The Contour Connection Method: an Automated Algorithm for Detecting Landslide Deposits with Lidar

Ben A. Leshchinsky, Assistant Professor, Oregon State University
Michael J. Olsen, Assistant Professor, Oregon State University
Burak F. Tanyu, Assistant Professor, George Mason University

Background

- The Pacific Northwest is significantly prone to slope failures due to heavy rainfall and geology.
- Often, landslide deposits are not easy to find due to heavy vegetation and canopy cover.
- These landslides have a range in size, but some are enormous and their consequences grim.

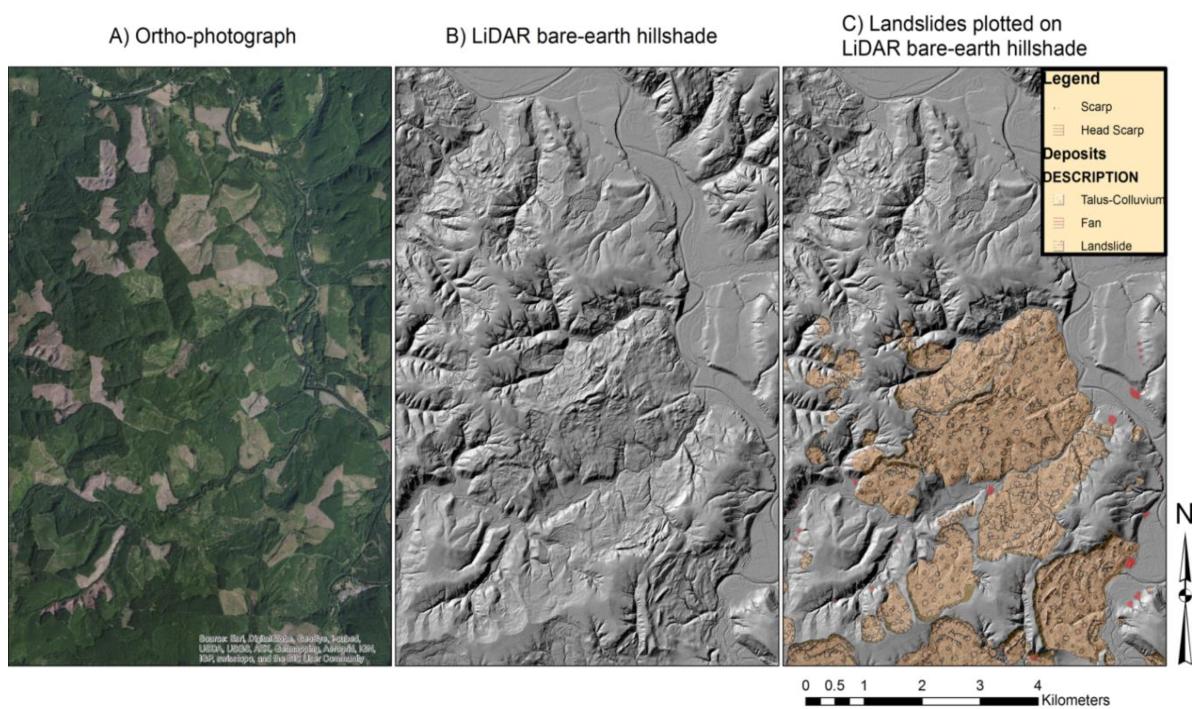
Landslide Hazard Mapping

- Oregon is one of the first states to develop a landslide inventorying program targeting landslide mapping of the entire state
- The resulting database, SLIDO, is openly available over the web, and serves as a useful resource for land management, risk assessment and much more.
- This process has been expedited by the development of a remote sensing tool: **<u>lidar</u>.**

What is Lidar?

- Light Detection and Ranging Technology has developed rapidly in the past years as remote sensing technique
- Airborne (planes, helicopter, UAV), terrestrial (tripod, vehicular)
- Provides digital elevation model (DEM) of terrain, can be processed to remove tree canopy and expose bare terrain

Quantum Spatial (Watershed Sciences) Oregon LIDAR Consortium, & DOGAMI



Inventory \ Susceptibility Mapping Techniques

- Field Mapping
- Manual digitizing
- Statistical \ Machine Learning
- Combination with another sensor
  - hyperspectral

Data Courtesy of Quantum Spatial (Watershed Sciences) Oregon LIDAR Consortium, & DOGAMI

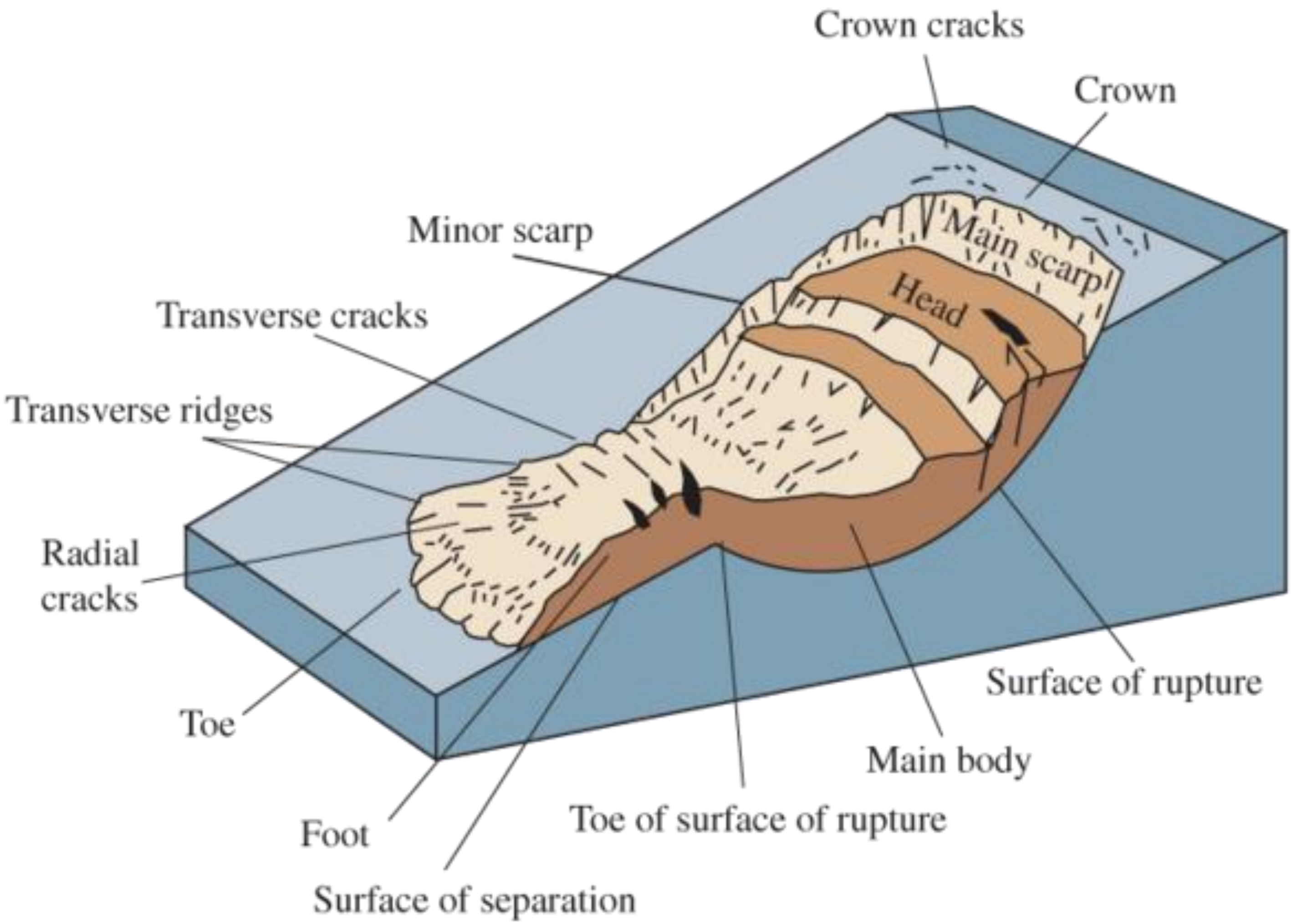
How can we use LiDAR to detect Landslide Prone Areas?

- Landslides tend to occur in places where they have in the past due to:
  - Weathering
  - Progressive Slope Failures
  - Destabilization from:
    - Erosion
    - Construction (Highway cuts, urbanization)
- Lidar gives allows us to see beneath the tree canopy

How do we tell a computer to detect what we can clearly see with a lidar bare earth DEM?

How can we use LiDAR to detect Landslide Prone Areas?

