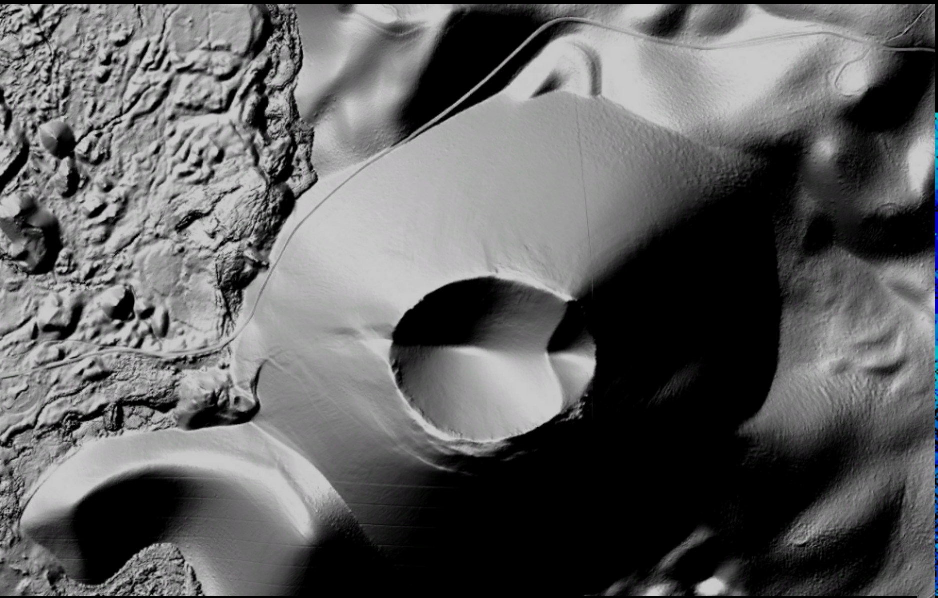
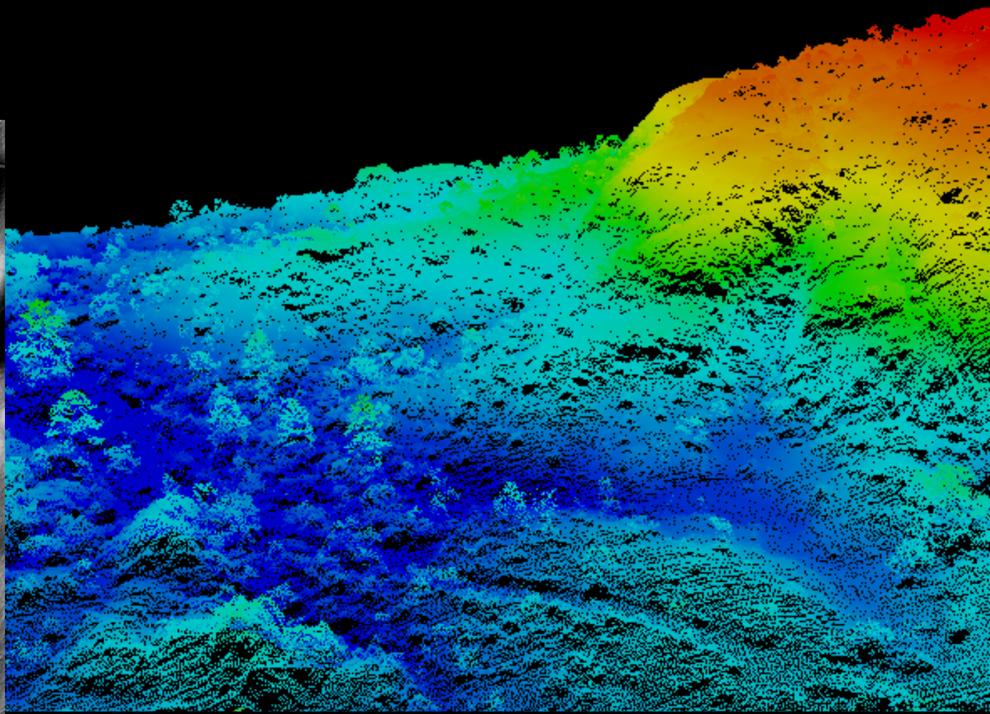
Sharpening our view of earth processes with high resolution topography

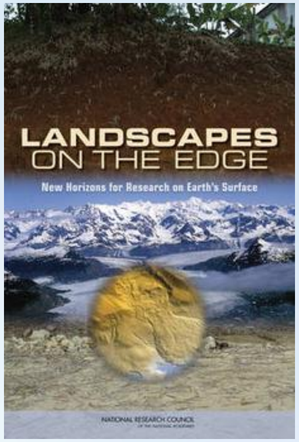


Sunset Crater Arizona hillshade (US NPS)

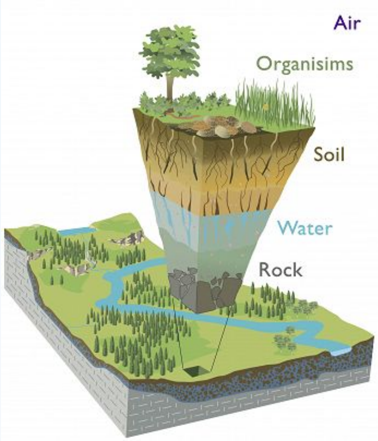


Granite Dells AZ point cloud (NCALM student seed grant)

Example scientific motivations



- How do geopatterns on the Earth's surface arise and what do they tell us about processes?
- How do landscapes influence and record climate and tectonics?
- What are the transport laws that govern the evolution of the Earth's surface?



- Coupled hydrogeomorphic-ecosystem response to natural and anthropogenic change
- Landscape and ecosystem dynamics

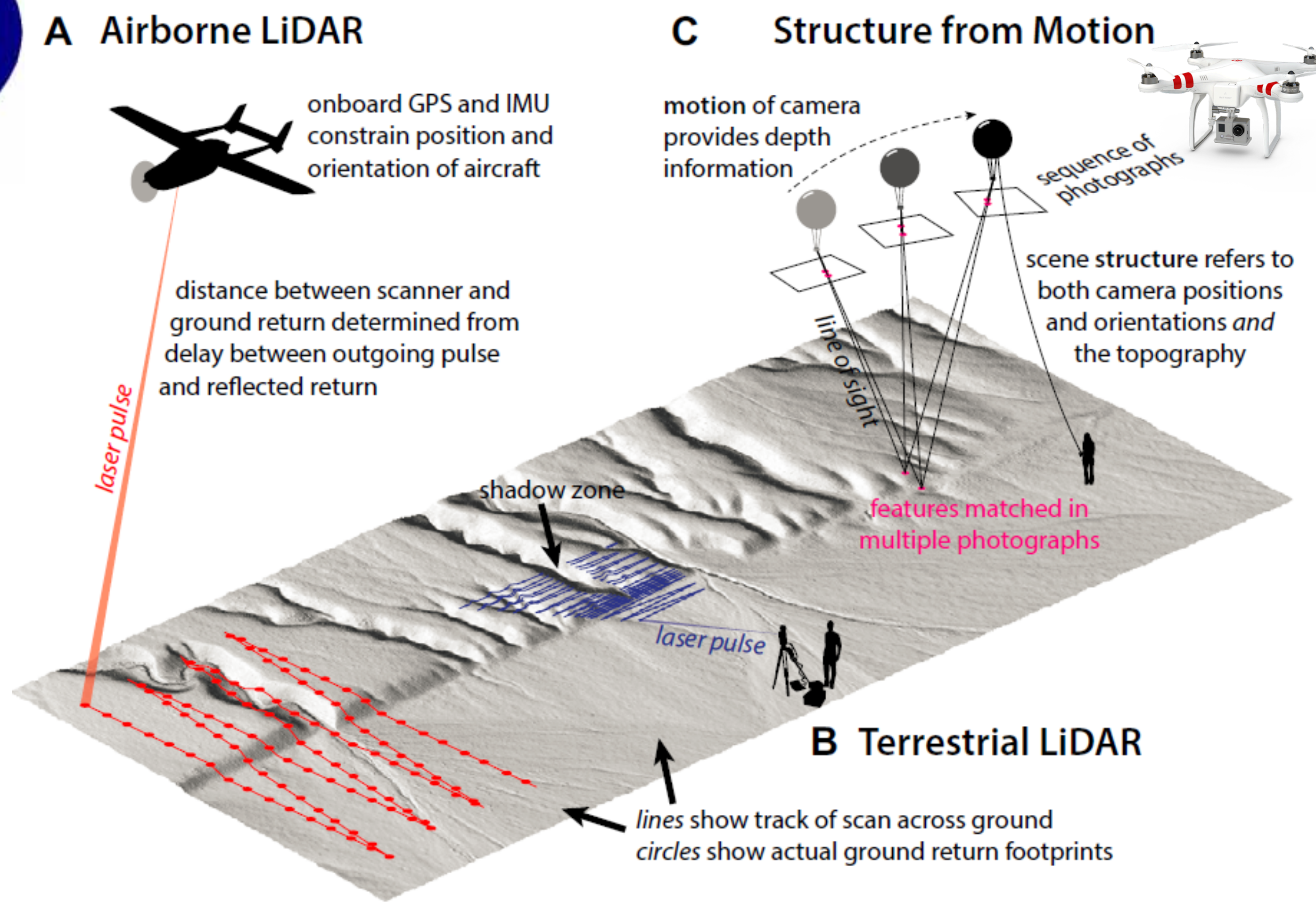
- Volcano form and process
- Changes in volume of domes, edifice, flows over time

Global and regional topography/bathy (10s-100s m/pix)

+ASTER

Getting the right coverage in time, space, and resolution for the question

Local to site scale topography (dm to m / pix)



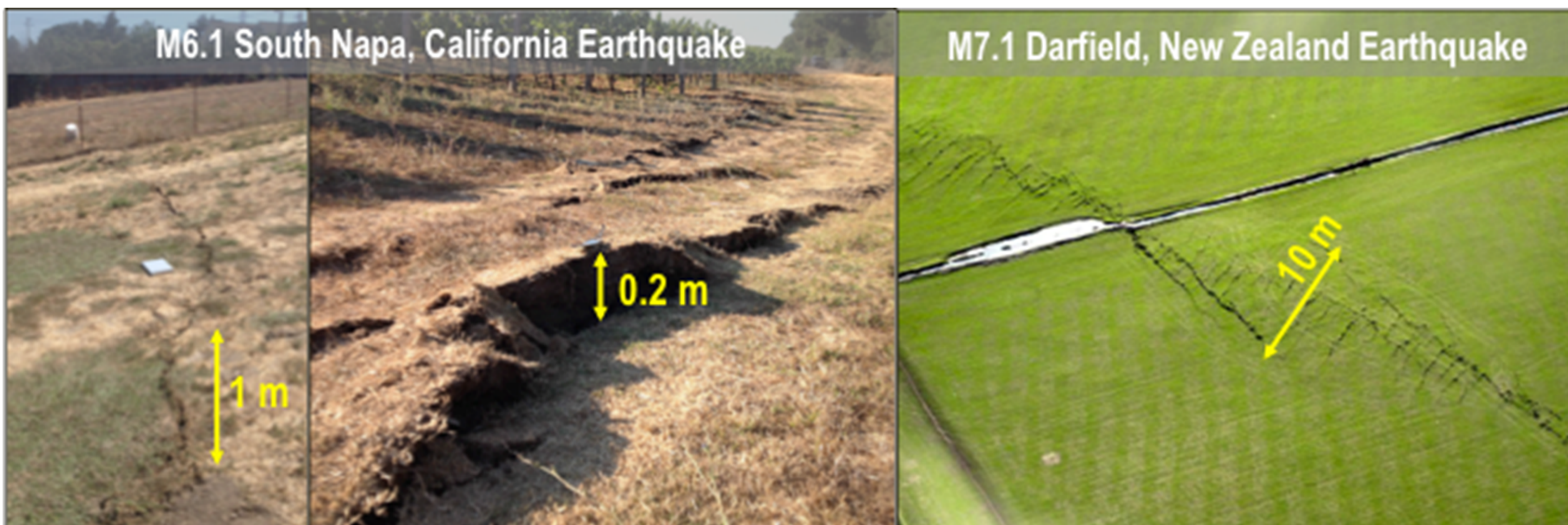
Johnson, K., Nissen, E., Saripalli, S., Arrowsmith, J R., McGarey, P., Scharer, K., Williams, P., Blisniuk, K., Rapid mapping of ultra-fine fault zone topography with Structure from Motion, Geosphere, v. 10; no. 5; p. 1–18; doi:10.1130/GES01017.1, 2014.

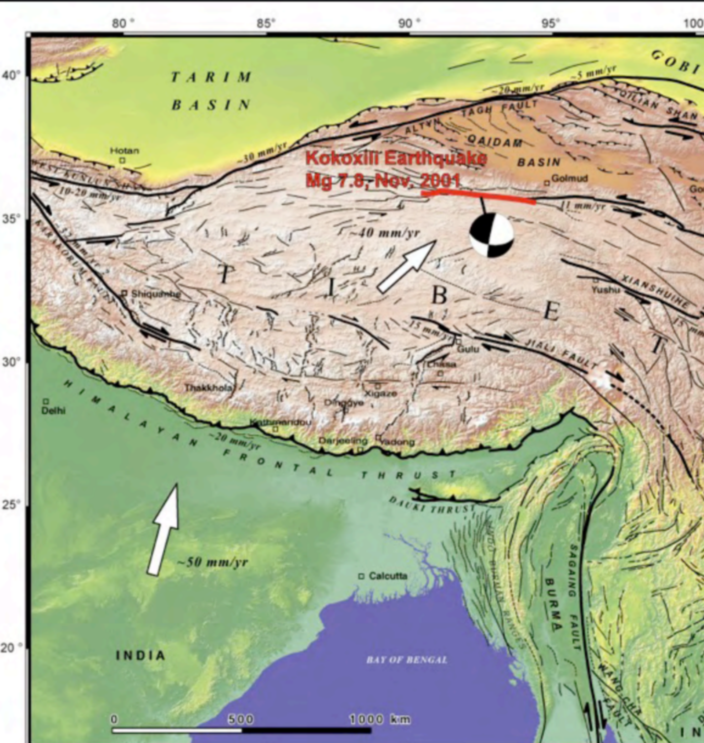
Presentation outline

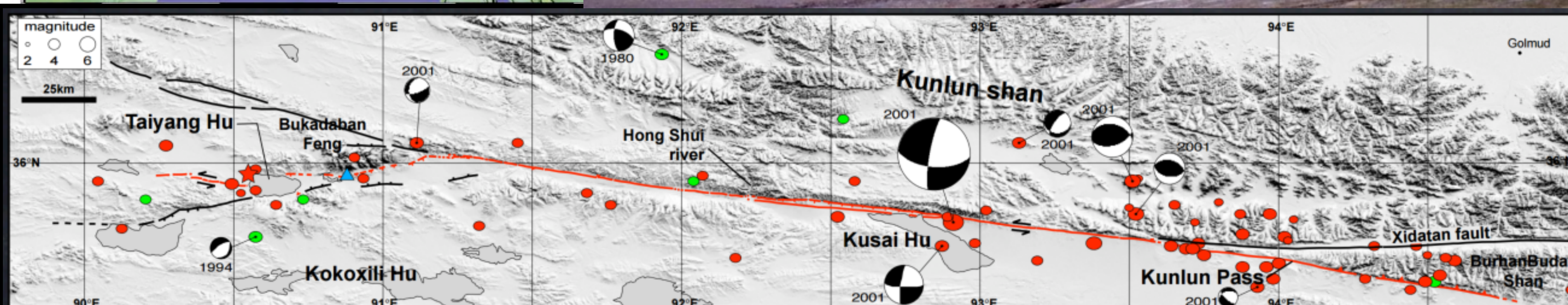
- Introduction and measuring topography
- **“Seeing” and working at the appropriate scale**
- High resolution topography application examples

Science requirements

- Need topography data with sufficient spatial extent and resolution to capture phenomena of interest
- Need topography data with sufficient temporal repeat to capture changes of interest





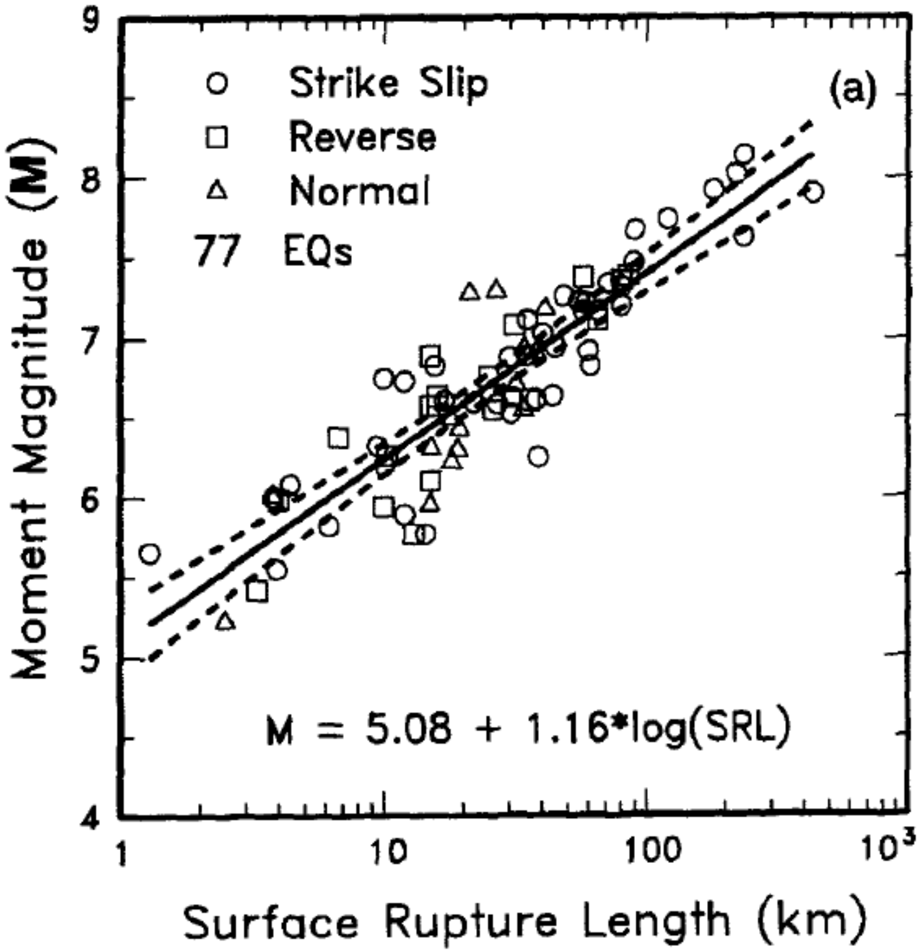


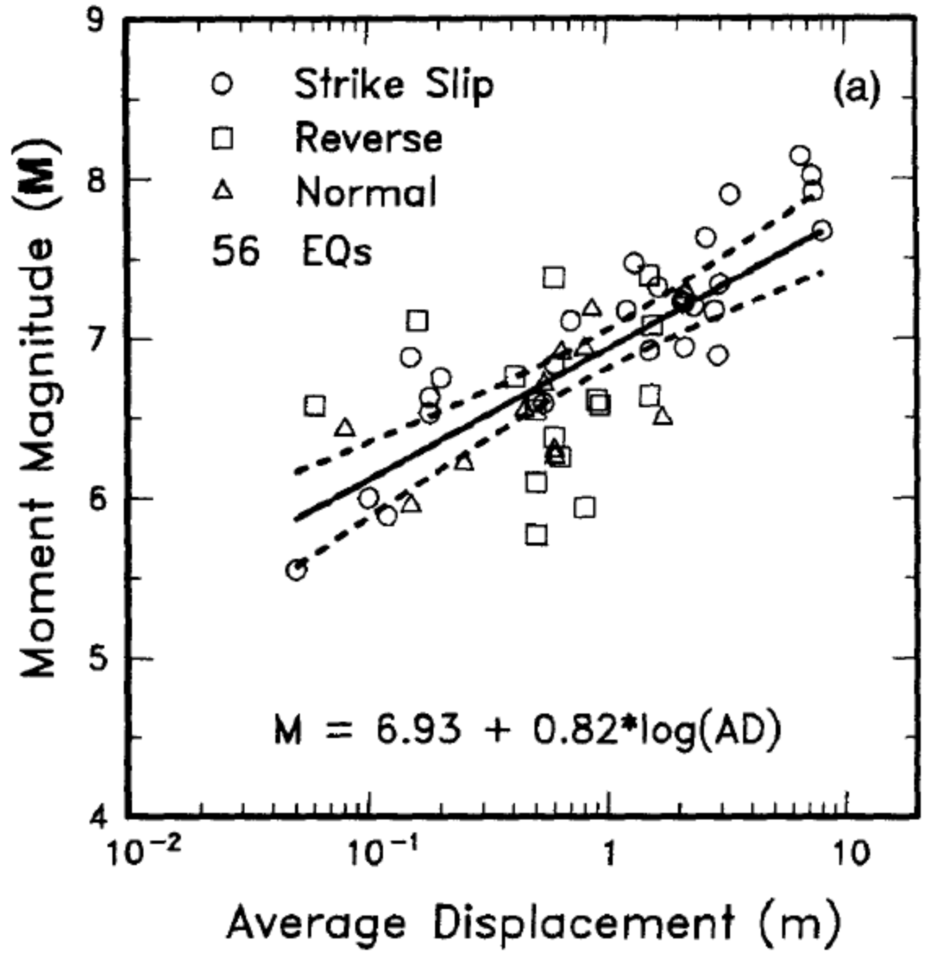
430km of ground rupture, above 4000m

Yann Klinger, IPGP; http://peer.berkeley.edu/events/2009/sfdc_workshop/Klinger_Kunlun_EQ.pdf

