# Basin and Range Province Seismic Hazards Summit III

## Utah Geological Survey and Western States Seismic Policy Council

# Short Course Presentations

Characterizing Hazardous Faults – Techniques, Data Needs, and Analysis: *Steve Bowman, Utah Geological Survey*

West Valley Fault Zone, Baileys Lake Site: Fault Trenching on the Basin Floor: *Michael Hylland, Utah Geological Survey*

Using Agisoft PhotoScan Professional to Create High-Resolution Trench Logs: *Adam Hiscock, Utah Geological Survey*

New Surficial Geologic Mapping Redefines the Northernmost Sections of the Washington Fault Zone in SW Utah and NW Arizona: *Tyler Knudsen, Utah Geological Survey*

User Guide for Luminescence Sampling in Paleoseismic Contexts: *Shannon Mahan, and Harrison Gray, USGS; Michelle Nelson, and Tammy Rittenour, Utah State University*

Using LiDAR to Map Active Faults: *Adam McKean, Utah Geological Survey*

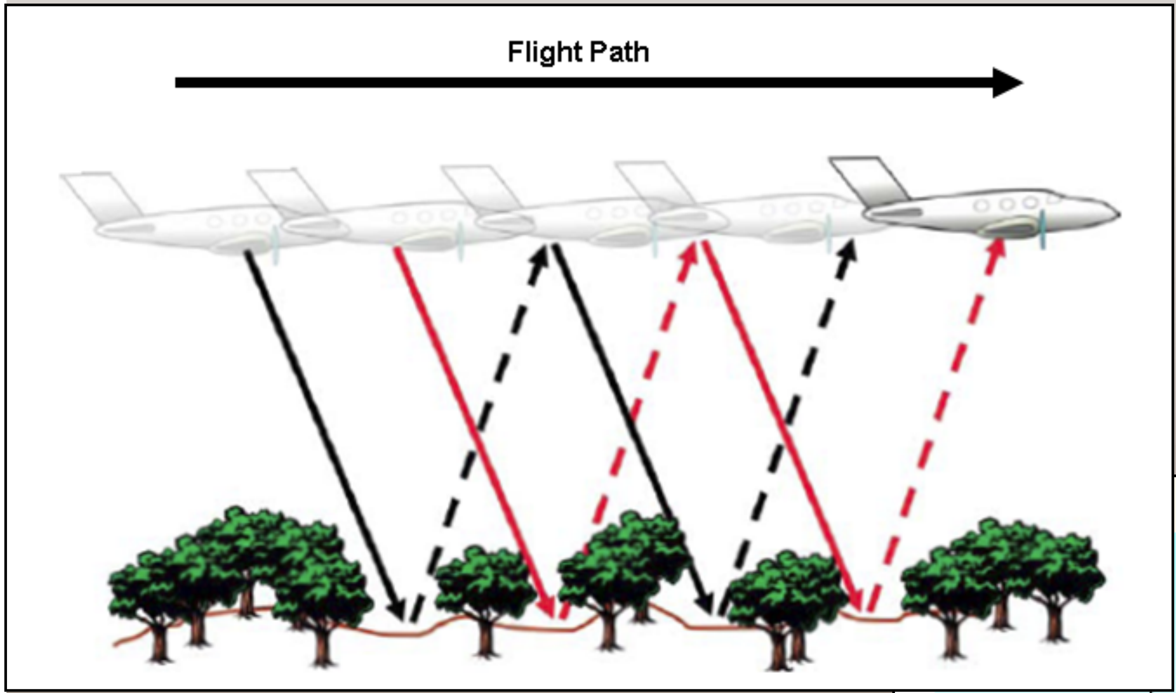
# Short Course: Characterizing Hazardous Faults – Techniques, Data Needs, and Analysis

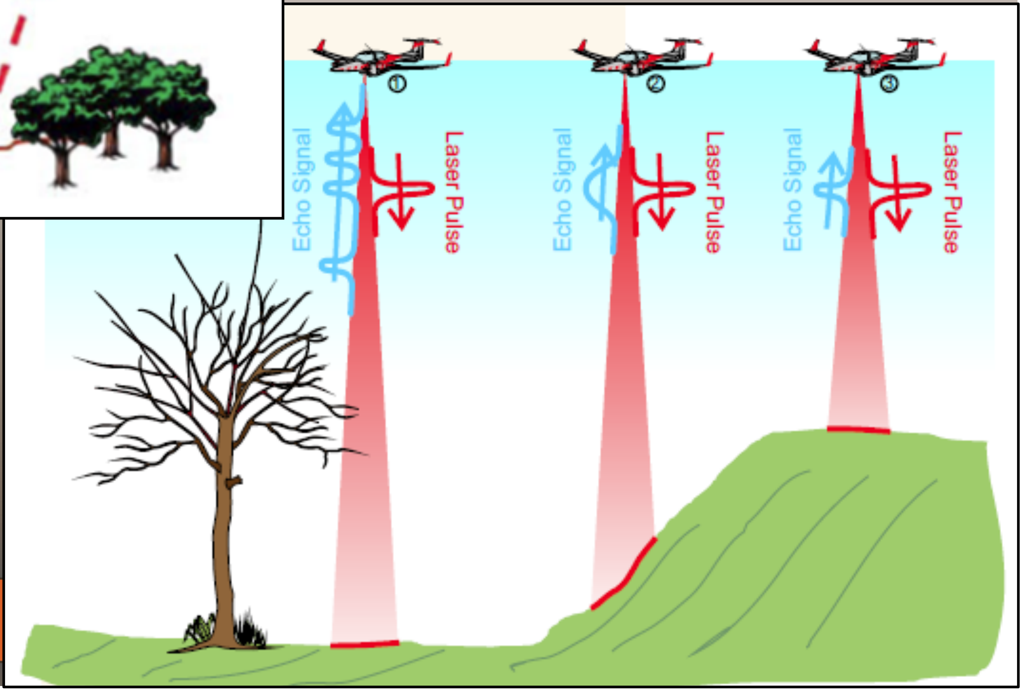
## LiDAR and Other Resources

Steve D. Bowman
Geologic Hazards Program

- LiDAR - Light detection and ranging is a technique of transmitting laser pulses and measuring the reflected returns to measure the distance to an object or surface. LiDAR is commonly used to determine ground surface elevations to create highly accurate, bare-earth digital elevation models (DEM).

# General Imaging Geometry of an Airborne LiDAR Instrument

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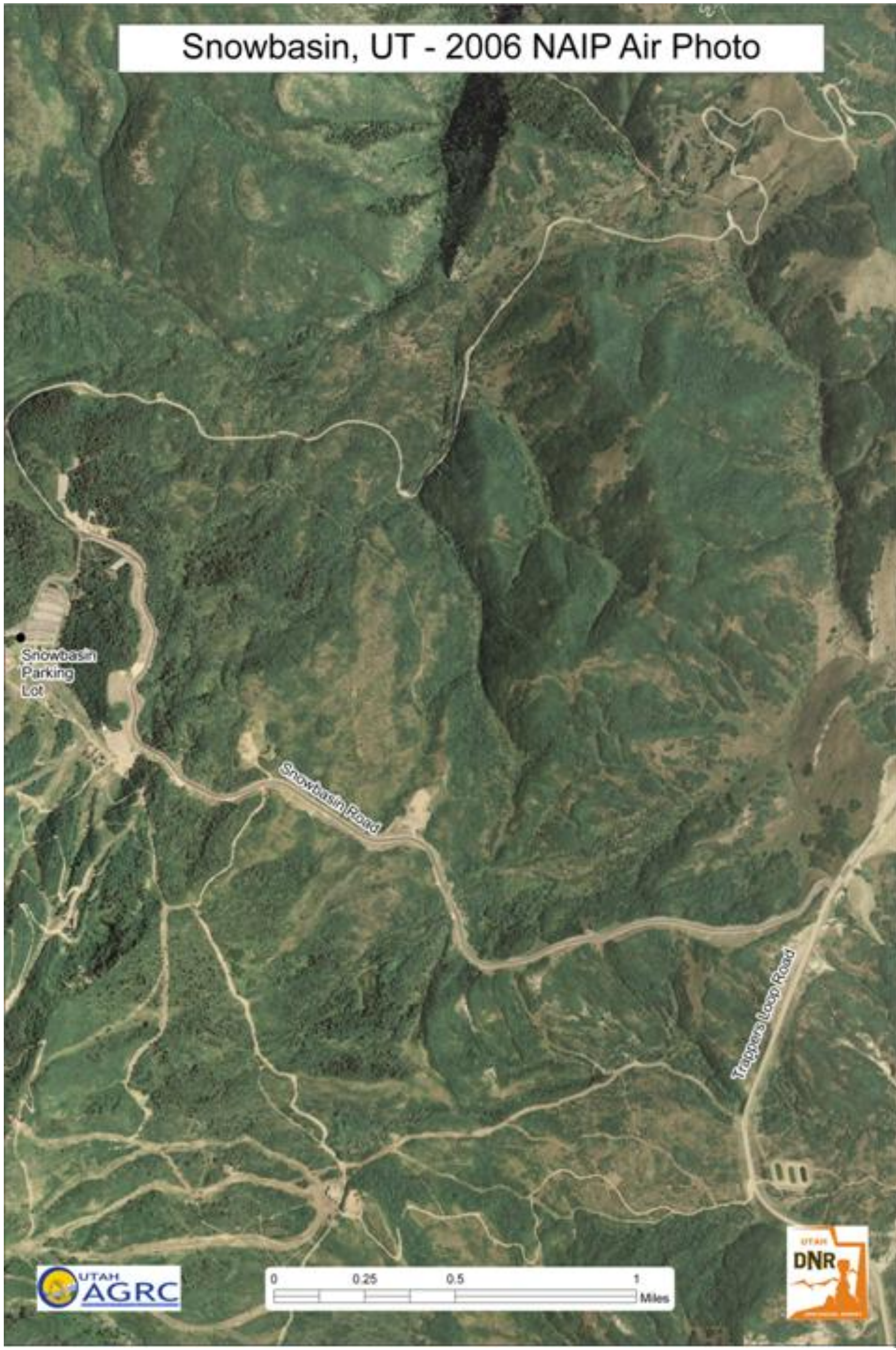
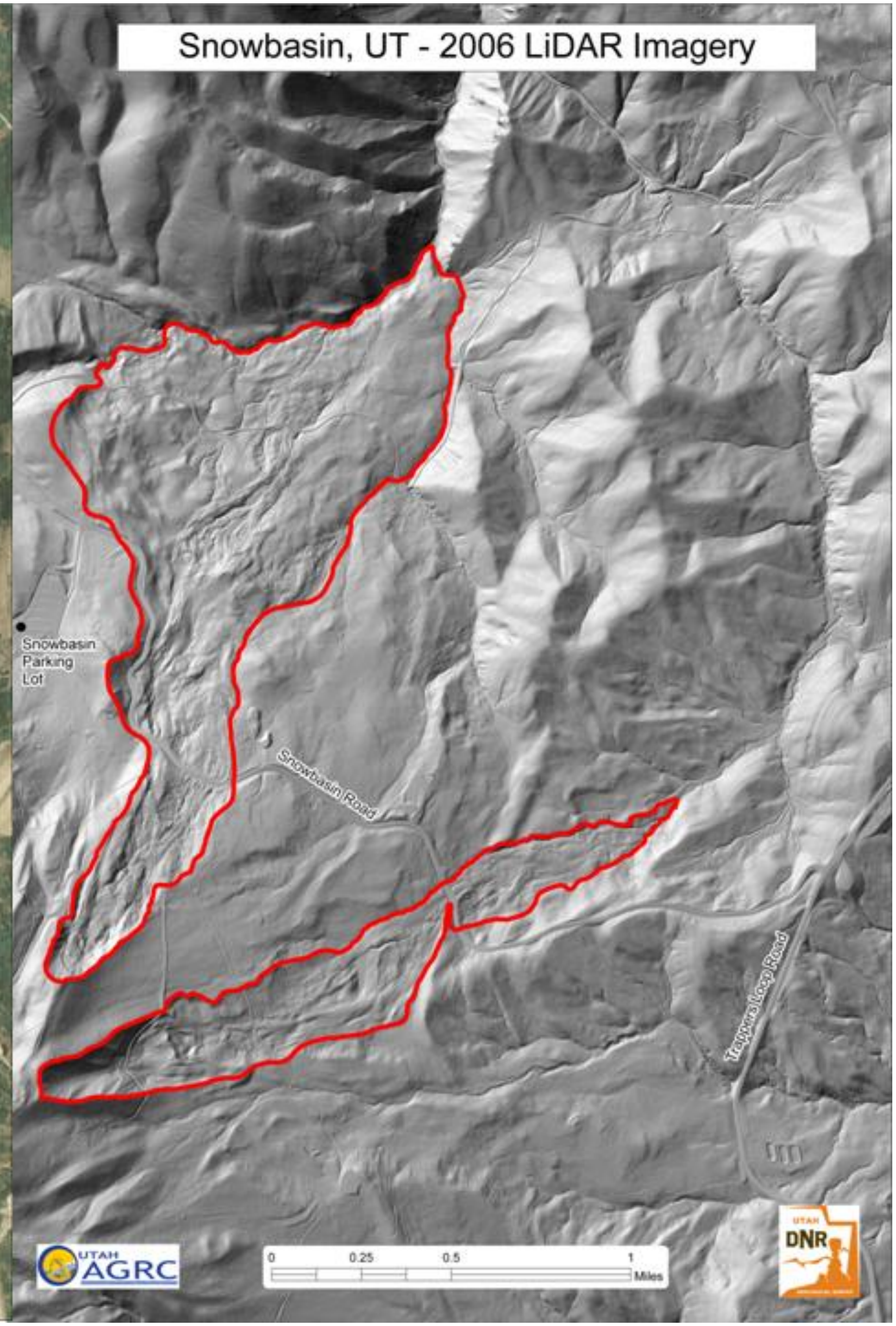
UTAH GEOLOGICAL SURVEY

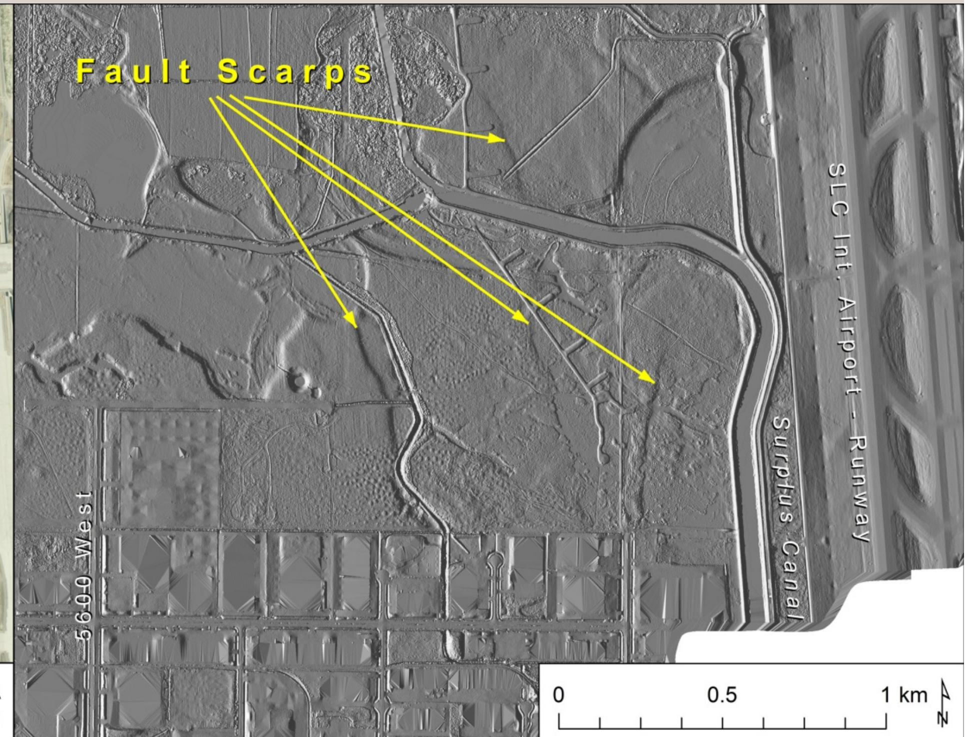

Snowbasin, UT - 2006 NAIP Air Photo
Snowbasin Parking Lot
Snowbasin Road
Trappers Loop Road
0
0.25
0.5
1
Miles
UTAH AGRC
UTAH DNR


Snowbasin, UT - 2006 LiDAR Imagery
Snowbasin Parking Lot
Snowbasin Road
Trappers Loop Road
0
0.25
0.5
1
Miles
UTAH AGRC
UTAH DNR

# More Faults Than Previously Mapped on the Grainger Fault, West Valley Fault Zone

2006 NAIP

2012 1-Meter LiDAR


Mapping for the Baileys Lake and Salt Lake City North 7-1/2 min. quadrangles.