- Let's look at landslide geometry (Source: USGS)

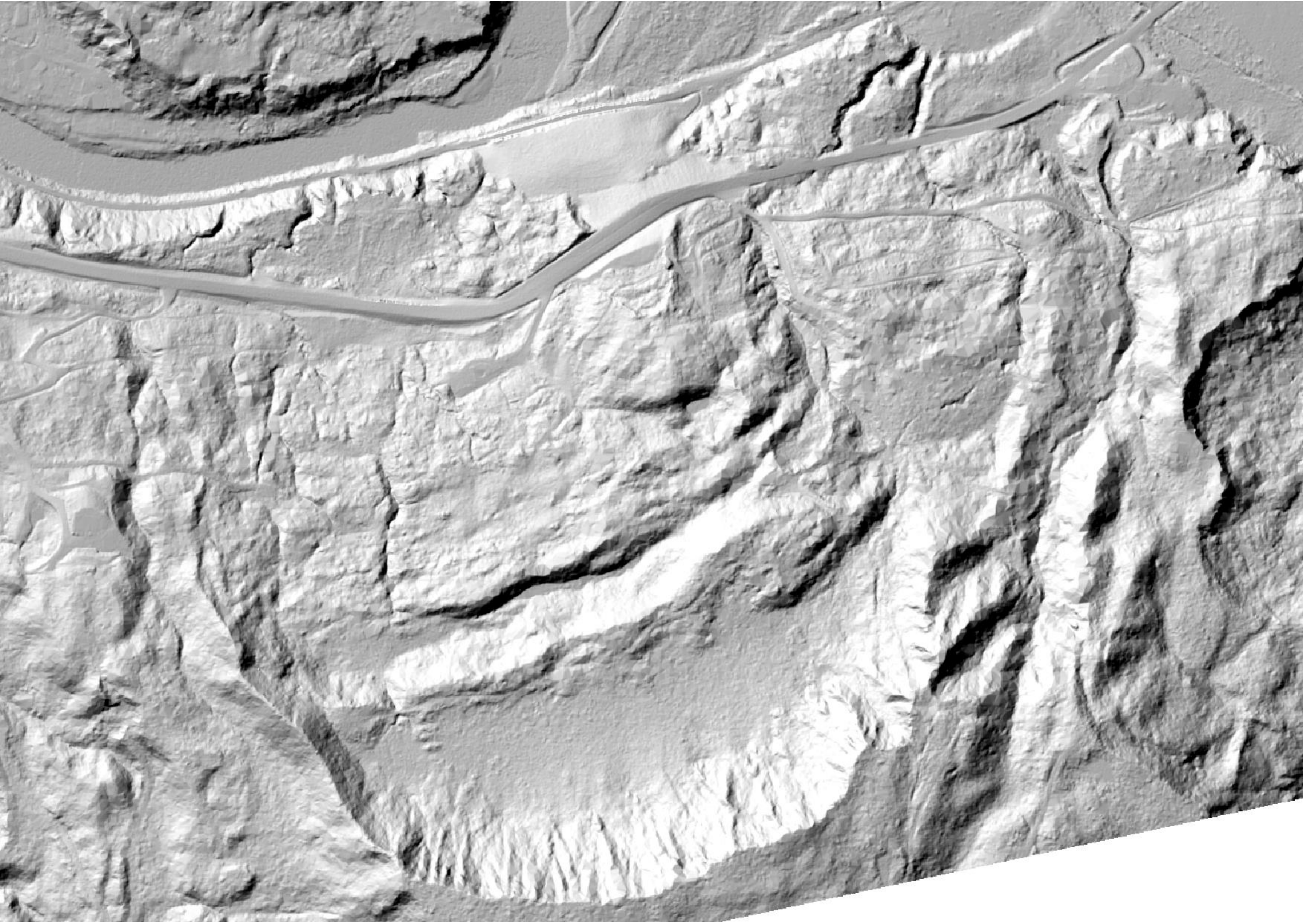


How can we use LiDAR to detect Landslide Prone Areas?

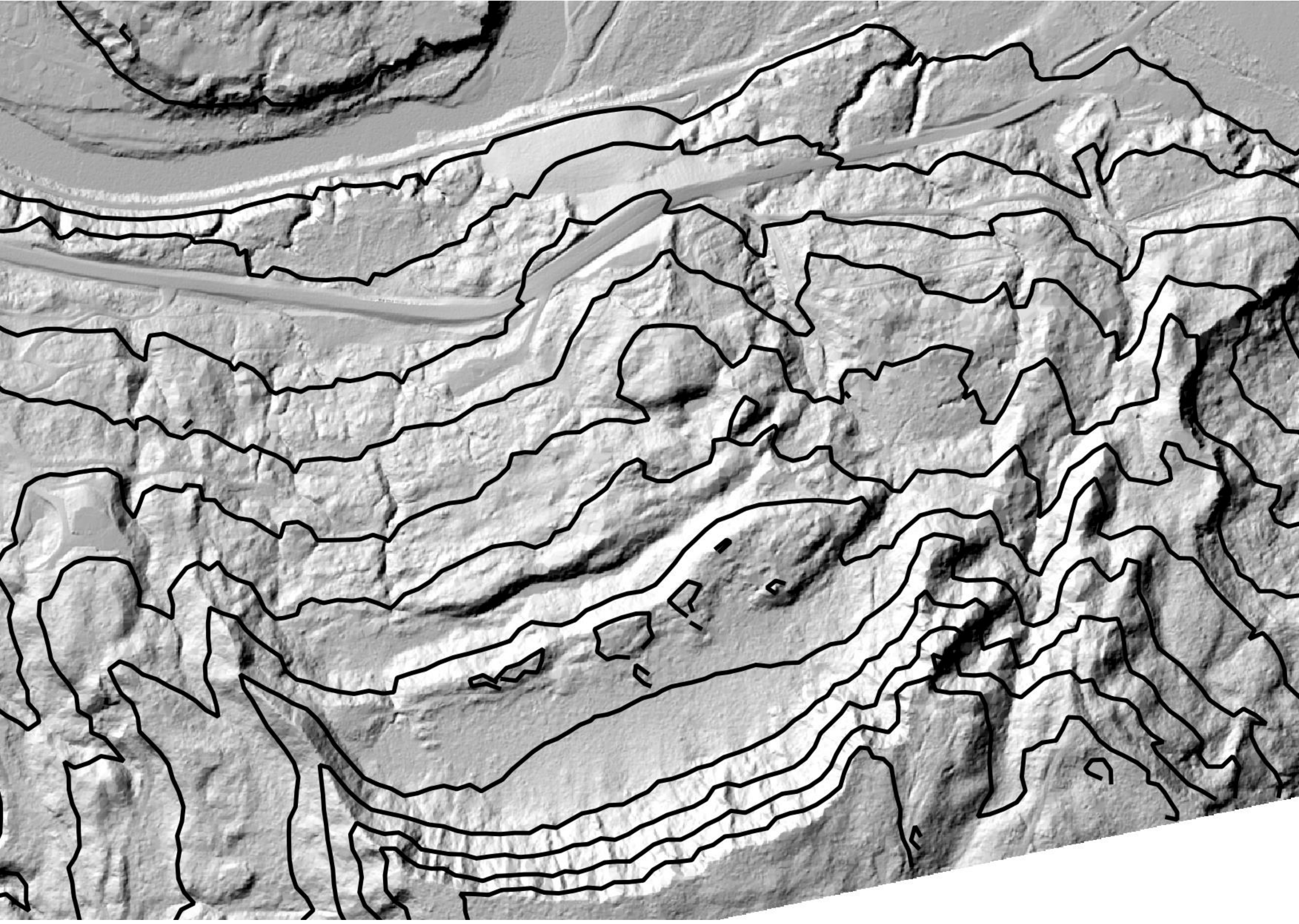
- LiDAR gives us the ability to see scarps, deposits and more underneath vegetation
- Scarps are always steep, followed by more gentle grades beneath (body, toe)

We can use the detection of scarps as a way to initiate hazard mapping, shallowness of deposits as a way to terminate a search.

This is the basis for the Contour Connection Method (CCM).