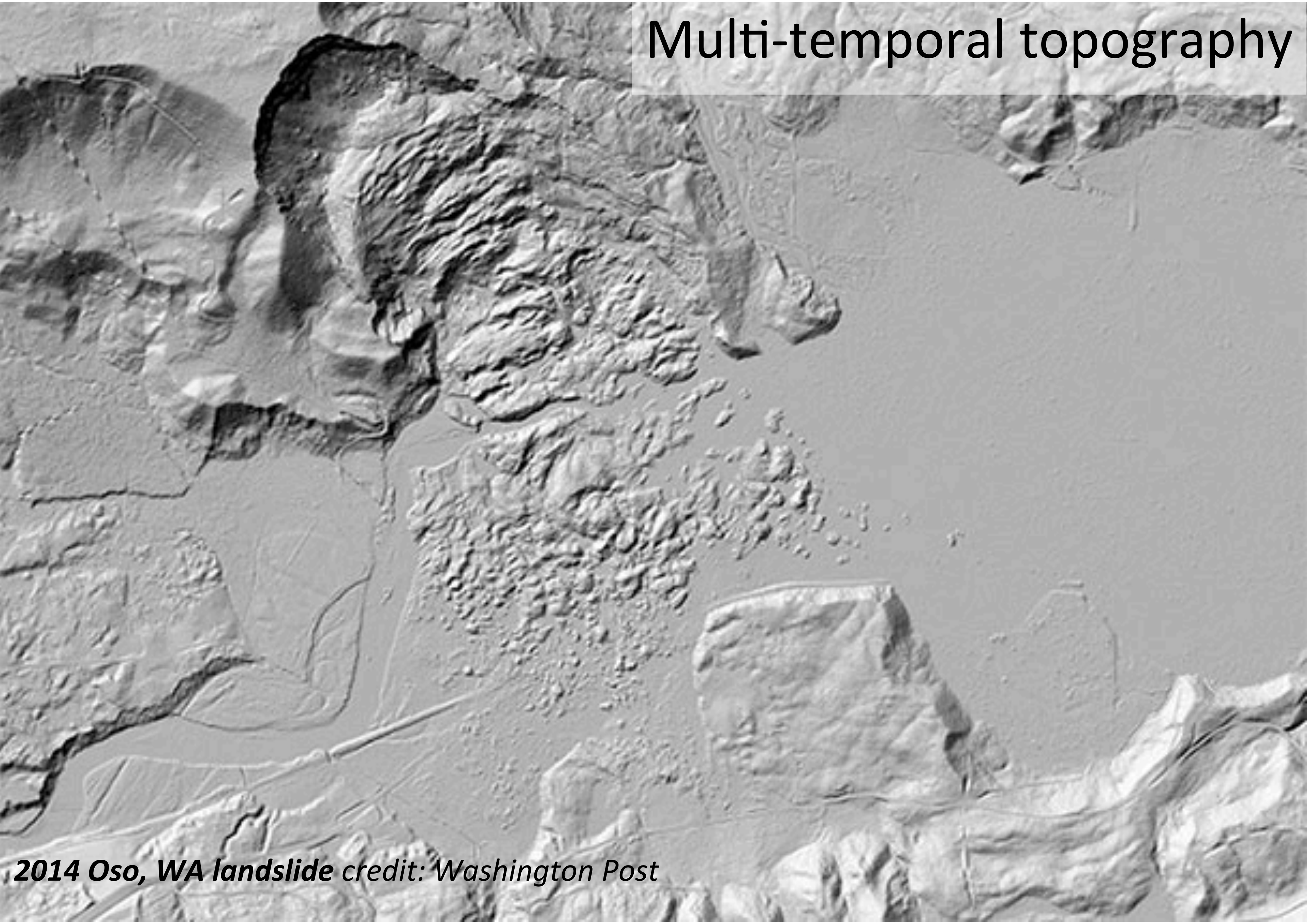
Length scales <1 m and >10^5m

Wells and Coppersmith, 1994



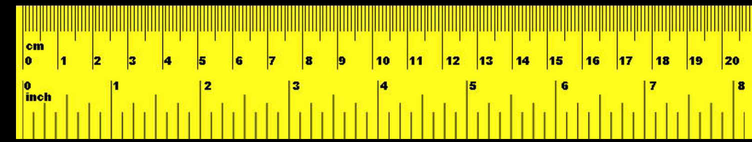


Multi-temporal topography



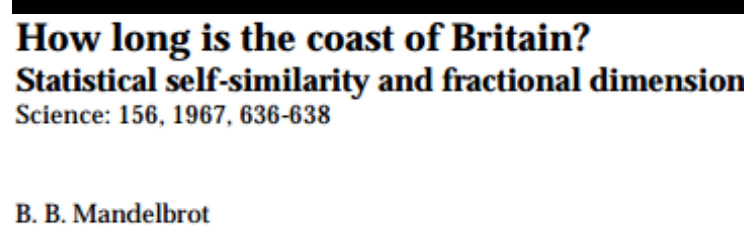
2014 Oso, WA landslide *credit: Washington Post*

"Seeing" at the appropriate scale means measuring at the right scale



Surface processes act to change elevation through erosion and deposition while tectonic processes depress or elevate the surface directly— their record is best characterized with the right fine scale.

Applies in particular to statistical self similarity

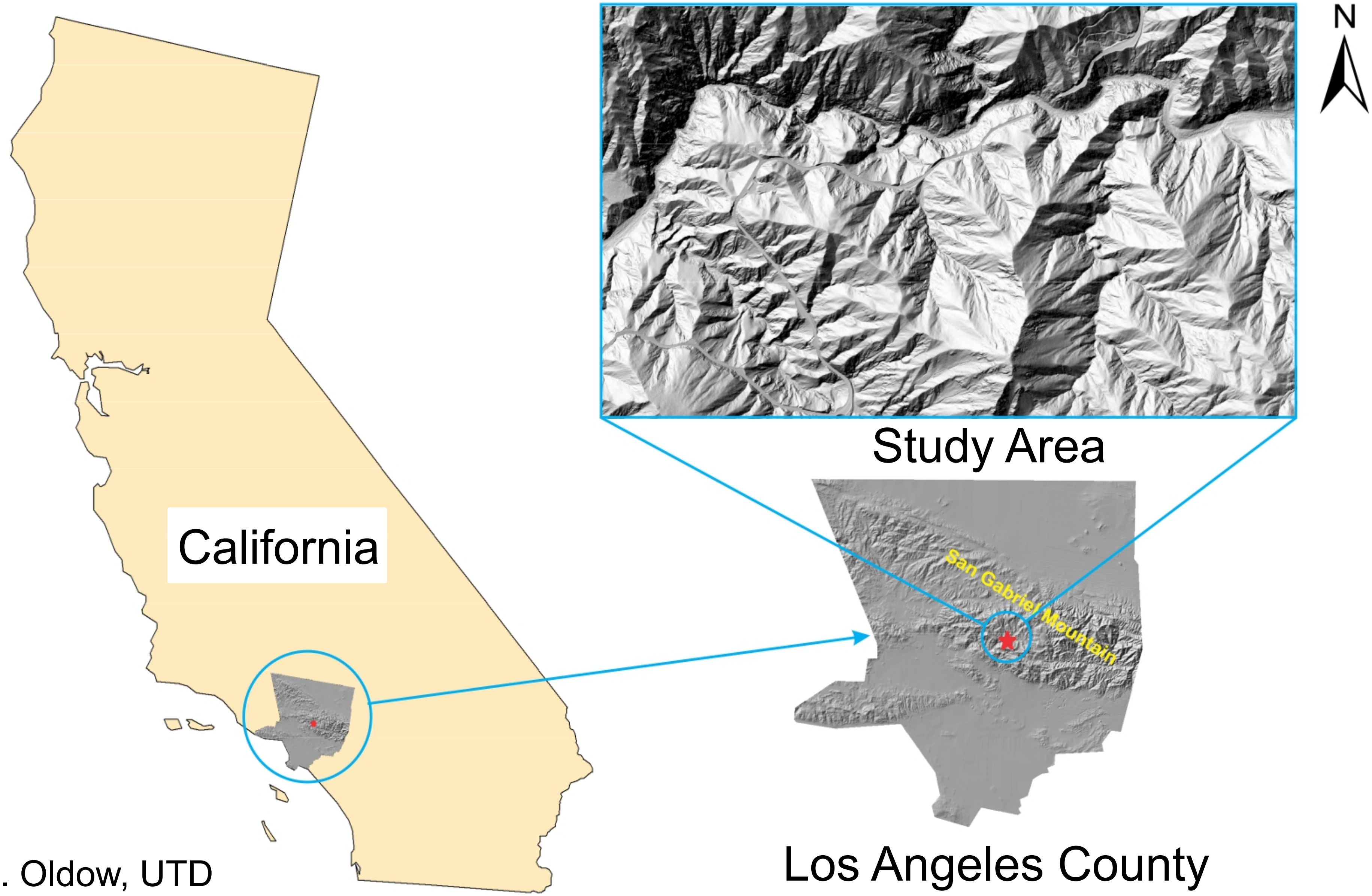


How long is the coast of Britain?
Statistical self-similarity and fractional dimension
Science: 156, 1967, 636-638

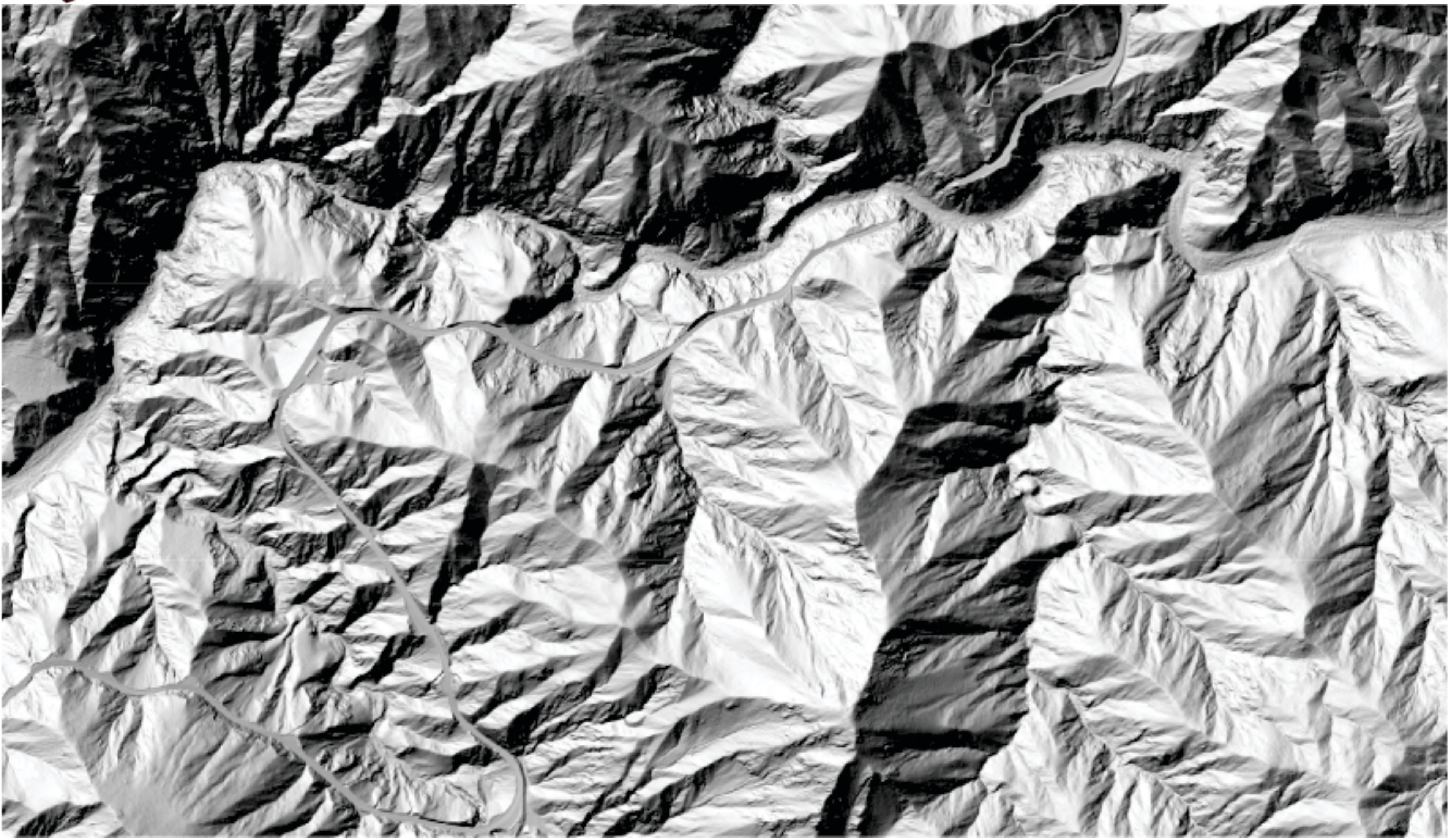
B. B. Mandelbrot

http://en.wikipedia.org/wiki/How_Long_Is_the_Coast_of_Britain%3F_Statistical_Self-Similarity_and_Fractional_Dimension

Using Terrestrial and Airborne Lidar



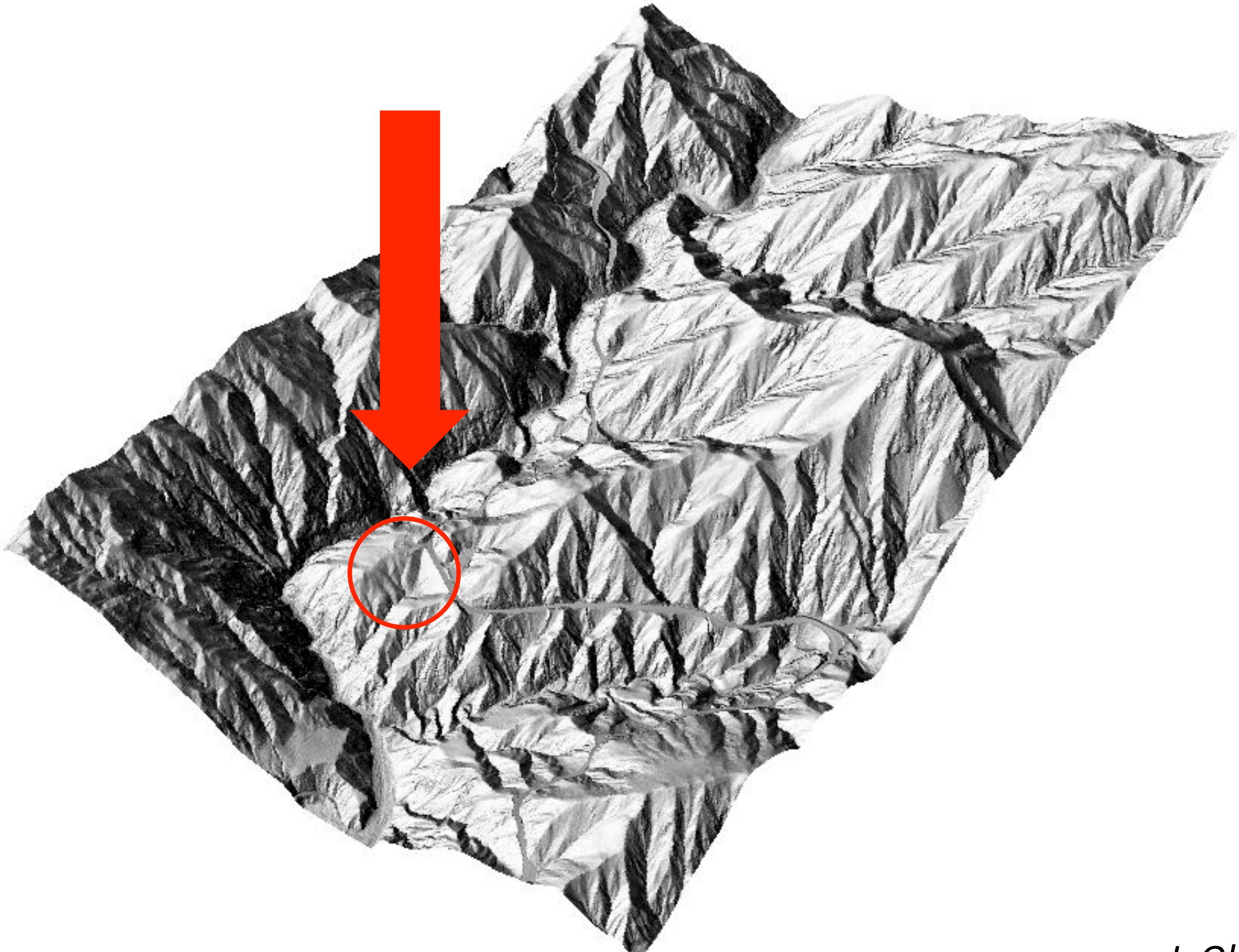
J. Oldow, UTD



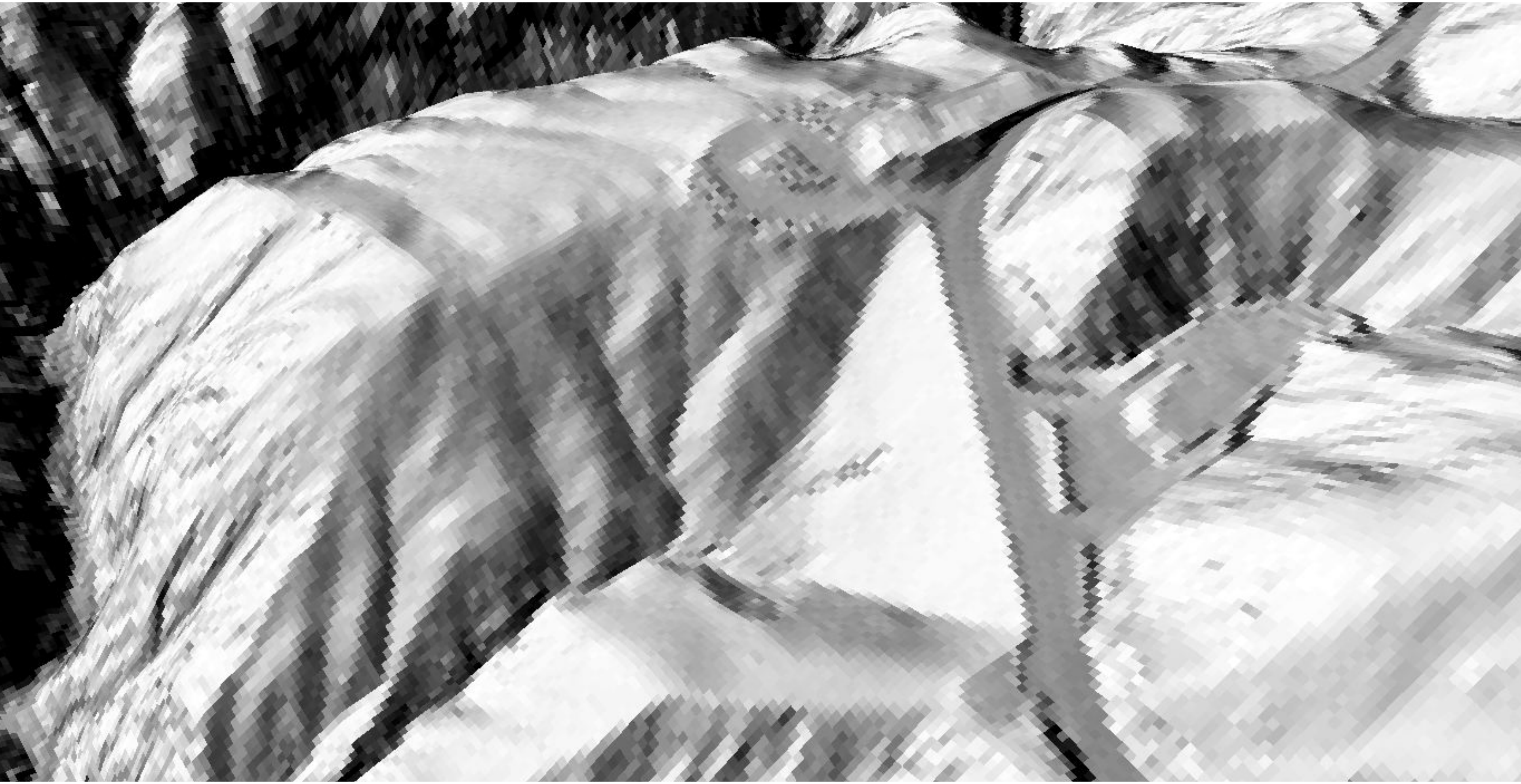
San Gabriel Mountain 1-m DEM from airborne lidar