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UTAH GEOLOGICAL SURVEY

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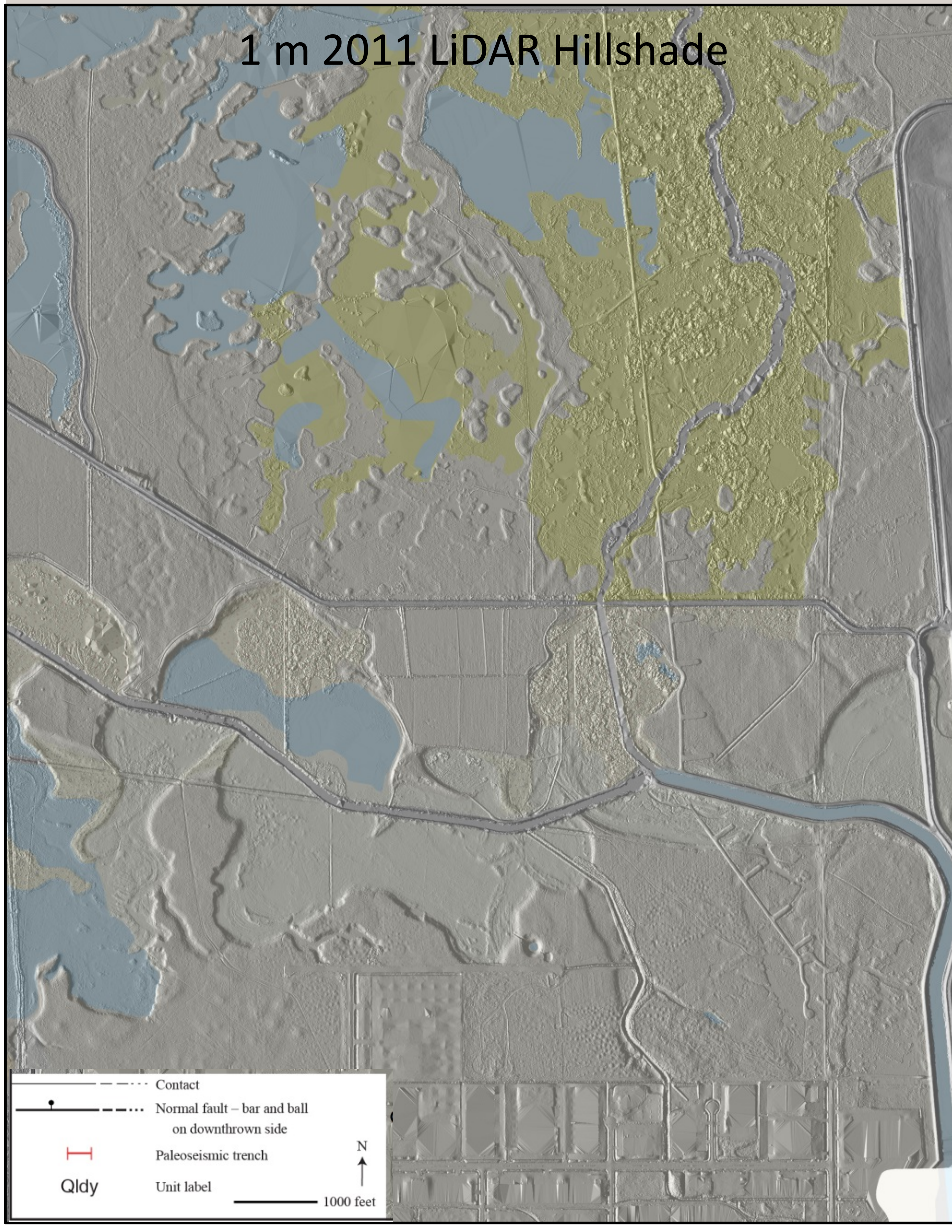
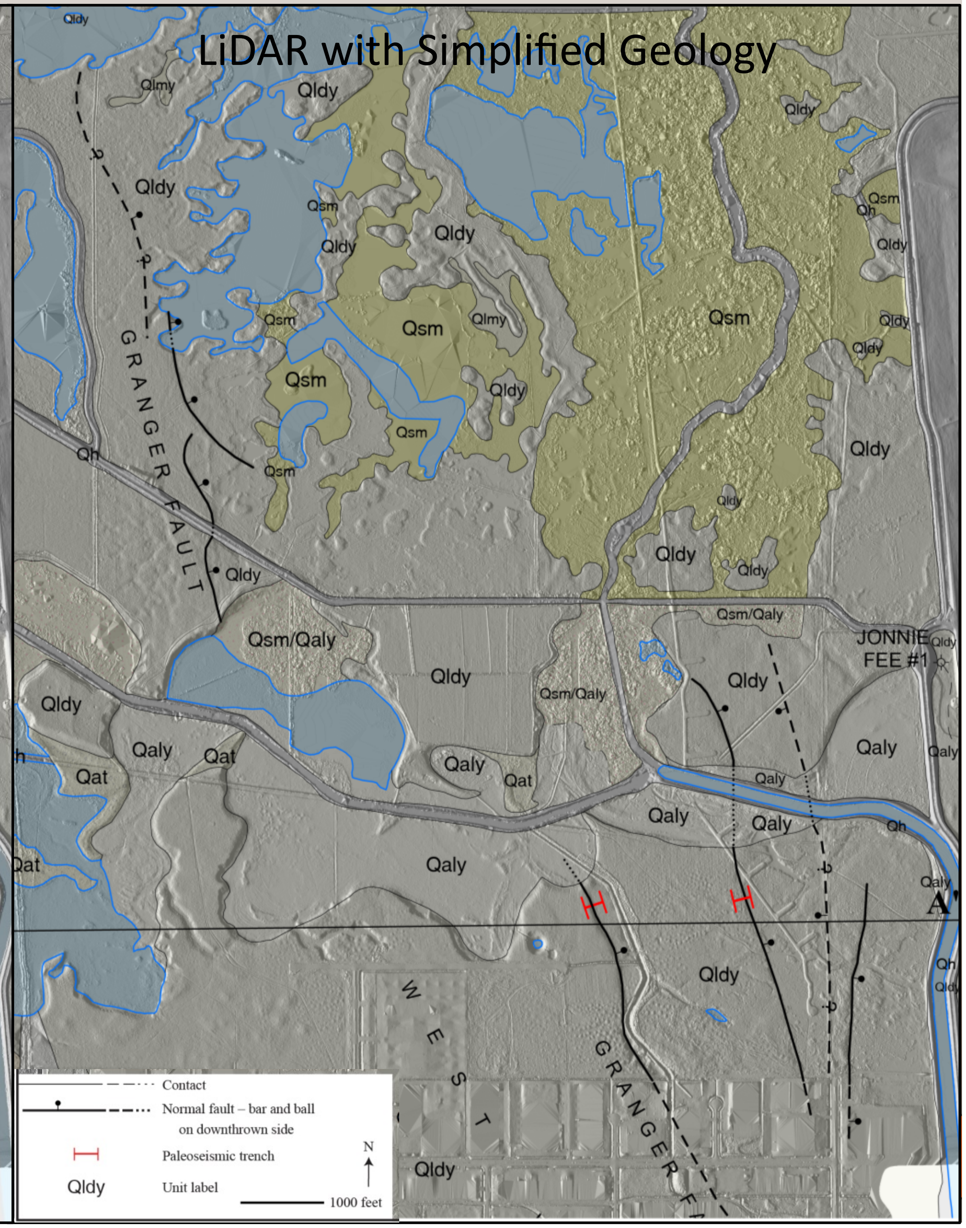
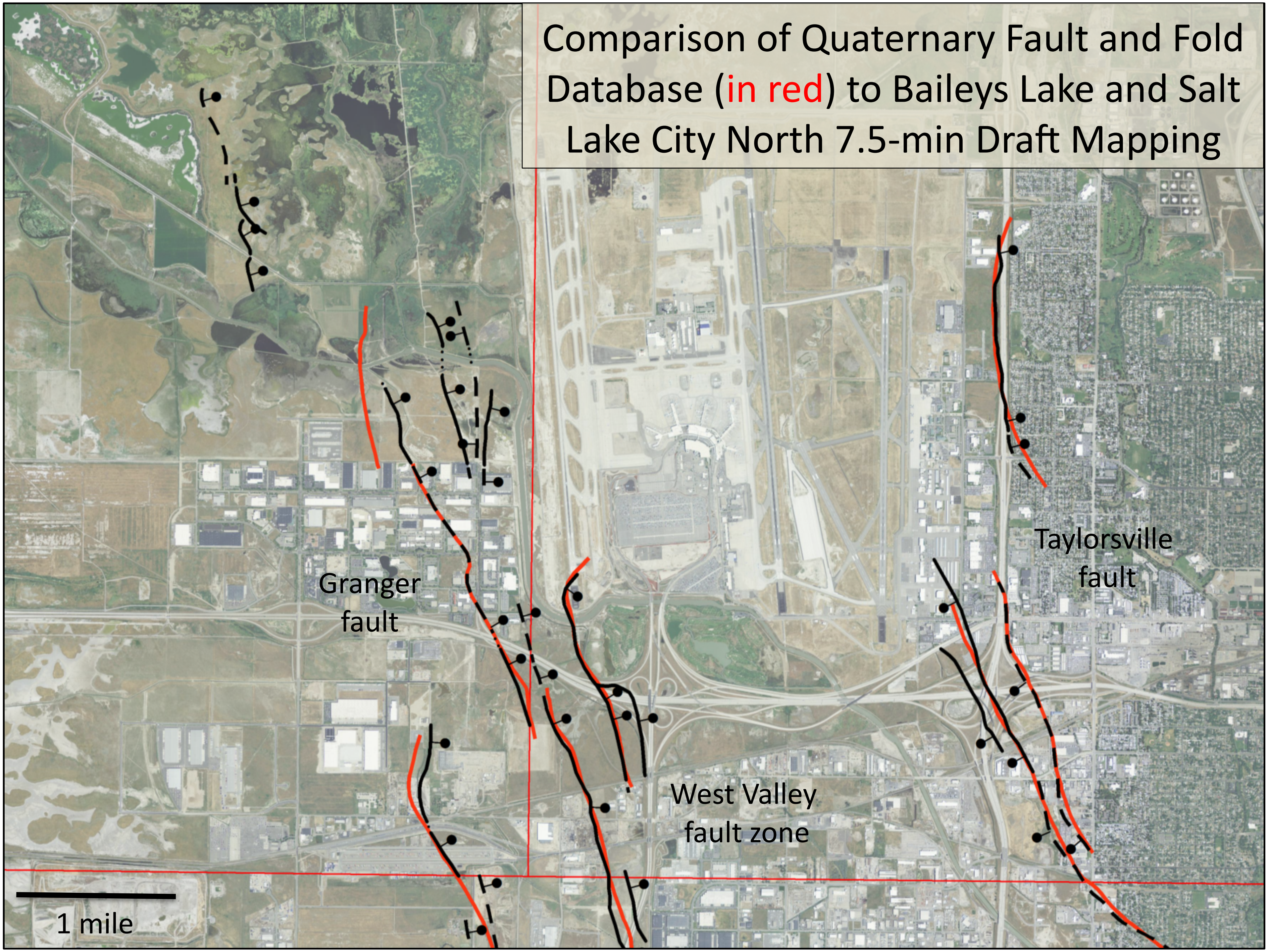
# LiDAR Mapping of the Granger Fault (Baileys Lake 7.5-min Quadrangle)




Comparison of Quaternary Fault and Fold Database (in red) to Baileys Lake and Salt Lake City North 7.5-min Draft Mapping
Granger fault
West Valley fault zone
Taylorsville fault
1 mile

- Extension of Granger fault with LiDAR
  - From about 9.5 miles
  - To between 10.9 or 11.5 miles
  - New strand is 0.7 to 1.2 miles long

- Measured vertical displacement of new surface fault ruptures:
  - Most new traces are in the 0.2 to 0.6 m range
  - As small as 0.1 to 0.2 m vertical displacement

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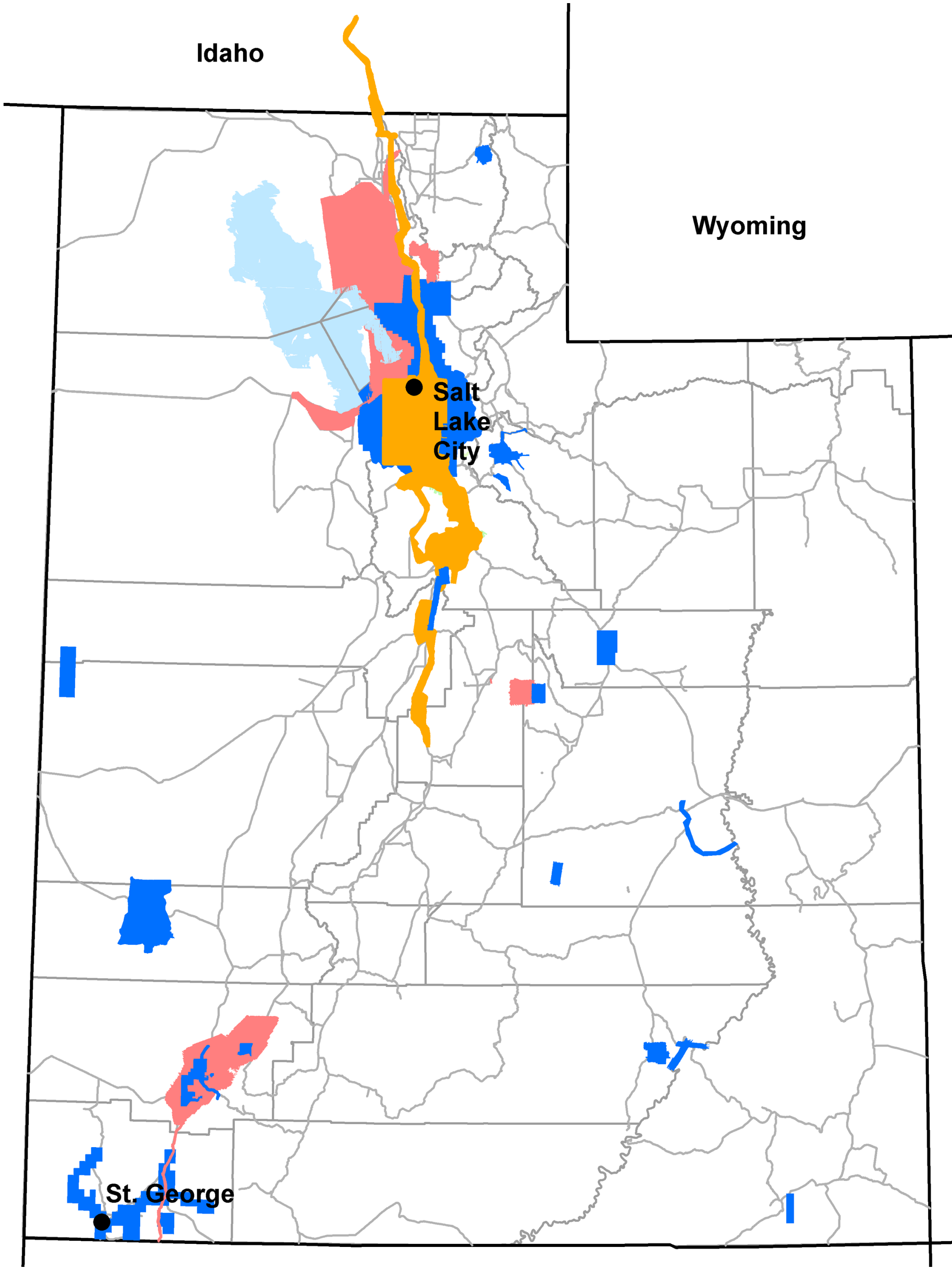


# Available Utah LiDAR Data

– 0.5 meter (2013-2014, orange area)

Includes Wasatch fault zone, additional data acquisition planned for Cache Valley, Bear Lake, and Great Salt Lake in 2015.

– 1 meter (2011, red area)

Includes Hurricane fault zone

– 2 meter (2006 + other, blue areas)

# LiDAR Data Availability

- UGS
  - LiDAR Data Web Page (includes extent/tile indexes and metadata only)
    - http://geology.utah.gov/databases/lidar/lidar.htm
- AGRC
  - DEM and Metadata Only
    - AGRC Raster Data Discovery, 1 Meter 2011 LiDAR Data
      http://stage.mapserv.utah.gov/raster/?cat=1%20Meter%20{2011%20LiDAR}
- OpenTopography
  - All Data
    - http://opentopography.org/

## Update of UGS Geologic Hazard Guidelines

- Engineering Geology Reports (1986)
- Surface-Fault-Rupture (2003)
- Landslides (1996)
- Debris Flows and Alluvial Fans (2005)
- Rock Fall (new)
- Ground Subsidence and Earth Fissures (new)

Updated guidelines will be separate chapters in a single volume for ease of use and future update. Users will be aware of all guidelines. Extensively referenced in new geologic hazard map sets and local government ordinances.


Flat Canyon Site (Joint USGS/UGS)

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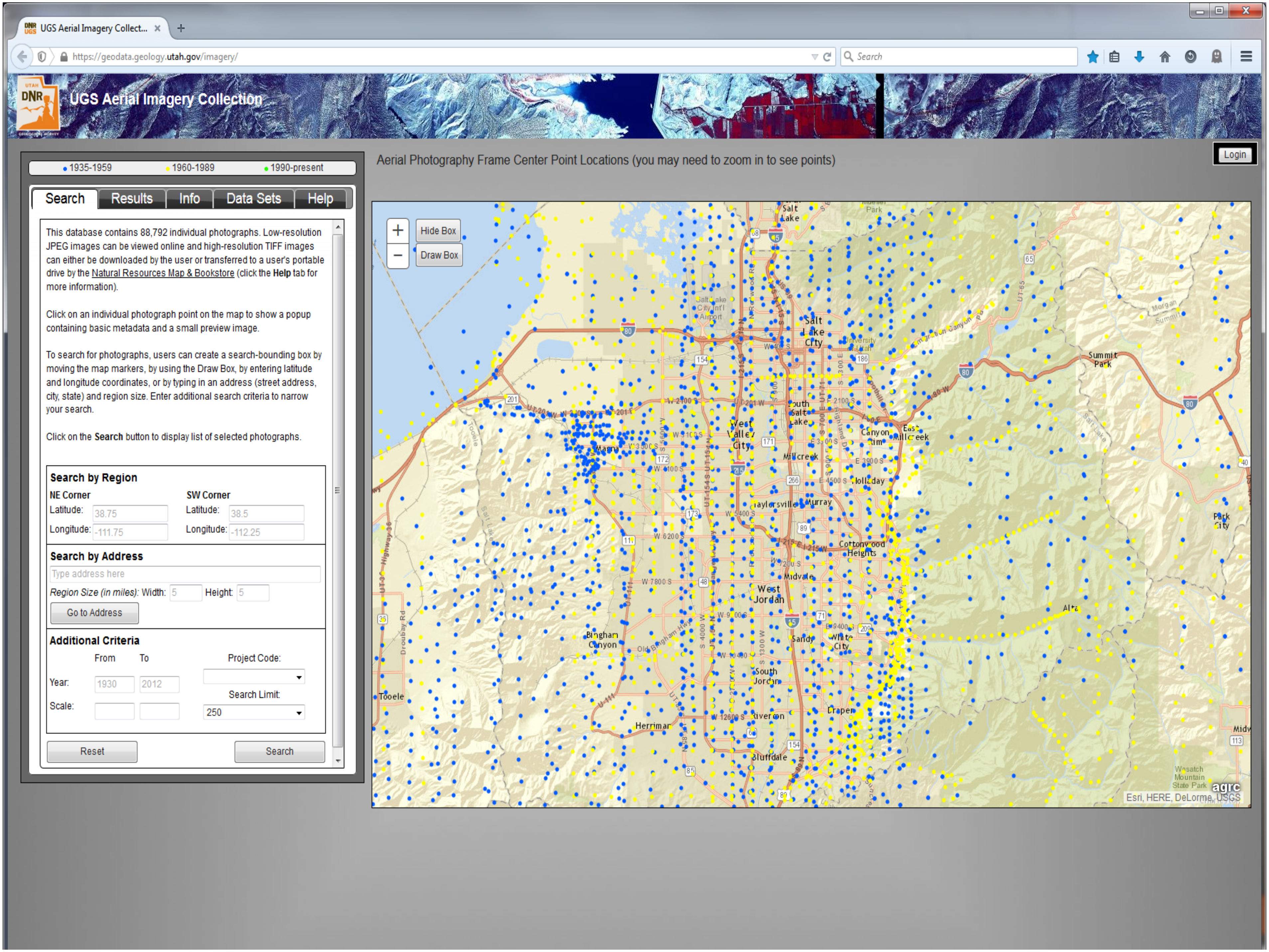
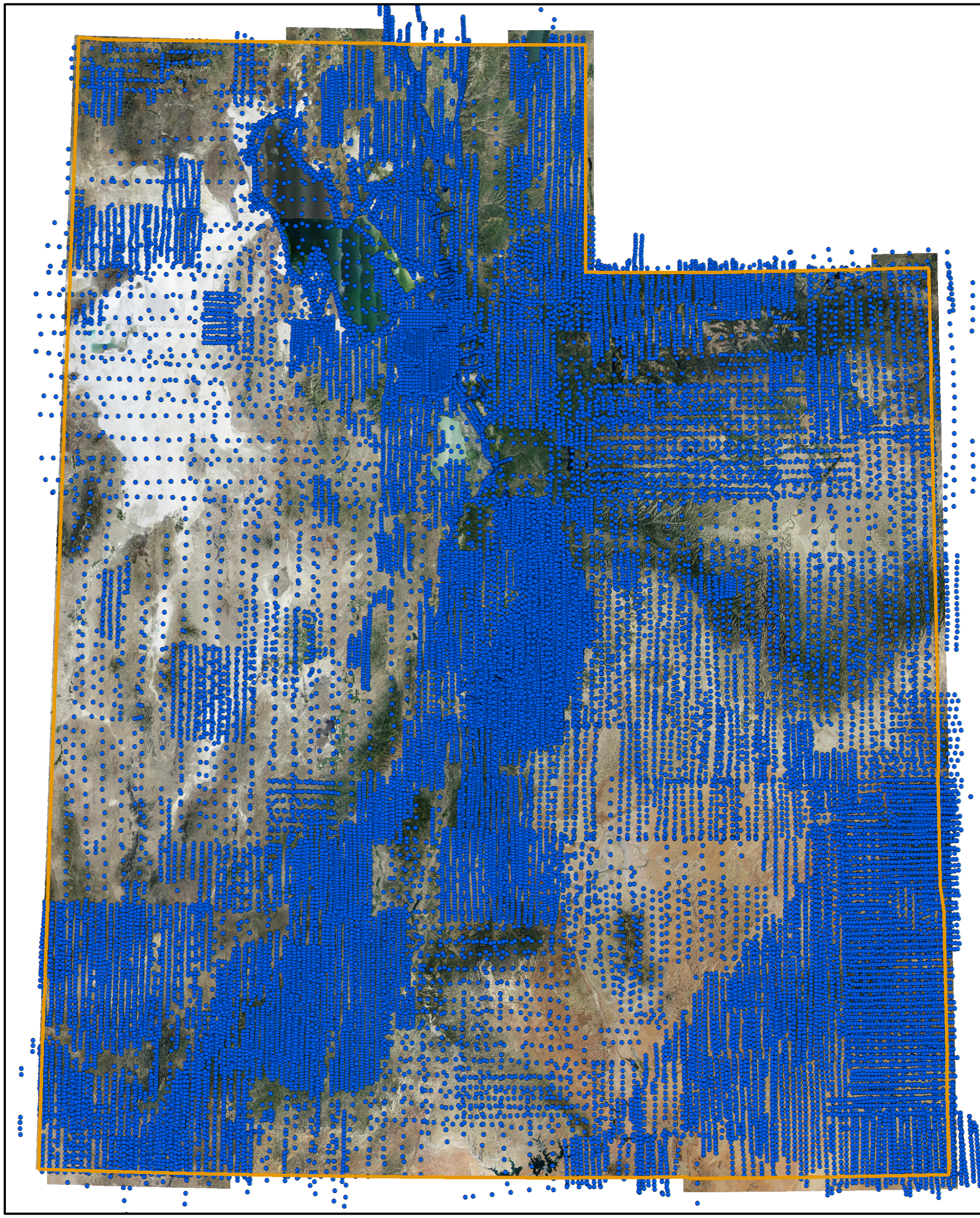
UTAH GEOLOGICAL SURVEY