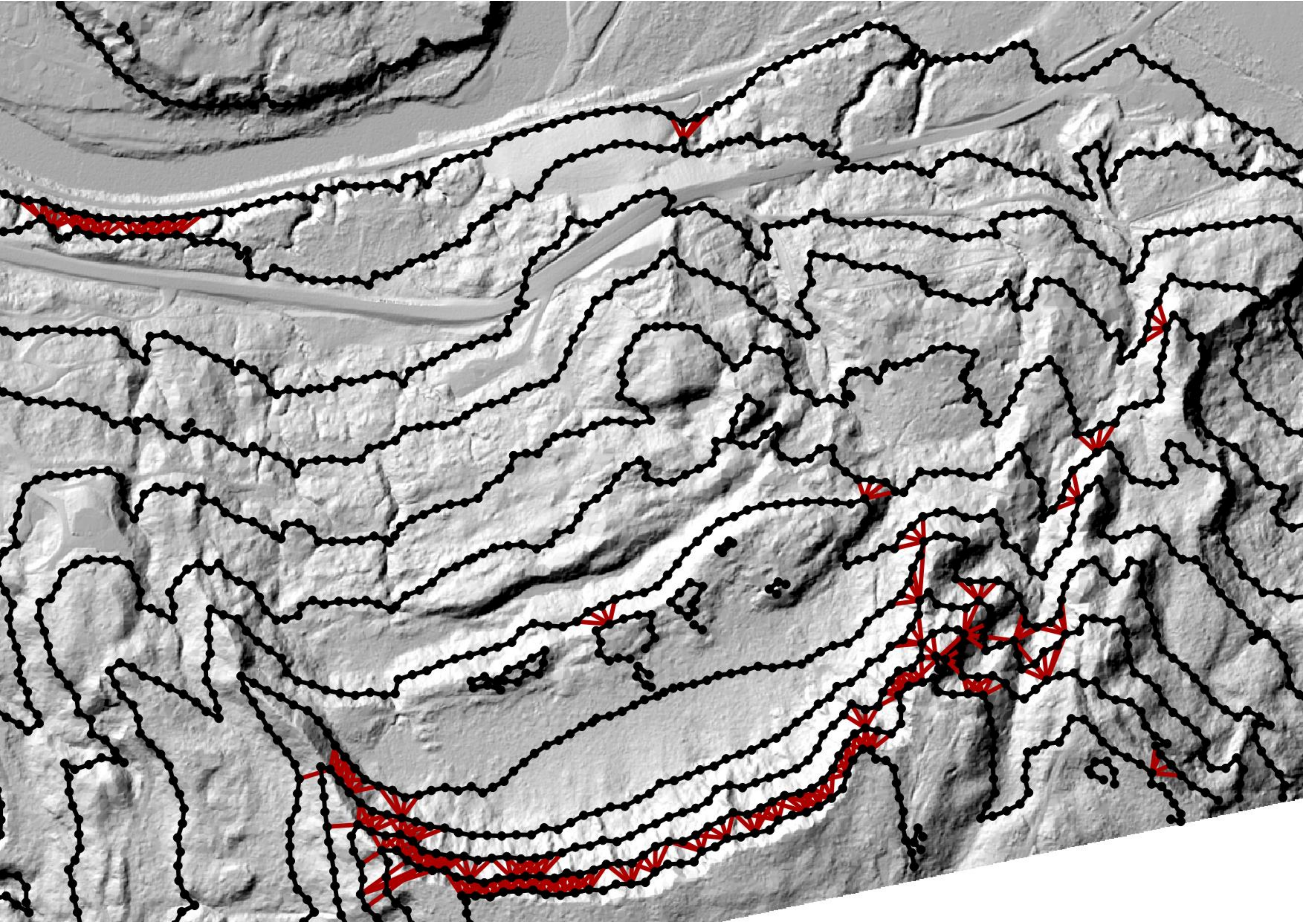


Credit: Puget Sound LIDAR Consortium / Quantum Spatial

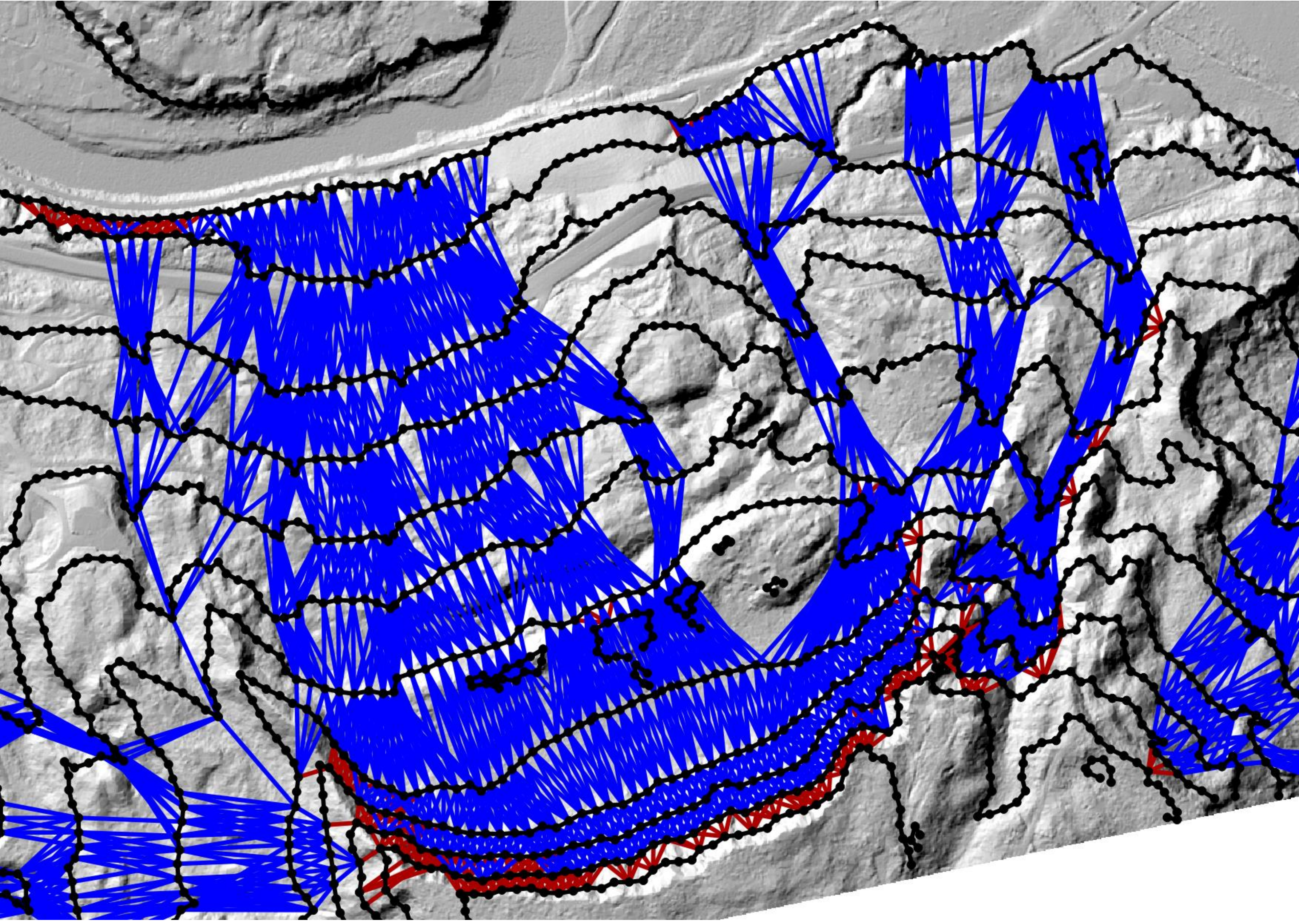


Credit: Puget Sound LIDAR Consortium / Quantum Spatial

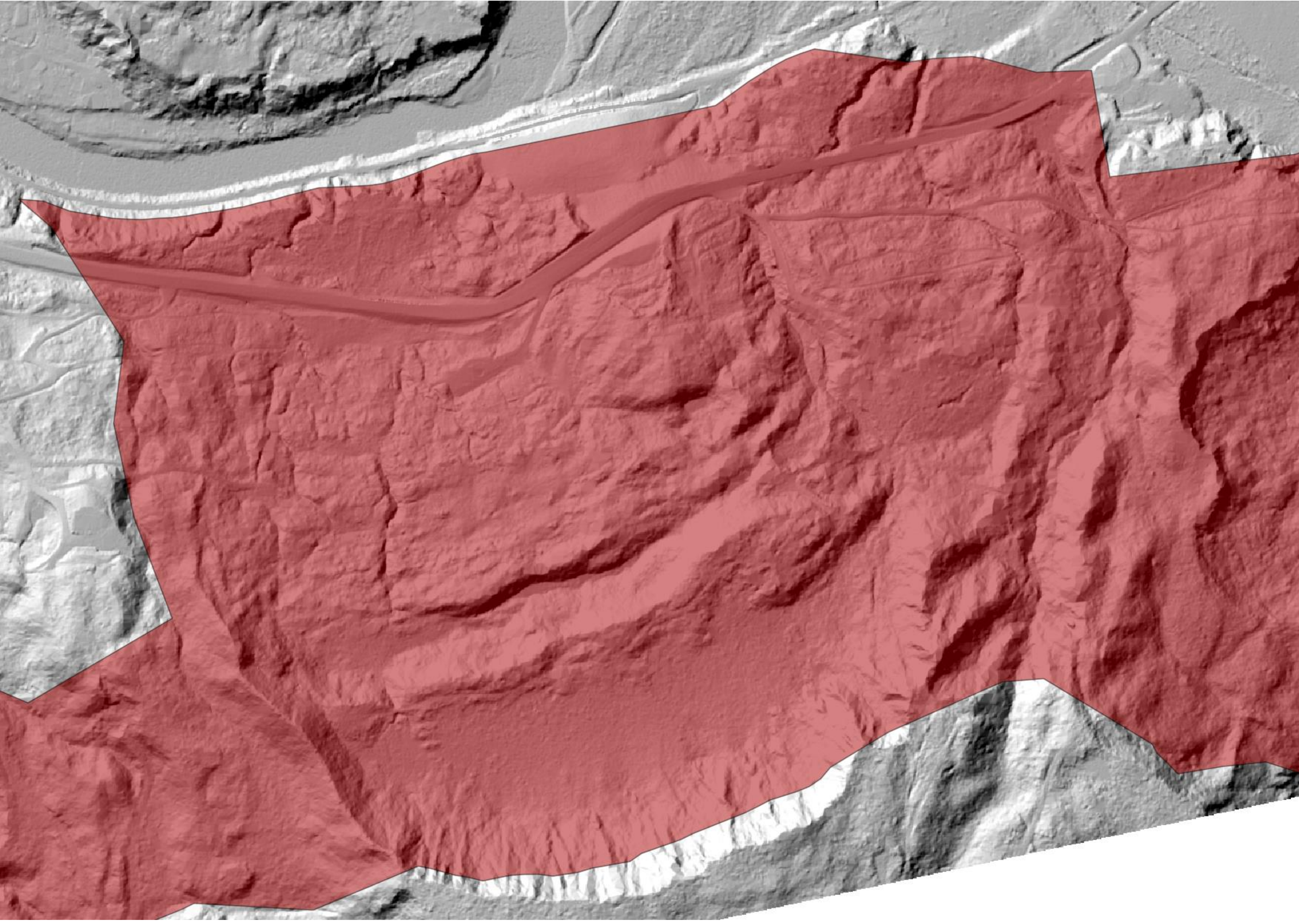
Credit: Puget Sound LIDAR Consortium / Quantum Spatial