J. Oldow, UTD

J. Oldow, UTD

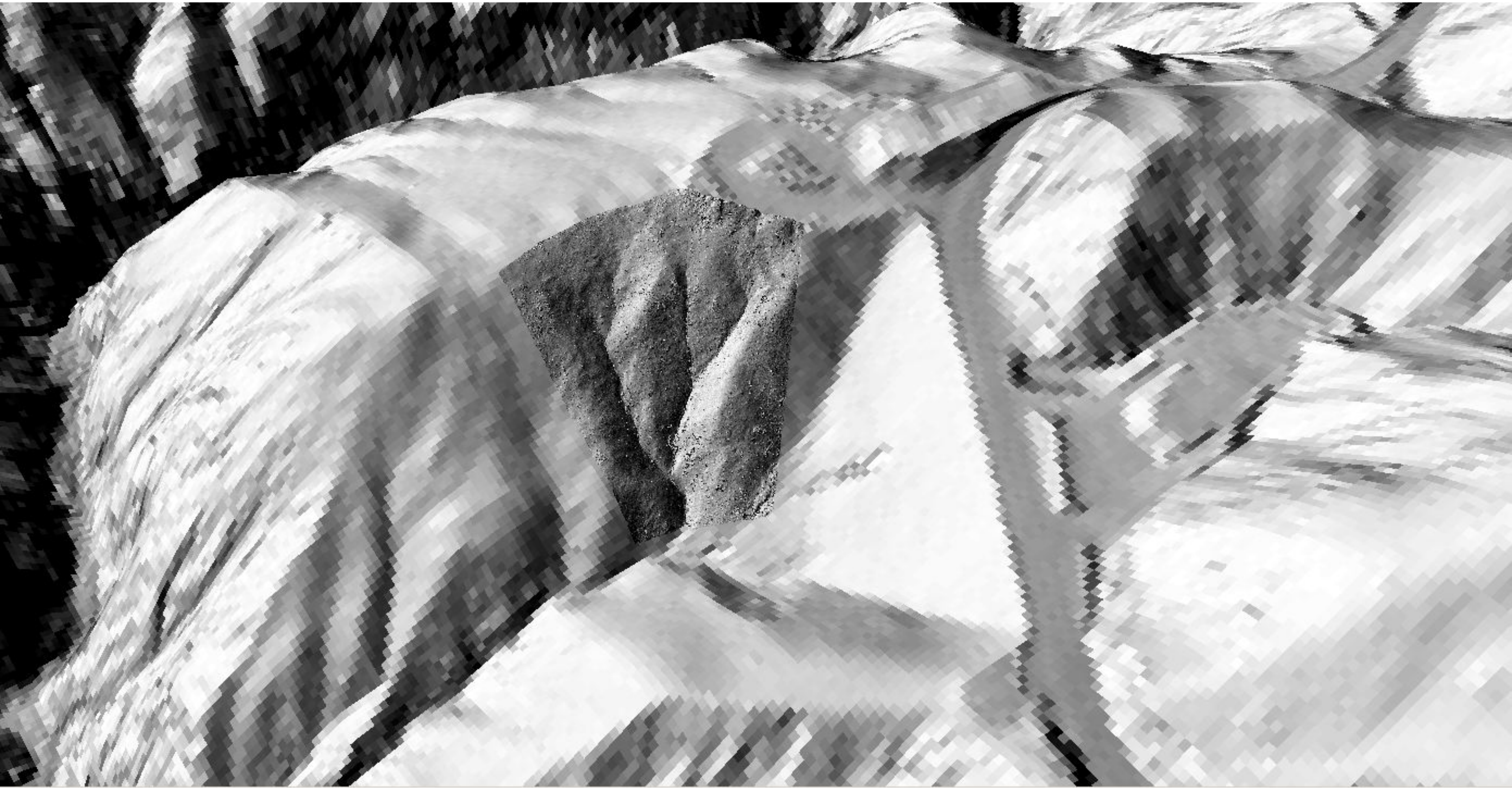


J. Oldow, UTD

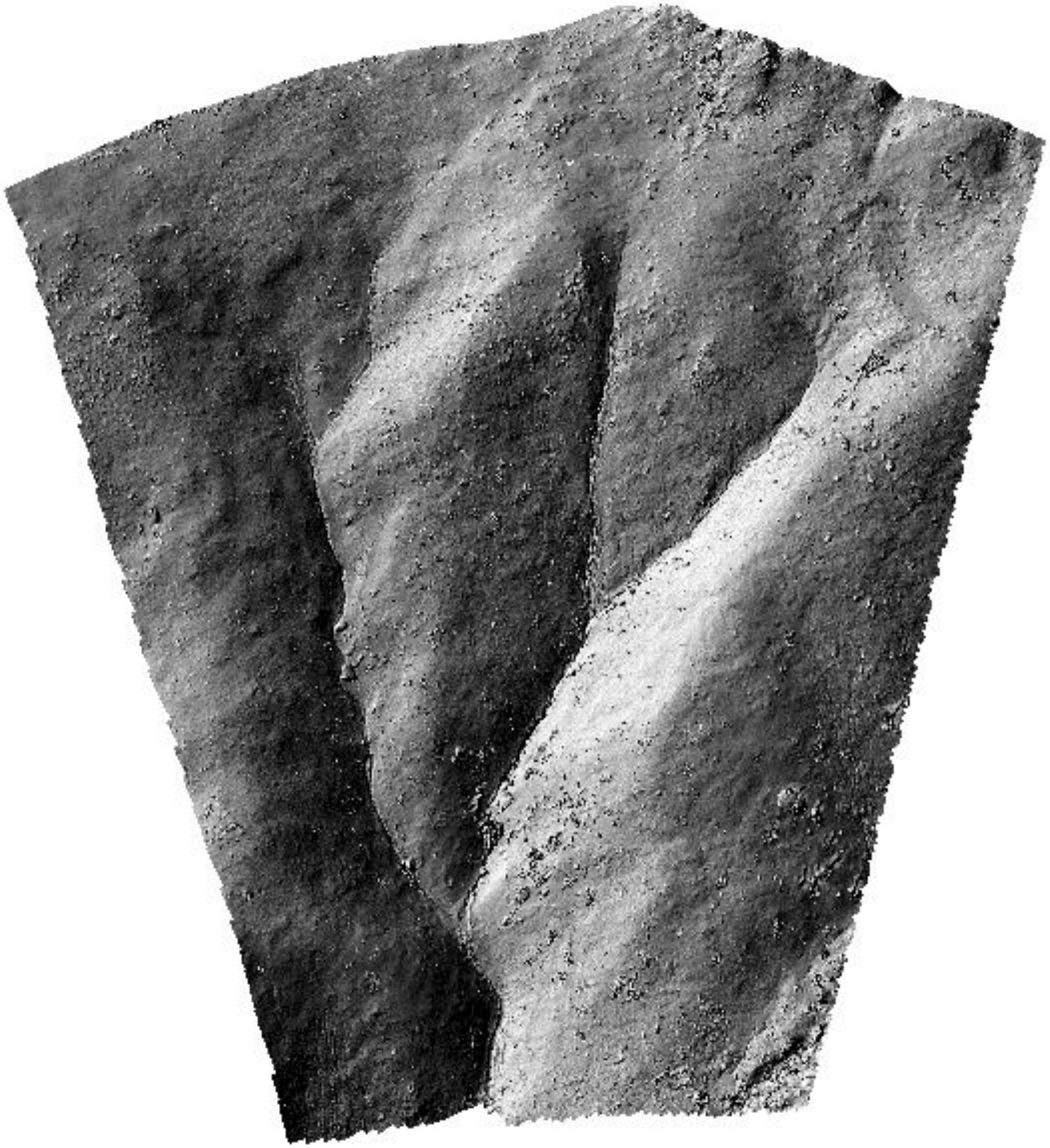


J. Oldow, UTD

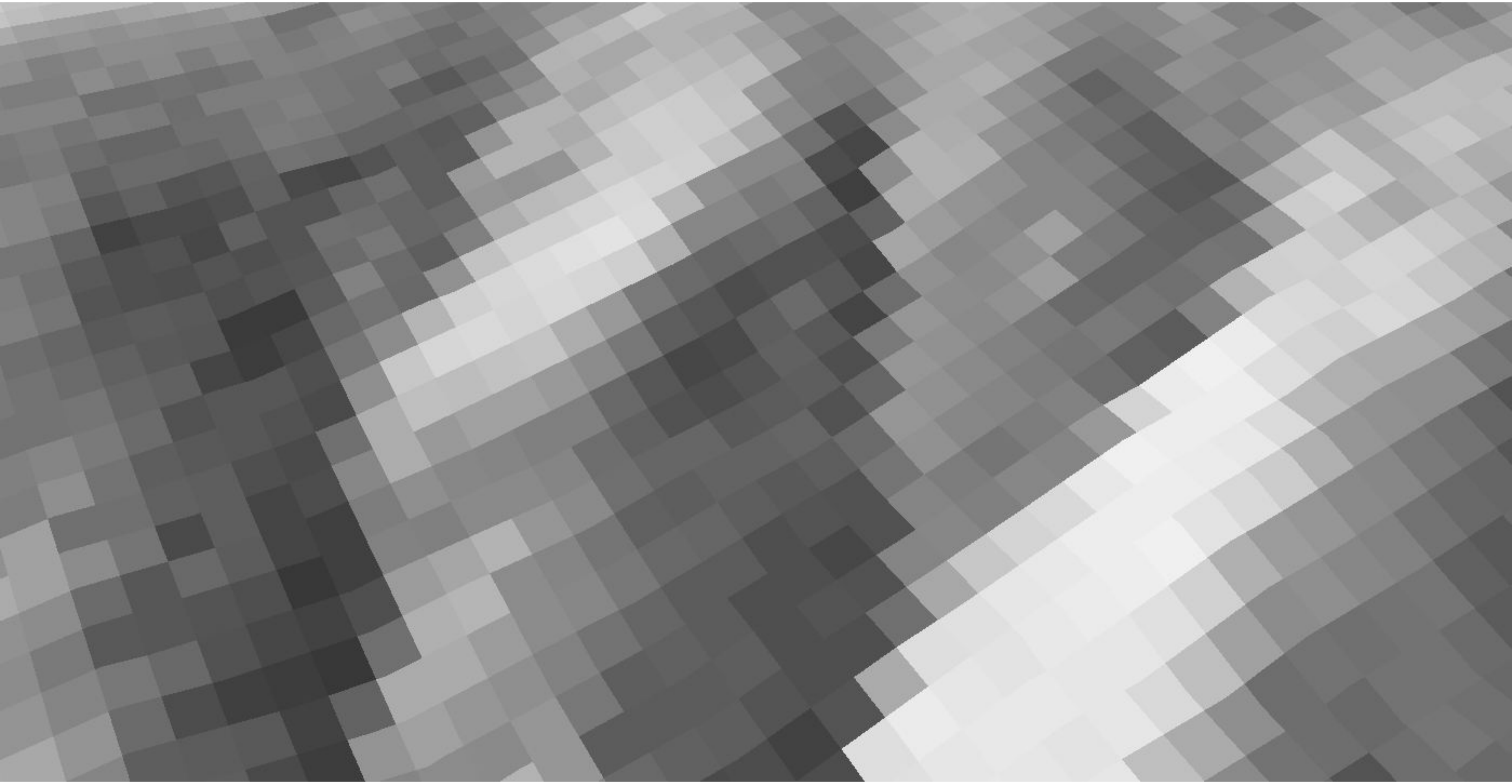
Using Terrestrial and Airborne Lidar



J. Oldow, UTD

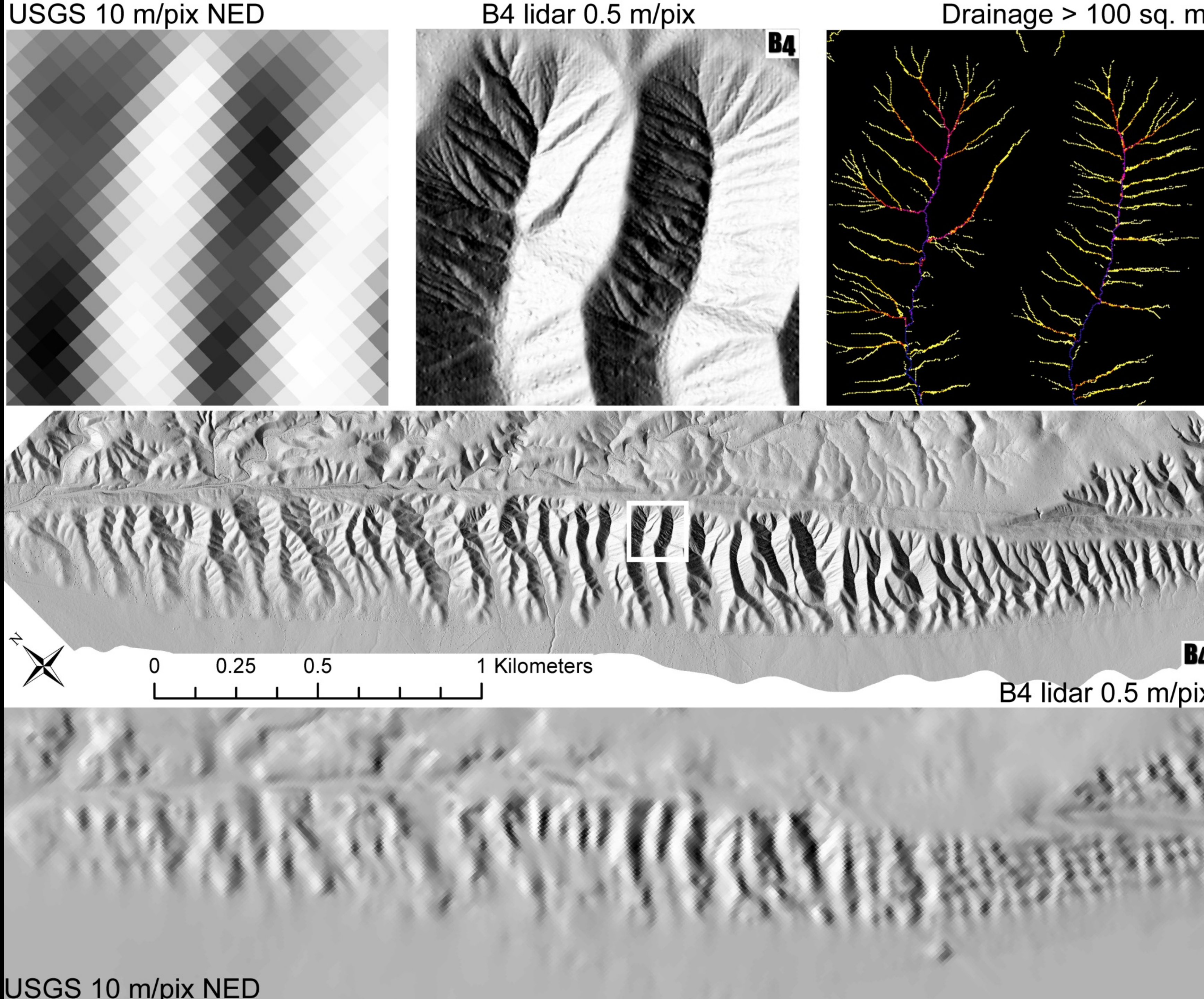


J. Oldow, UTD



J. Oldow, UTD

J. Oldow, UTD



USGS 10 m/pix NED
B4 lidar 0.5 m/pix
Drainage > 100 sq. m
B4
N
0
0.25
0.5
1 Kilometers
B4
B4 lidar 0.5 m/pix
USGS 10 m/pix NED


Bellemont
Flagstaff
© 2014 Google
Image Landsat
Sunset Crater topographic data


© 2014 Google
Google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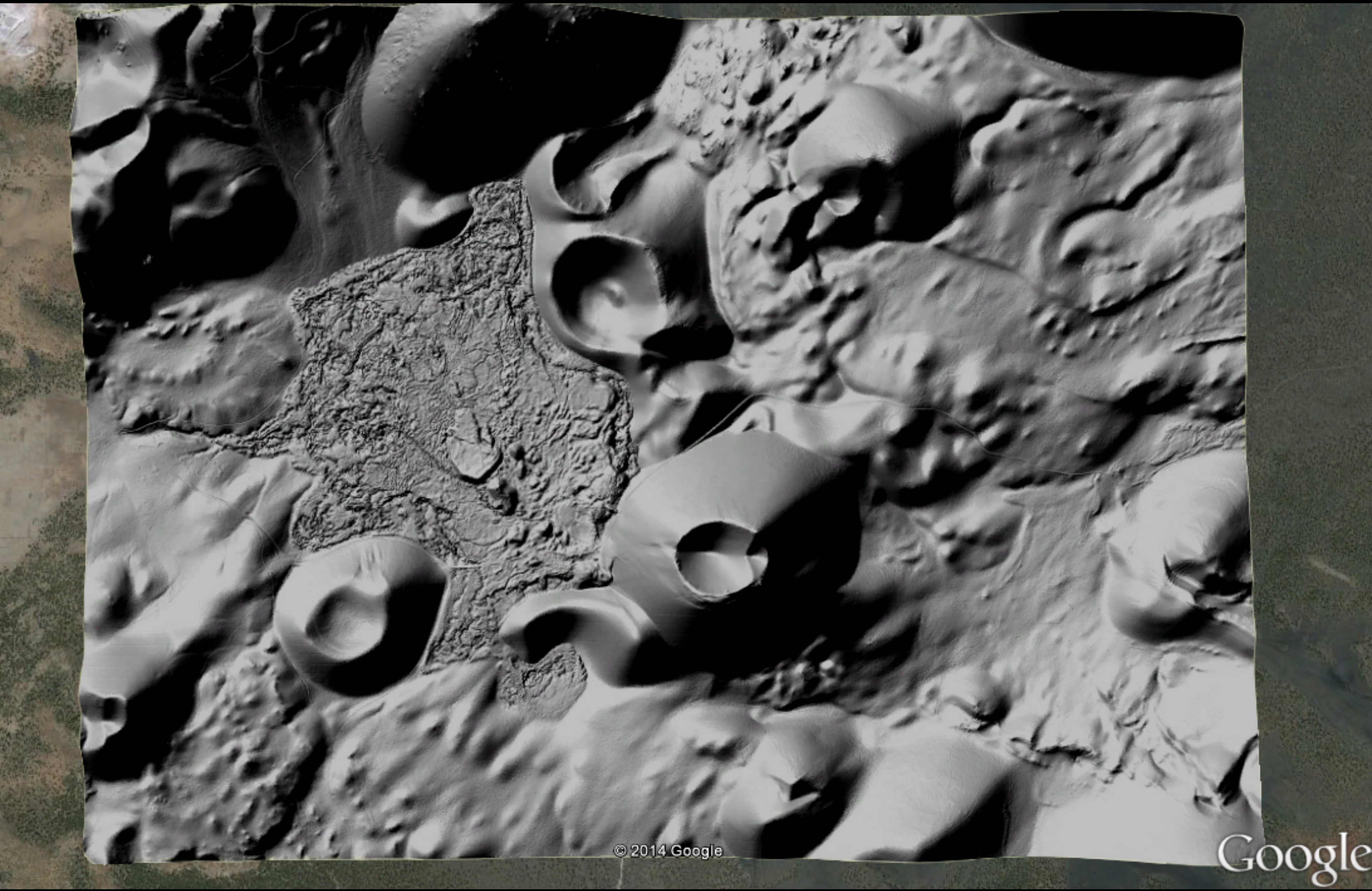
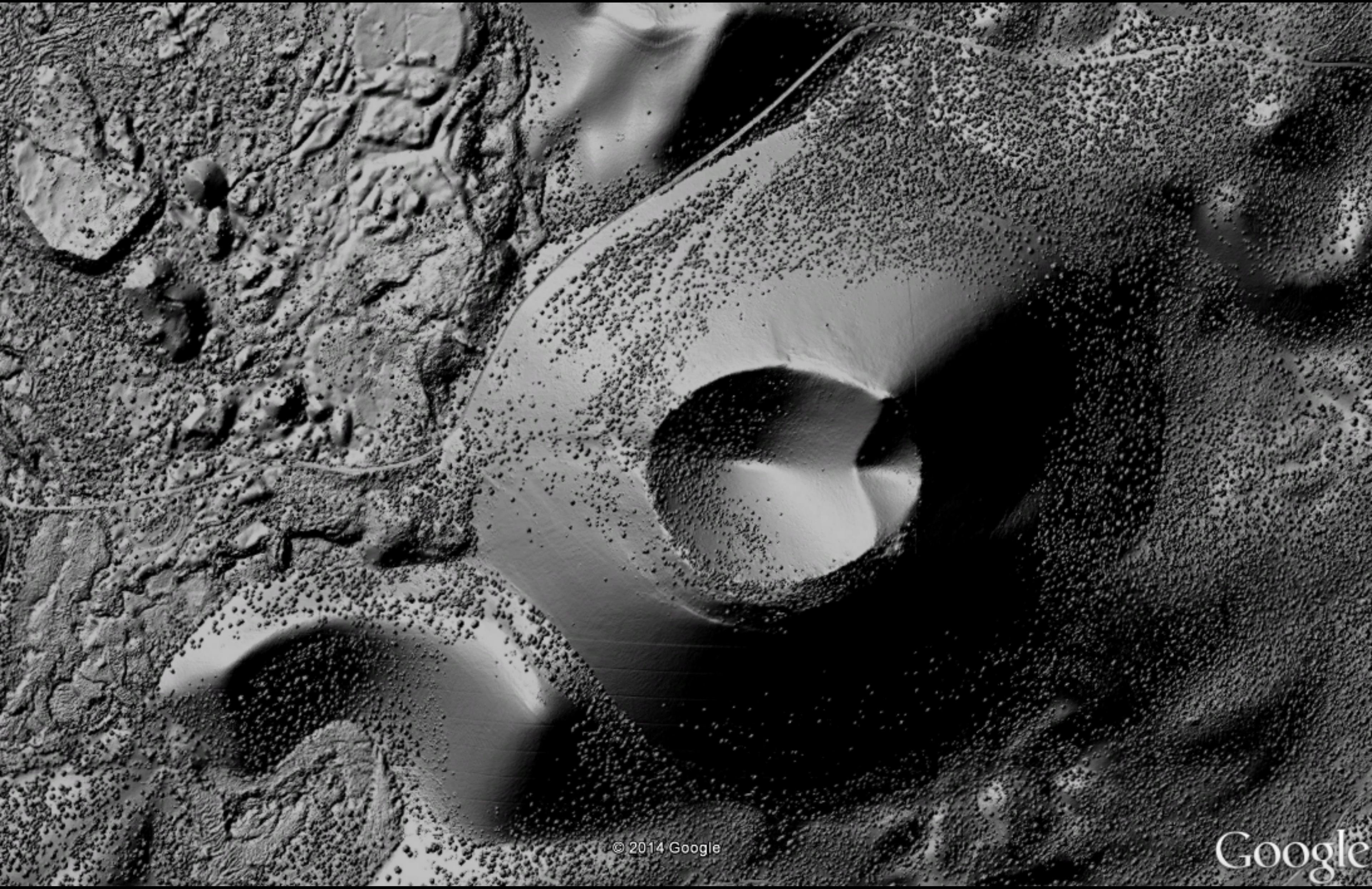
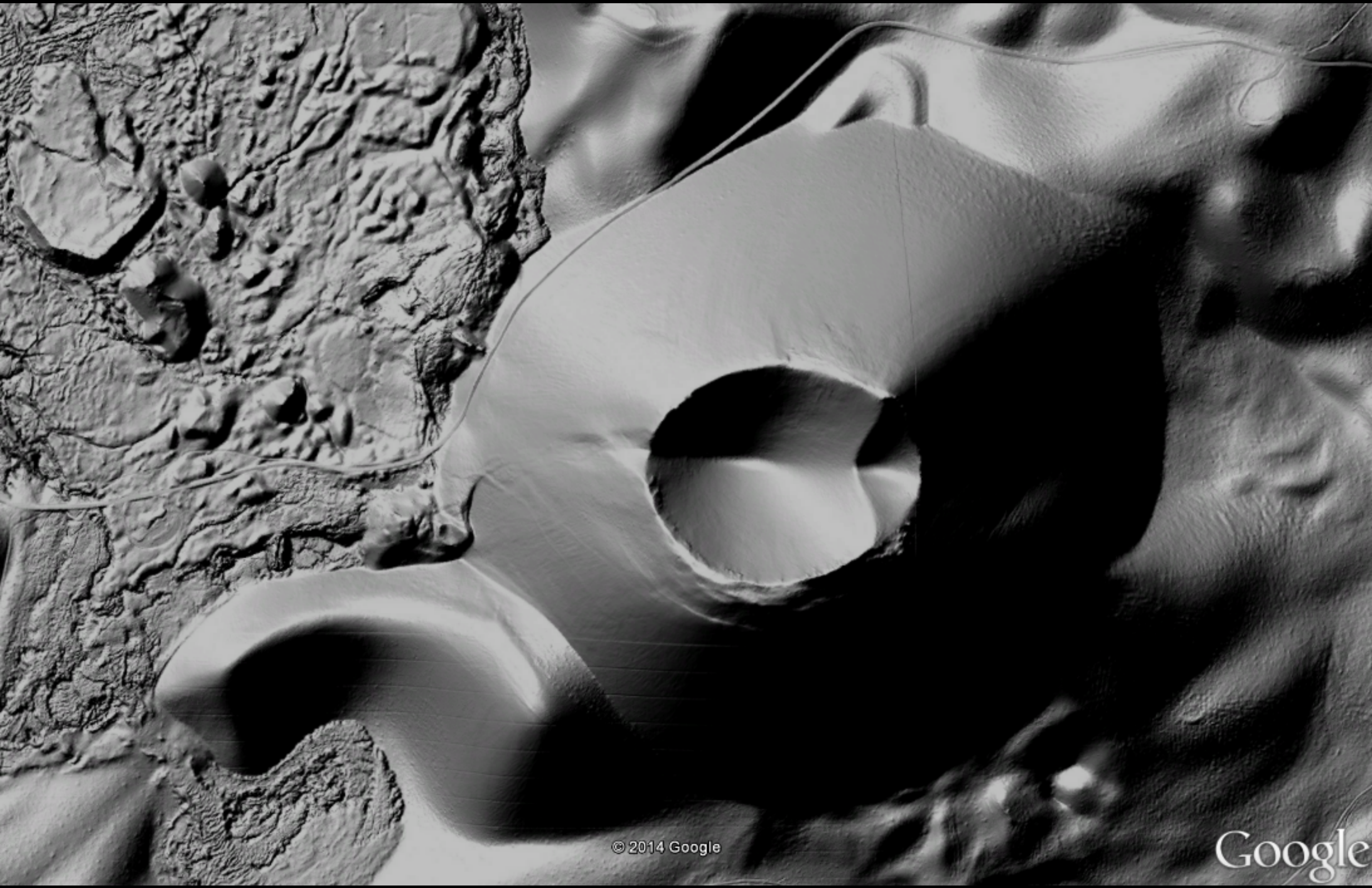