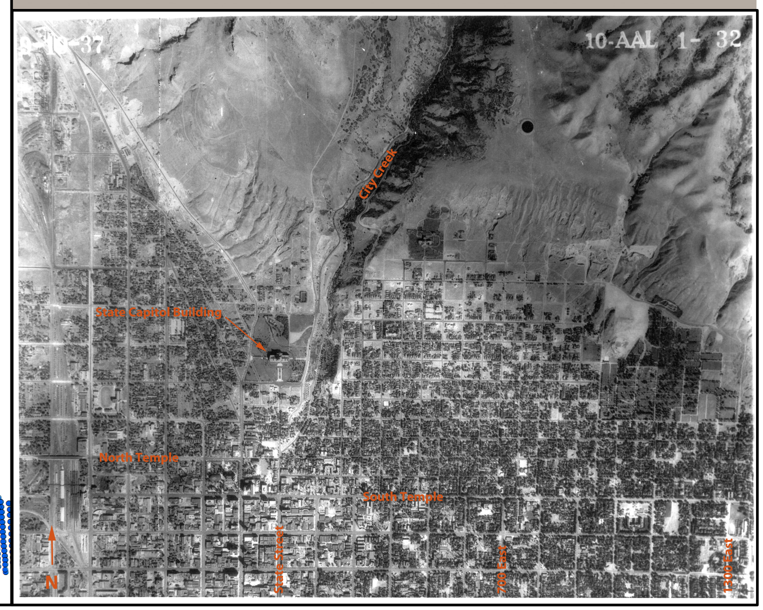
# Aerial Imagery Collection

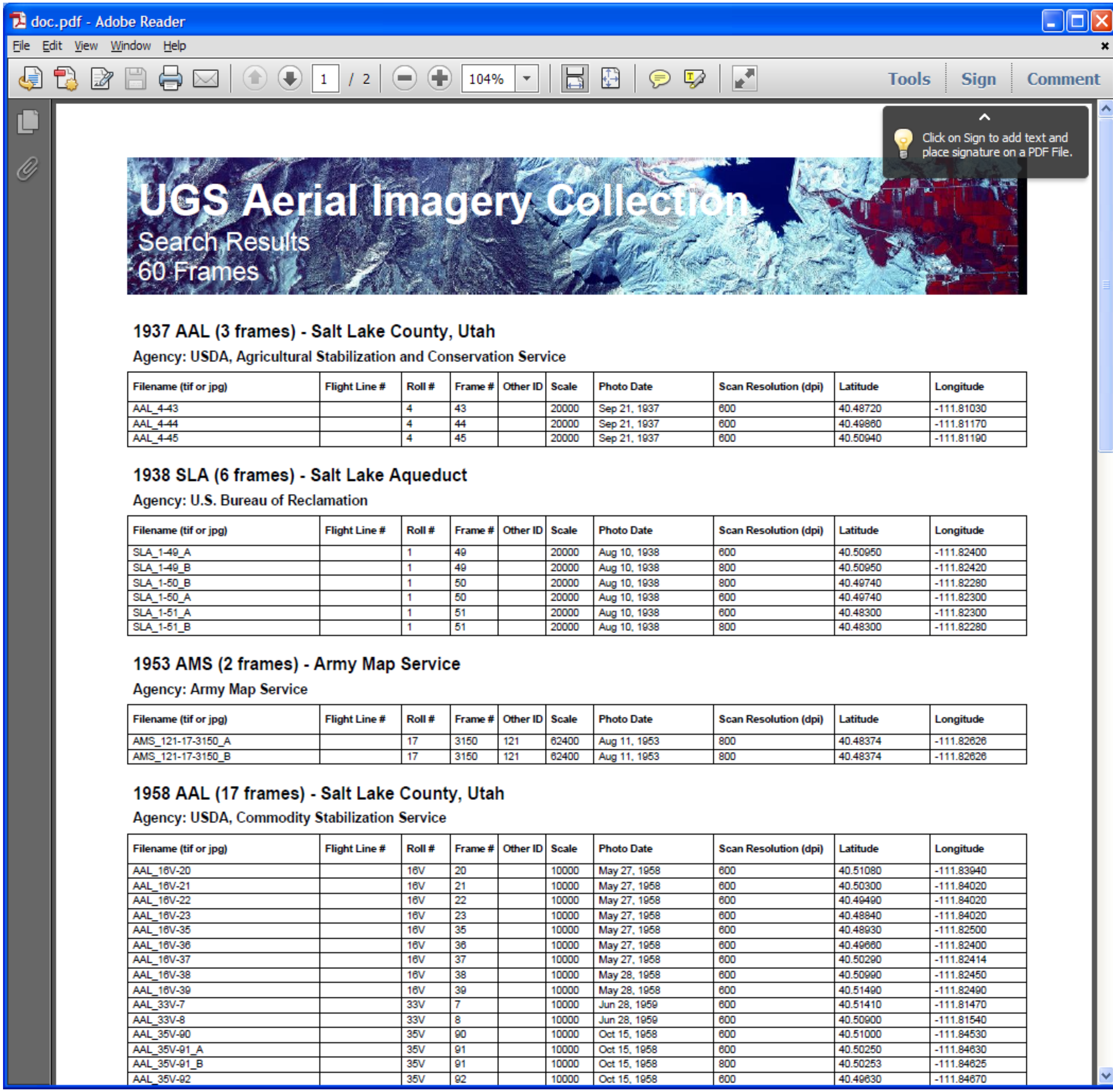
- UGS collection of about 120,000 frames from 1935 to 2002.
  - 71,800 in database (as of February 1)
  - 260 individual aerial projects
- Digitally scanned
  - Paper prints scanned at 600 or 800 (starting 2010) dpi
  - Film scanned at 1200 dpi
  - TIFF (archive) format with lossless ZIP compression
- Available online at https://geodata.geology.utah.gov/imagery/.


UGS Aerial Imagery Collect...
https://geodata.geology.utah.gov/imagery/
Search
UGS Aerial Imagery Collection
Login
1935-1959
1960-1989
1990-present
Search
Results
Info
Data Sets
Help
This database contains 88,792 individual photographs. Low-resolution JPEG images can be viewed online and high-resolution TIFF images can either be downloaded by the user or transferred to a user's portable drive by the Natural Resources Map & Bookstore (click the Help tab for more information).
Click on an individual photograph point on the map to show a popup containing basic metadata and a small preview image.
To search for photographs, users can create a search-bounding box by moving the map markers, by using the Draw Box, by entering latitude and longitude coordinates, or by typing in an address (street address, city, state) and region size. Enter additional search criteria to narrow your search.
Click on the Search button to display list of selected photographs.
Search by Region
NE Corner
Latitude: 38.75
Longitude: -111.75
SW Corner
Latitude: 38.5
Longitude: -112.25
Search by Address
Type address here
Region Size (in miles): Width: 5 Height: 5
Go to Address
Additional Criteria
From To
Year: 1930 2012
Scale:
Project Code:
Search Limit:
250
Reset
Search
Aerial Photography Frame Center Point Locations (you may need to zoom in to see points)
Hide Box
Draw Box
Salt Lake City
South Salt Lake
West Valley City
Millcreek
Holladay
Murray
Taylorsville
Cottonwood Heights
Midvale
West Jordan
Sandy
South Jordan
Riverton
Draper
Bluffdale
Herriman
Bingham Canyon
Tooele
Magna
Summit Park
Park City
Alta
Esri, HERE, DeLorme, USGS



Over 88,000 frames currently entered into the UGS Aerial Imagery database






# UGS Aerial Imagery Collection

Search Results

60 Frames

### 1937 AAL (3 frames) - Salt Lake County, Utah

**Agency: USDA, Agricultural Stabilization and Conservation Service**

| Filename (tif or jpg) | Flight Line # | Roll # | Frame # | Other ID | Scale | Photo Date | Scan Resolution (dpi) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|
| AAL_4-43 | | 4 | 43 | | 20000 | Sep 21, 1937 | 600 | 40.48720 | -111.81030 |
| AAL_4-44 | | 4 | 44 | | 20000 | Sep 21, 1937 | 600 | 40.49860 | -111.81170 |
| AAL_4-45 | | 4 | 45 | | 20000 | Sep 21, 1937 | 600 | 40.50940 | -111.81190 |

### 1938 SLA (6 frames) - Salt Lake Aqueduct

**Agency: U.S. Bureau of Reclamation**

| Filename (tif or jpg) | Flight Line # | Roll # | Frame # | Other ID | Scale | Photo Date | Scan Resolution (dpi) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|
| SLA_1-49_A | | 1 | 49 | | 20000 | Aug 10, 1938 | 600 | 40.50950 | -111.82400 |
| SLA_1-49_B | | 1 | 49 | | 20000 | Aug 10, 1938 | 800 | 40.50950 | -111.82420 |
| SLA_1-50_B | | 1 | 50 | | 20000 | Aug 10, 1938 | 800 | 40.49740 | -111.82280 |
| SLA_1-50_A | | 1 | 50 | | 20000 | Aug 10, 1938 | 600 | 40.49740 | -111.82300 |
| SLA_1-51_A | | 1 | 51 | | 20000 | Aug 10, 1938 | 600 | 40.48300 | -111.82300 |
| SLA_1-51_B | | 1 | 51 | | 20000 | Aug 10, 1938 | 800 | 40.48300 | -111.82280 |

### 1953 AMS (2 frames) - Army Map Service

**Agency: Army Map Service**

| Filename (tif or jpg) | Flight Line # | Roll # | Frame # | Other ID | Scale | Photo Date | Scan Resolution (dpi) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|
| AMS_121-17-3150_A | | 17 | 3150 | 121 | 62400 | Aug 11, 1953 | 800 | 40.48374 | -111.82626 |
| AMS_121-17-3150_B | | 17 | 3150 | 121 | 62400 | Aug 11, 1953 | 800 | 40.48374 | -111.82626 |

### 1958 AAL (17 frames) - Salt Lake County, Utah

**Agency: USDA, Commodity Stabilization Service**

| Filename (tif or jpg) | Flight Line # | Roll # | Frame # | Other ID | Scale | Photo Date | Scan Resolution (dpi) | Latitude | Longitude |
|---|---|---|---|---|---|---|---|---|---|
| AAL_16V-20 | | 16V | 20 | | 10000 | May 27, 1958 | 600 | 40.51080 | -111.83940 |
| AAL_16V-21 | | 16V | 21 | | 10000 | May 27, 1958 | 600 | 40.50300 | -111.84020 |
| AAL_16V-22 | | 16V | 22 | | 10000 | May 27, 1958 | 600 | 40.49490 | -111.84020 |
| AAL_16V-23 | | 16V | 23 | | 10000 | May 27, 1958 | 600 | 40.48840 | -111.84020 |
| AAL_16V-35 | | 16V | 35 | | 10000 | May 27, 1958 | 600 | 40.48930 | -111.82500 |
| AAL_16V-36 | | 16V | 36 | | 10000 | May 27, 1958 | 600 | 40.49660 | -111.82400 |
| AAL_16V-37 | | 16V | 37 | | 10000 | May 27, 1958 | 600 | 40.50290 | -111.82414 |
| AAL_16V-38 | | 16V | 38 | | 10000 | May 28, 1958 | 600 | 40.50990 | -111.82450 |
| AAL_16V-39 | | 16V | 39 | | 10000 | May 28, 1958 | 600 | 40.51490 | -111.82490 |
| AAL_33V-7 | | 33V | 7 | | 10000 | Jun 28, 1959 | 600 | 40.51410 | -111.81470 |
| AAL_33V-8 | | 33V | 8 | | 10000 | Jun 28, 1959 | 600 | 40.50900 | -111.81540 |
| AAL_35V-90 | | 35V | 90 | | 10000 | Oct 15, 1958 | 600 | 40.51000 | -111.84530 |
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| AAL_35V-92 | | 35V | 92 | | 10000 | Oct 15, 1958 | 600 | 40.49630 | -111.84670 |

PDF report of search results with basic metadata

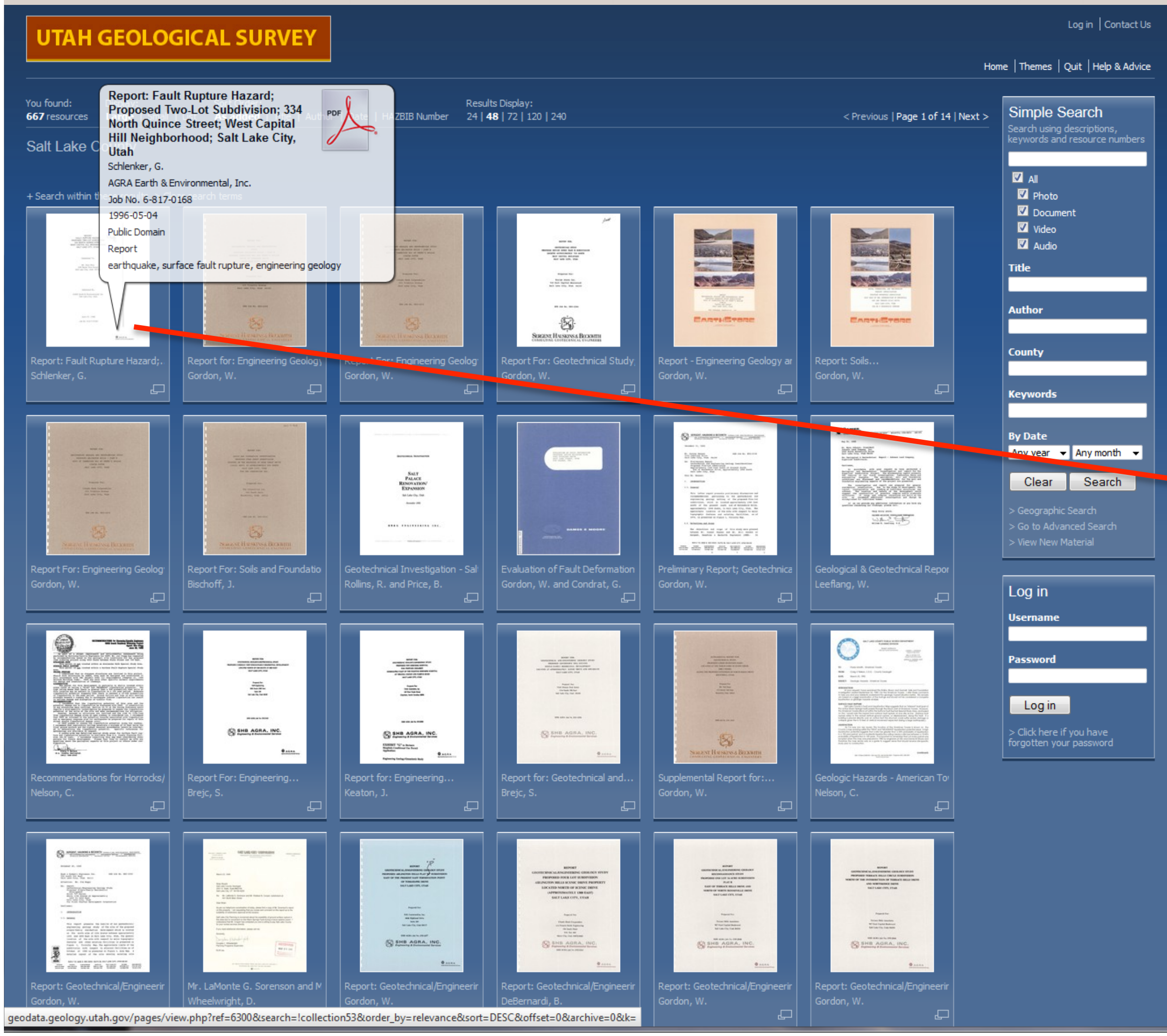
**1970s Woodward-Lundgren Low-Sun-Angle Aerial Photographs**
**Corner Canyon Area, Draper, Utah**

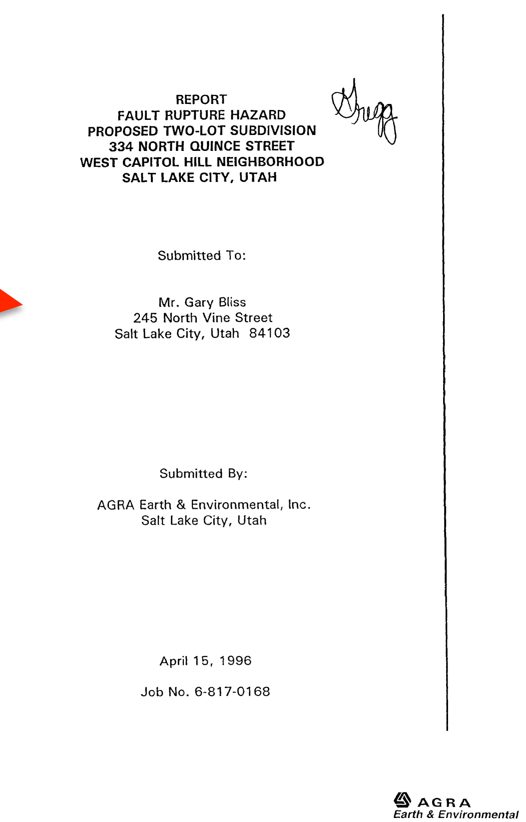
Scan From Print (600 dpi)
UGS Open-File Report 548

Scan From Original Film (1200 dpi)
Future UGS Publication

# Engineering Geology and Geologic Hazard Document Collection

- Scanned unpublished engineering geology and geotechnical reports, photographs, and data from UGS files available at http://geodata.geology.utah.gov.