Credit: Puget Sound LIDAR Consortium / Quantum Spatial



Credit: Puget Sound LIDAR Consortium / Quantum Spatial



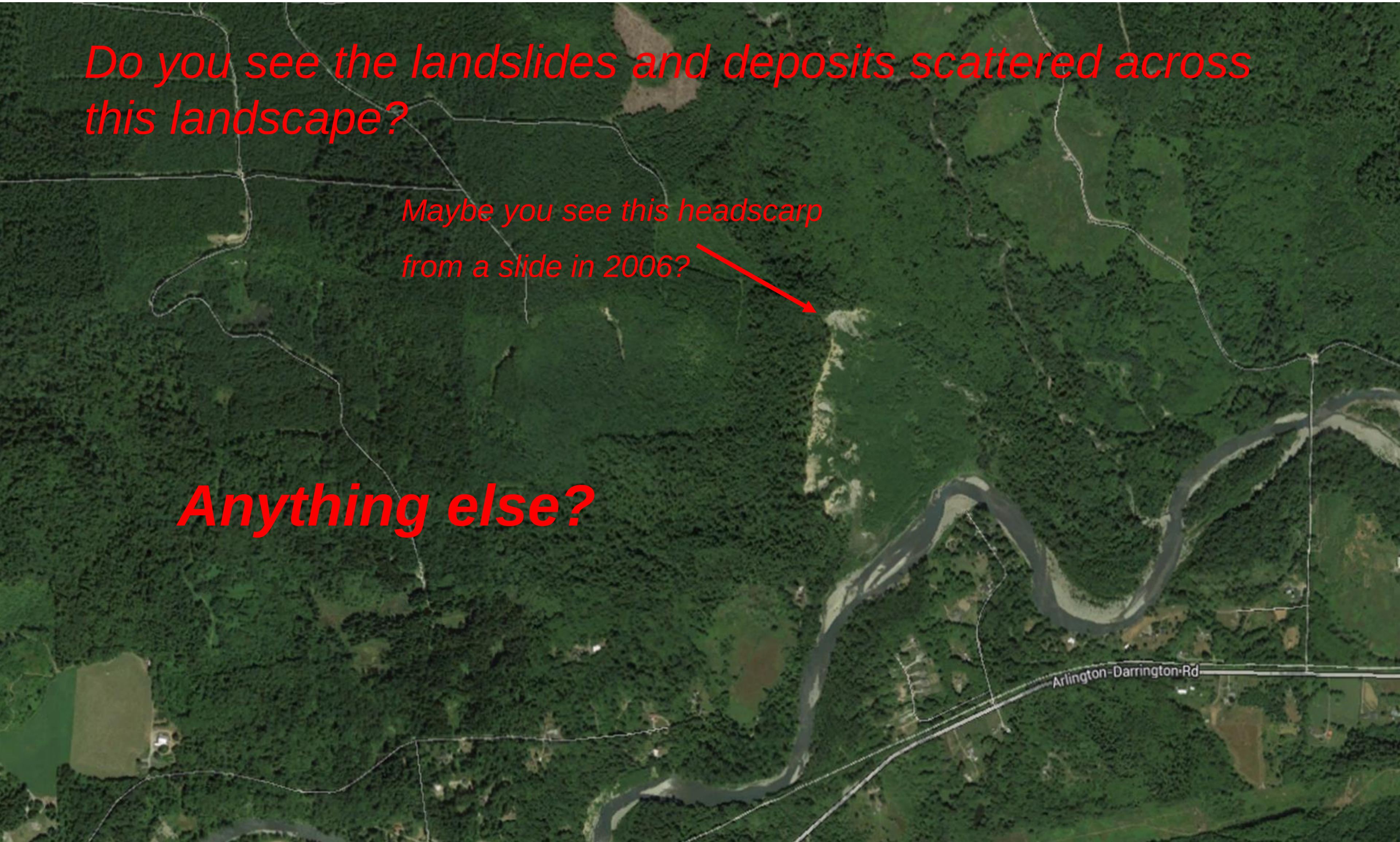
Credit: Puget Sound LIDAR Consortium / Quantum Spatial

Agreement with Manual Inventories

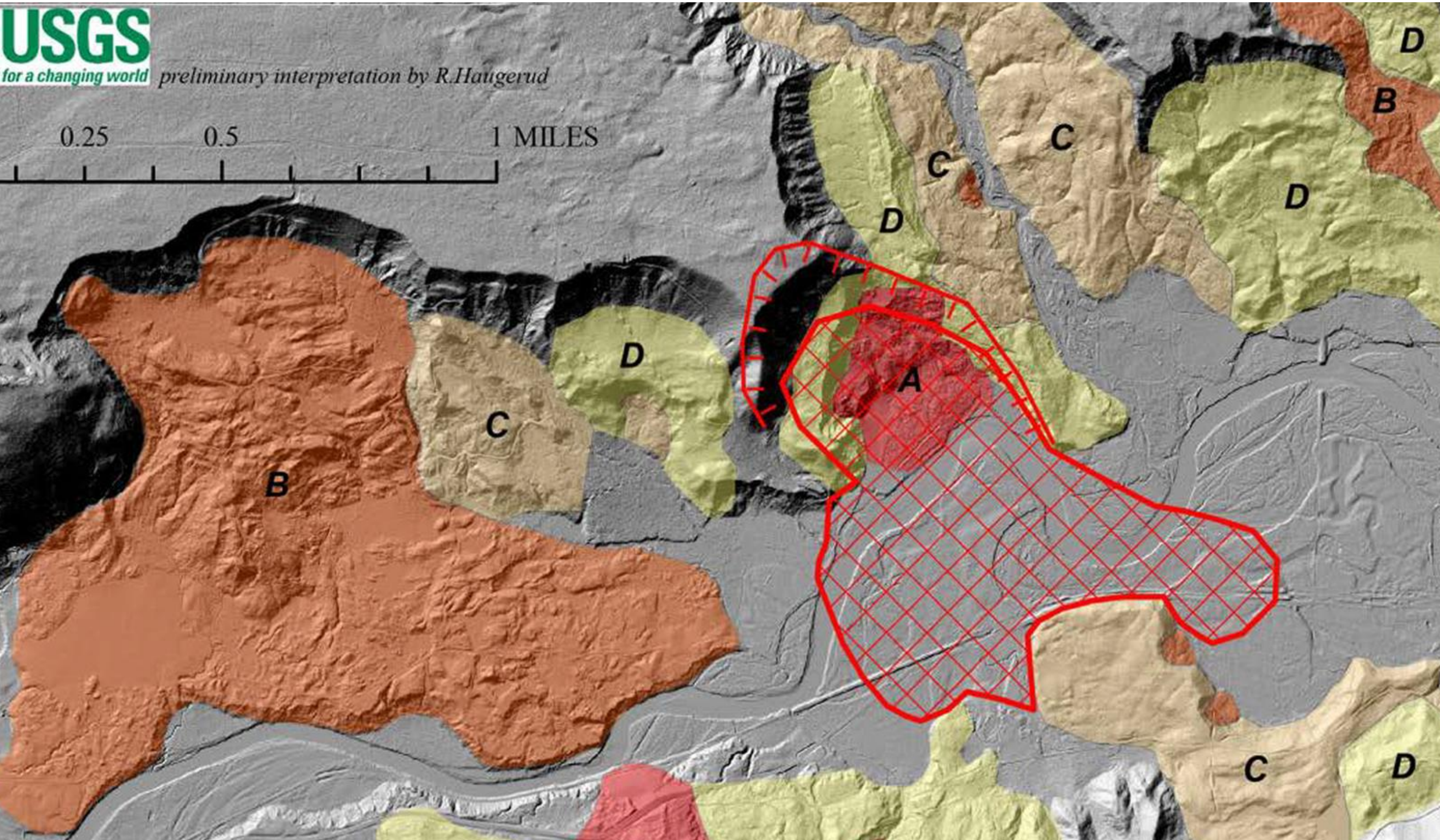
- A comparison was performed with several large-scale landslide inventories
- Three examples:
  - Stillaguamish Valley (WA)
  - Pittsburg Quadrangle (OR)
  - Dixie Mountain Quadrangle (OR)
- Agreement was generally good with manually delineated landslide maps
- Good tool to facilitate rapid mapping of hazards by geologists, other professionals