© 2014 Google
Google

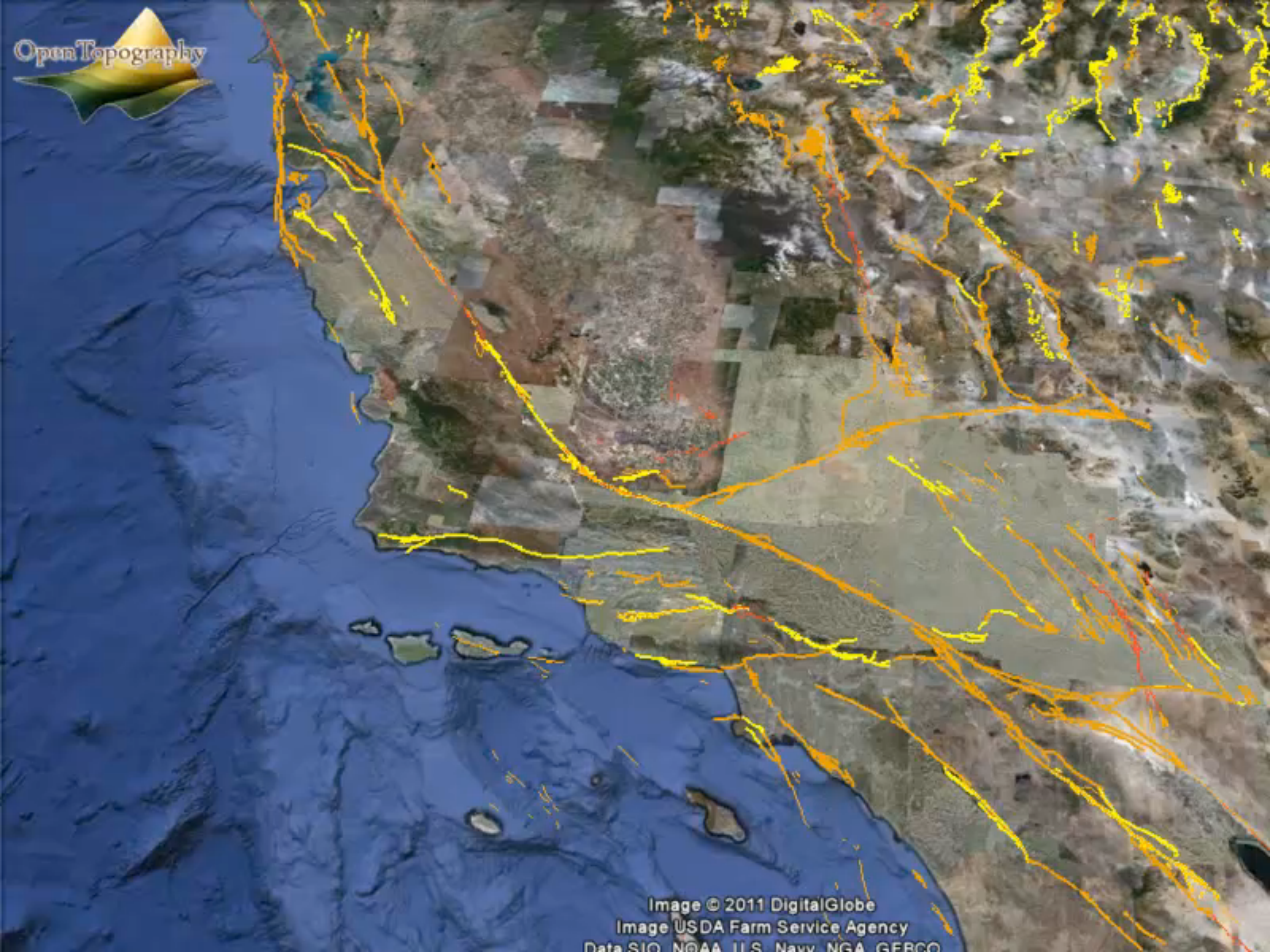

© 2014 Google
Google

Lidar: full feature (all returns)



Lidar: bare earth

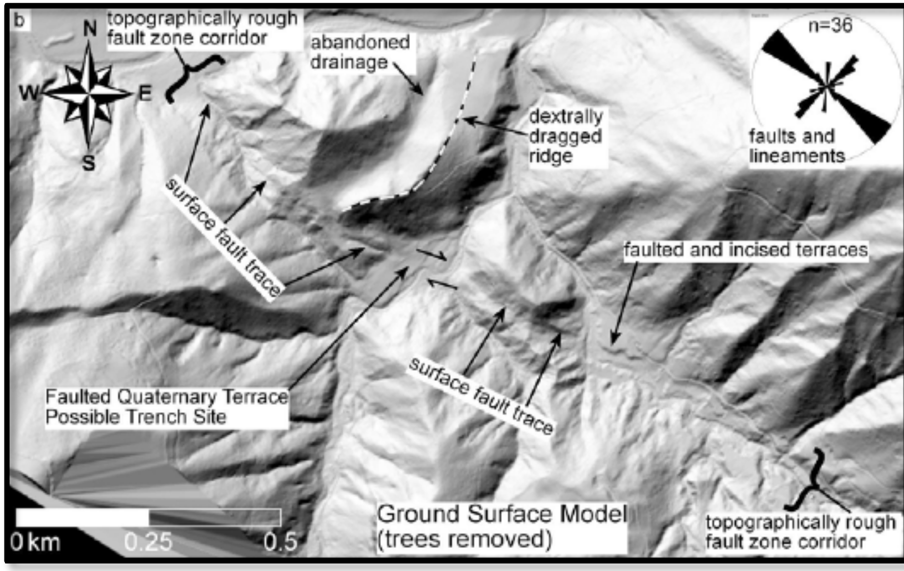



OpenTopography
Image © 2011 DigitalGlobe
Image USDA Farm Service Agency
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Northern San Andreas Fault, California (40 km SE of Point Arena)

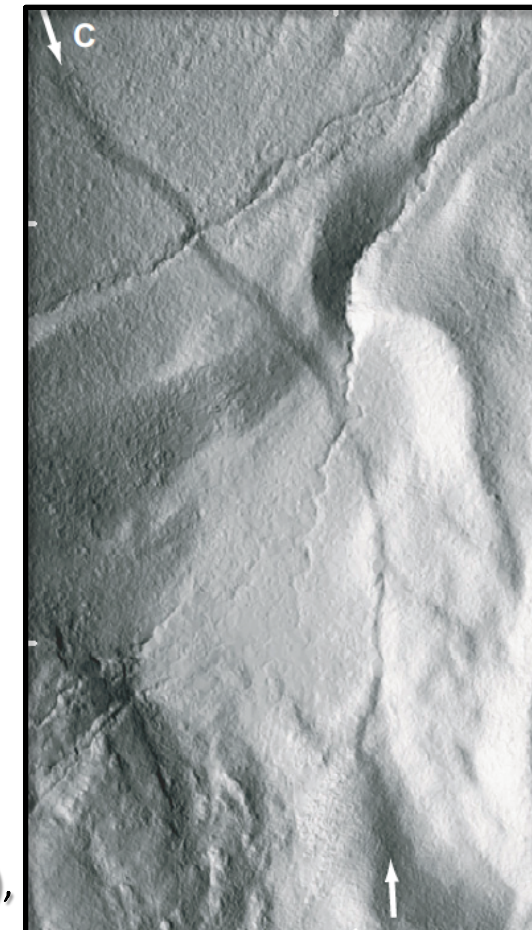
Northern San Andreas Fault, California

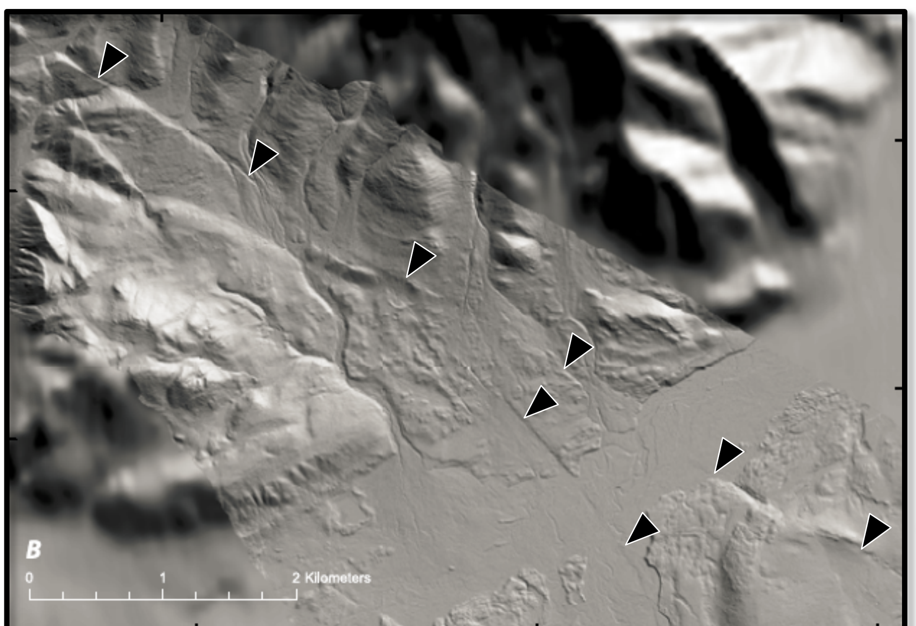
Identifying faults in presence of dense vegetation



Idrija Fault (Slovenia)
Cunningham et al. (2005),
Geophys. Res. Lett.

Tahoe-Sierra frontal fault zone
Howle et al. (2012),
Geol. Soc. Am. Bull.



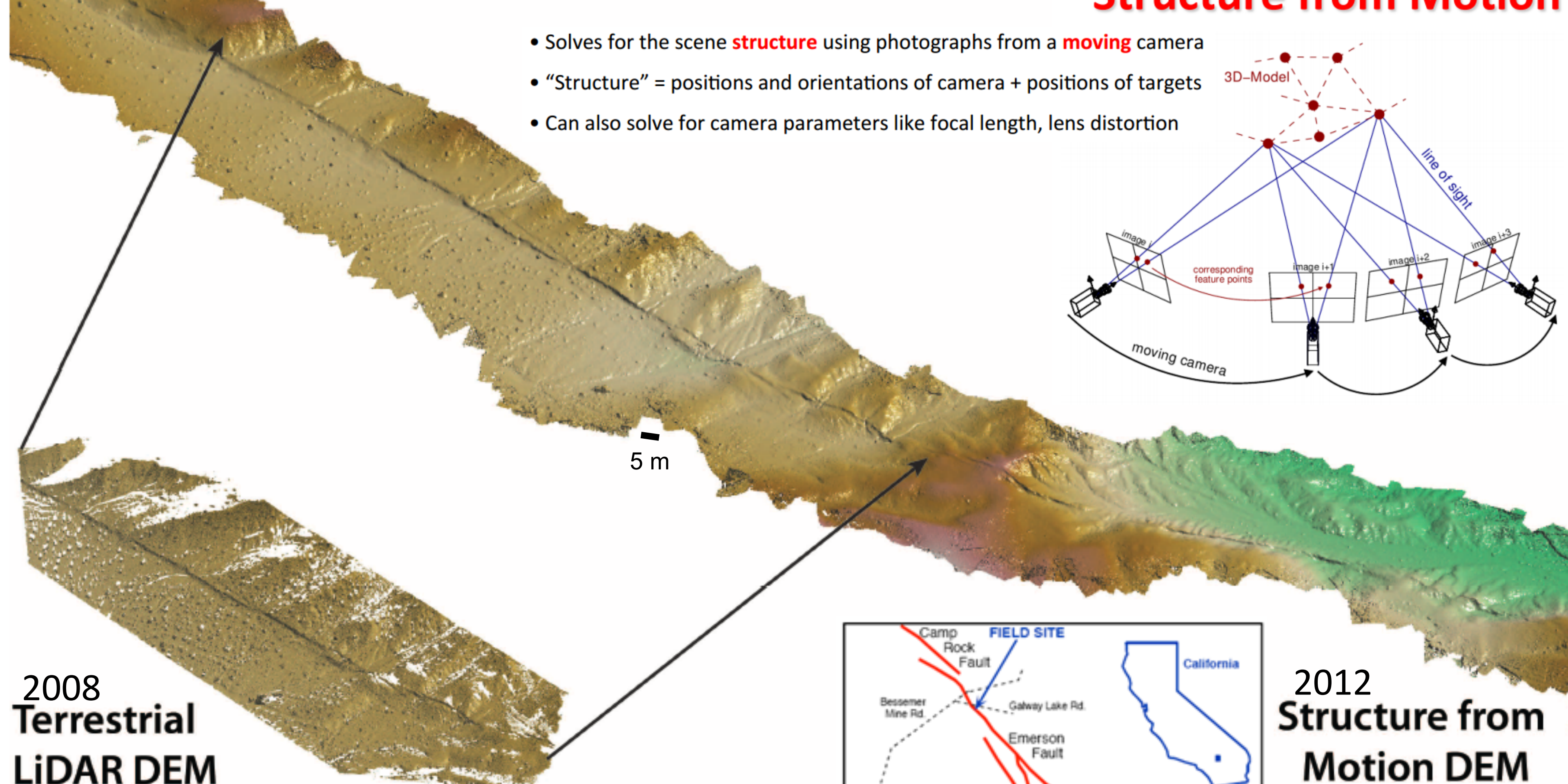


Denali fault
Schwartz et al. (2012),
J. Geophys. Res.

-E. Nissen

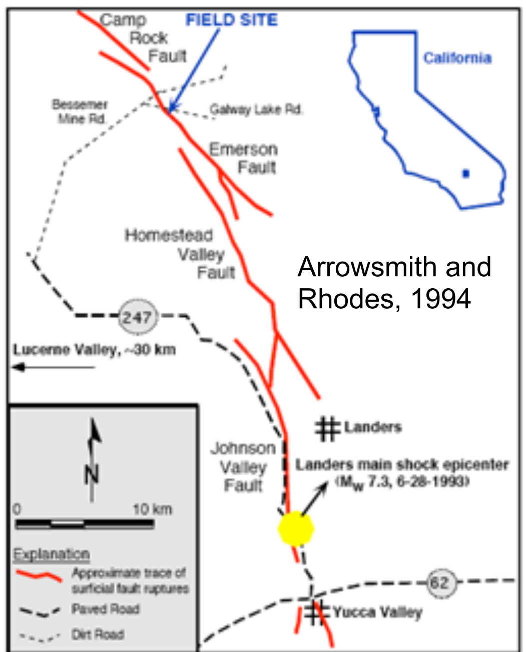
Structure from Motion

- Solves for the scene **structure** using photographs from a **moving** camera
- "Structure" = positions and orientations of camera + positions of targets
- Can also solve for camera parameters like focal length, lens distortion



2008
Terrestrial LiDAR DEM
Haddad, et al., 2012

2012
Structure from Motion DEM
Johnson, et al. 2014

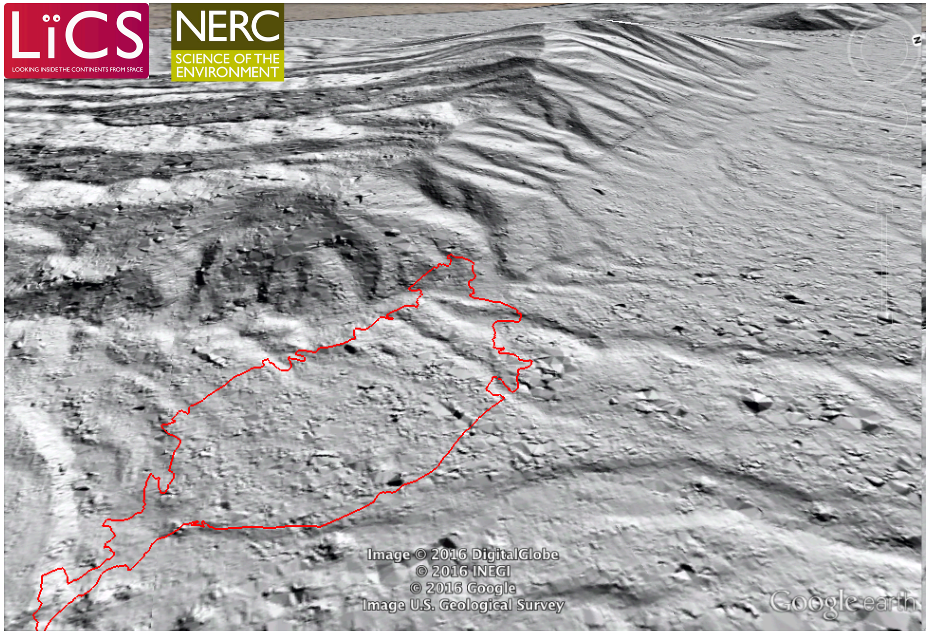


Arrowsmith and Rhodes, 1994

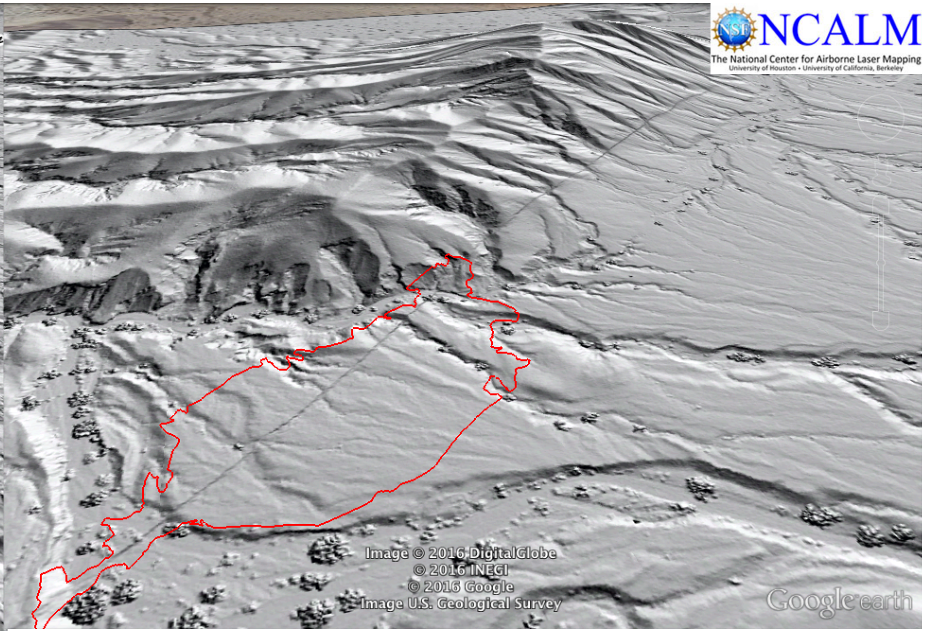
Landers, 1992 earthquake rupture repeated investigations on the decadal time scale: rupture zone sharp with secondary structures still evident

PHOTOGRAMMETRY CURRENTLY IN OT

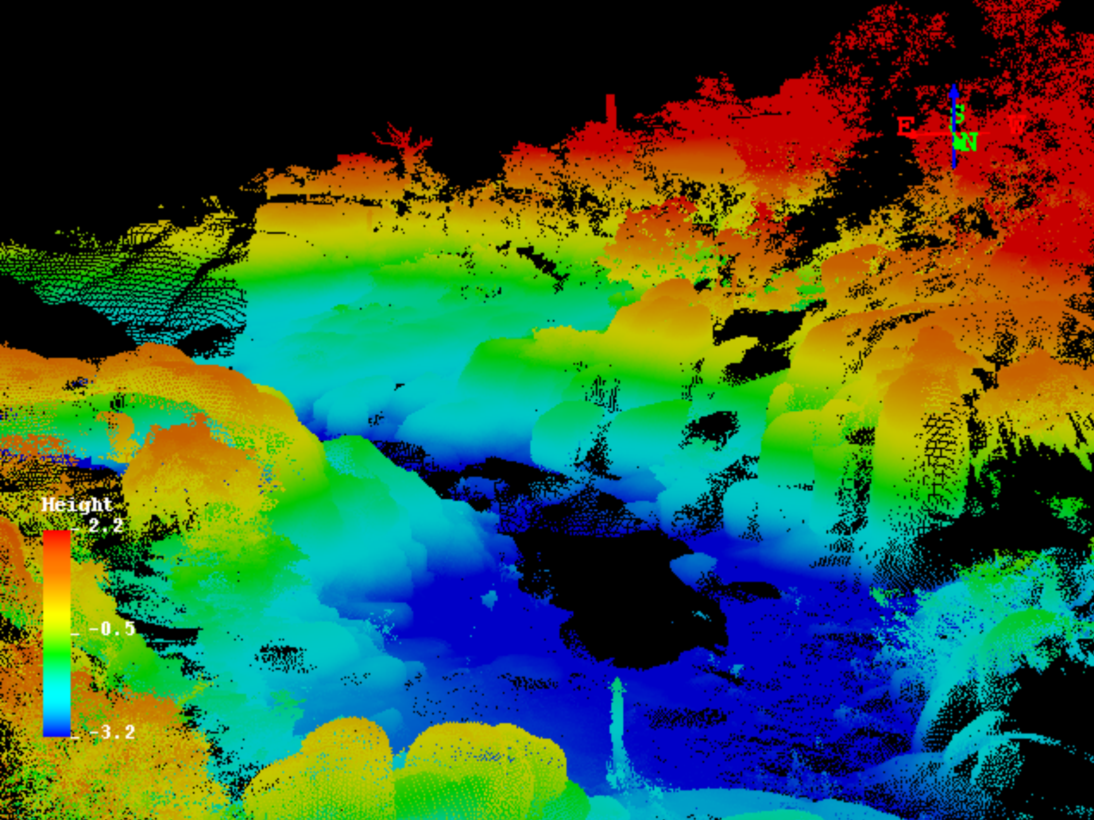
- Pleiades 1A & 1B tri-stereo data
- East Helanshan Fault, China
- El Mayor-Cucapah EQ