REPORT
FAULT RUPTURE HAZARD
PROPOSED TWO-LOT SUBDIVISION
334 NORTH QUINCE STREET
WEST CAPITOL HILL NEIGHBORHOOD
SALT LAKE CITY, UTAH

Submitted To:

Mr. Gary Bliss
245 North Vine Street
Salt Lake City, Utah 84103

Submitted By:

AGRA Earth & Environmental, Inc.
Salt Lake City, Utah

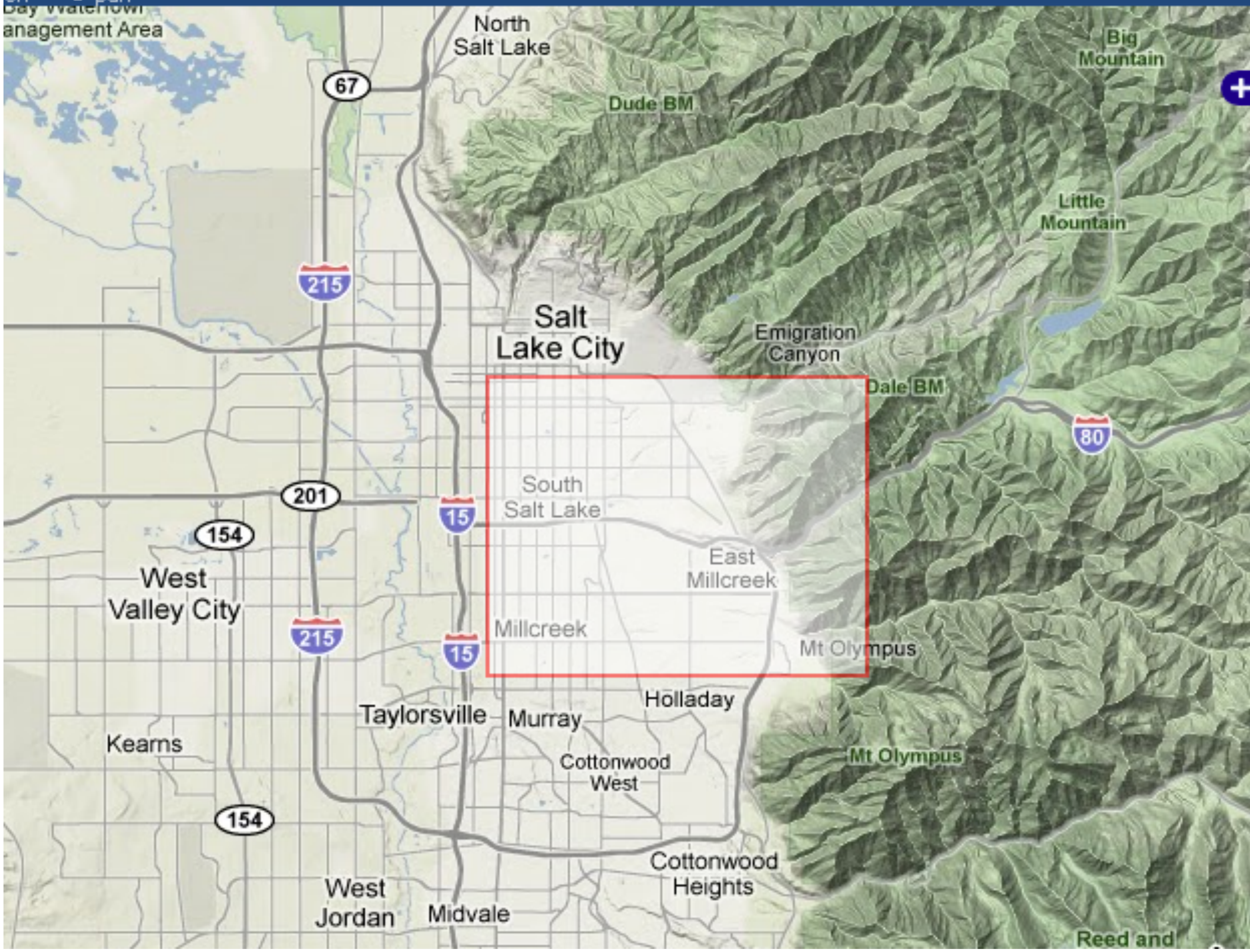
April 15, 1996

Job No. 6-817-0168

AGRA
Earth & Environmental

area.

on pan

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**Author**

**Date**

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**Geologic Hazard Keywords**

**By Date**

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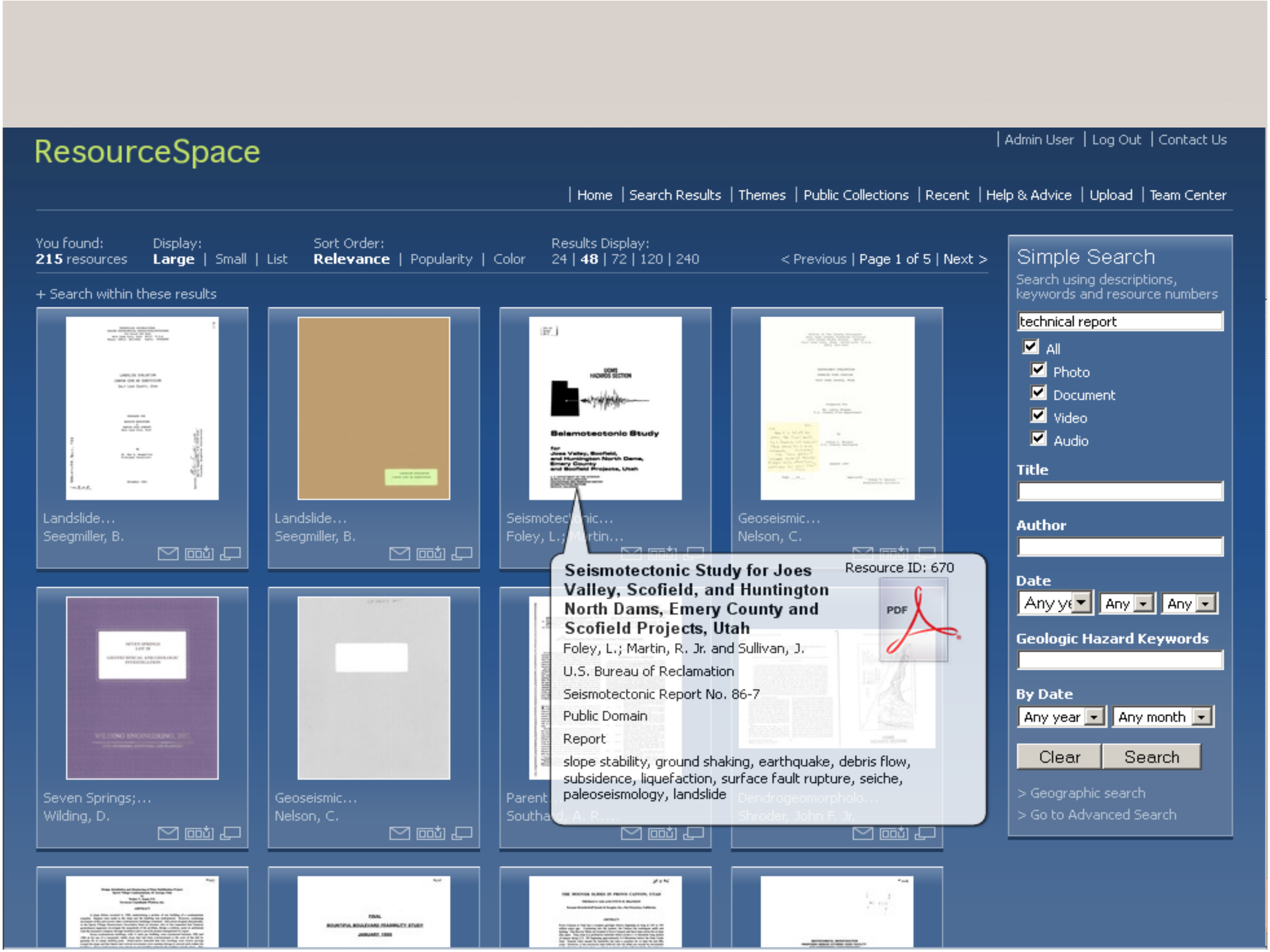
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Landslide... Seegmiller, B.
Seismotectonic... Foley, L.; Martin...
Geoseismic... Nelson, C.
Seven Springs;... Wilding, D.
Geoseismic... Nelson, C.
Parent... Southard, A. R....
Dendrogeomorpholo... Shroder, John F. Jr.
Seismotectonic Study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah
Resource ID: 670
PDF
Foley, L.; Martin, R. Jr. and Sullivan, J.
U.S. Bureau of Reclamation
Seismotectonic Report No. 86-7
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Report
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## Seismotectonic Study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah

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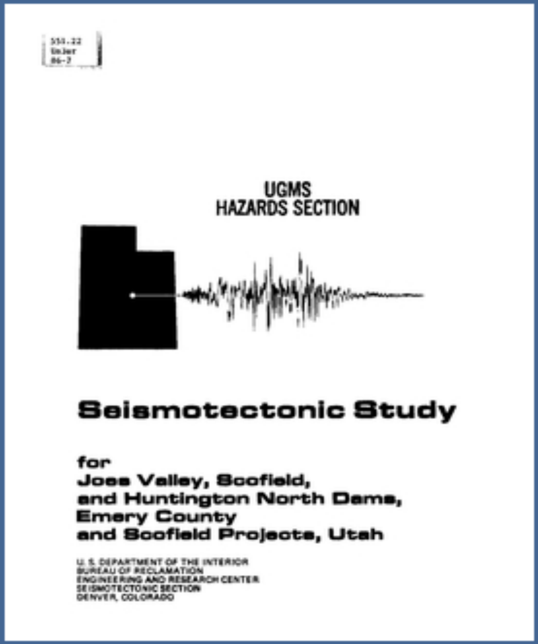


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### Resource Details

| Resource ID | Access | Title | Author |
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| 670 | Open | Seismotectonic Study for Joes Valley, Scofield, and Huntington North Dams, Emery County and Scofield Projects, Utah | Foley, L.; Martin, R. Jr. and Sullivan, J. |

Publisher
U.S. Bureau of Reclamation

Publication

### Simple Search

Search using descriptions, keywords and resource numbers

technical report

- [x] All
- [x] Photo
- [x] Document
- [x] Video
- [x] Audio

**Title**

**Author**

**Date**
Any ye | Any | Any

**Geologic Hazard Keywords**

**By Date**
Any year | Any month

Clear | Search

> Geographic search
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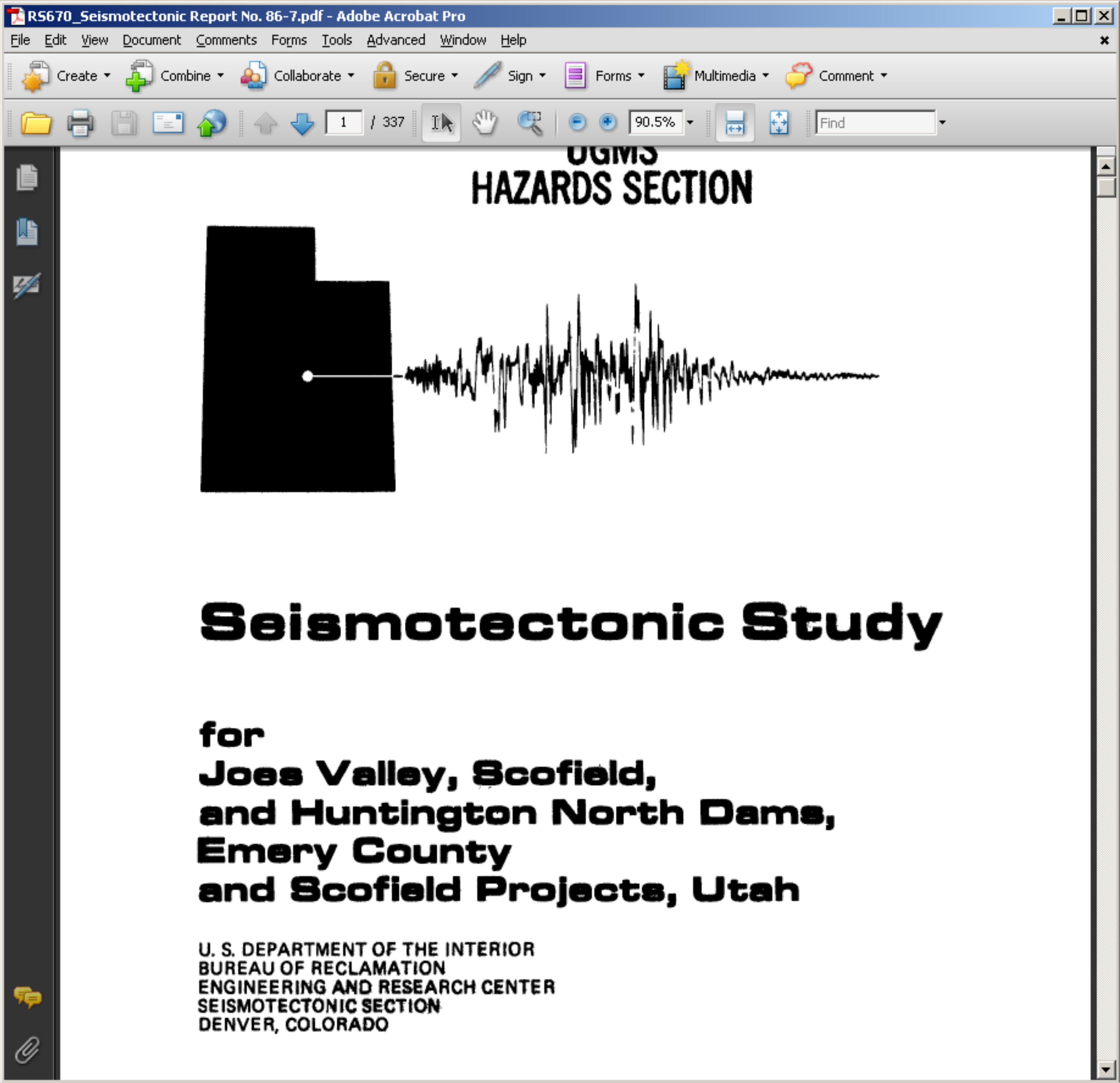


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geology.utah.gov

# West Valley Fault Zone, Baileys Lake Site: Fault Trenching on the Basin Floor


***Michael Hylland***
***Utah Geological Survey***

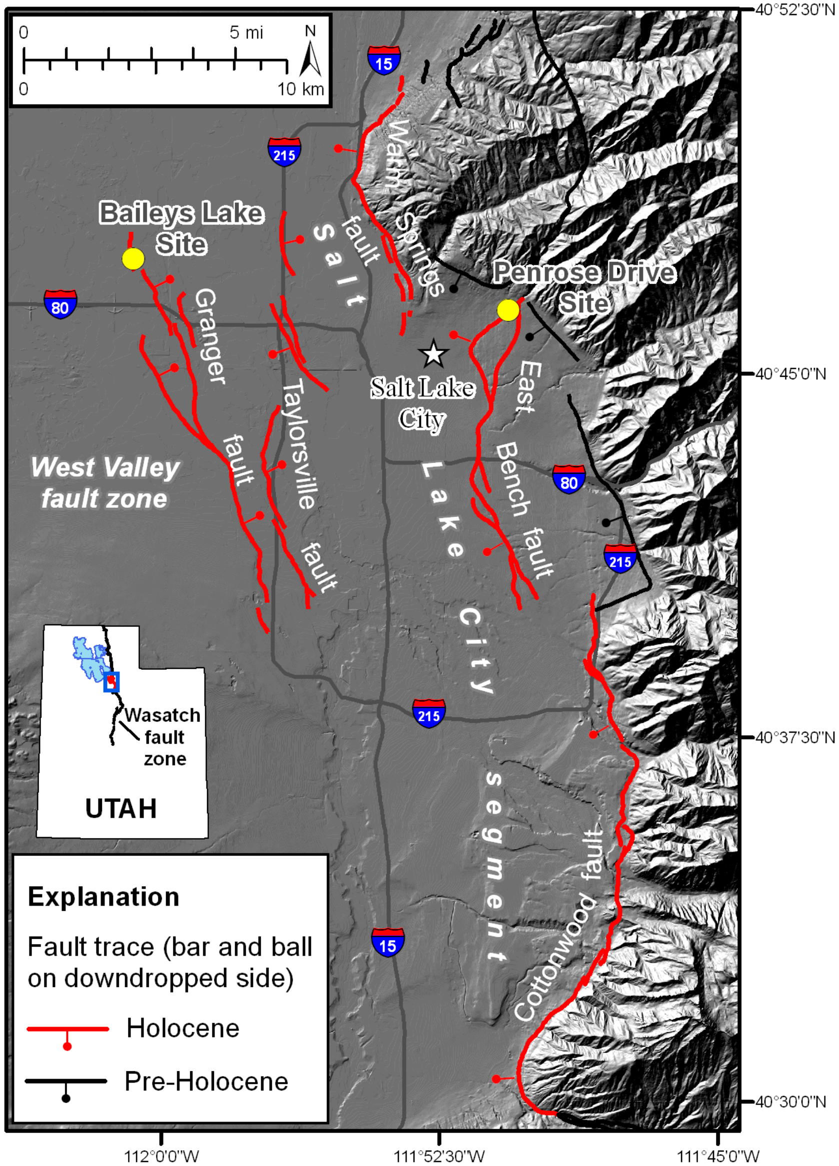

*Research partners:*
*Chris DuRoss (UGS, now USGS), Greg McDonald (UGS)*
*Tony Crone, Steve Personius, Shannon Mahan (USGS)*
*Susan Olig (URS)*
*Jack Oviatt (Kansas State University)*


Basin and Range Province Seismic Hazards Summit III
January 12, 2015



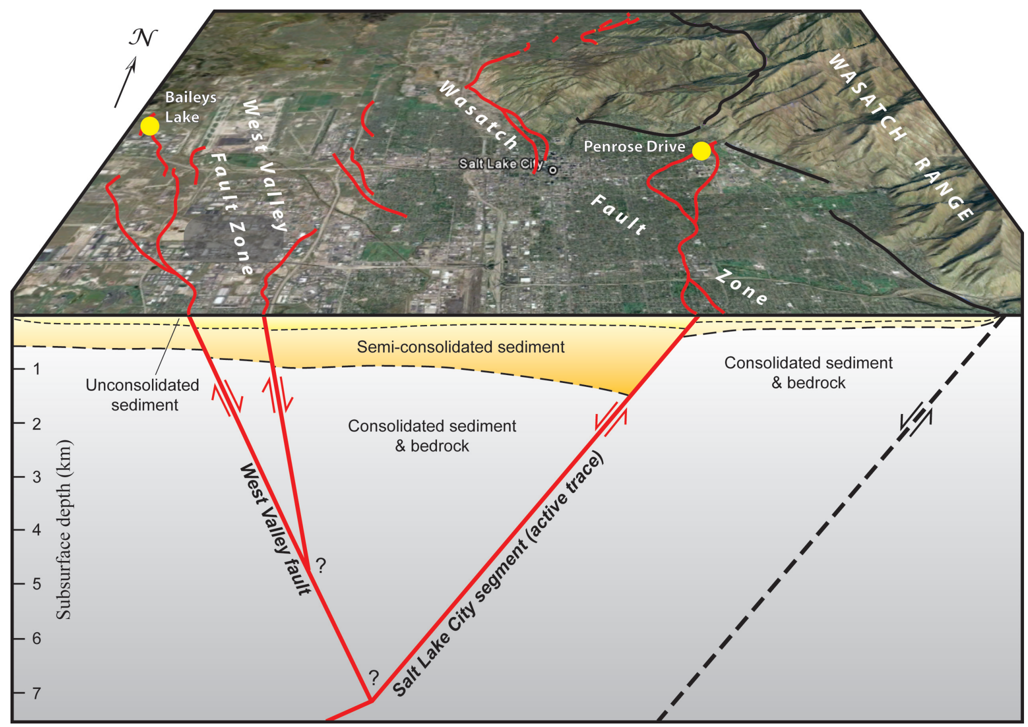
*Research funded by the Utah Geological Survey and U.S. Geological Survey, National Earthquake Hazards Reduction Program*

