsmith, 2013 SCEC Annual Report

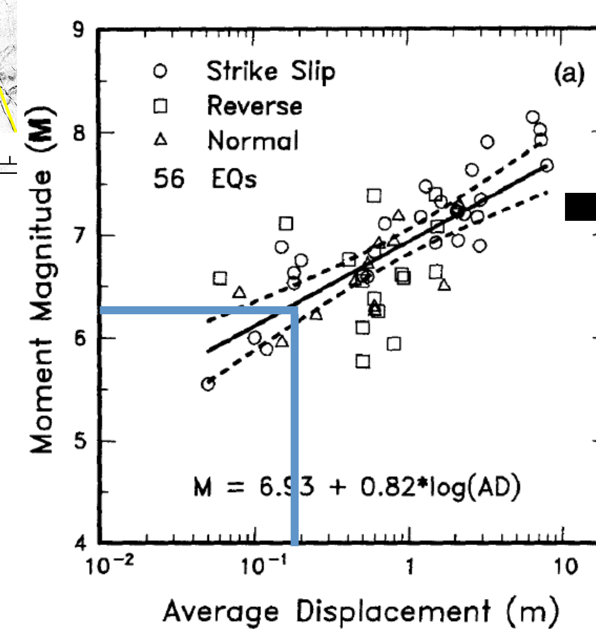
Preliminary
Pre- and Post-event Comparison