March 2014 Pleiades 1B tri-stereo DSM



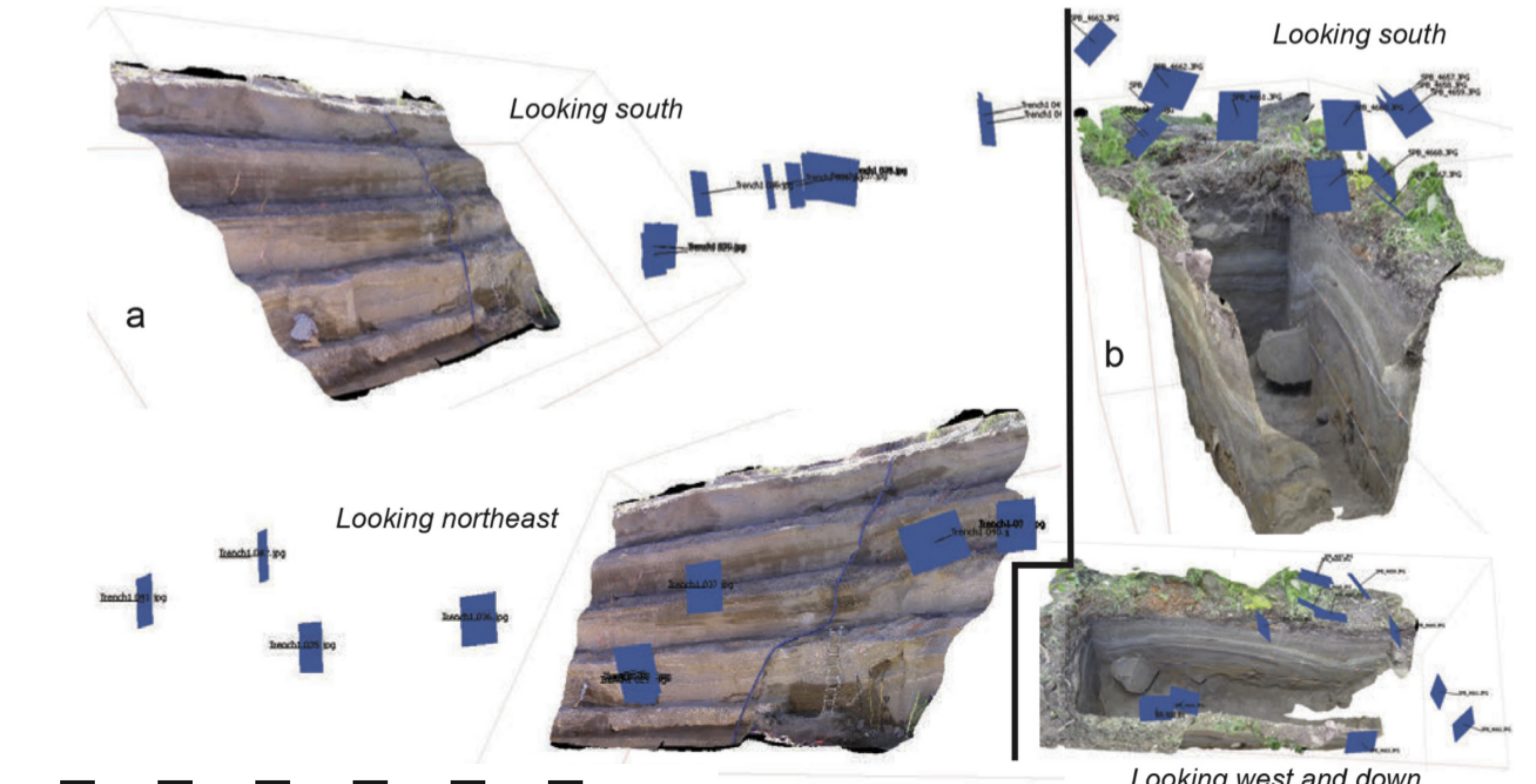
August 2010 NCALM ALS DSM

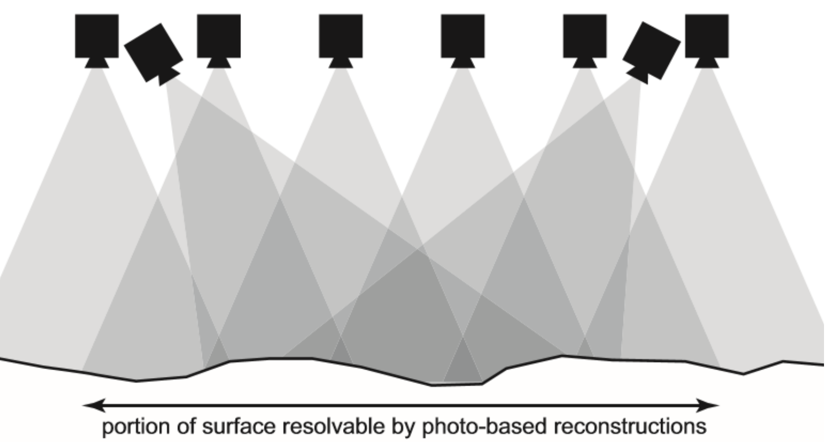


Granite Dells AZ point cloud (Haddad, et al. 2012)

UNAVCO Terrestrial Laser Scanner

absolute measurement capability sufficient to characterize features and changes in challenging geometric arrangements





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journal homepage: www.elsevier.com/locate/jsg

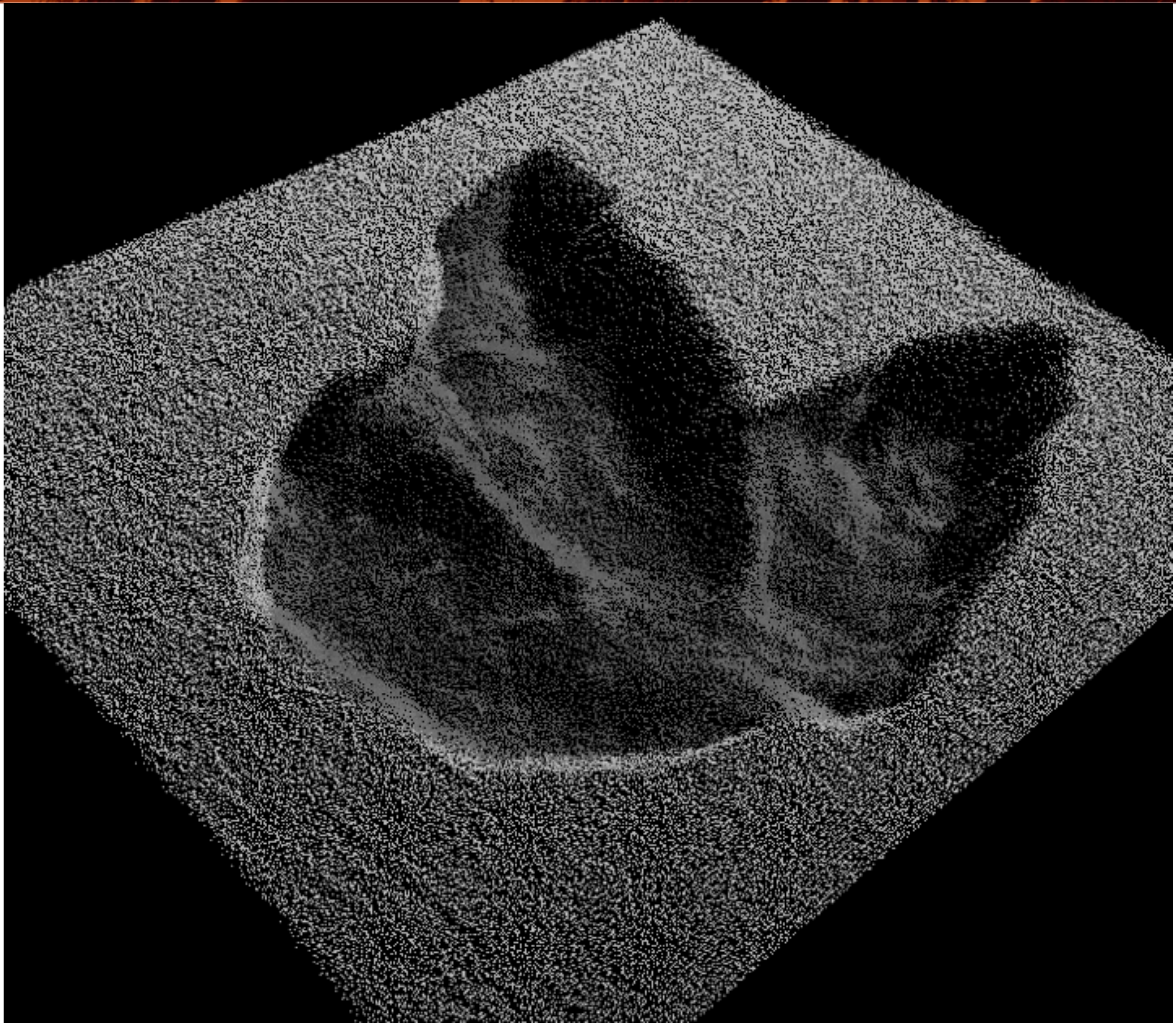
ELSEVIER

Review article

Ground-based and UAV-Based photogrammetry: A multi-scale, high-resolution mapping tool for structural geology and paleoseismology

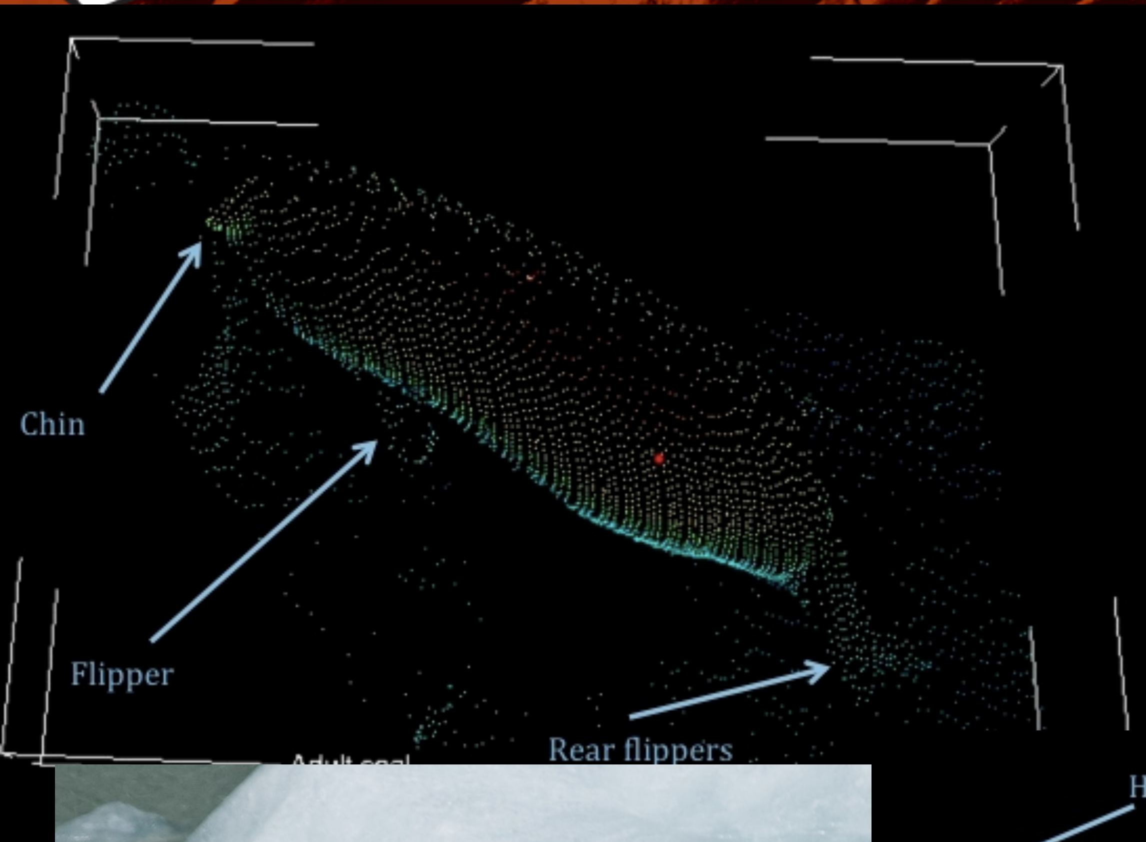
Sean P. Bemis [a,*], Steven Micklethwaite [b], Darren Turner [c], Mike R. James [d], Sinan Akciz [e], Sam T. Thiele [b], Hasnain Ali Bangash [b]

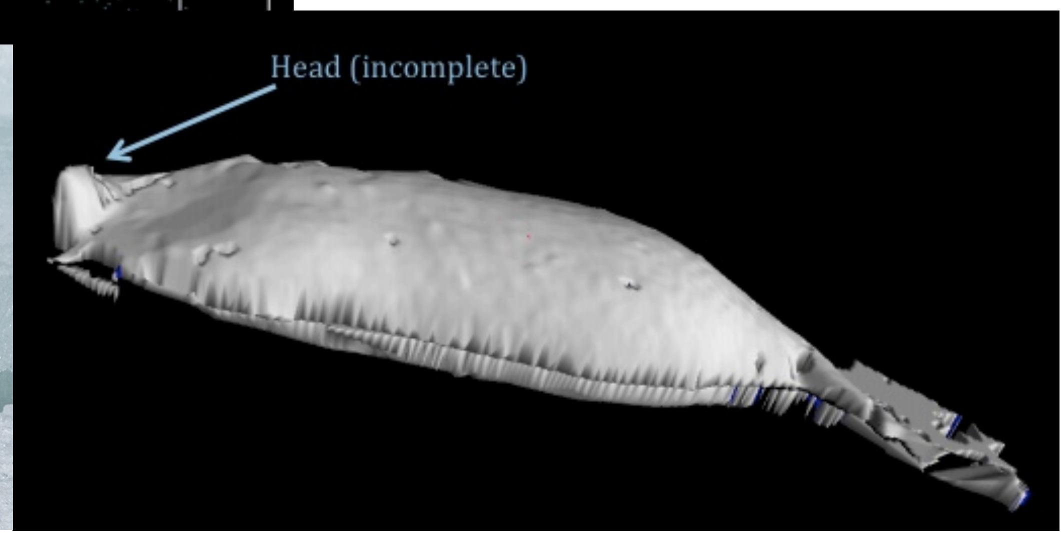
Dinosaur Trackway, Fiorello



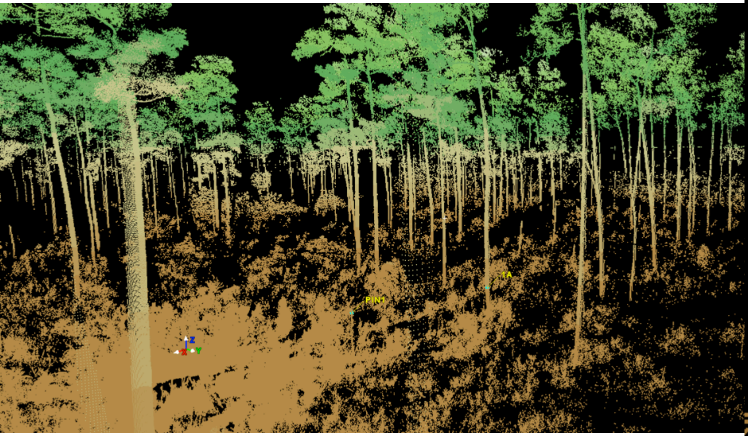
Using TLS to Obtain Volumetric Measurements of Weddell Seals in the McMurdo Sound

Seal body mass = proxy for availability of marine food resources

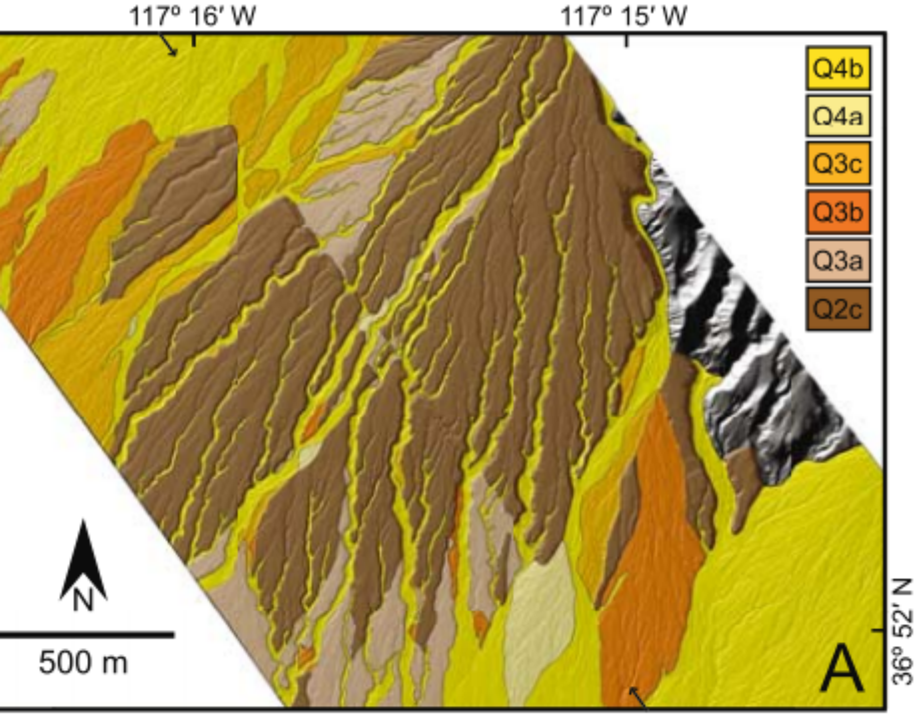


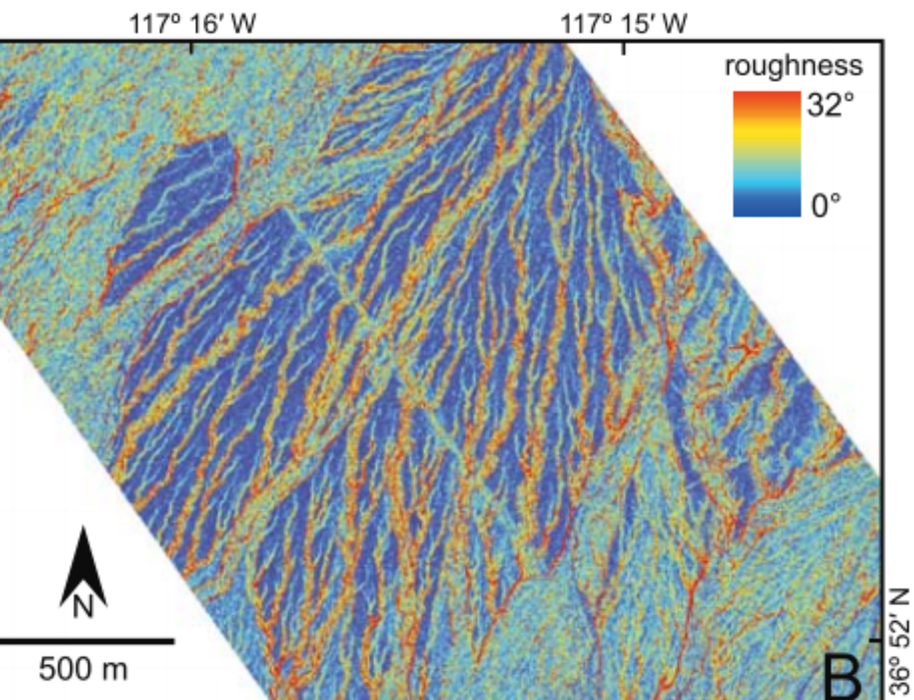


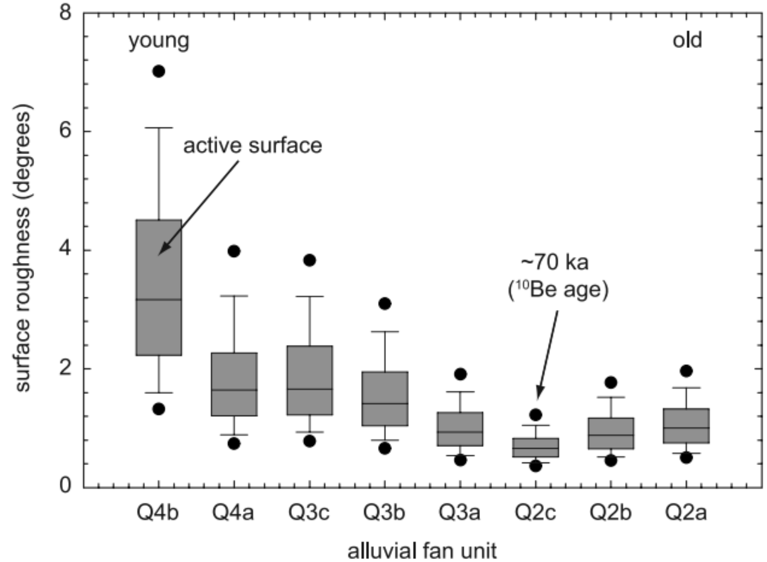
Everglades Biomass, Wdowinski



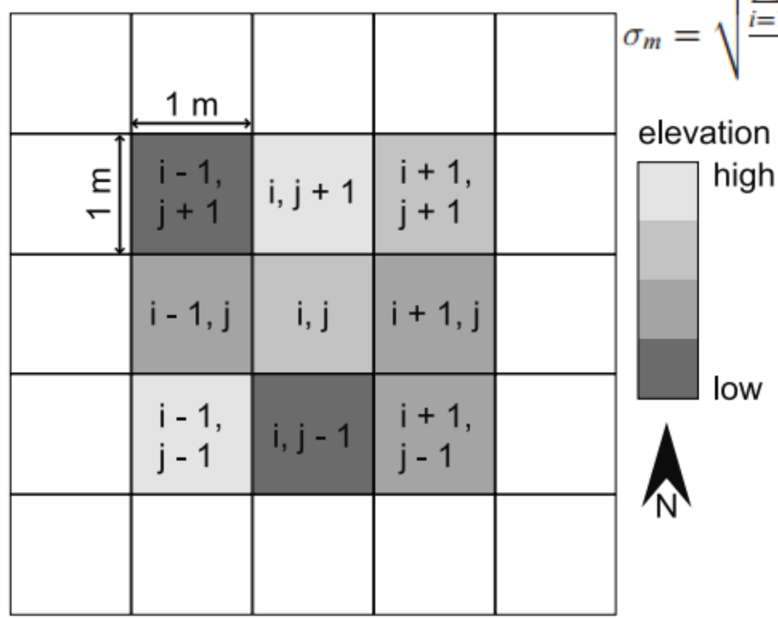
Going beyond pretty pictures…







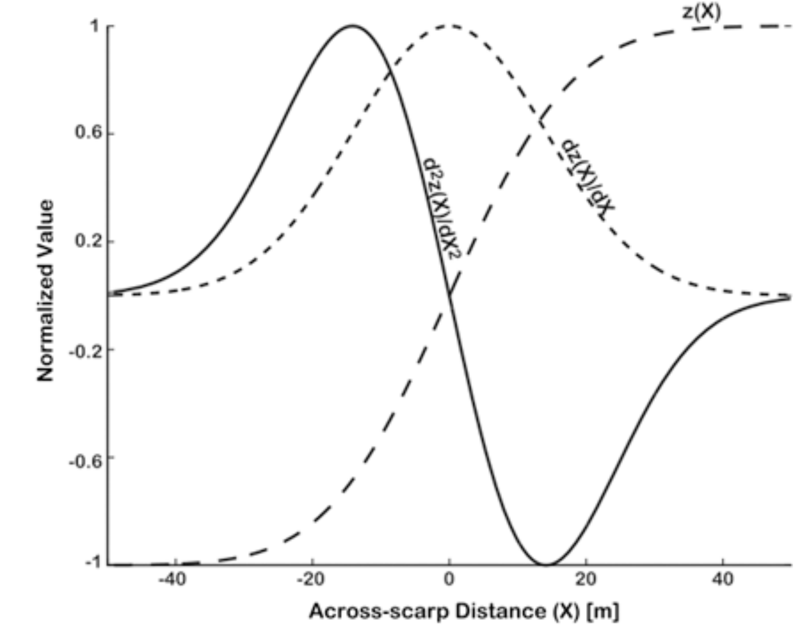
$$\sigma_m = \sqrt{\frac{\sum_{i=1}^{n}(m_i - \overline{m})^2}{n}},$$