# Baileys Lake Trench Site – Background

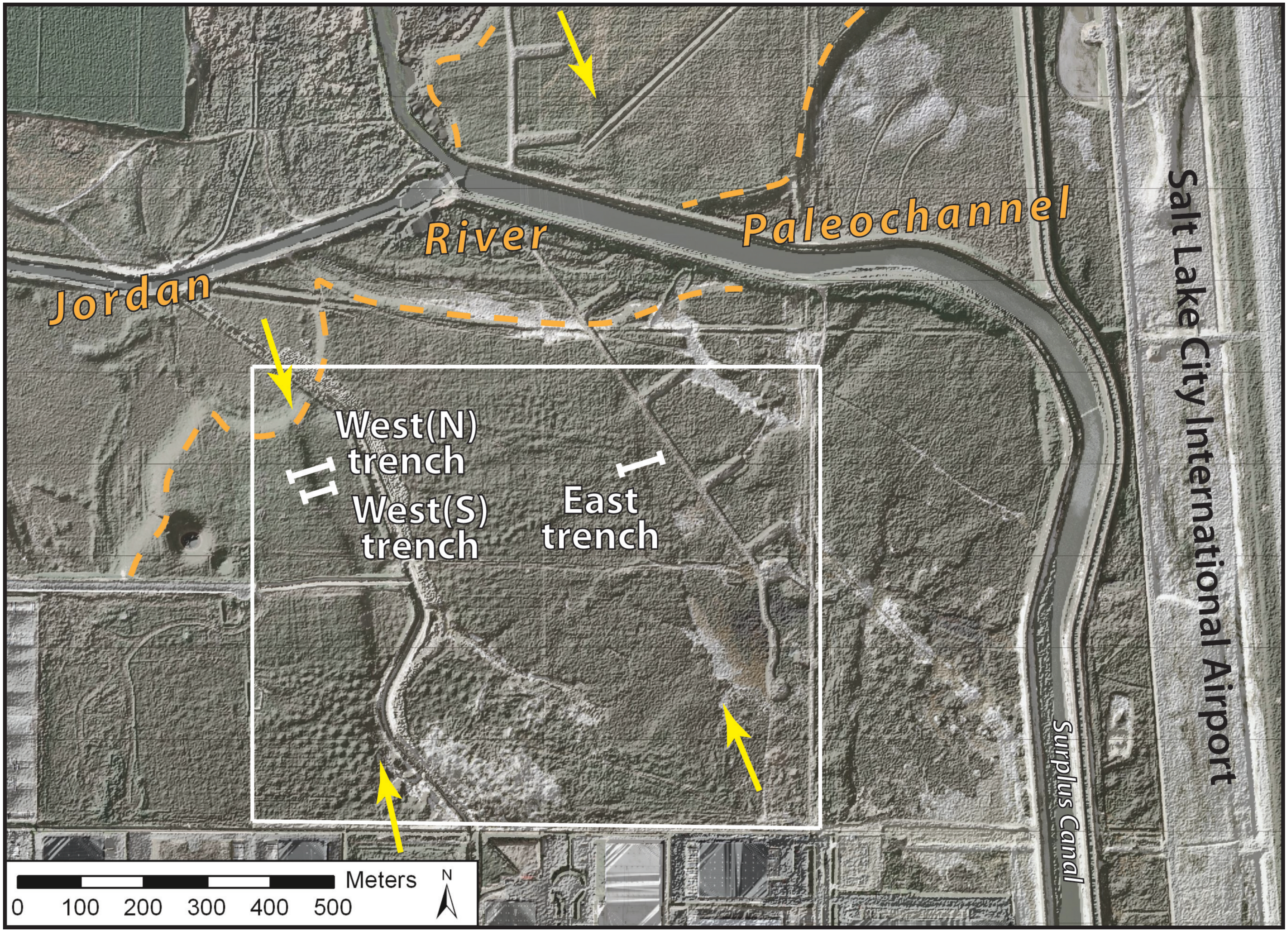



- WVFZ antithetic to SLCS
- Intrabasin graben
- Holocene active

**Project goal: Compare timing of surface-faulting earthquakes on the WVFZ and SLCS**

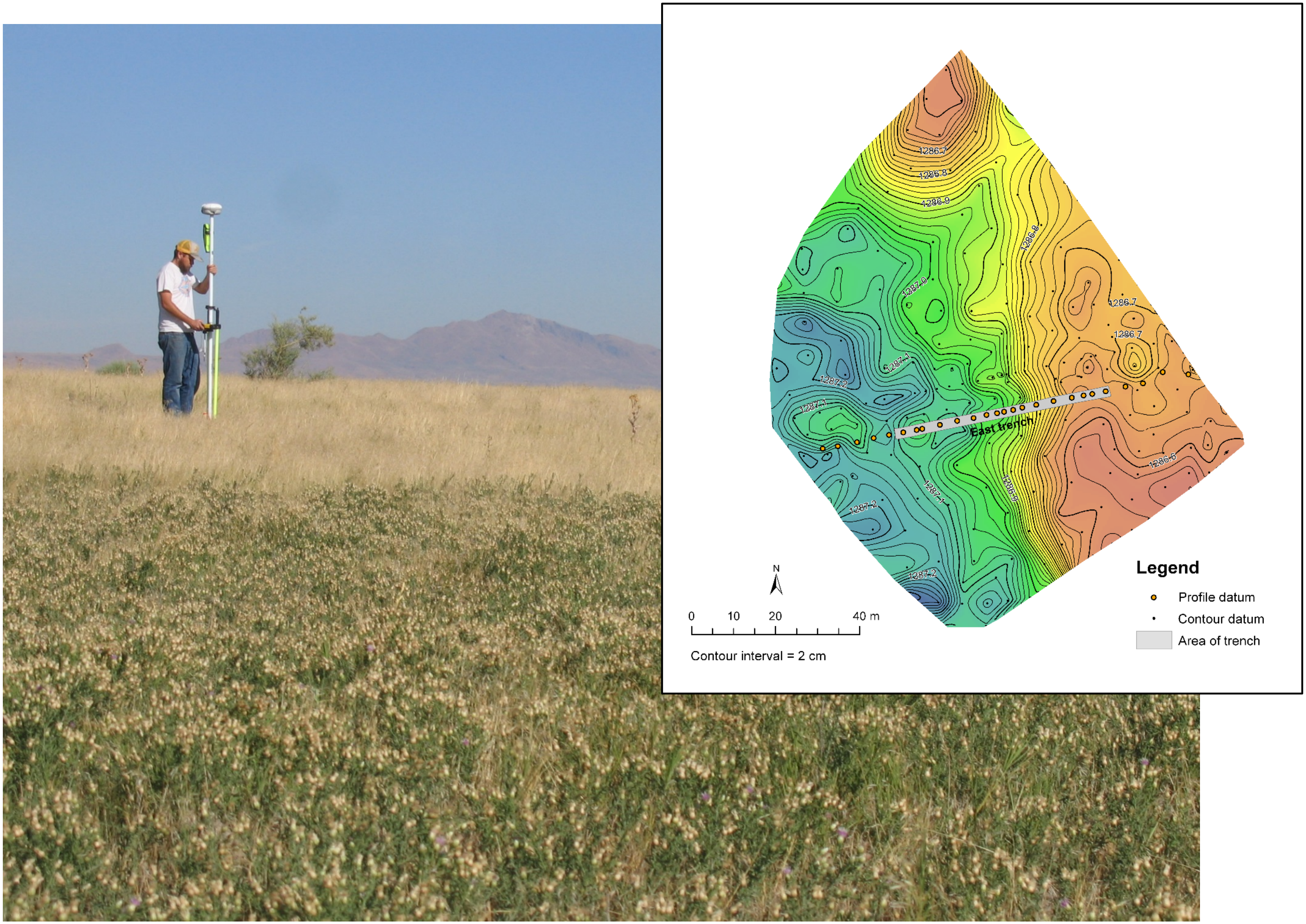


# Baileys Lake Trench Site – Locating Fault Scarps

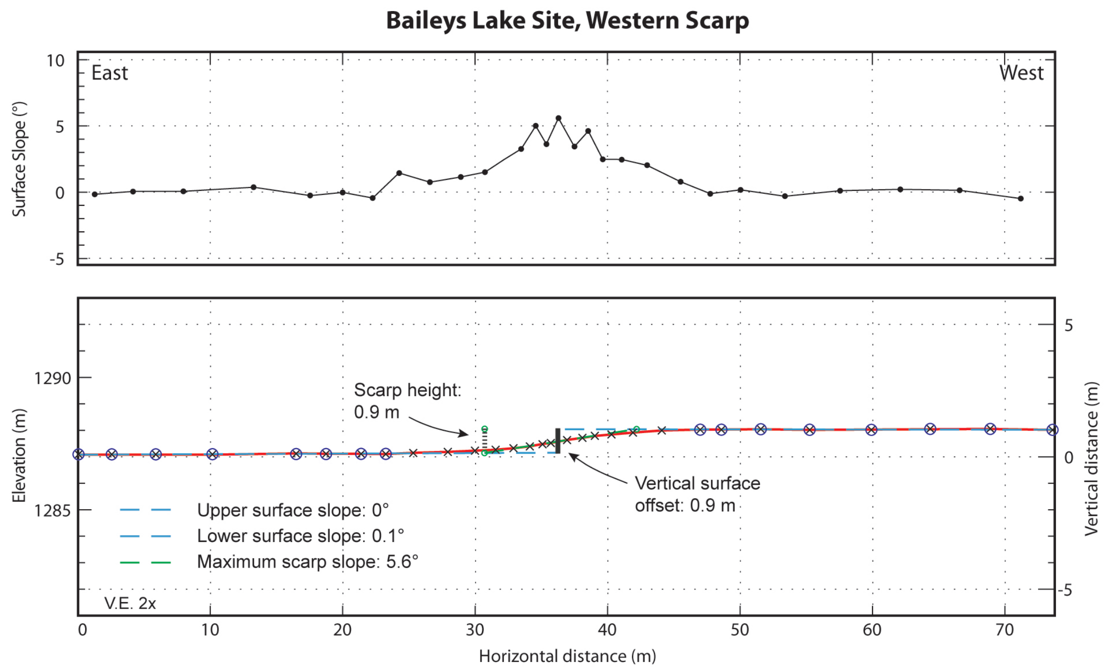


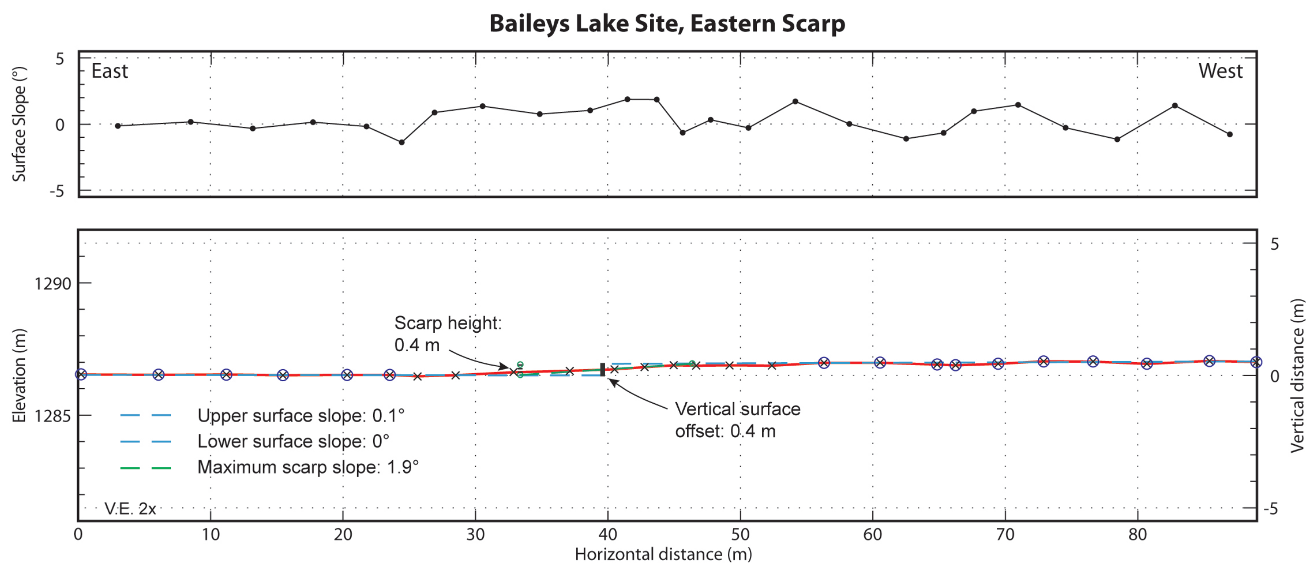

*LiDAR image from Utah Automated Geographic Reference Center (2006; 2 m, illumination from NW)*

# Baileys Lake Trench Site – Site Topography from GPS Survey

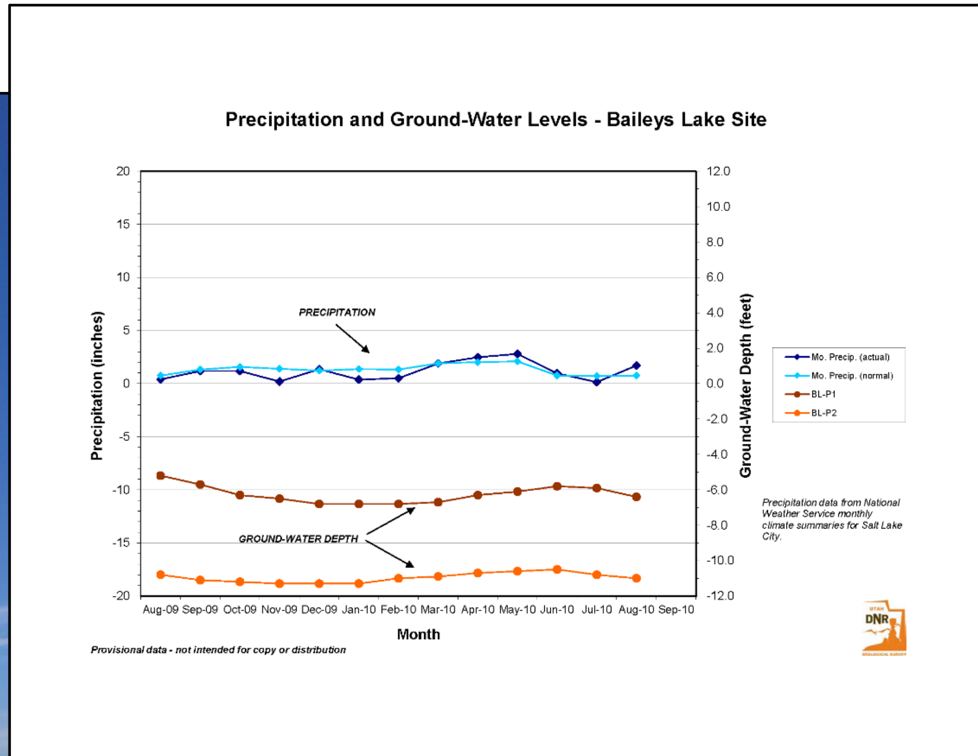


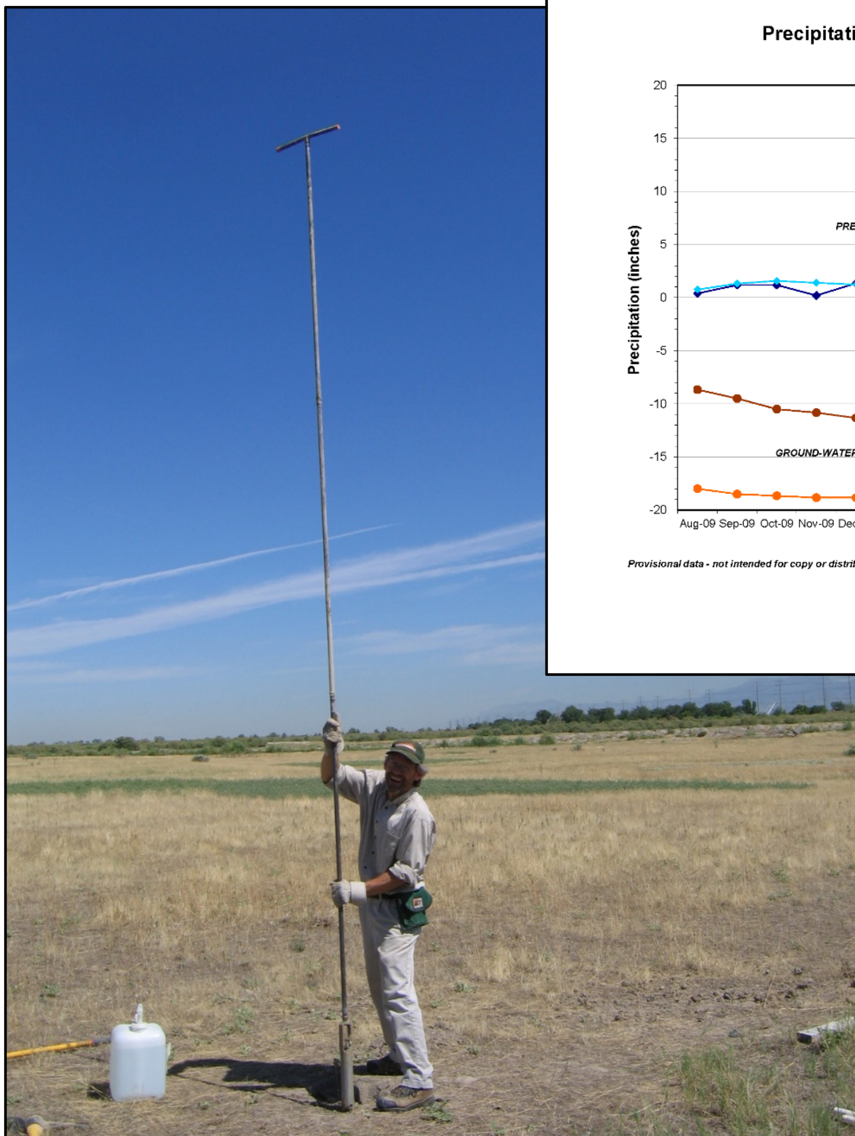
# Baileys Lake Trench Site – Scarp Profiles