Satellite Image: Pre-Landslide, Oso, WA

© 2013 Google Images

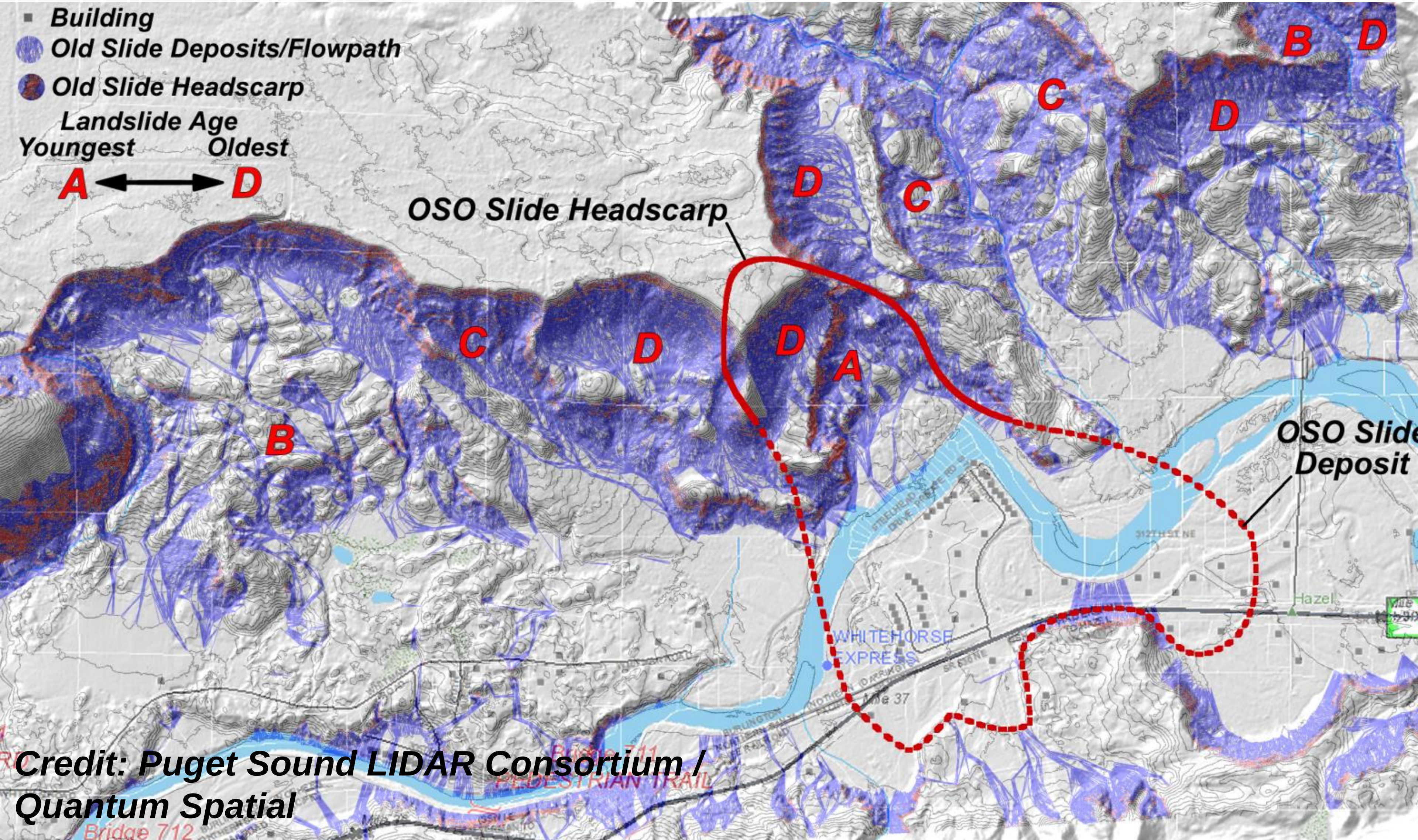


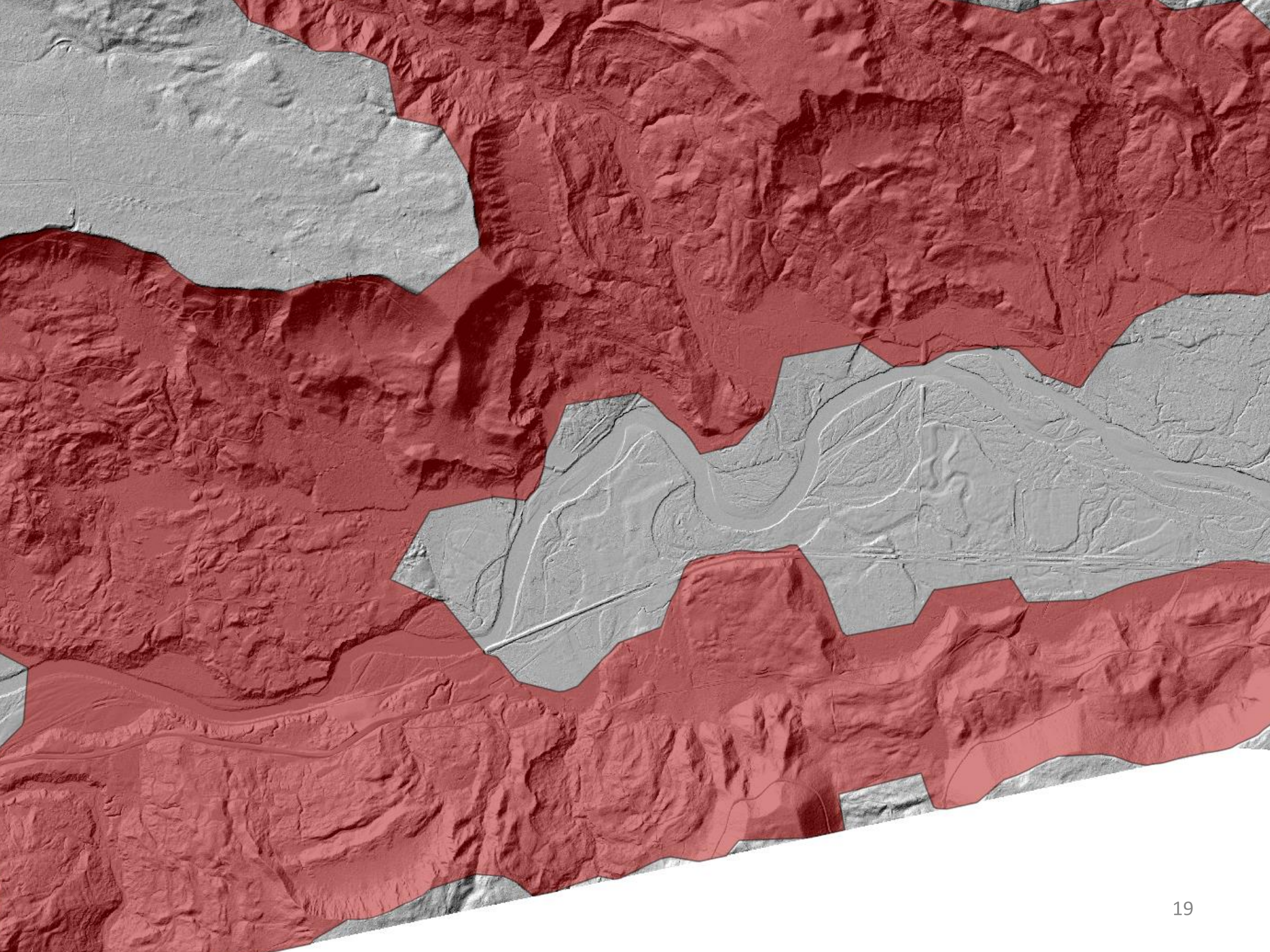
LiDAR Bare Earth Map: Landslide Inventory
Credit: 2014 USGS, R. Haugerud
A – D (youngest – oldest)



CCM Analysis

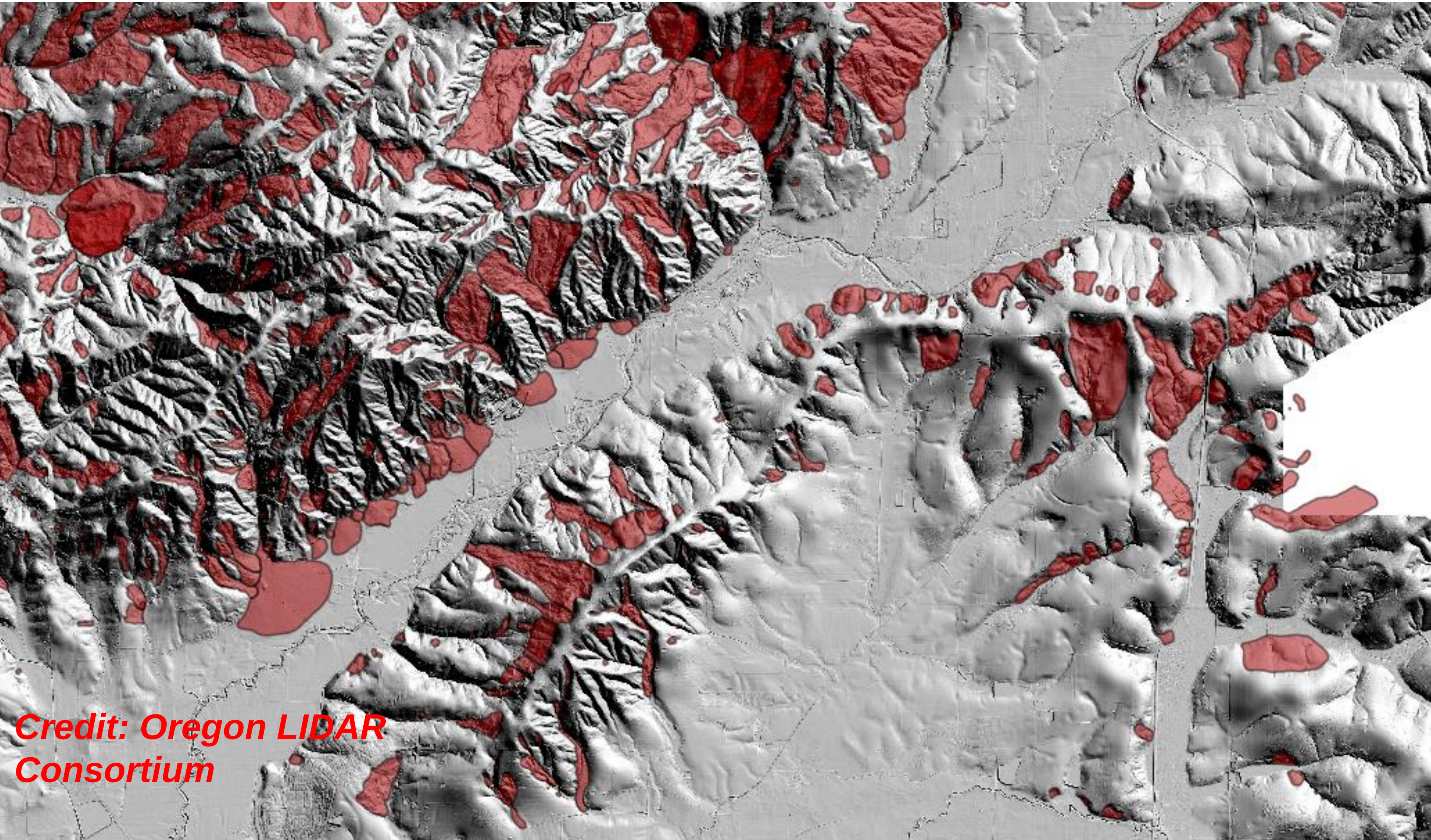
(Highlighted Scarps in Red, Deposits in Blue)