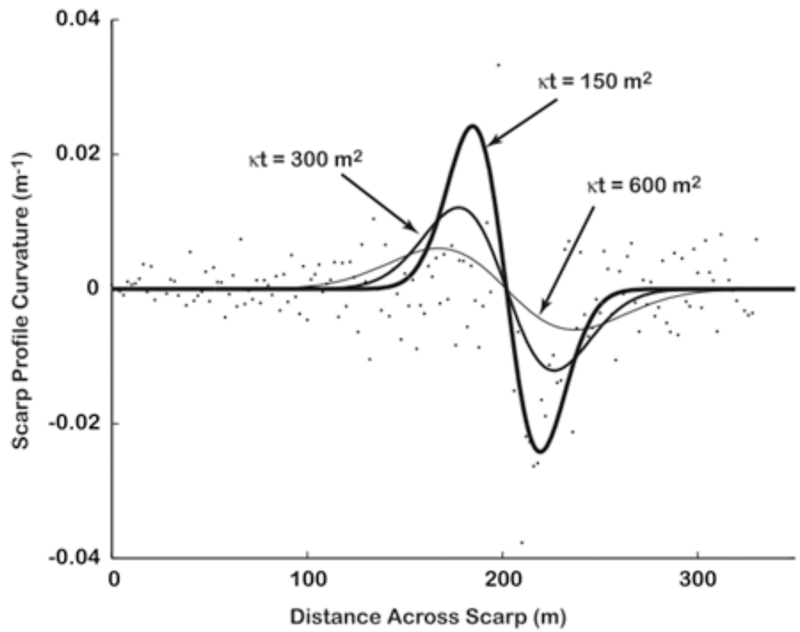


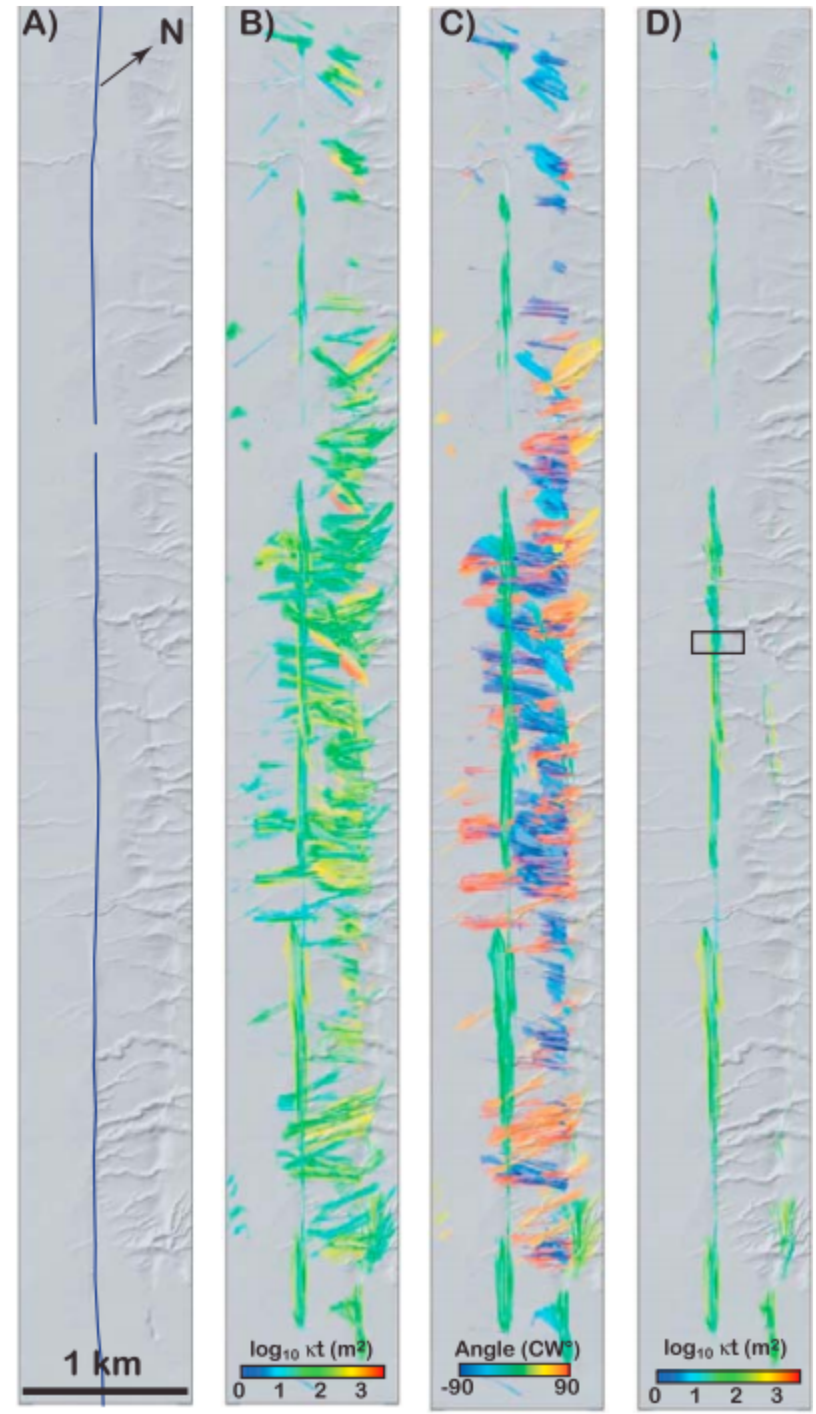
Characterizing arid region alluvial fan surface roughness with airborne laser swath mapping digital topographic data

Kurt L. Frankel[1] and James F. Dolan[1]

JGR, 2007



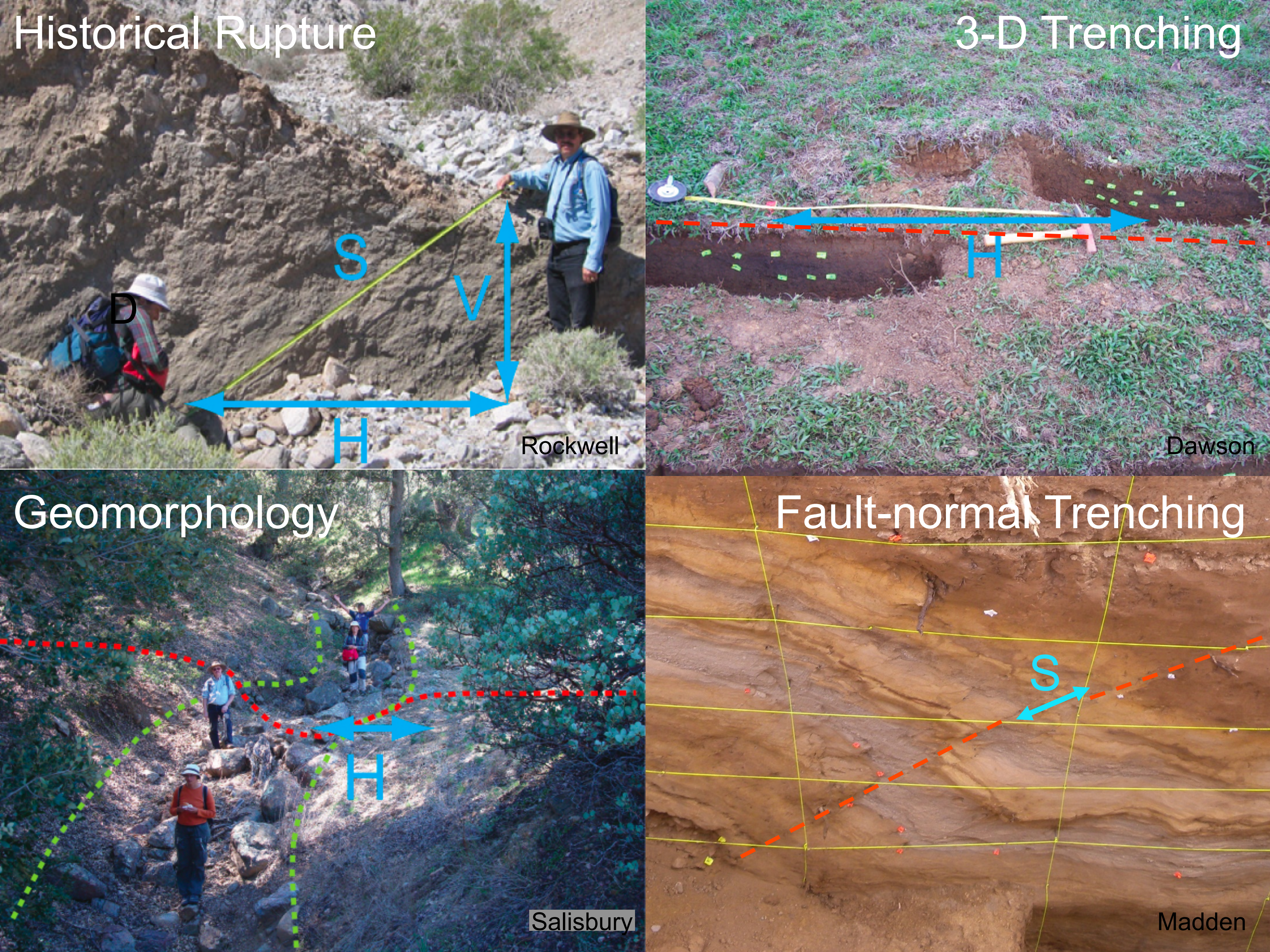




Morphologic dating of fault scarps using airborne laser swath mapping (ALSM) data

GRL, 2010

G. E. Hilley,[1] S. DeLong,[2] C. Prentice,[2] K. Blisniuk,[3] and JR. Arrowsmith[4]


Historical Rupture
S
V
D
H
Rockwell
3-D Trenching
H
Dawson
Geomorphology
H
Salisbury
Fault-normal Trenching
S
Madden

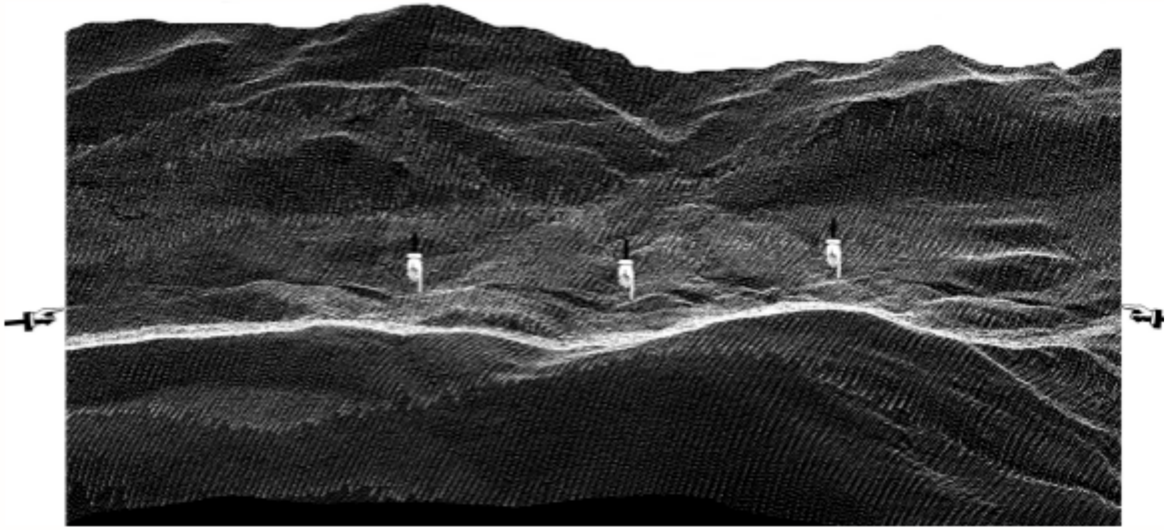


Figure 2. Oblique view of Hector Mine earthquake surface rupture that experienced 3.5–4.5 m of right-lateral displacement. The rupture trace is pointed out by finger icons; the light and dark bands below and above the surface rupture are subparallel, topographic escarpments. Several offset ridges are now juxtaposed with gullies, forming ‘shutter’ ridges. Raw laser hits are used to illuminate the ground surface in this point-cloud image. From tens to hundreds of hits per square meter were collected along the primary surface ruptures.

Bulletin of the Seismological Society of America, Vol. 92, No. 4, pp. 1570–1576, May 2002

High-Resolution Topography along Surface Rupture of the 16 October 1999 Hector Mine, California, Earthquake (M_w 7.1) from Airborne Laser Swath Mapping

by K. W. Hudnut, A. Borsa, C. Glennie, and J.-B. Minster

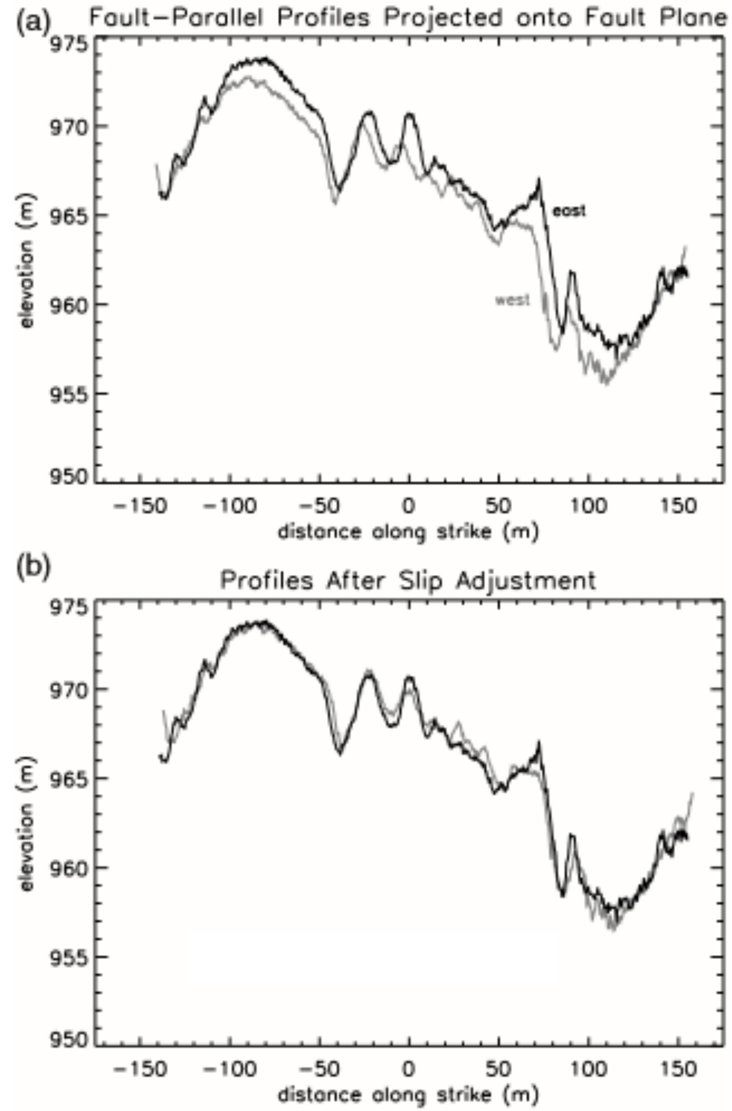
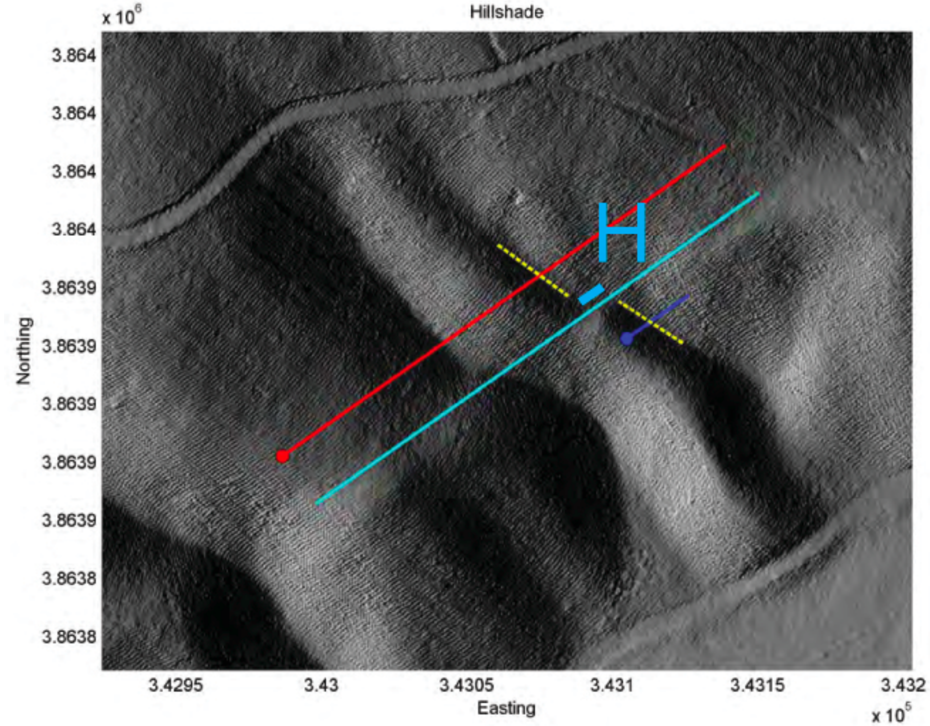
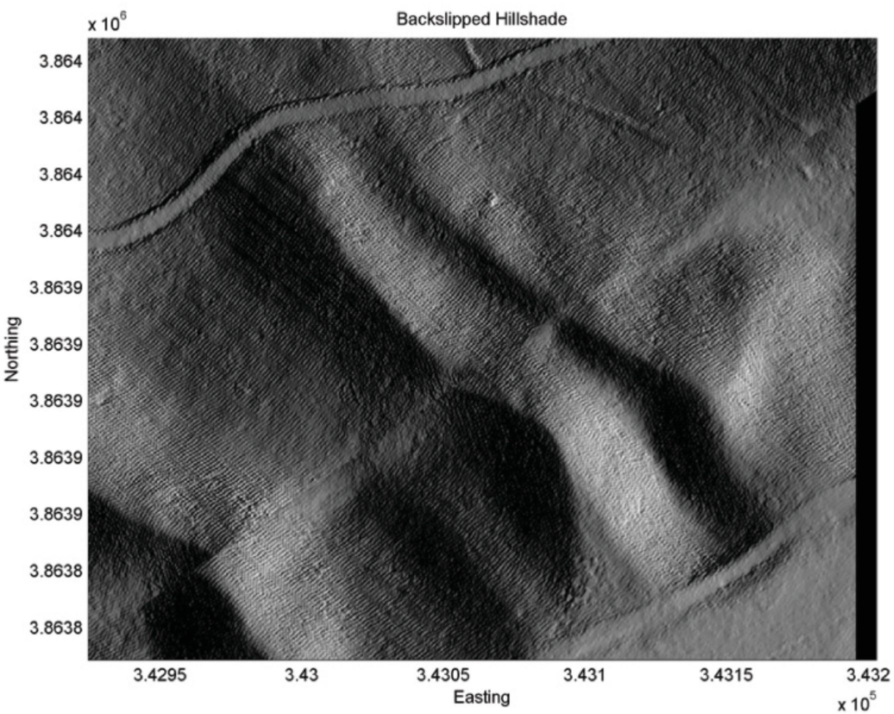
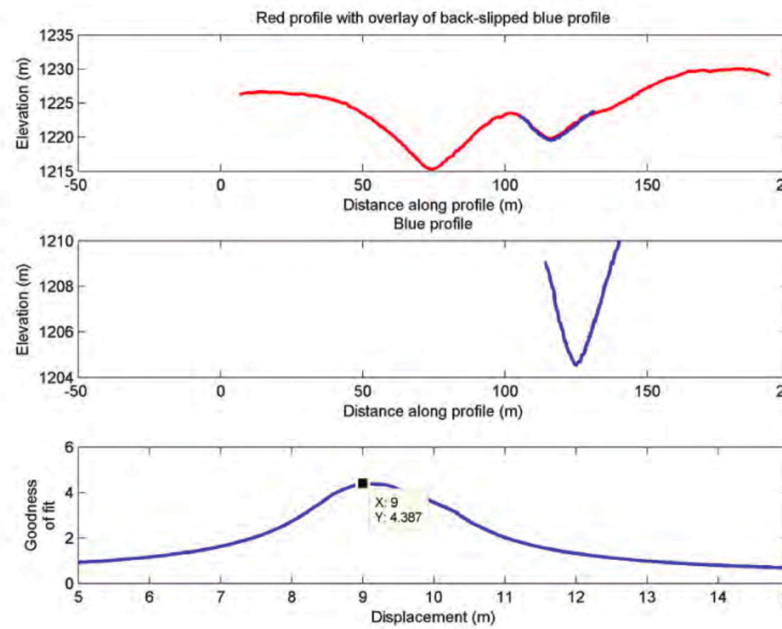


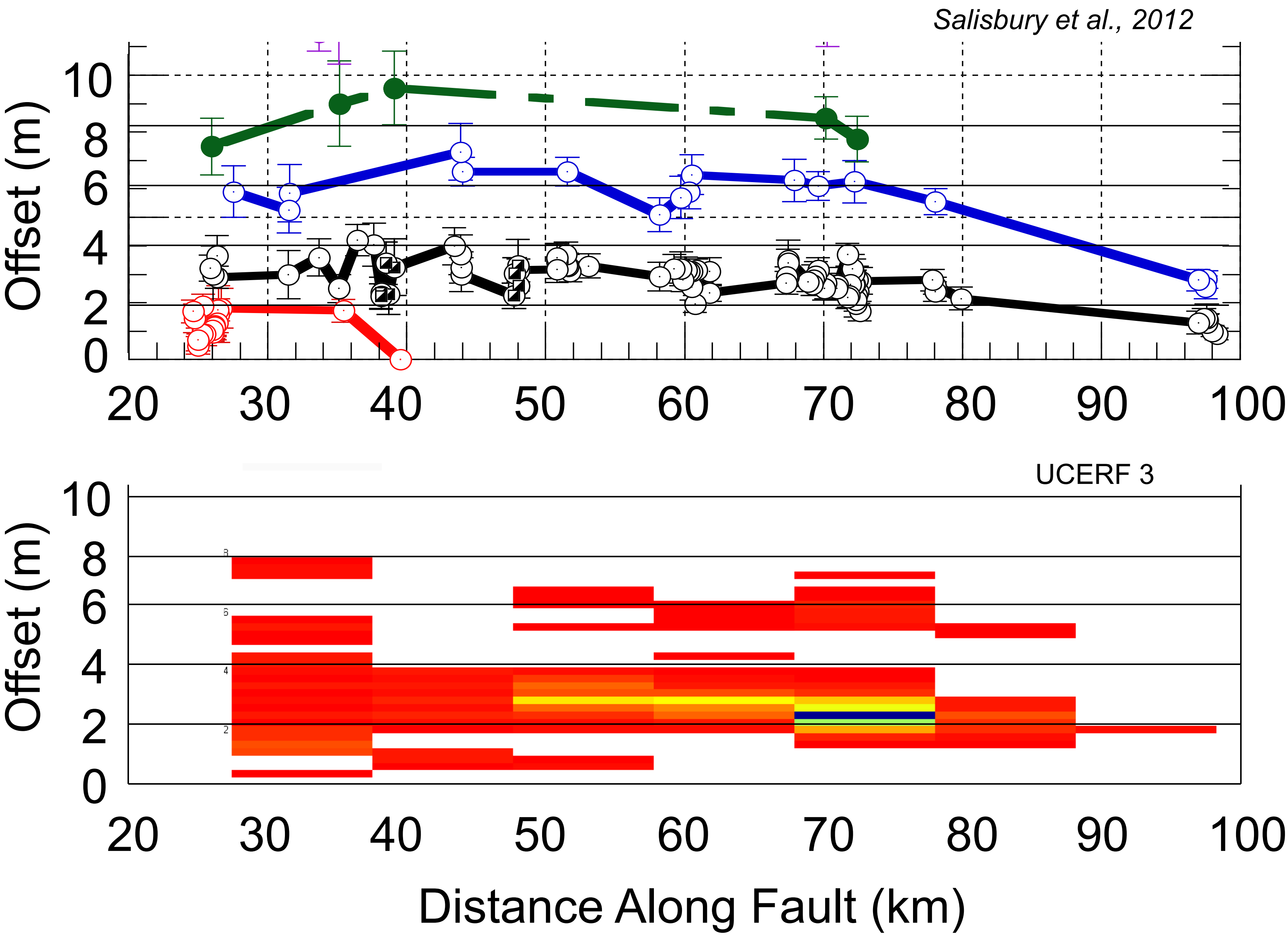
Figure 6. (a) Cross sections through the raw laser data on either side of the surface rupture, along the east and west profiles shown in Figure 4, are shown projected onto the fault plane (a ground-slope correction has already been removed). (b) Comparison of the topographic profiles on either side of the fault, after shifting the profiles shown in Figure 6a to remove our best estimate of the lateral and vertical offset along this 300-m section.