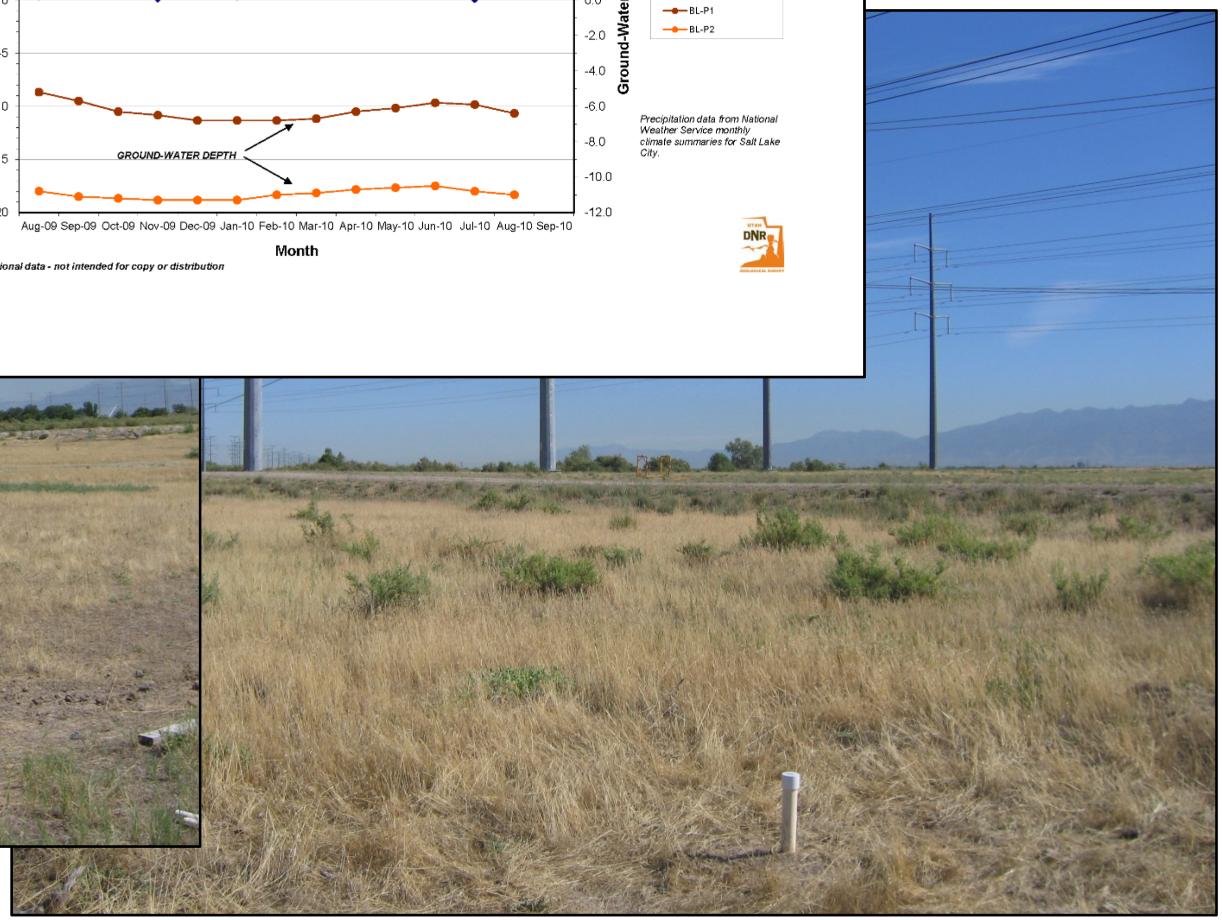


# Baileys Lake Trench Site – Groundwater Levels



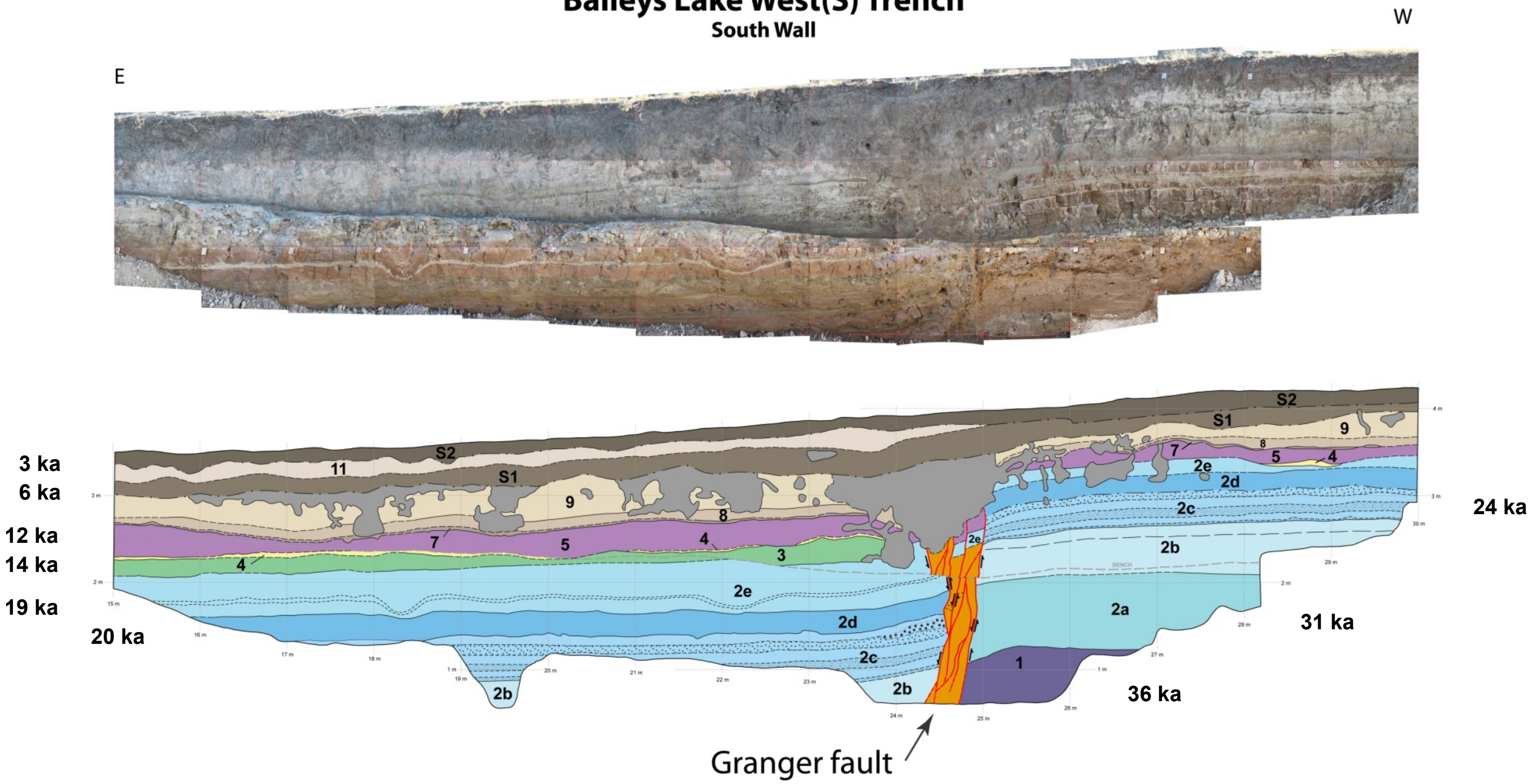


# Baileys Lake Trench Site – Trenching Equipment

# Baileys Lake Trench Site – Trench Configuration

# Baileys Lake West(S) Trench

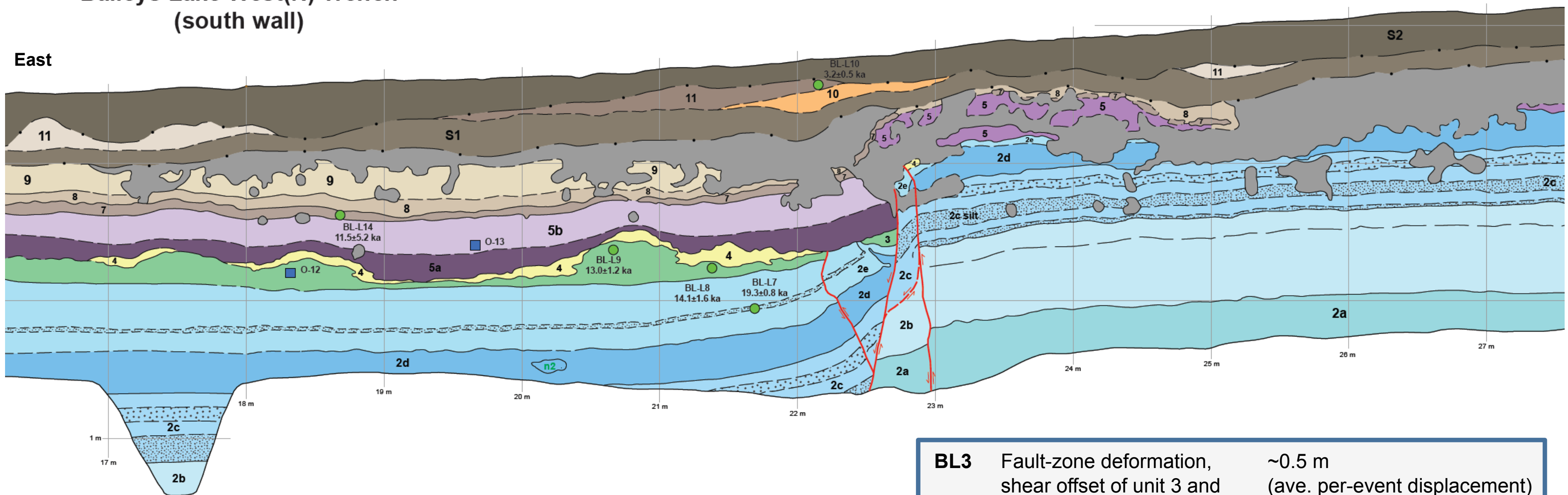
## South Wall




| | |
|---|---|
| S2 | Modern soil (A horizon) |
| S1 | Buried soil (Bt horizon) |
| 11 | Loess (younger) |
| 9 | Loess (older) |
| 8 | Laminated marl (Gilbert phase) |
| 7 | Shoreline sand (Gilbert phase) |
| 5 | Laminated marl (Gilbert phase) |
| 4 | Shoreline tufa (Gilbert phase) |
| 3 | Bonneville laminated clay and silt (regressive) |
| 2e | Bonneville clay (mid- to late transgressive) |
| 2d | Turbidite marker bed |
| 2c | Bonneville clay with turbidites (transgressive) |
| 2b | Bonneville clay (transgressive) |
| 2a | Bonneville sand, silt, clay (early transgressive) |
| 1 | Wetland/alluvial marsh (pre-Bonneville) |
| | Sheared sediment |
| | Burrowed sediment |

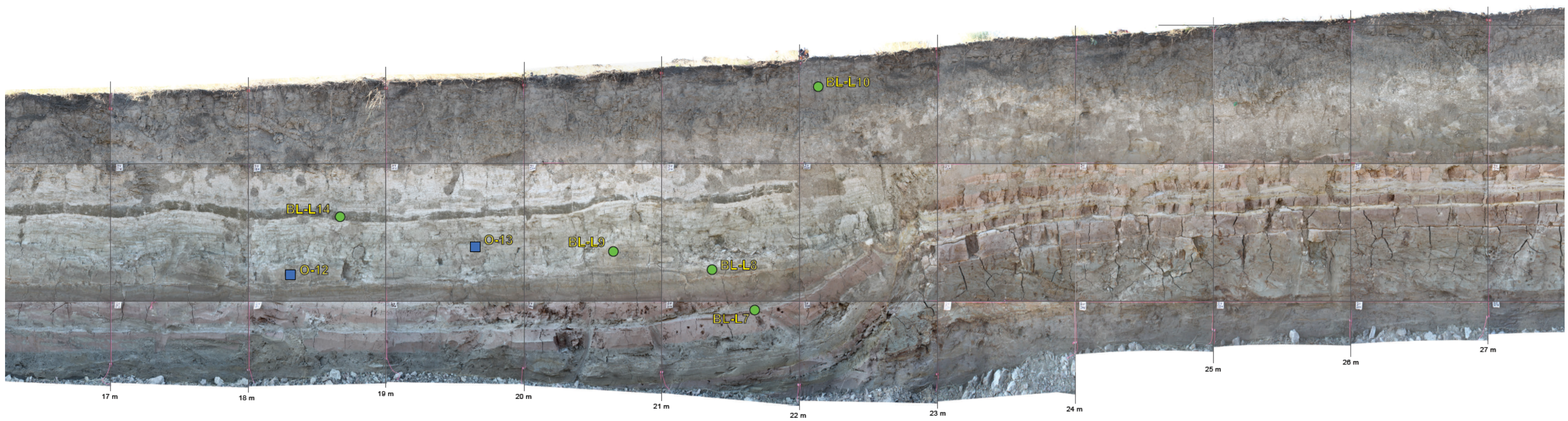
Note: Units 6 and 10 are scarp-derived colluvial wedges associated with the two most recent surface-faulting earthquakes; not mapped on this log.

## Baileys Lake West(N) Trench
## (south wall)

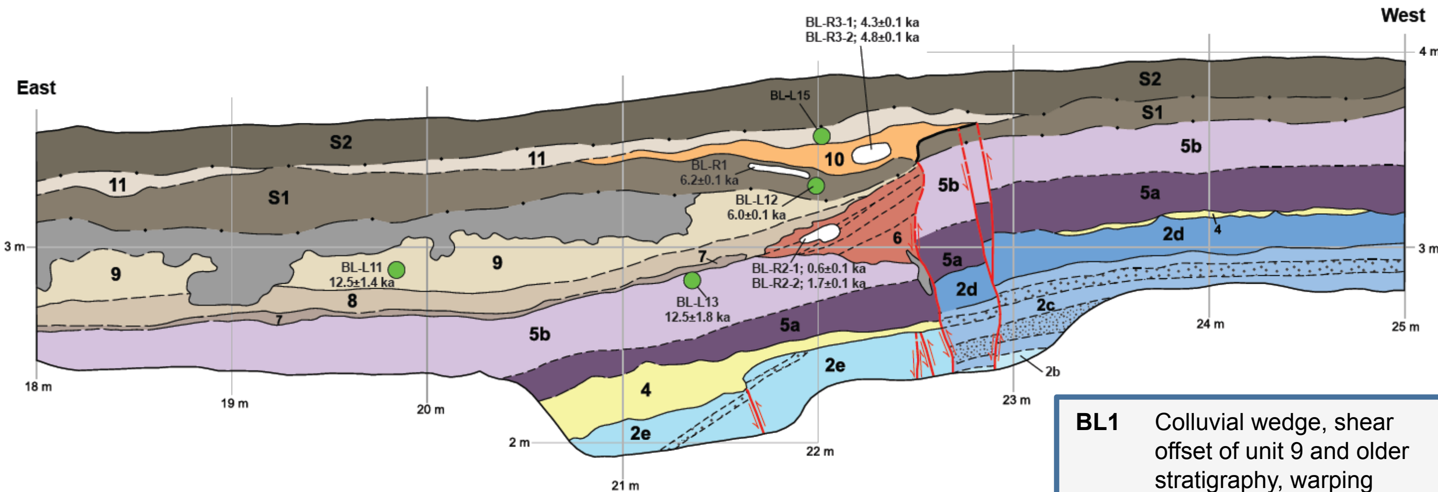



| | | |
|---|---|---|
| **BL3** | Fault-zone deformation, shear offset of unit 3 and older stratigraphy | ~0.5 m (ave. per-event displacement) |
| **BL4** | Warping of pre-unit 3 stratigraphy, thinning of unit 2e | ~0.5 m (ave. per-event displacement) |

## Photomosaic of Baileys Lake West(N) Trench
## (south wall)

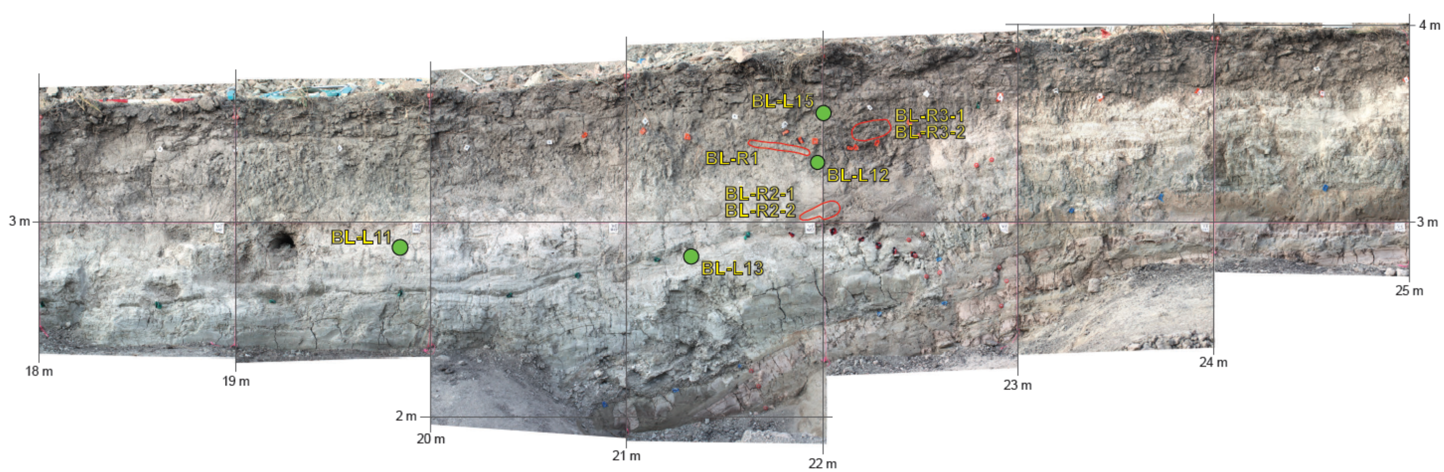


## Baileys Lake West(N) Trench (north wall, mirror image)

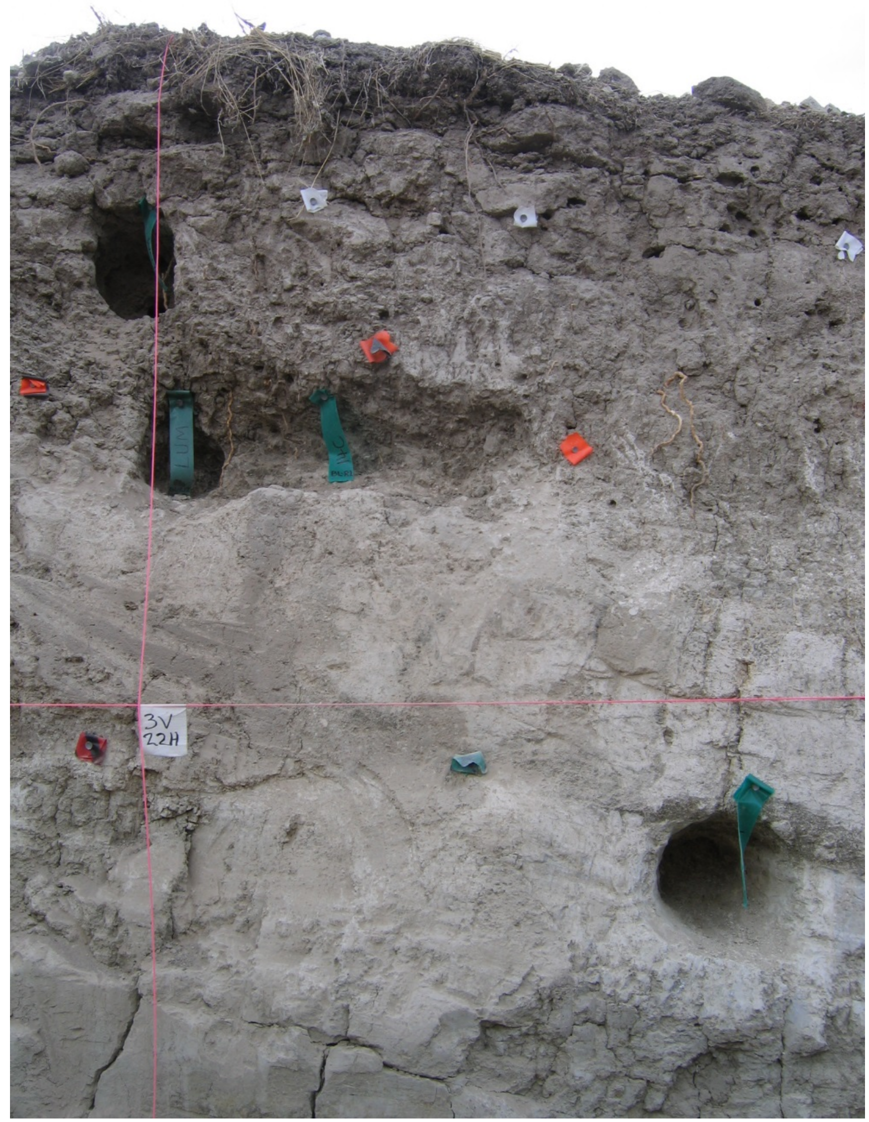



| | | |
|---|---|---|
| **BL1** | Colluvial wedge, shear offset of unit 9 and older stratigraphy, warping | 0.17 (max. wedge thickness)<br>+ 0.3 (warping)<br>0.47 m |
| **BL2** | Colluvial wedge, shear offset of unit 5 and older stratigraphy | ~0.5 m<br>(max. wedge thickness) |