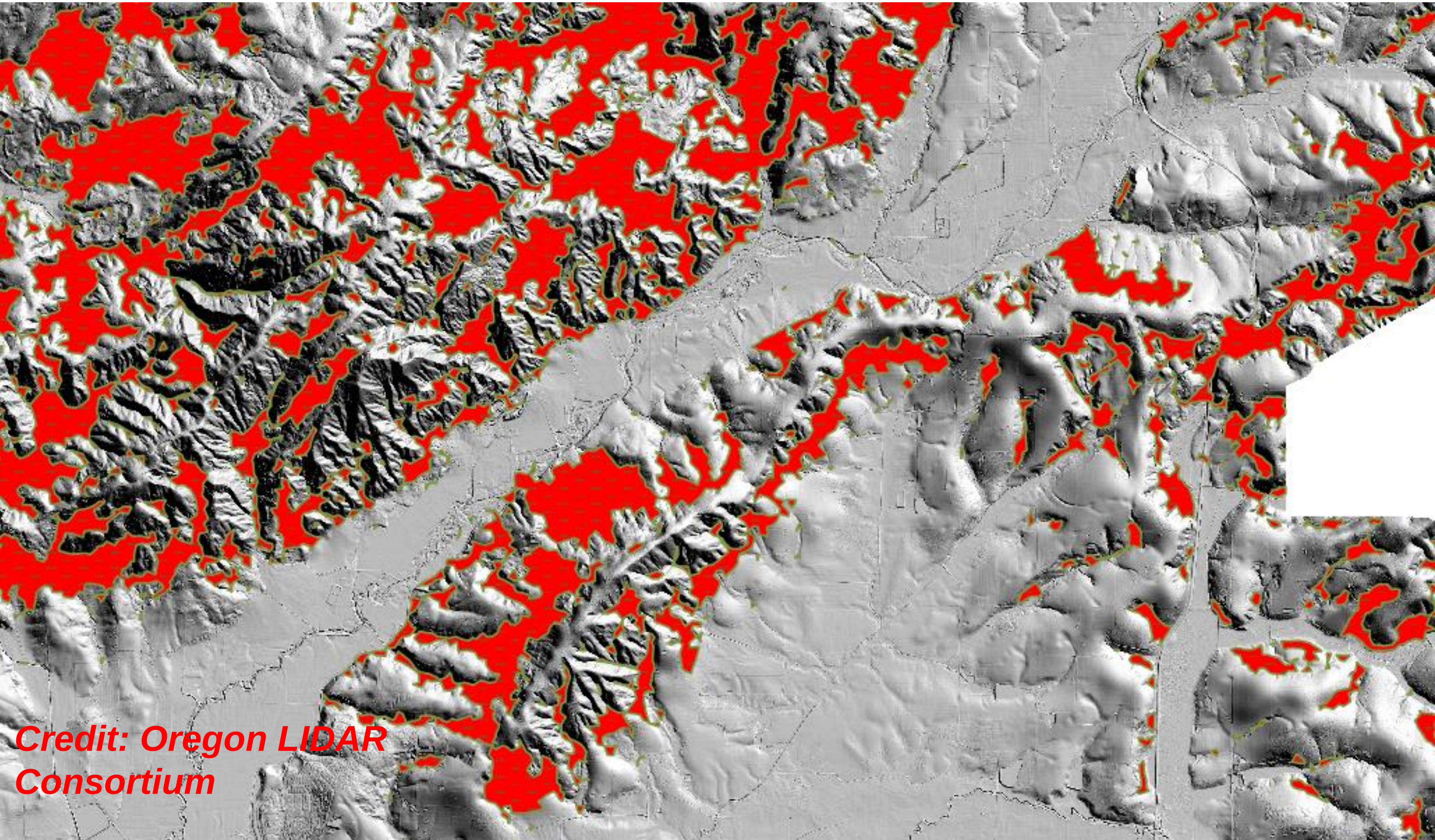
Pittsburg Quadrangle – Geologist Inventory

55 Square Miles, 750 manually inventoried landslides



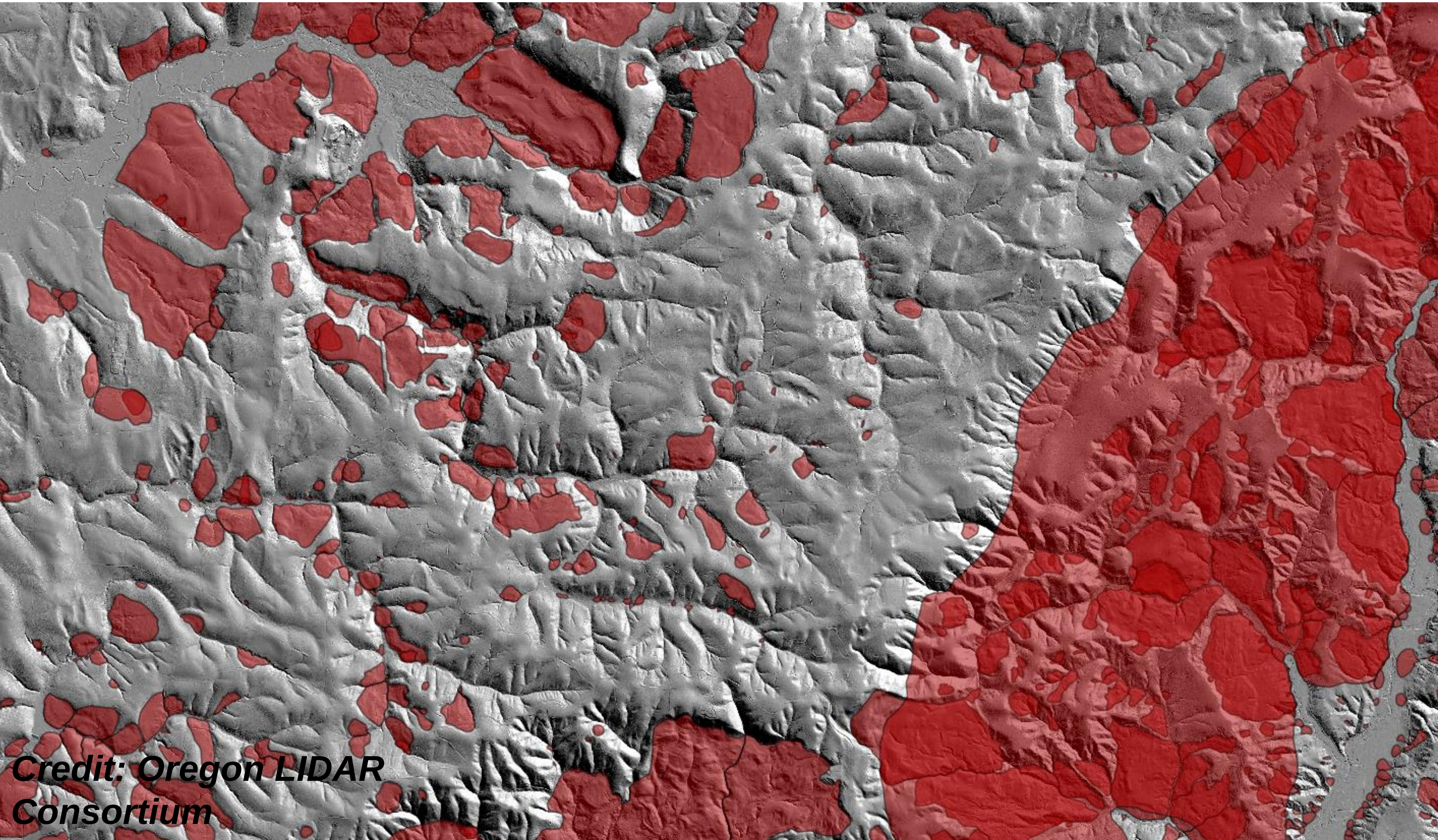
Pittsburg Quadrangle – CCM Inventory

One processor, 20 minutes of analysis, 91% agreement (pixel-pixel)



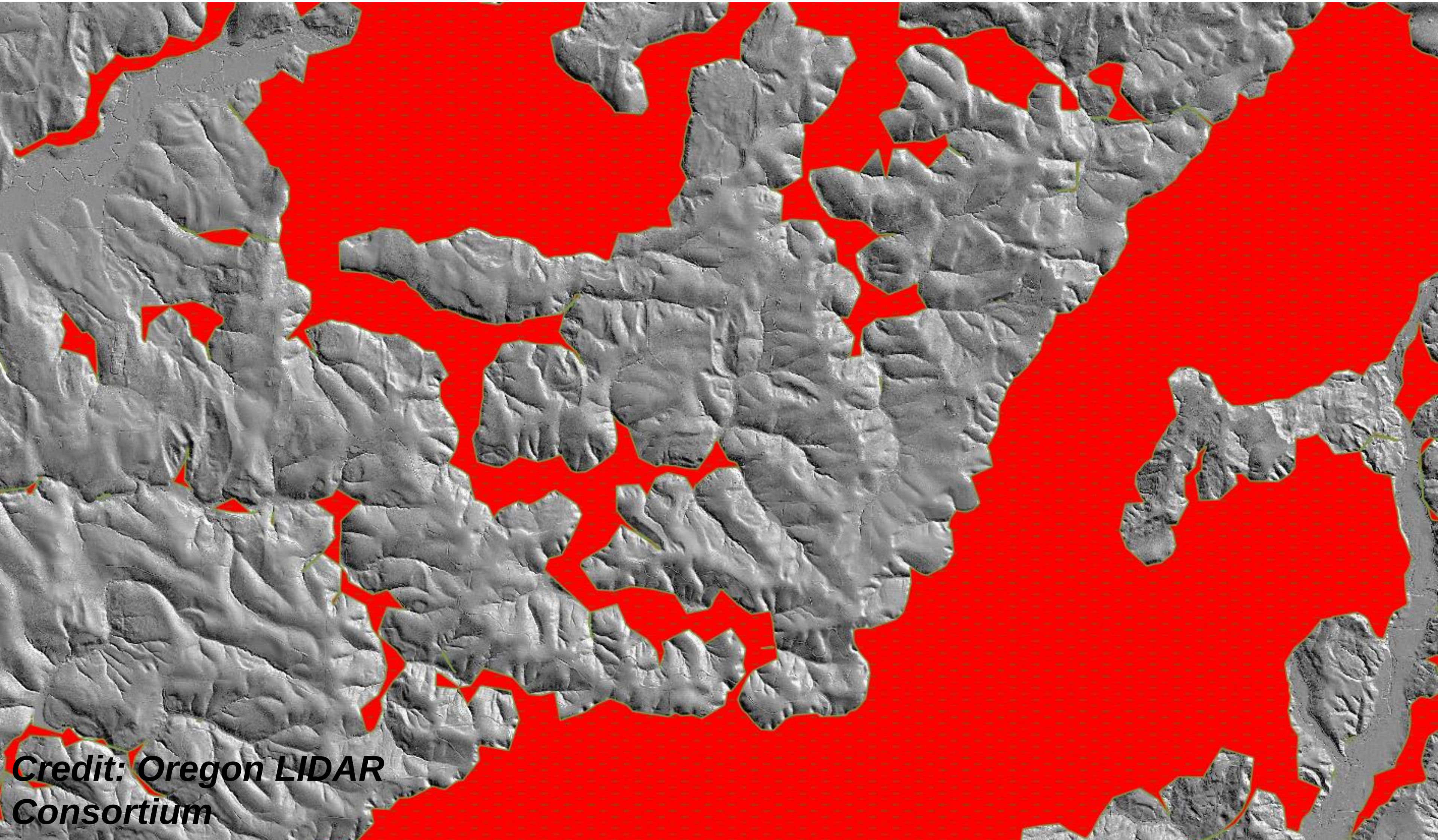
Dixie Mountain – Geologist Inventory

55 Square Miles, over 940 manually inventoried landslides



Dixie Mountain – CCM Inventory

One Processor, 45 Minutes of analysis, 70% agreement (pixel-pixel)