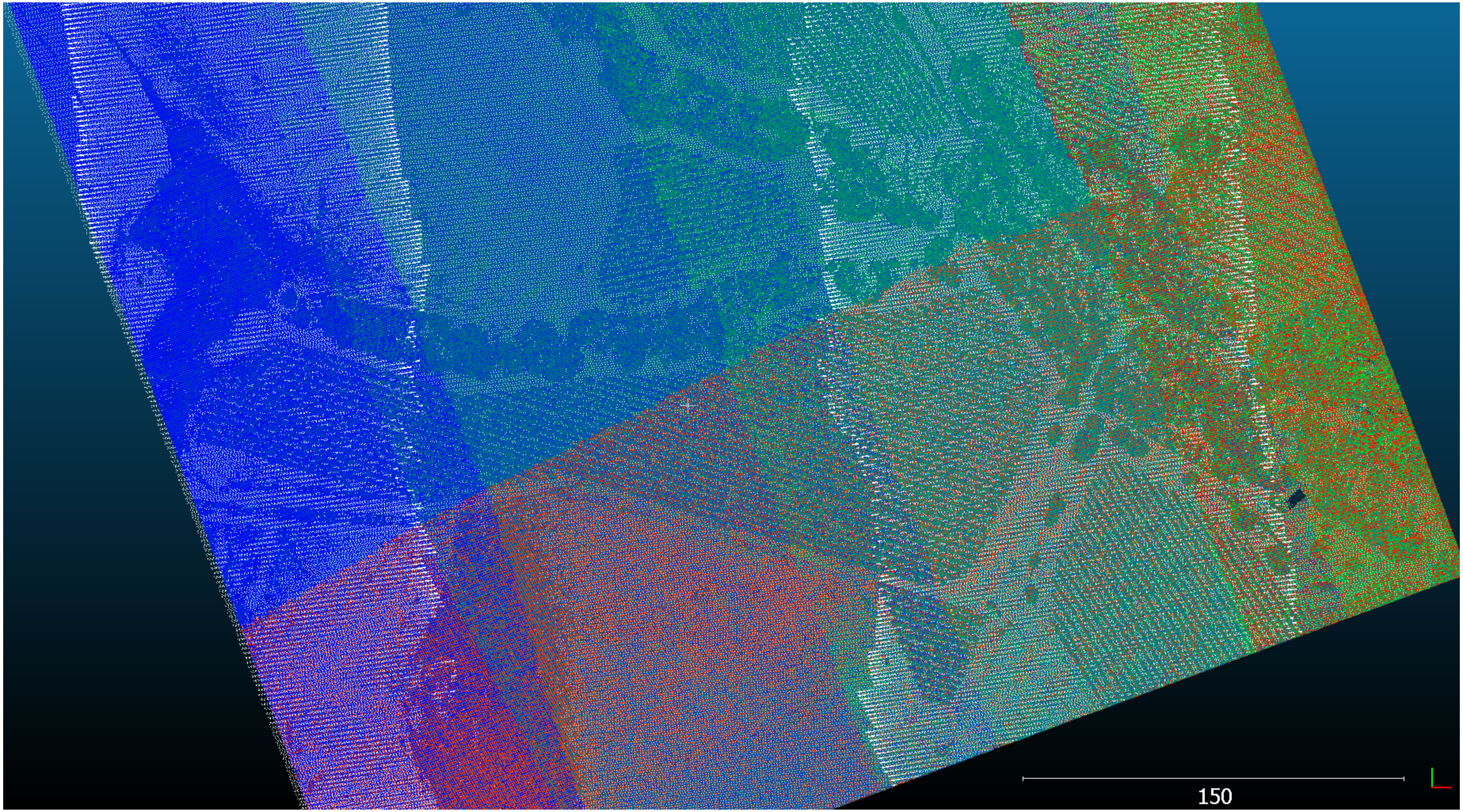


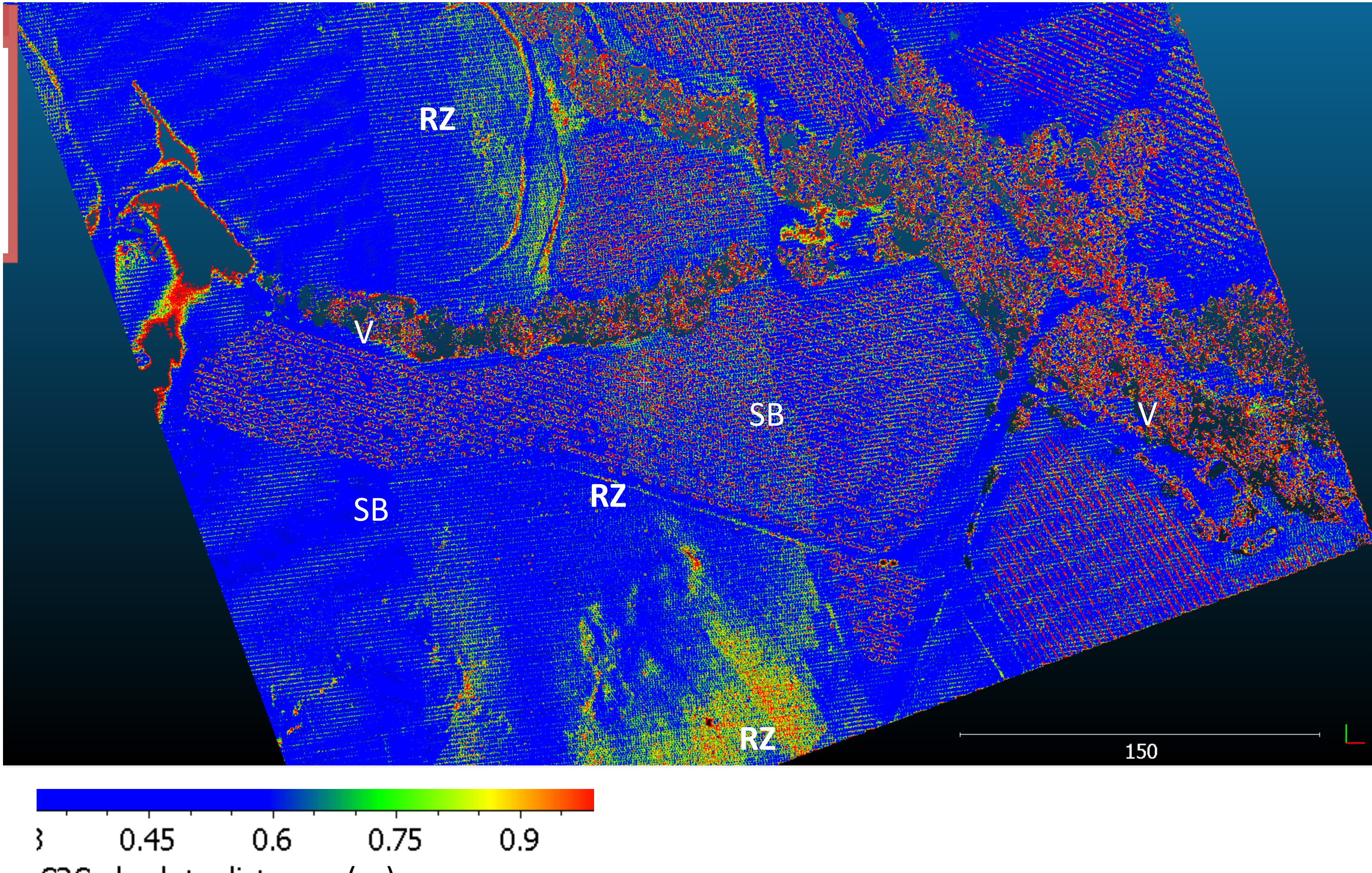
2003 = 2 pts/m^2
2014 = 40 pts/m^2

August 24, 2014, Mw 6.3



Pre event acquired for watershed management
Post event challenging to fund and acquire
Some alignment problems with post-event data (low signal to noise)