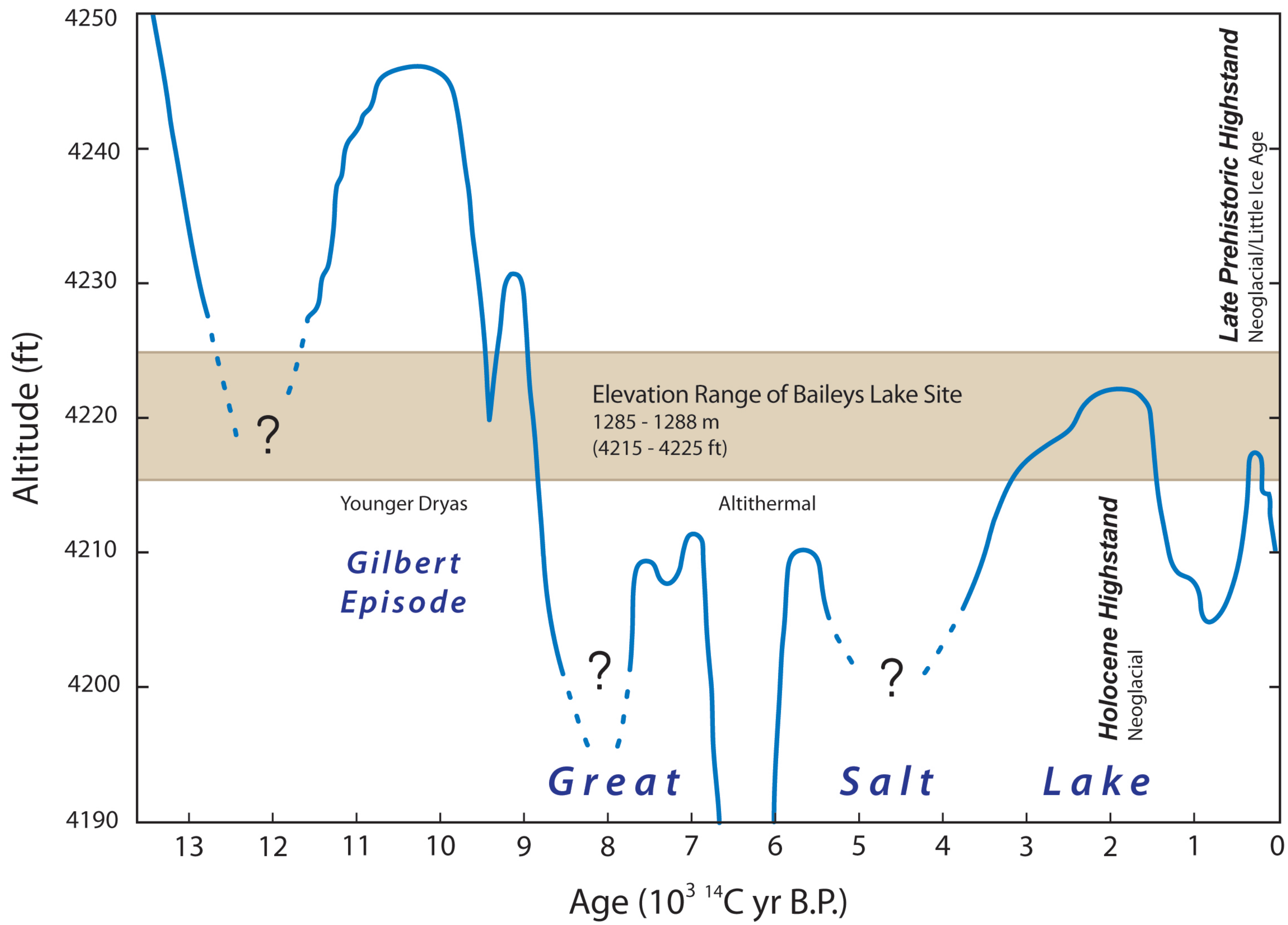
## Photomosaic of Baileys Lake West(N) Trench (north wall, mirror image)



# Baileys Lake Trench Site – OSL, C-14, and Ostracode Sampling

# Baileys Lake Trench Site
# Reconstructing Water Saturation History of OSL Samples

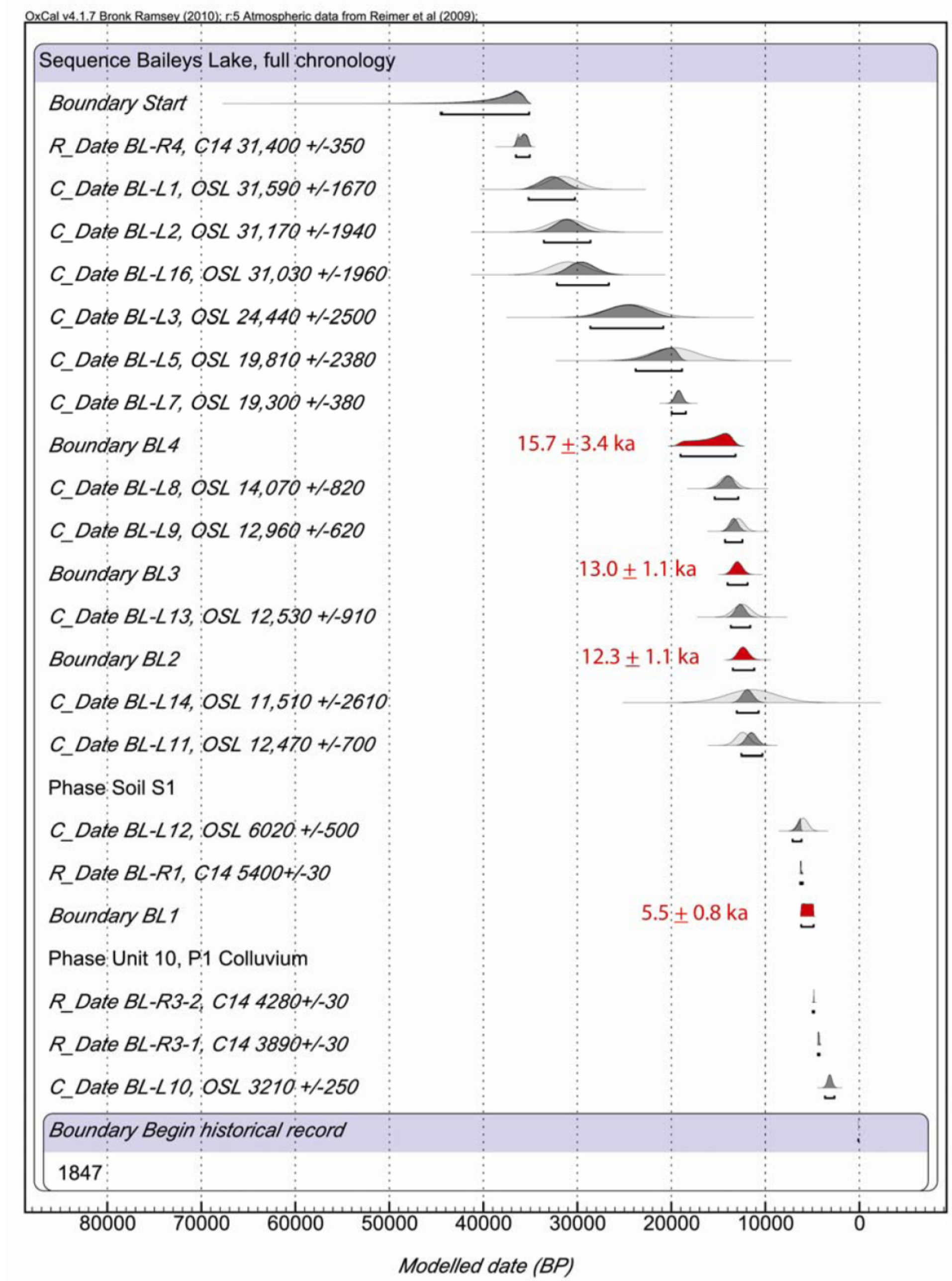


# Baileys Lake Site – OxCal Model Results

## 13 OSL ages, 4 $^{14}$C ages used in model

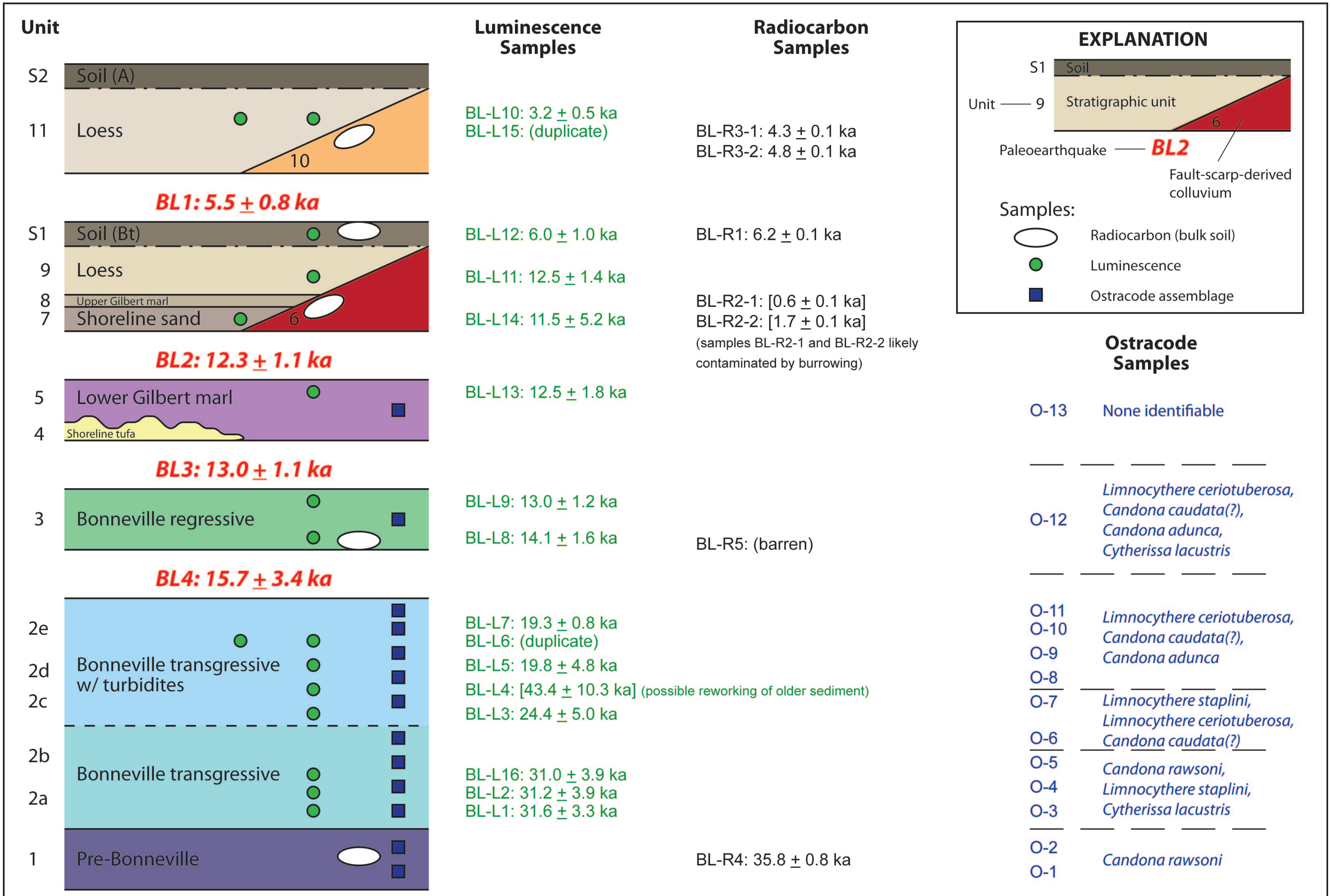
**Model Output**

| Baileys Lake Full Chronology | Unmodelled (BP) mean | Unmodelled (BP) sigma | Modelled (BP) mean | Modelled (BP) sigma | Agreement |
|---|---|---|---|---|---|
| Boundary Start | 38450 | 3010 | | | |
| R_Date BL-R4, C14 31,400 ±350 | 35850 | 420 | 35780 | 410 | 99.7 |
| C_Date BL-L1, OSL 31,590 ±1670 | 31530 | 1670 | 32660 | 1250 | 97.5 |
| C_Date BL-L2, OSL 31,170 ±1940 | 31110 | 1940 | 31090 | 1240 | 119 |
| C_Date BL-L16, OSL 31,030 ±1960 | 30970 | 1960 | 29470 | 1400 | 95.6 |
| C_Date BL-L3, OSL 24,440 ±2500 | 24380 | 2500 | 24730 | 1990 | 109.3 |
| C_Date BL-L5, OSL 19,810 ±2380 | 19750 | 2380 | 21050 | 1340 | 112.5 |
| C_Date BL-L7, OSL 19,300 ±380 | 19240 | 380 | 19210 | 380 | 100.3 |
| **Boundary BL4** | | | **15700** | **1690** | |
| C_Date BL-L8, OSL 14,070 ±820 | 14010 | 820 | 14080 | 630 | 112.5 |
| C_Date BL-L9, OSL 12,960 ±620 | 12900 | 620 | 13360 | 460 | 95 |
| **Boundary BL3** | | | **12960** | **530** | |
| C_Date BL-L13, OSL 12,530 ±910 | 12470 | 910 | 12640 | 520 | 121.2 |
| **Boundary BL2** | | | **12340** | **570** | |
| C_Date BL-L14, OSL 11,510 ±2610 | 11450 | 2610 | 11890 | 580 | 136.2 |
| C_Date BL-L11, OSL 12,470 ±700 | 12410 | 700 | 11450 | 560 | 62.6 |
| Phase Soil S1 | | | | | |
| C_Date BL-L12, OSL 6020 ±500 | 5960 | 500 | 6540 | 260 | 76.8 |
| R_Date BL-R1, C14 5400±30 | 6220 | 50 | 6220 | 50 | 98 |
| **Boundary BL1** | | | **5540** | **400** | |
| Phase Unit 10, P1 Colluvium | | | | | |
| R_Date BL-R3-2, C14 4280±30 | 4850 | 30 | 4850 | 30 | 98.9 |
| R_Date BL-R3-1, C14 3890±30 | 4330 | 50 | 4330 | 50 | 99.9 |
| C_Date BL-L10, OSL 3210 ±250 | 3150 | 250 | 3150 | 250 | 100 |
| Boundary Begin historical record, 1847 | 100 | 0 | 100 | 0 | 100 |



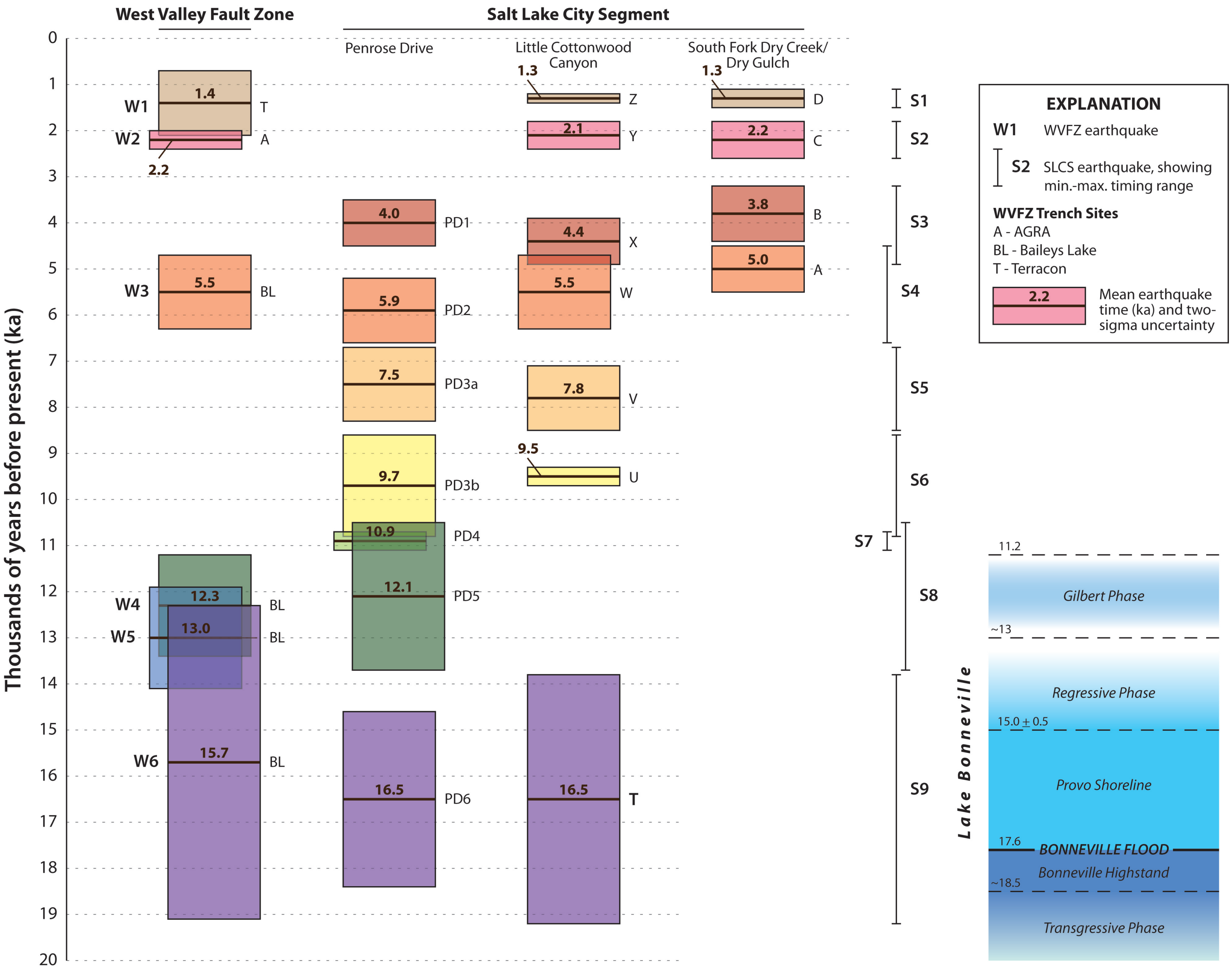

Red = mean earthquake time ± 2σ

# Baileys Lake Site – Chronostratigraphic Summary




*Modeled earthquake times (red) and all numerical ages are reported with two-sigma uncertainty.*
*Brackets indicate age out of stratigraphic order.*

# Comparison of WVFZ and SLCS Paleoearthquake Chronologies




Thank you!
Questions?

# Using Agisoft PhotoScan Professional to Create High-Resolution Trench Logs

**Adam Hiscock**

Geologic Hazards Program

Utah Geological Survey

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Gregg Beukelman

Ben Erickson

Chris DuRoss

Scott Bennett

Nadine Reitman

Ryan Gold

Rich Briggs

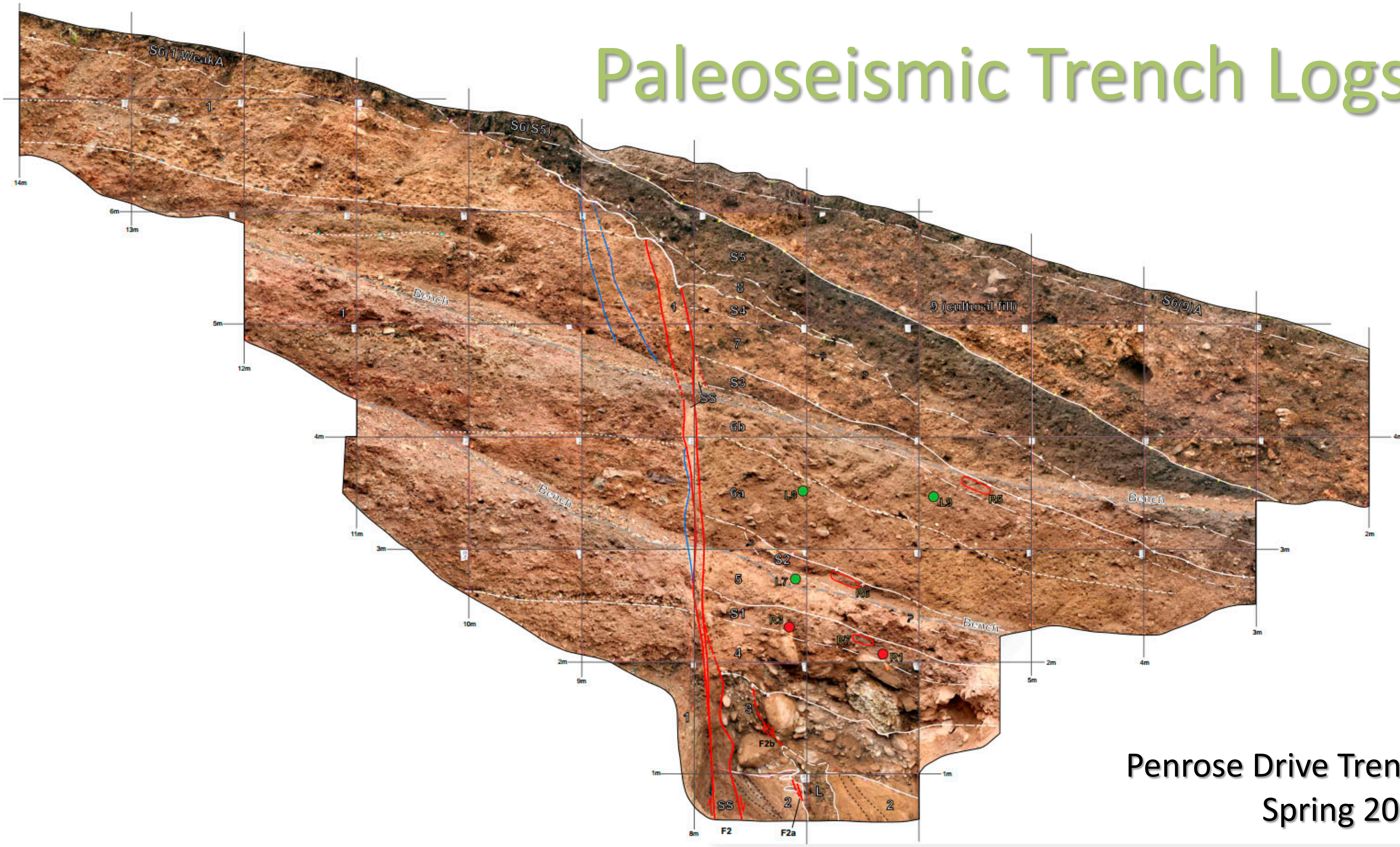
Basin & Range Province Seismic Hazards Summit III – January 9, 2015

# What is Agisoft Photoscan?

- Photogrammetric software for creating high-resolution georeferenced orthophotos and highly detailed DEM's.
- Partially automated – streamlined and easy user interface
- Many uses – Paleoseismology, landslides, paleontology, site mapping, archaeology, etc.