LiDAR Measurements

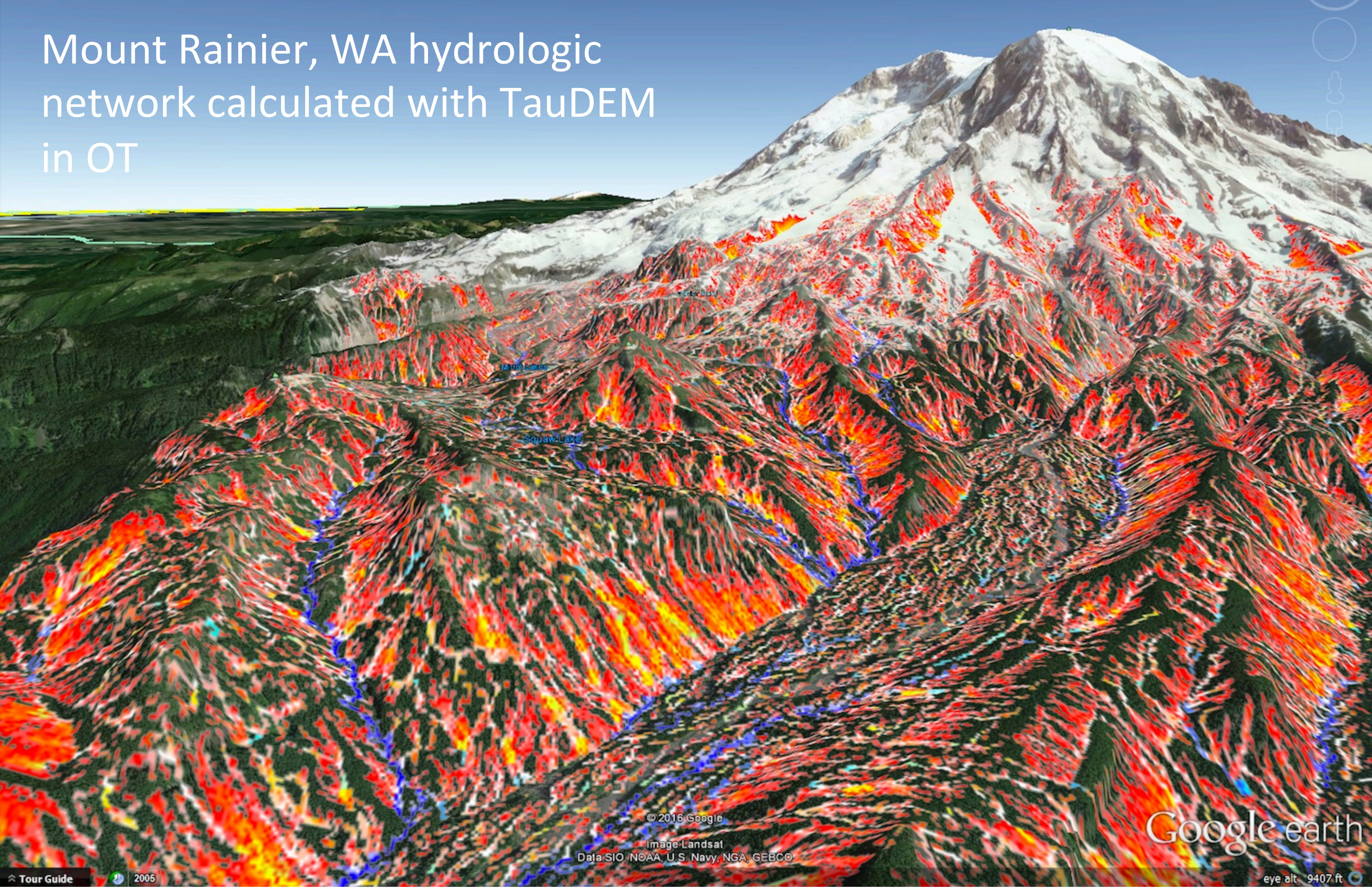







Salisbury et al., 2012
Offset (m)
10
8
6
4
2
0
20
30
40
50
60
70
80
90
100
UCERF 3
Offset (m)
10
8
6
4
2
0
20
30
40
50
60
70
80
90
100
Distance Along Fault (km)

Mount Rainier, WA hydrologic network calculated with TauDEM in OT



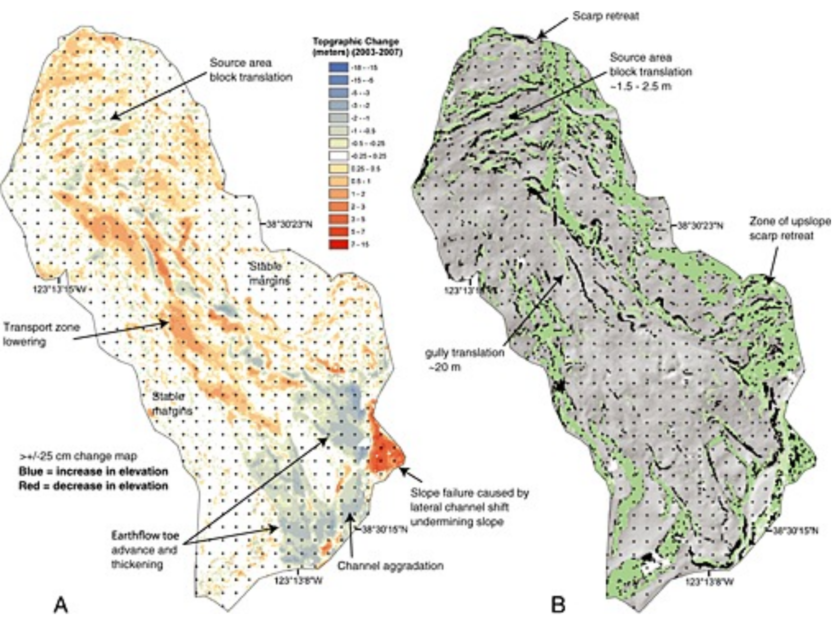
Red = catchment area of 100 m^{2}. Blue = catchment area > 610,000 m^{2}. Kautz Creek flows through the large valley near the center of the image.

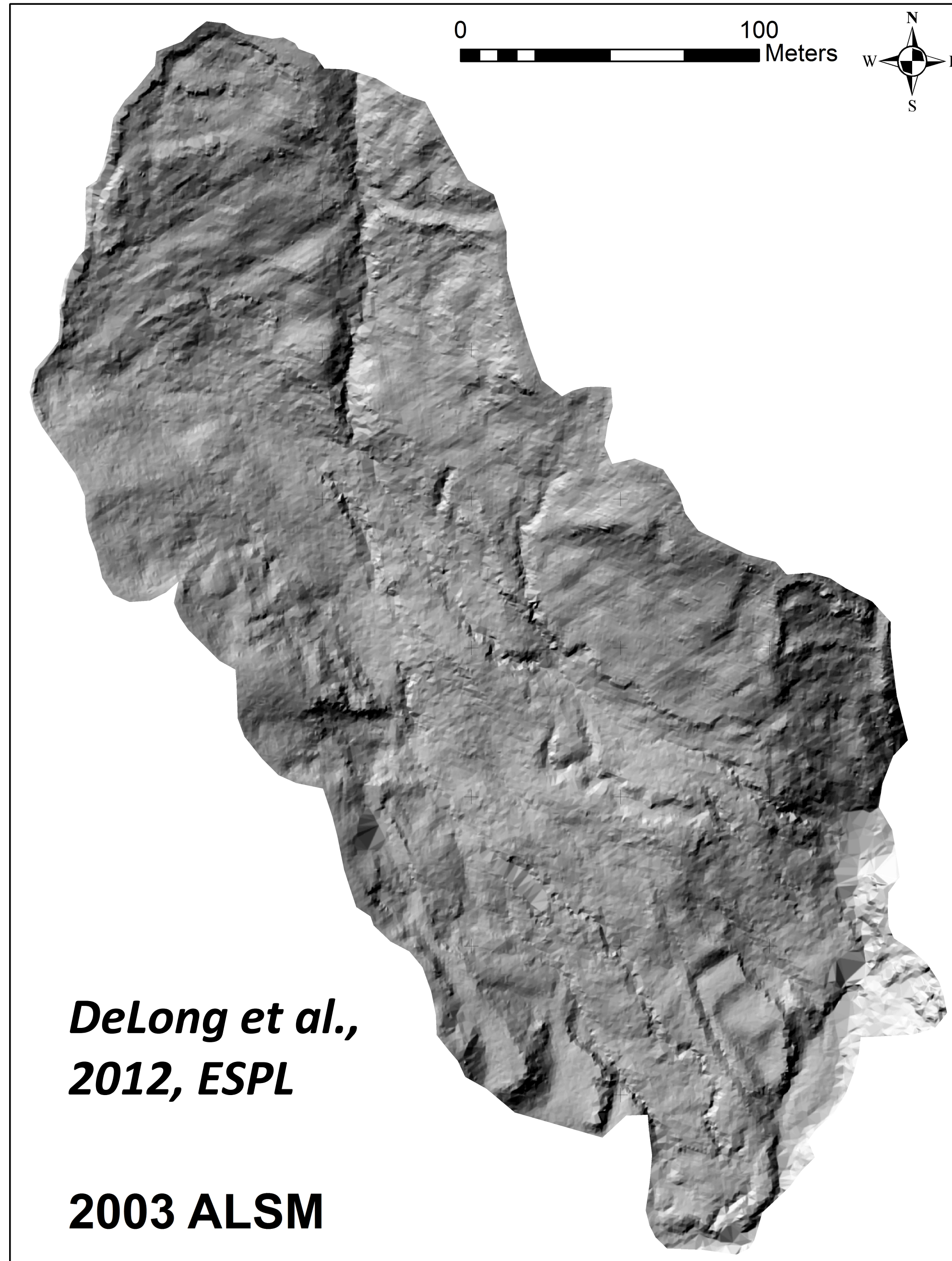
Differential topography

Showcase Tool #1: TLS Terrestrial Laser Scanner

UNAVCO

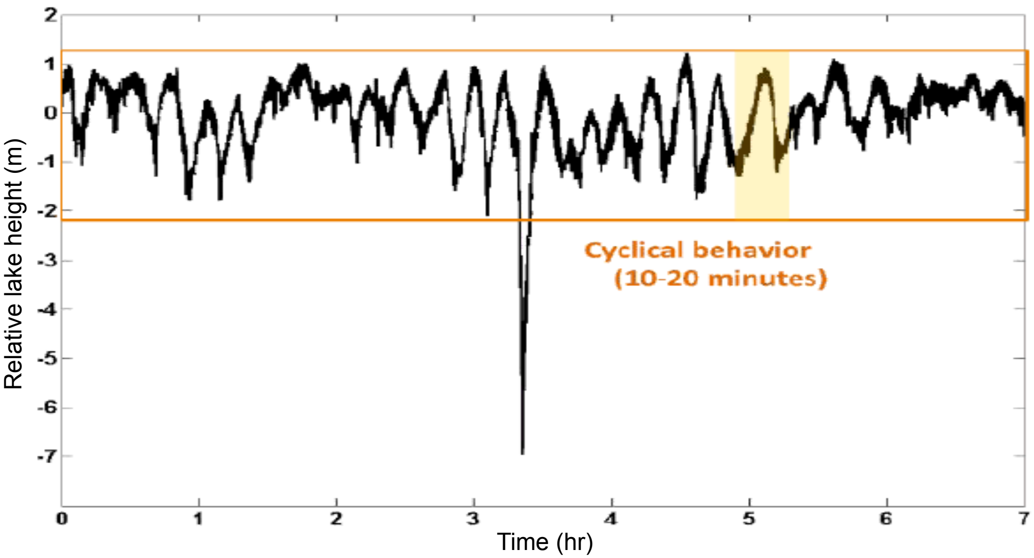

Pt. Arena
Mill Gulch earthflow
Santa Rosa
California
38°30'0"N
38°0'0"N
123°30'0"W
123°0'0"W


Source area block translation
Topgraphic Change (meters) (2003-2007)
38°30'23"N
123°13'15"W
Stable margins
Transport zone lowering
Stable margins
>+/-25 cm change map
Blue = increase in elevation
Red = decrease in elevation
Slope failure caused by lateral channel shift undermining slope
Earthflow toe advance and thickening
38°30'15"N
123°13'8"W
Channel aggradation
A
Scarp retreat
Source area block translation ~1.5 - 2.5 m
38°30'23"N
Zone of upslope scarp retreat
gully translation ~20 m
38°30'15"N
123°13'8"W
B

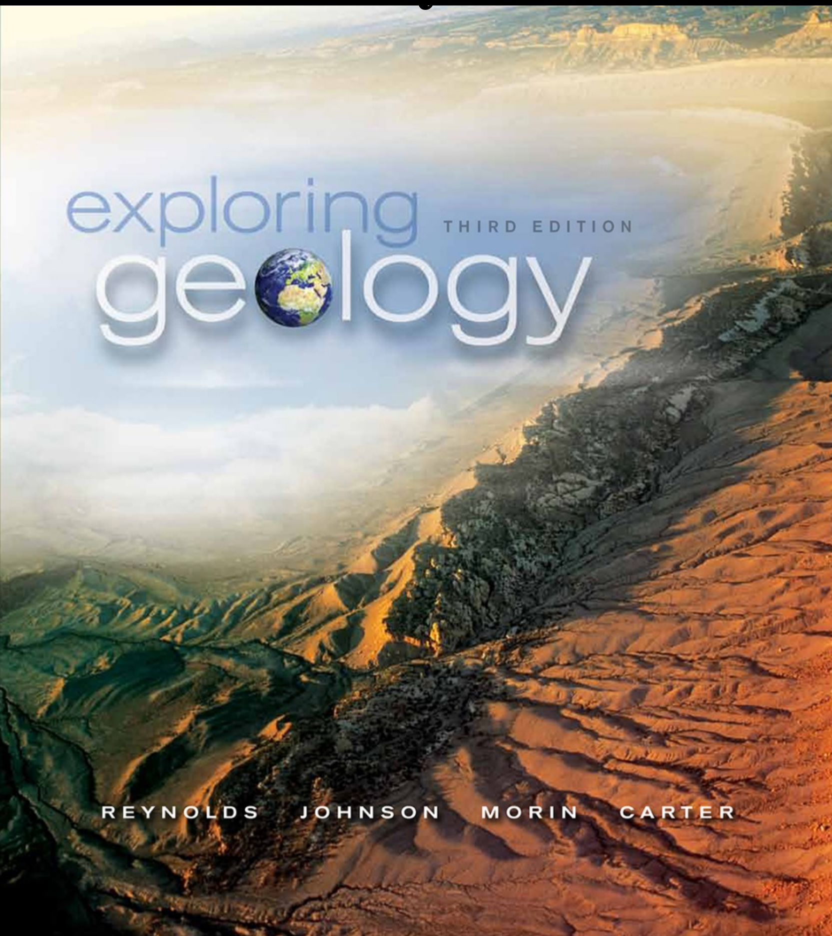

0
100
Meters
N
W
E
S
DeLong et al., 2012, ESPL
2003 ALSM

Mount Erebus, Antarctica

- Lava lake scanned 2008–2013, revealing behaviors invisible to naked eye
- Inner crater scan used to augment and truth 2003 aerial scans
- Scans of ice caves and ice towers help determine thermal / energy budget of volcano



Extra…



Chapter 8

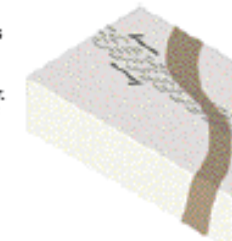
Image Number: 08.00.a3: © Duncan Heron; 08.01.mtb1: Spokane Research Lab/NIOSH/CDC; Courtesy of J.M. Logan and F.M. Chester, Center for Tectonophysics, Texas A&M University; 08.02.mtb1: Spokane Research Lab/NIOSH/CDC; 08.03.c6: © Dean Conger/Corbis; 08.10.c2: Ohio State University, USGS, National Center for Airborne Laser Mapping, OpenTopography, and J Ramon Arrowsmith, Arizona State University; 08.11.a9: © Dr. Marli Miller/Visuals Unlimited;

B Where Do Strike-Slip Faults and Shear Zones Form?

During strike-slip movement, one block of rock is sheared sideways past another block of rock. This can various settings, including transform plate boundaries and within the interiors of plates.


08.10.b1

Stresses can form a strike-slip zone that functions as a plate boundary or that is totally within a tectonic plate (▶). A strike-slip zone may offset the rocks hundreds of kilometers or less than a meter. A strike-slip fault with relatively small amounts of displacement is typically a single fault or several adjacent faults, but zones with larger displacements are thick zones of shear (shear zones).


08.10.b2

Shear stresses can be imposed on rocks horizontally, vertically, or at some intermediate angle. When the shear stresses are horizontal (▲), they act to shear the two sides of a block in opposite horizontal directions. As a result of the stresses, shearing moves rocks horizontally past one another. Shearing in the upper parts of the crust occurs along a fault, as shown here, and is accompanied by fracturing of adjacent rocks. Shearing at depth will occur along a zone of ductile deformation and will be accompanied by metamorphism and the formation of foliation and lineation.

08.10.b3

◀ All transform boundaries are faults that accommodate the la placement of one plate past a Most are a boundary betwee oceanic plates, as are the o here by small white arrows, transform fault can also se two continental plates or separate an oceanic pla a continental one.

C What Features Form Along Strike-Slip Faults?

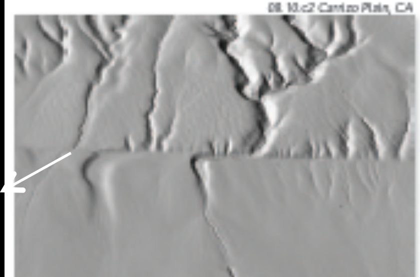
Strike-slip faults result in a number of distinctive features, including offset streams. They also can have fe formed where one block of rock shears past another or where rocks are forced around a bend in the fau

Strike-slip faults displace rocks on either side horizontally relative to one another, so in a simple case would not uplift or downdrop either side. However, many strike-slip faults have bends, where the fault changes its trace across the land surface from one orientation to another. Right-lateral motion on the fault shown here causes compression along the bend, forming ridges and troughs that are the surface expression of folds and thrust faults.