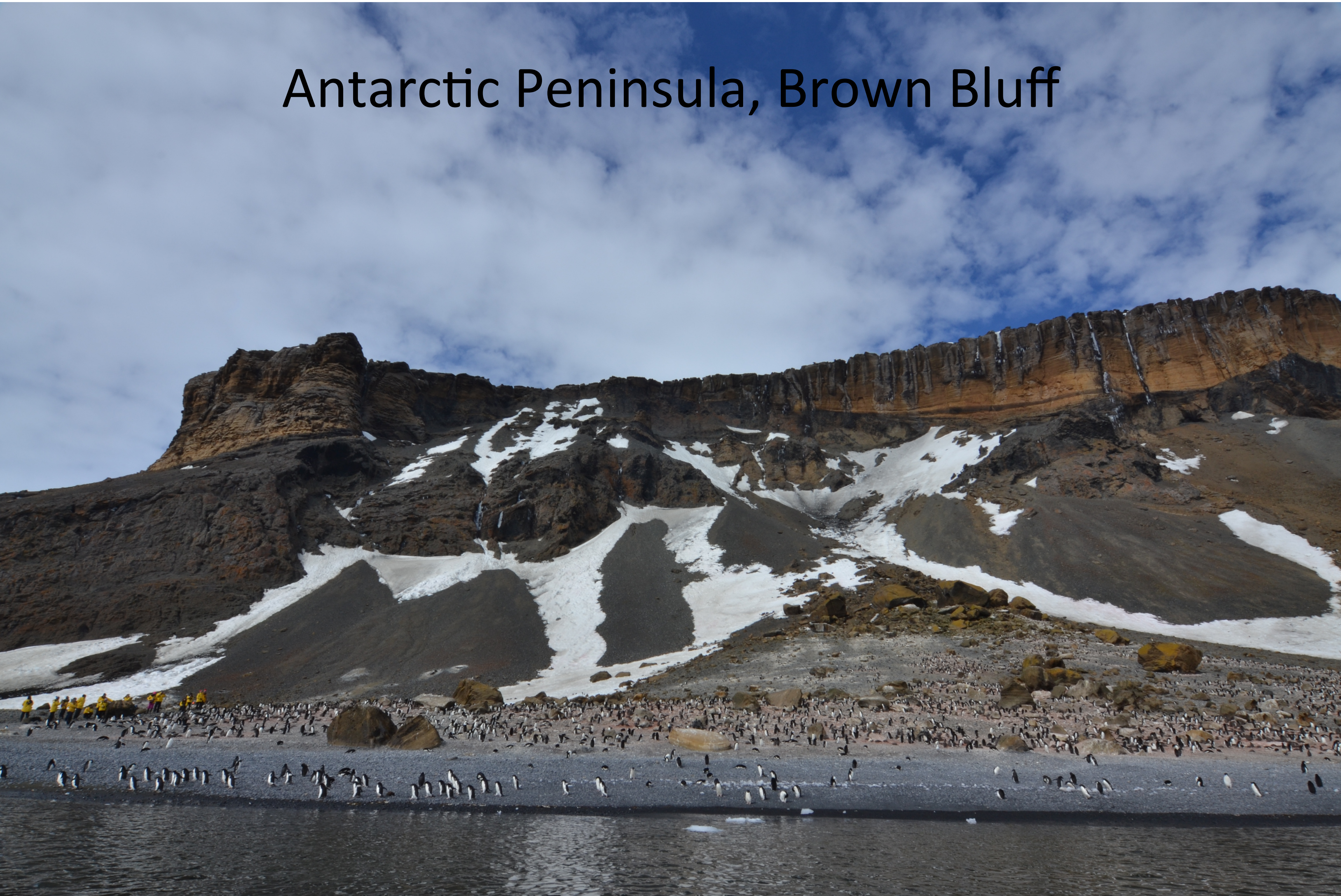

150

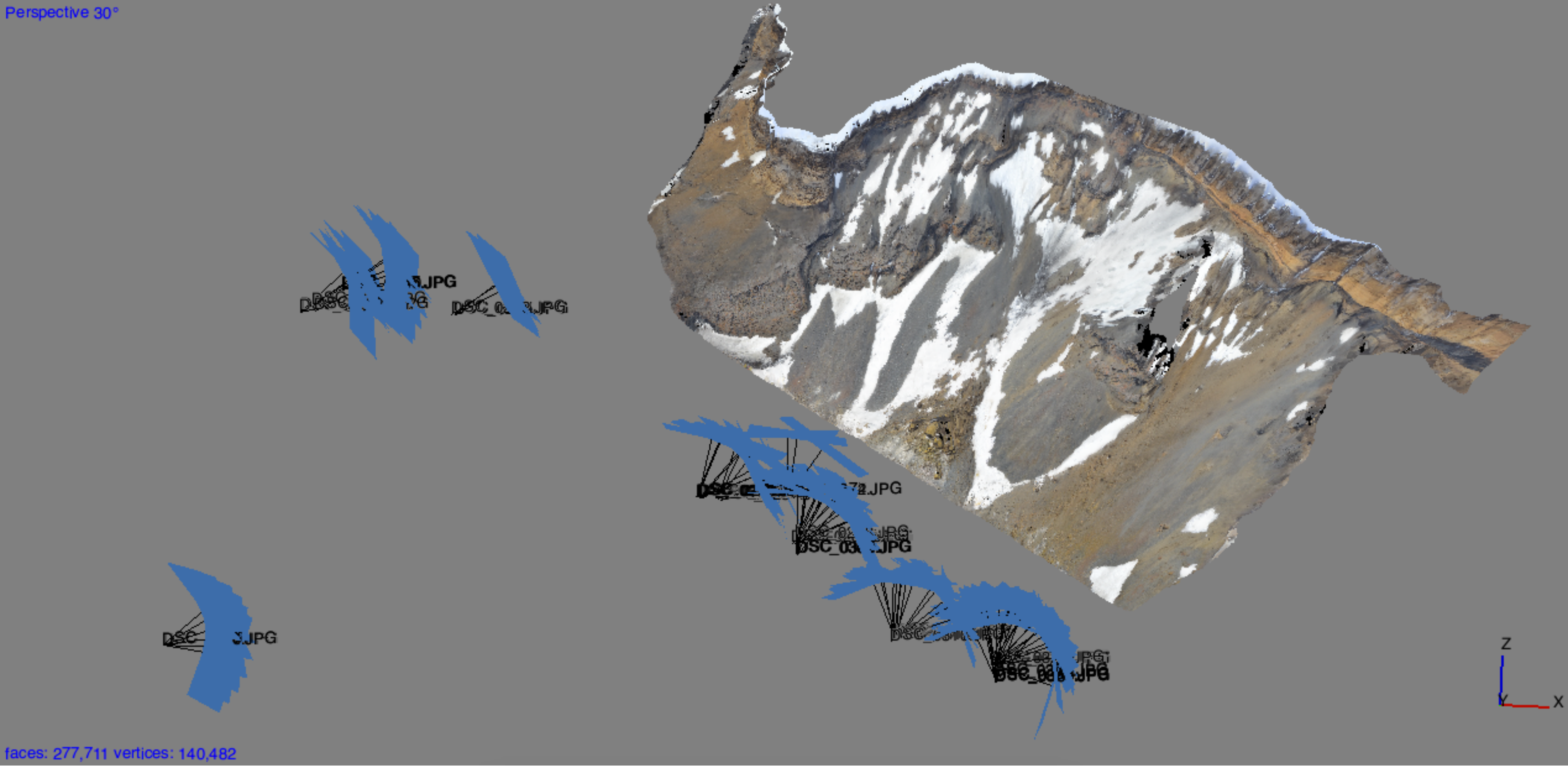

RZ
V
SB
V
SB
RZ
RZ
150
0.45
0.6
0.75
0.9
C2C absolute distances (m)