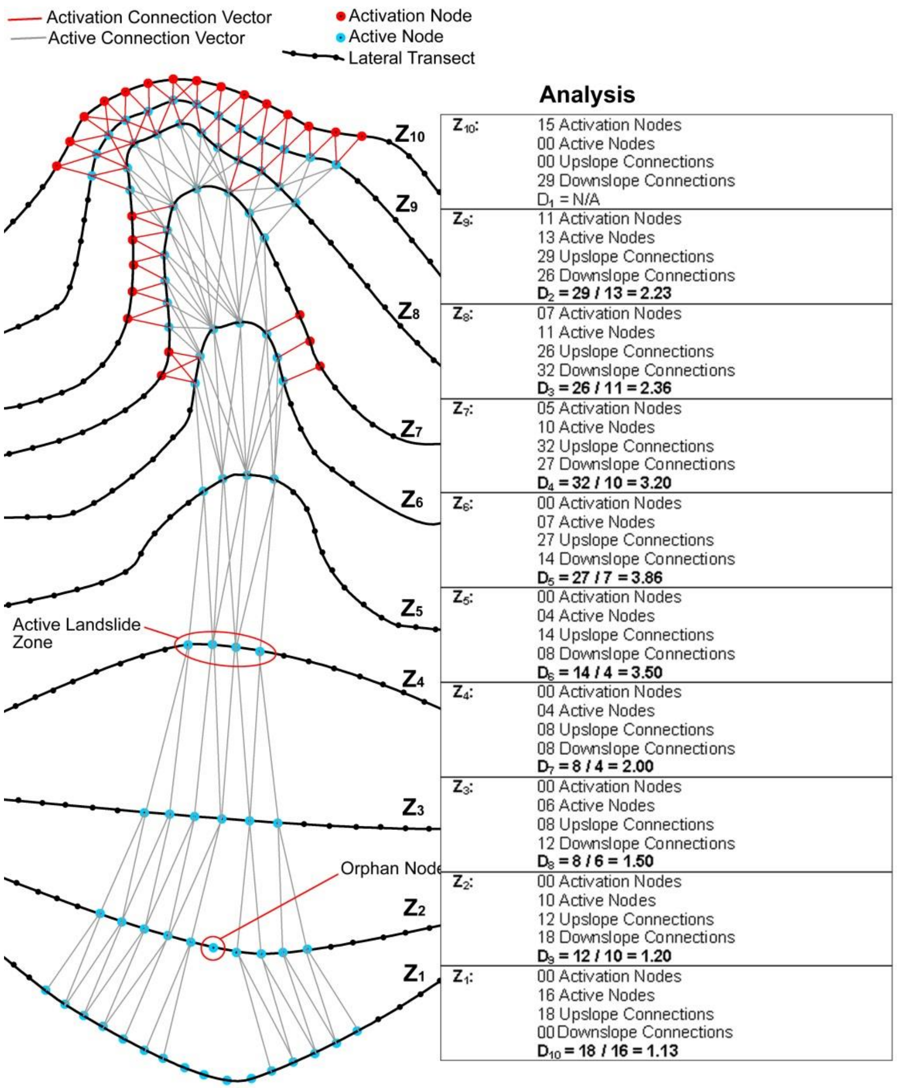
Comparison with Reality

- Generally good agreement, useful as a tool to supplement manual delineation
- Objective, Consistent and Fast

These connections created in the analysis can be used for classification and risk analysis…

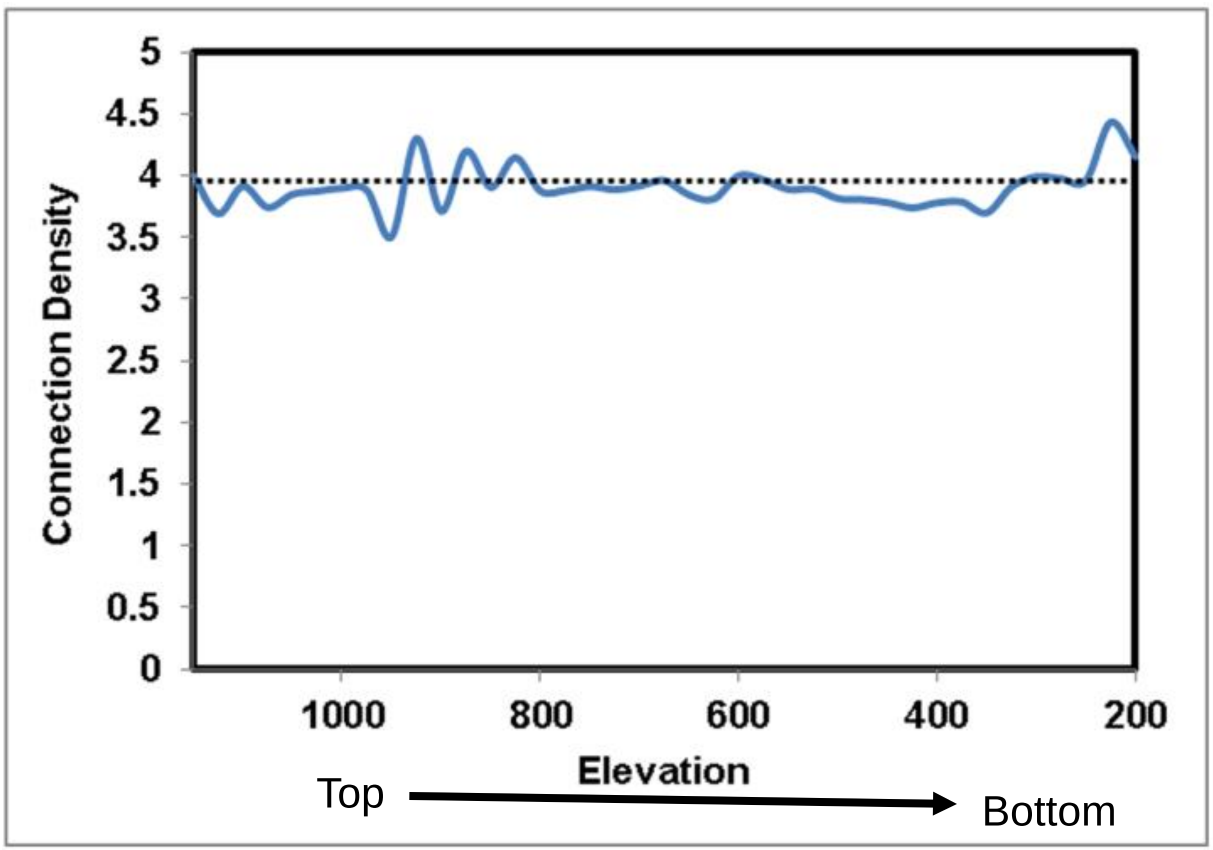
Signatures

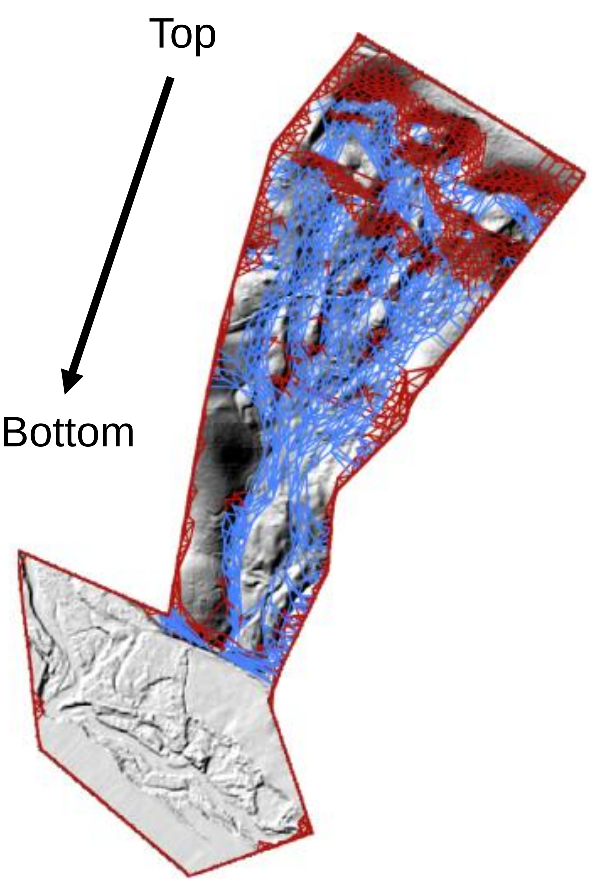
- Density of connections on each layer is indicative of concavity, convexity, roughness
- Change in density over layers yields a unique signature for a given landslide
- Can be used for classification of age, erosion potential, etc.