08.10.c1

Horizontal displacement surface features, includi agricultural fields, and s beds. Over time, offse develop a characteris where they jog para fault, before contin their prefaulting c direction of the j the direction of movement acro

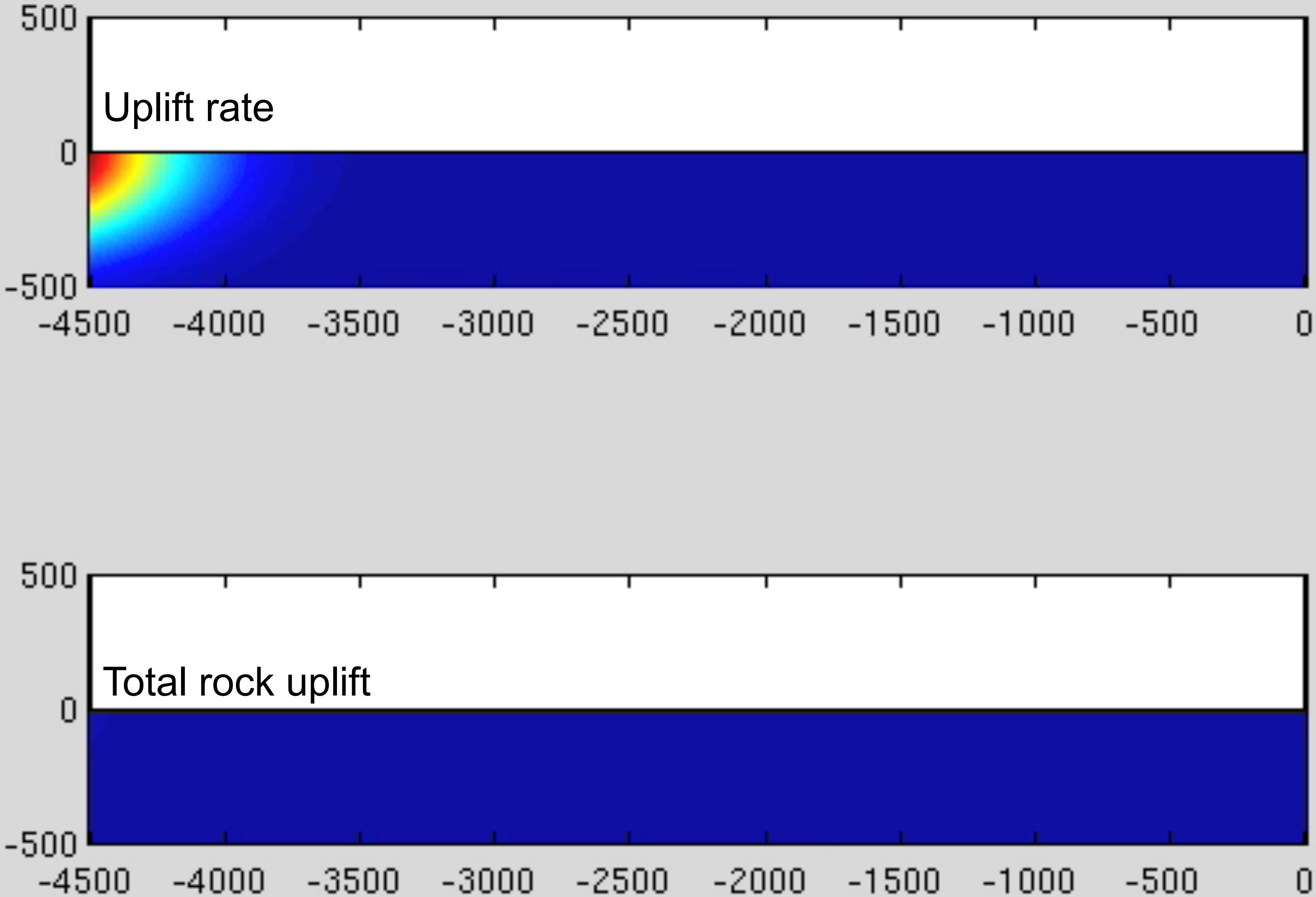
08.10.c2 Carrizo Plain, CA



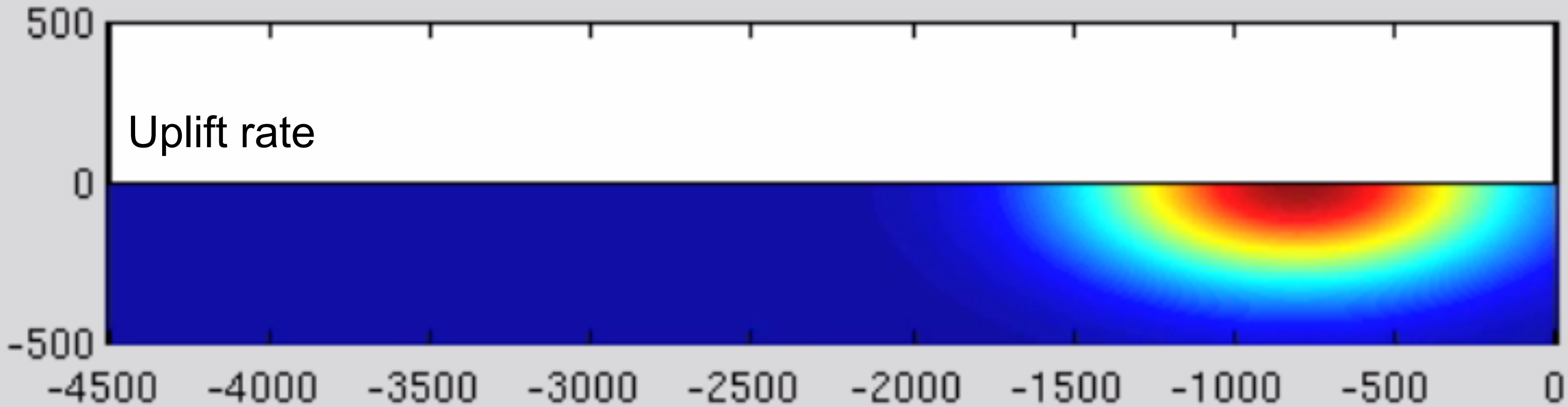
◀ Faults that are currently active can offset streams, ridges, and other topographic features. The San Andreas fault in central California is the linear feature cutting across drainages in the center of this computer-generated view (looking east). The large offset stream takes a jog as it crosses the fault. Is this fault a left-lateral or right-lateral strike-slip fault? Hint: Imagine you are standing in the streambed on the near side of the fault, and then observe which way the streambed on the opposite side has been displaced relative to you.

Before You Leave This Be Able To

- ✓ Describe or sketch how def and metamorphism occur in continental rifts, rifted cont margins, and mid-ocean rid
- ✓ Describe strike-slip faults, s settings where they occur, a features formed on the land


Uplift rate
500
0
-500
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0
Total rock uplift
500
0
-500
-4500
-4000
-3500
-3000
-2500
-2000
-1500
-1000
-500
0

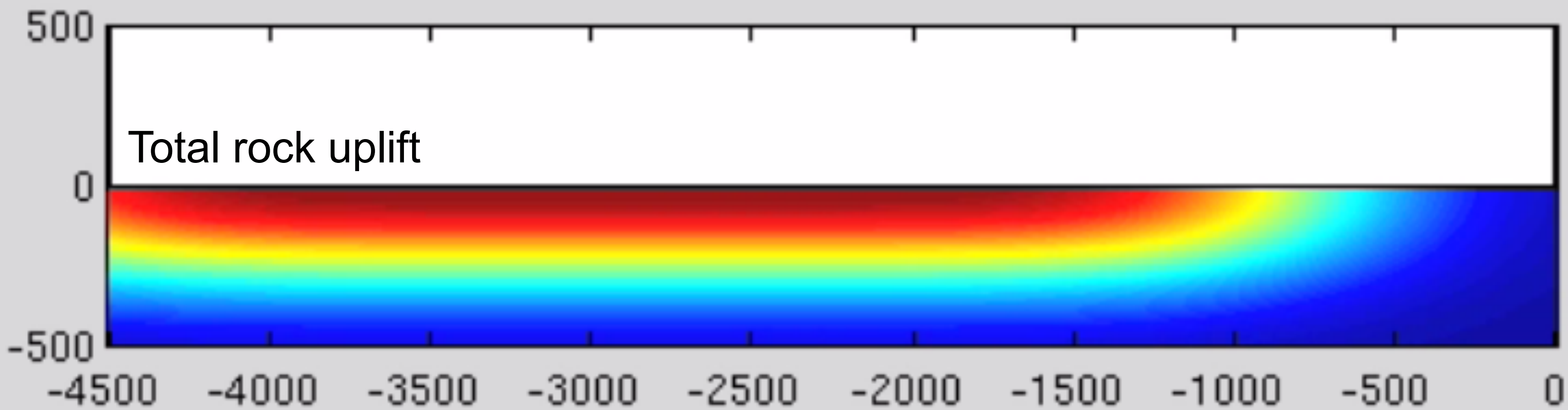
Understanding geomorphic response to uplift



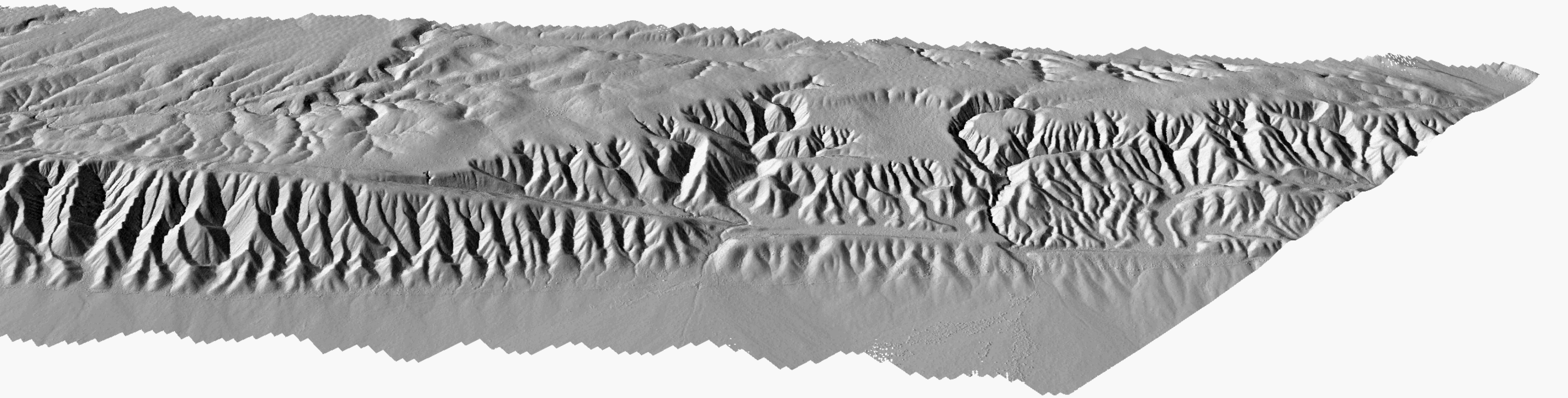
Material moves along fault though relatively stationary uplift zone:

How does landscape respond?

What will the landscape tell us about the geometry of the uplift?

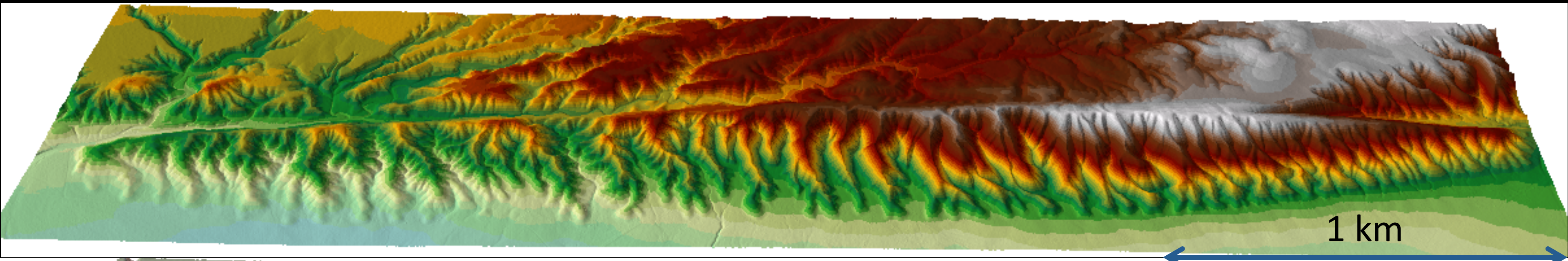


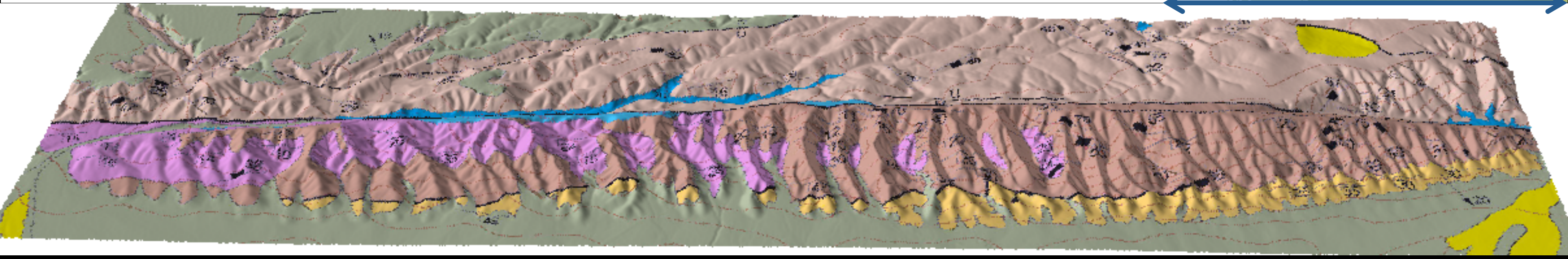
-G. E. Hilley

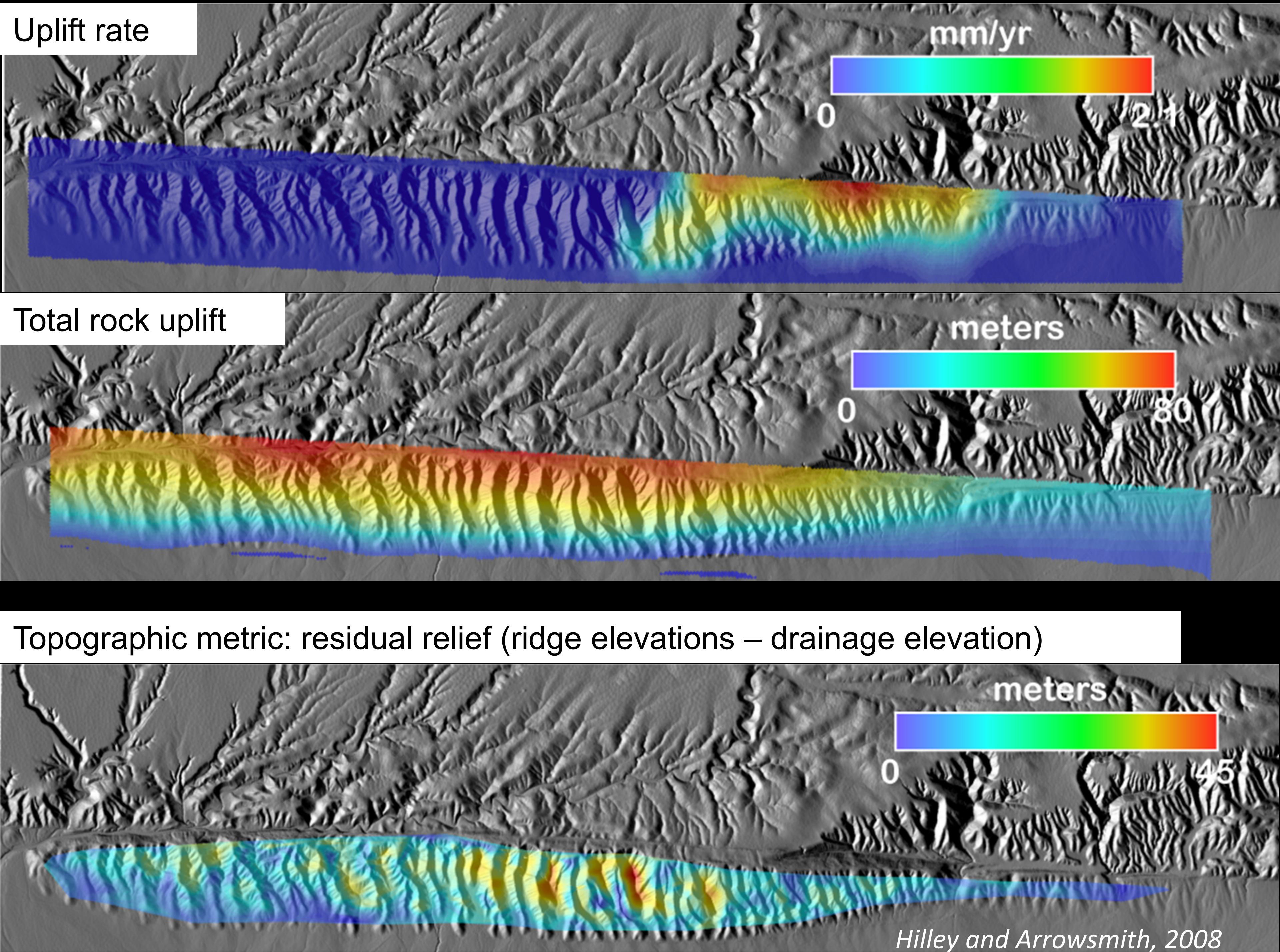


Dragon’s Back Pressure Ridge, Carrizo Plain California

Arrowsmith, 1995; Hilley, 2001; Hilley and Arrowsmith, 2008





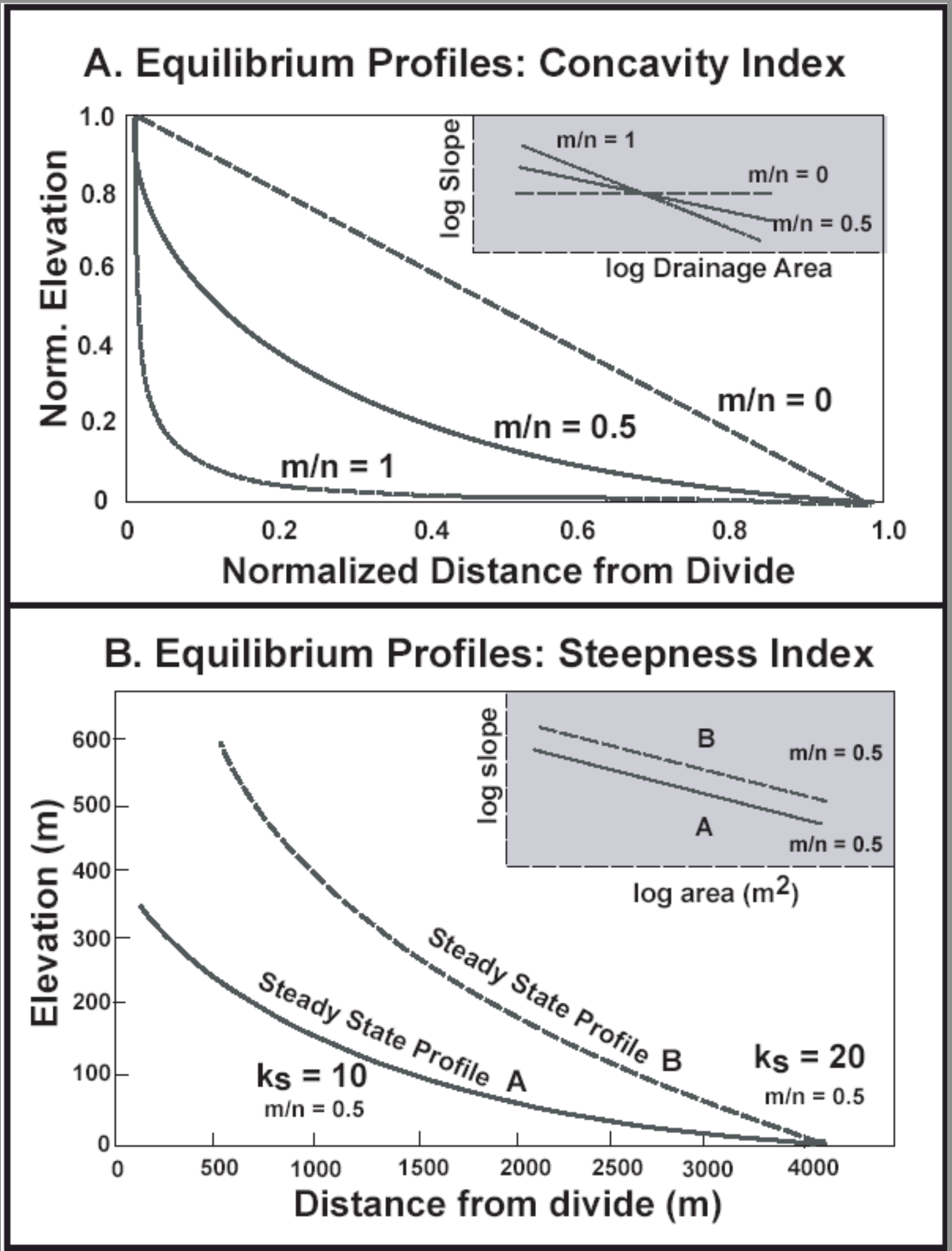

Uplift rate
mm/yr
0
2.1
Total rock uplift
meters
0
80
Topographic metric: residual relief (ridge elevations – drainage elevation)
meters
0
45
Hilley and Arrowsmith, 2008

Duvall, Kirby, and Burbank, 2004, JGR-ES

U = Rock Uplift Rate

Concavity (θ) invariant with U

Steepness (Ks) varies with U

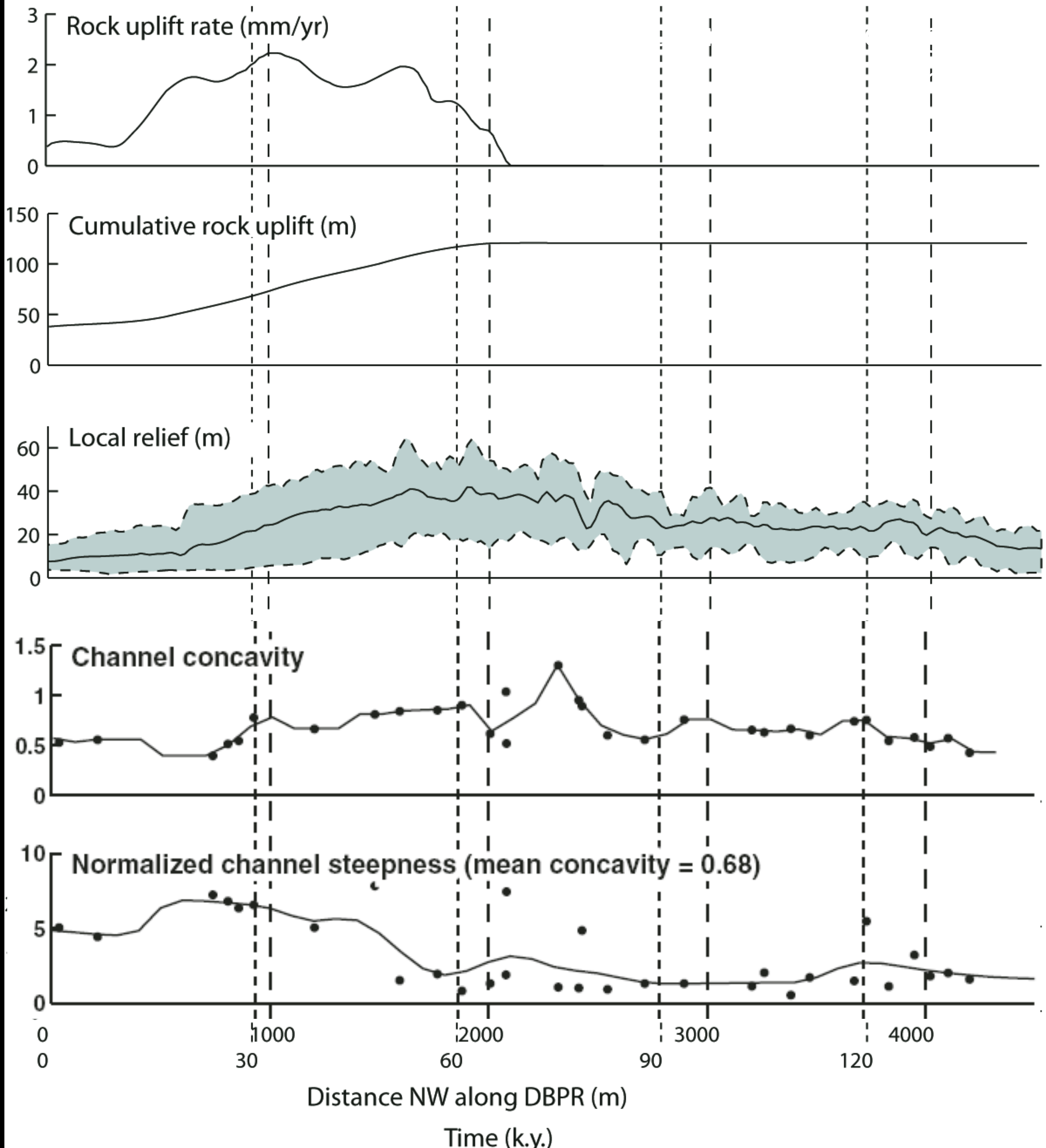


$\theta = m/n$

$S = k_s A^{-\theta}$

k_s

--K. X Whipple



Hilley and Arrowsmith, 2008