Outcrop Studies

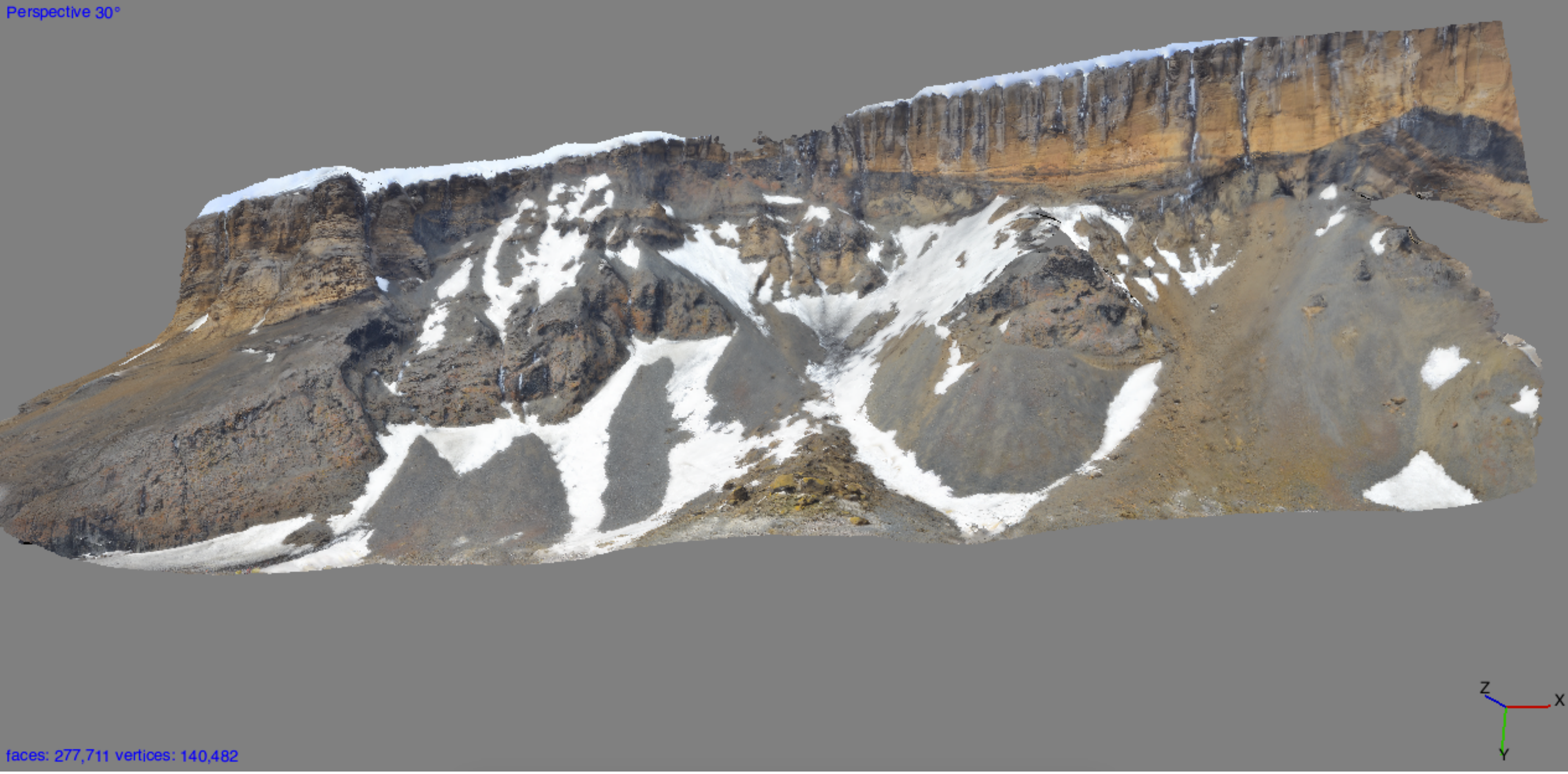
- Antarctic Peninsula, Brown Bluff

Outcrop Studies





Perspective 30°
faces: 277,711 vertices: 140,482
Z
Y
X


Perspective 30°
faces: 277,711 vertices: 140,482
Z
X
Y

Closed Objects