Signatures – Earth Flow

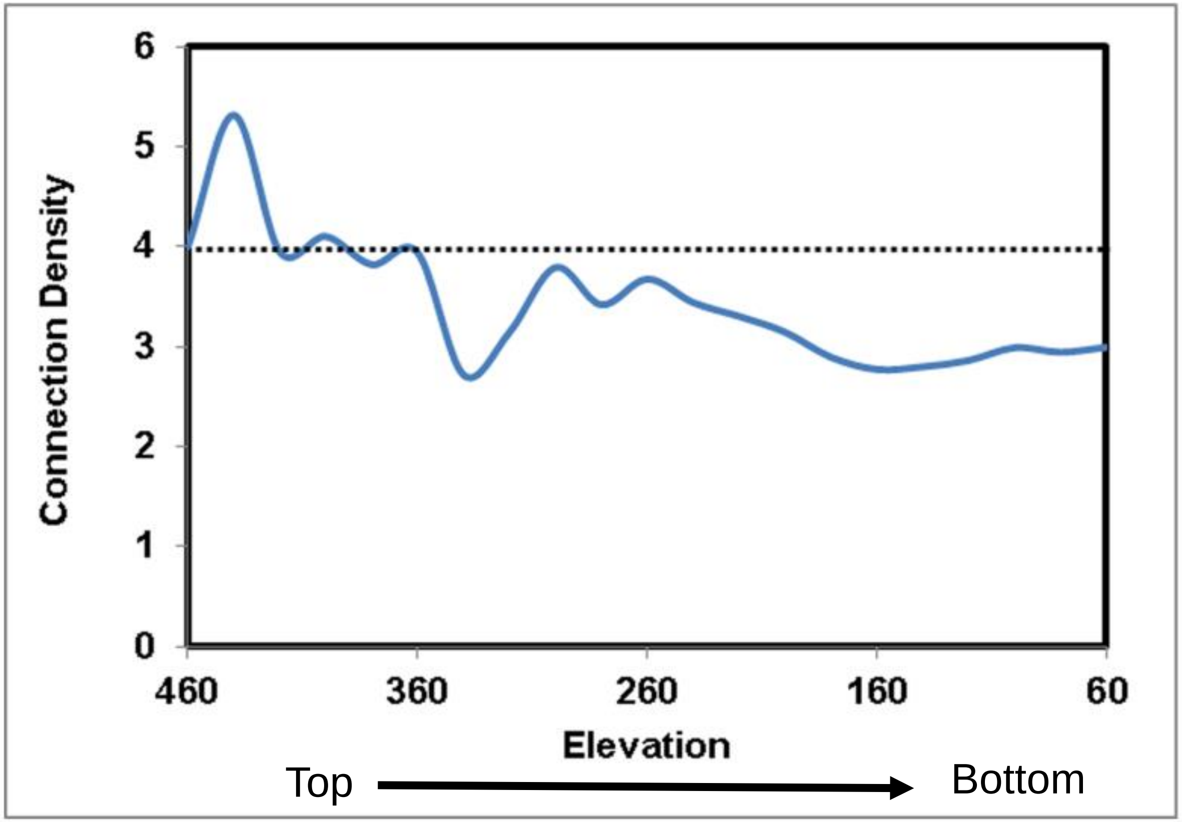
- Little change in convexity/concavity
- Erratic nature implies roughness, i.e. “young” feature

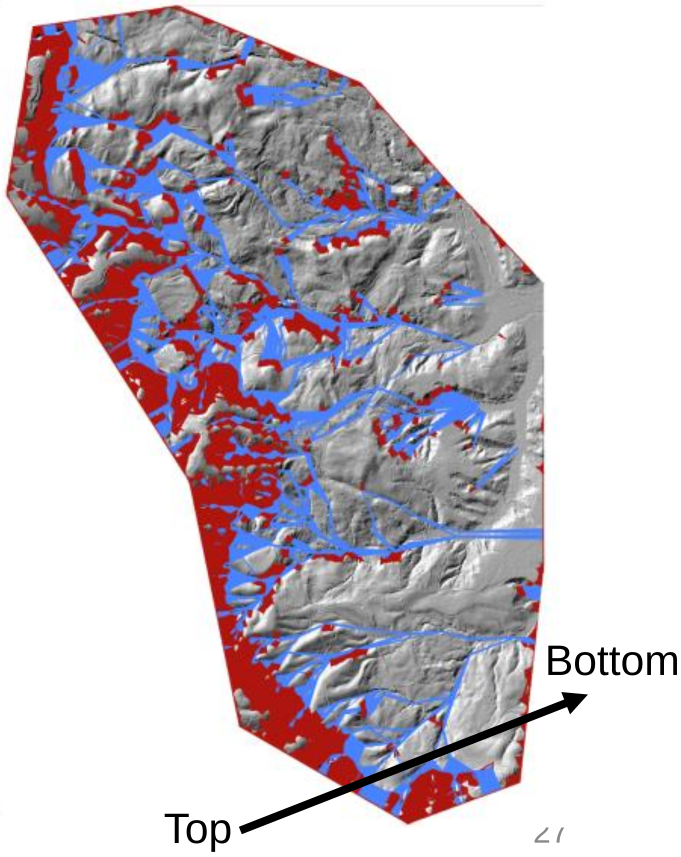




Signatures – Complex

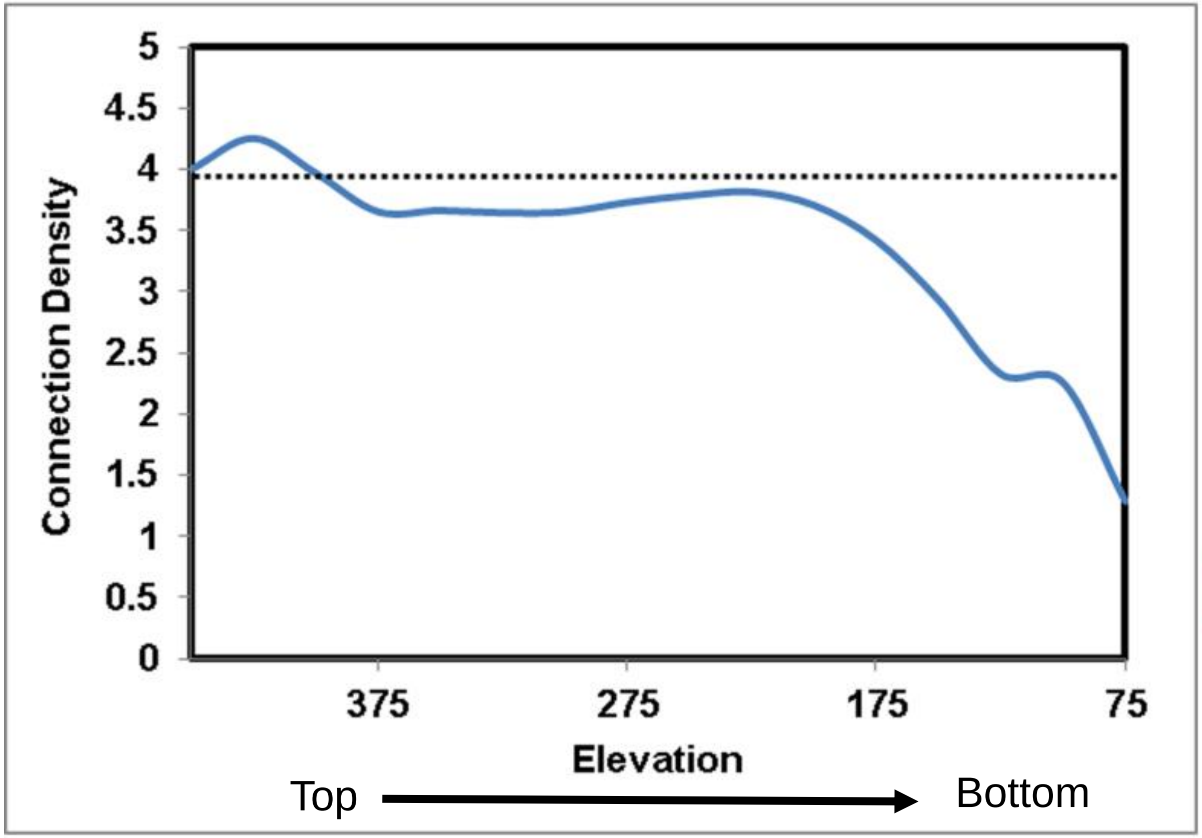
- Initial concave behavior, outward flow at base
- Again erratic nature implies “young” feature

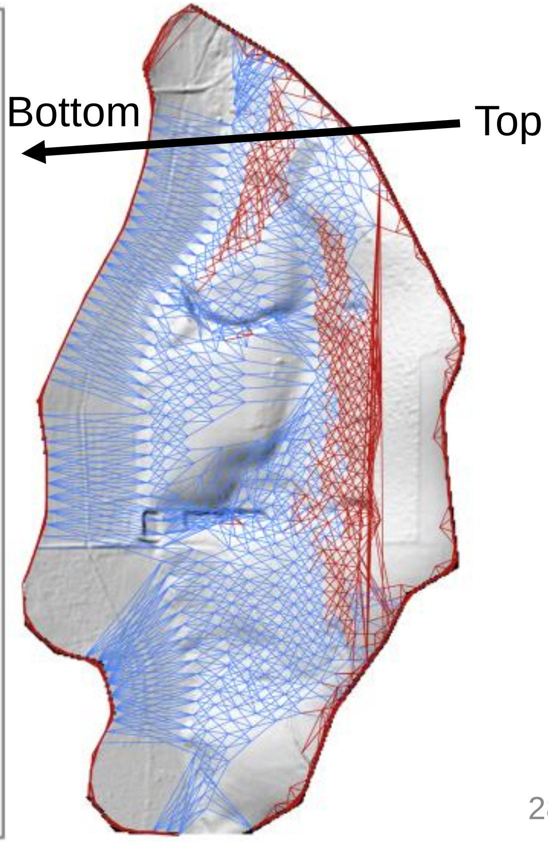




Signatures – Slide

- Initial concavity followed by convexity suggests outward flow, typically associate with slides
- Smooth nature suggests an older feature





Signatures

- These signatures could potentially be associated with classifying landslide types, associated hazards/risks, and other relevant topics including:
  - Mitigation techniques
  - Cost of construction/risk/insurance
  - Erosion risks
- This presents a consistent, objective and <u>quantitative</u> means of classifying landslides

Current Constraints and Future Work

- Yields false positives because search begins with steep terrain
- Soil strength, rock strength, fault orientation
- Reliability-based analyses
- GIS data/layers for added input (geology, roads, soil, streams, springs, etc.)
- Requires minimal user input and experience

Conclusions

- Lidar is an excellent tool for surveying and mapping landslides on a landscape scale
- The US will continue to be mapped using lidar, especially near highways, infrastructure and populated regions, providing usable terrain data for analysis
- CCM presents a simple algorithmic approach to mapping hazards and classifying landslides, <u>*can be used with judgment from trained geologists*</u>

Classifying these hazards consistently and objectively has implications for assessing <u>land use</u>, hazard <u>mitigation</u>, and landslide <u>policy</u> and on a **landscape** scale.

QUESTIONS?