Agisoft
3D Modeling and Mapping

# Paleoseismic Trench Logs




Penrose Drive Trench
Spring 2010

- High-resolution photo mosaic of trench wall for detailed logging of various stratigraphic and tectonic contacts.

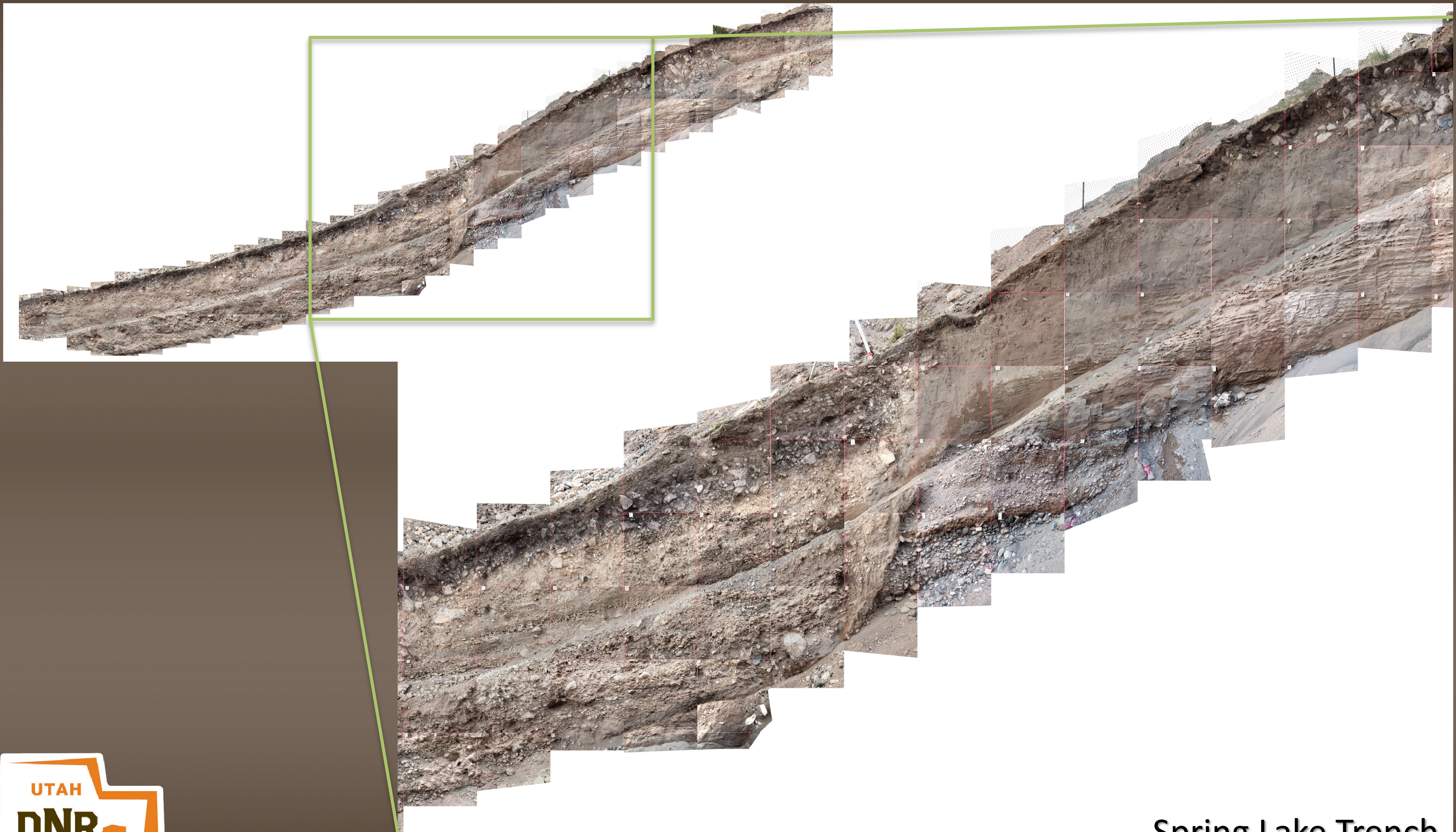
# Old Method – Field Workflow

- Grid trench walls using Total Station surveying equipment – 1 x 1 meter grid.
- String grid lines (vertical & horizontal).
- Label grid intersection points
- Photograph every 1m square - taking care to stay orthogonal to wall. Include grey card for color correction in every photo.
- For partial squares, measure distances to nearest intersection point.

# Old Method – Adobe Photoshop Workflow

- Download photos.
- Apply grey card color correction.
- Crop to 1x1 grid using lines on photo.
- Use Photoshop Free Transform tools (Skew & Warp) to match features between photos, and to warp partial squares to fit grid.
- Print 11x17 inch portions, mount on foam-core with Mylar Overlay for field mapping.
- Log faults and contacts in field.

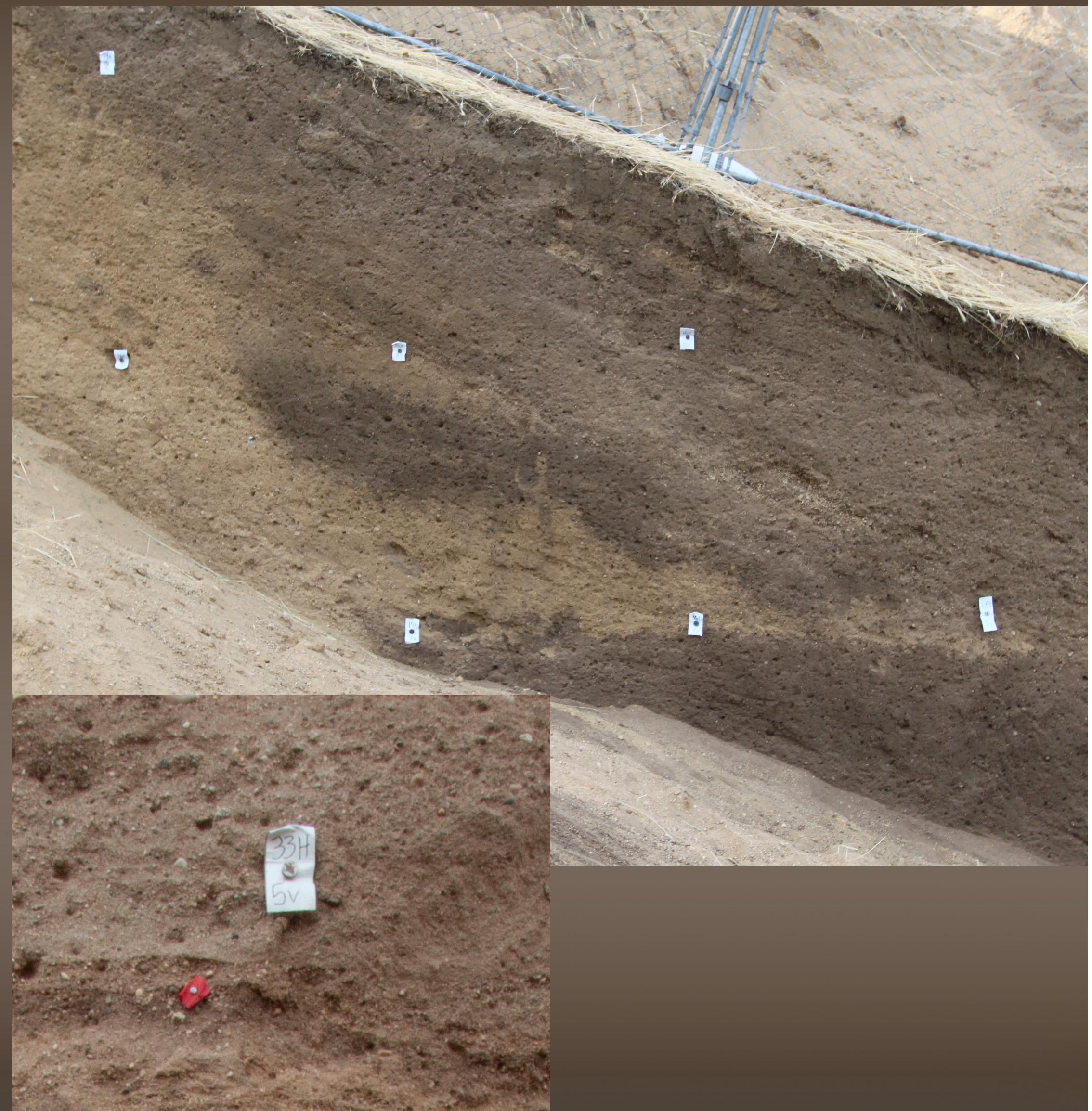
# Old Method – Adobe Photoshop Workflow



Spring Lake Trench
Spring 2012

# New Method – Field Workflow

- Grid trench walls using Total Station
- Pound spikes at every 1 meter grid intersection point
- Label every spike with horizontal & vertical coordinates
- Photograph trench walls, aiming for 50-60% overlap horizontally & vertically
- Re-survey every spike head and store in Total Station (for later use as Ground Control Points in Agisoft)



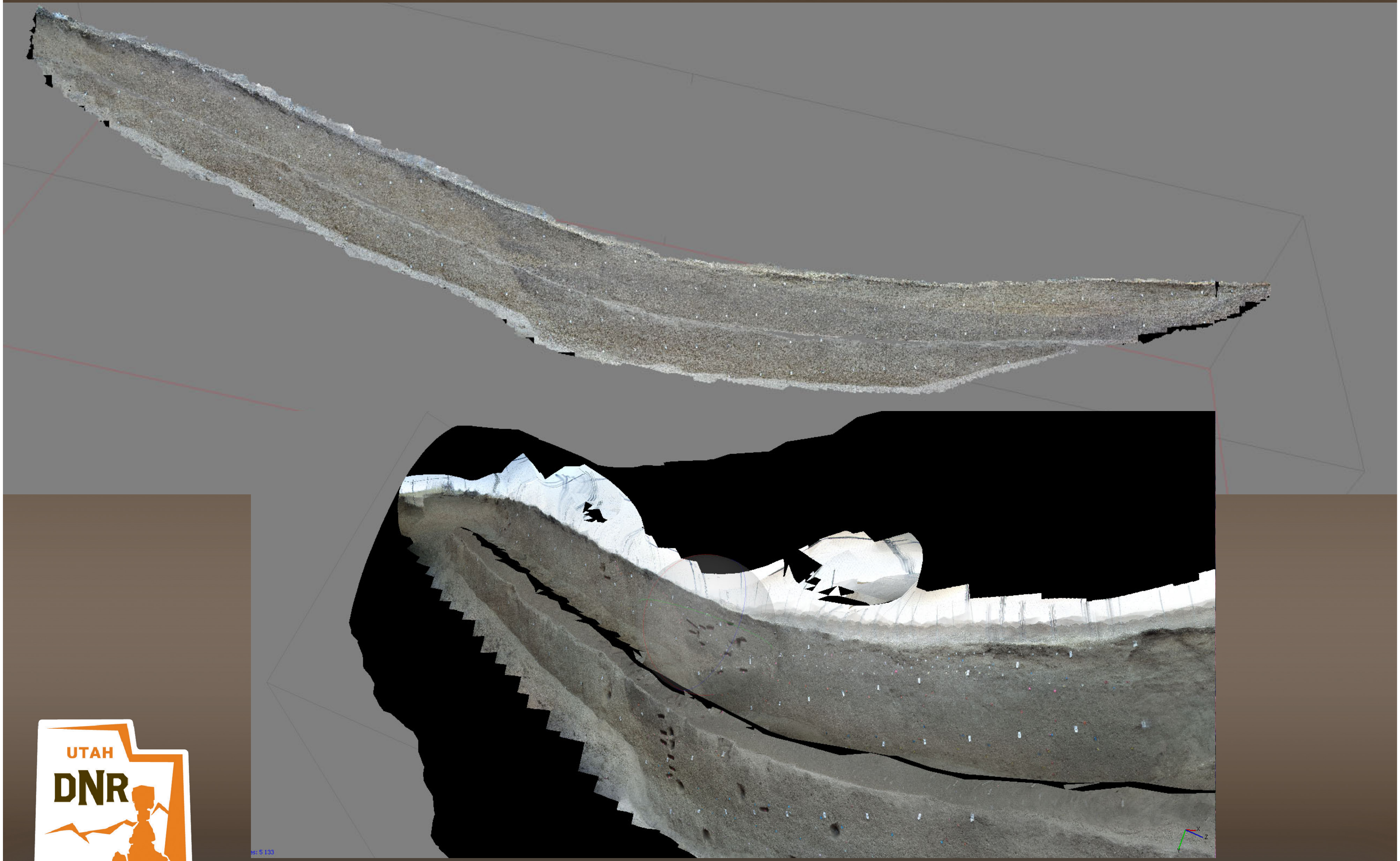
# New Method – Agisoft Workflow

- Download Photos
- Load photos into Agisoft
- Perform initial alignment of photos – having geo-tag information in metadata speeds up this process
  - Builds point cloud with RGB values
- Add Ground Control Points (GCP) from total station survey
  - GCP's should be well distributed spatially, for best accuracy
  - More GCP's = lower photo alignment error
  - Add approximately 20 GCP's to save time
- Build Mesh & Texture – Builds DEM based on photos
- Export Orthophoto as PNG or TIFF

# New Method – Agisoft Workflow

- Load orthophoto into ArcGIS
- Georeference to 1x1 meter grid using spike locations on photo
- Print 11x17 inch portions of photo for field mapping
- Mount on foam-core with Mylar overlay
- Log faults and contacts in field!

# Agisoft Trench Log Samples



# Agisoft Trench Log Samples

Corner Canyon Trench
South Wall
June 2014

UTAH DNR GEOLOGICAL SURVEY

# Agisoft Trench Log Samples

Corner Canyon Trench
South Wall
June 2014

UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

geology.utah.gov

# Agisoft Trench Log Samples

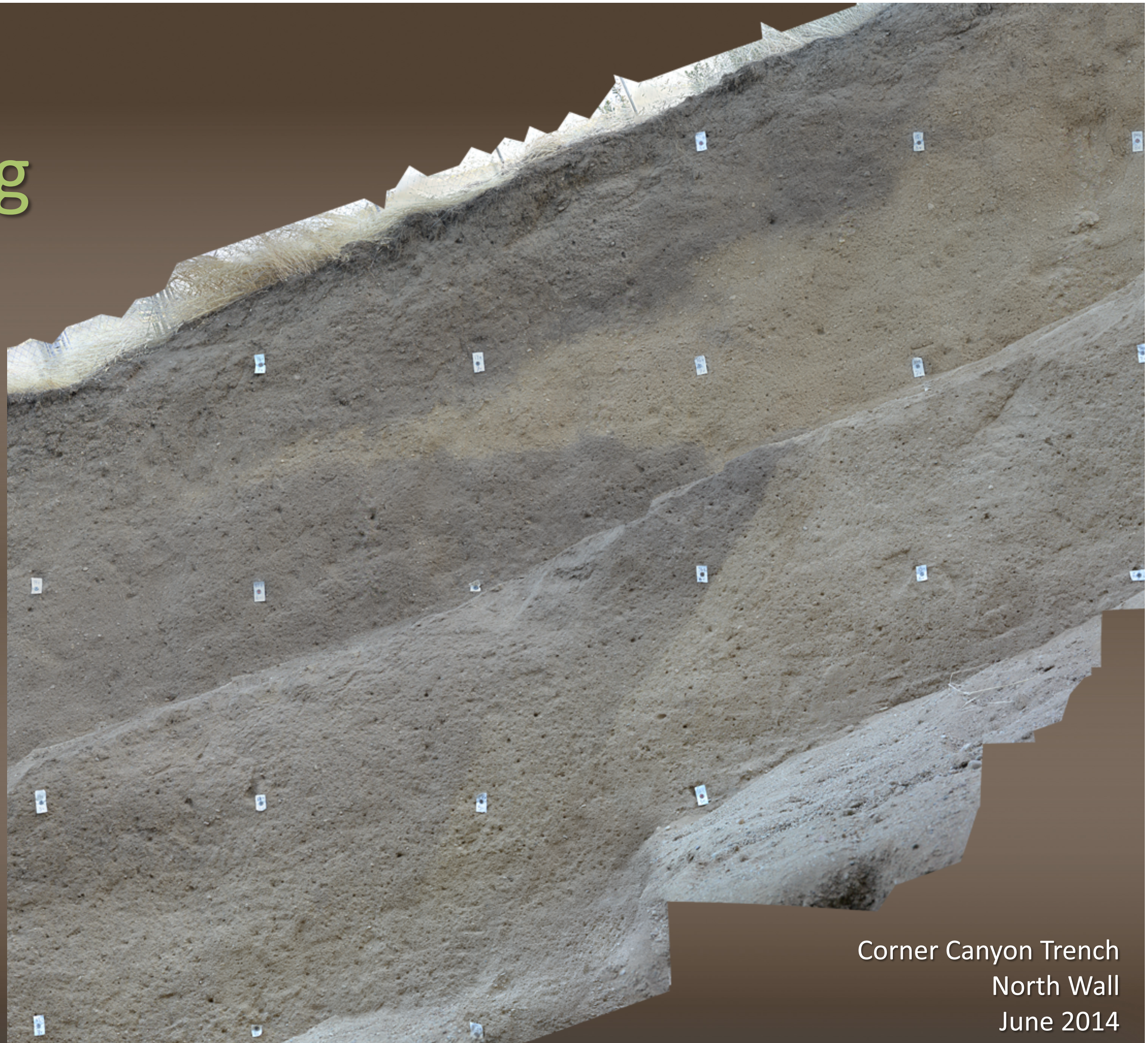
Corner Canyon Trench
North Wall
June 2014

UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

geology.utah.gov

# Agisoft Trench Log Samples



Corner Canyon Trench
North Wall
June 2014

Credit:
Scott Bennett
Nadine Reitman

USGS
science for a changing world

Flat Canyon Trench
North Wall
October 2013

# Agisoft


# Photoshop

# Agisoft Pros/Cons

## Pros

- 4-5 hours per trench wall – mostly automated processing time.
- 3D Representation of trench – including horizontal distances (bench width) and full 3D surface model.
- Much better color blending throughout mosaic – Agisoft automatically color corrects.
- More accurate representation of trench wall (no feature duplication).

## Cons

- Price of software - $3499 professional edition license.
- Requires high processing power to complete model in a reasonable timeframe.

# Photoshop Pros/Cons

## Pros

- Can be completed on any decent computer running Adobe Photoshop.
- Photoshop license - $699 (CS6).
- Final mosaic is slightly higher resolution – no downsampling.

## Cons

- 15-20 hours per trench wall – all human hours, no automation.
- Manual color correction of every photo required.
- While shooting, much more precision and care must be taken to align camera with wall, etc.
- Much poorer color and geometric blending between photos.

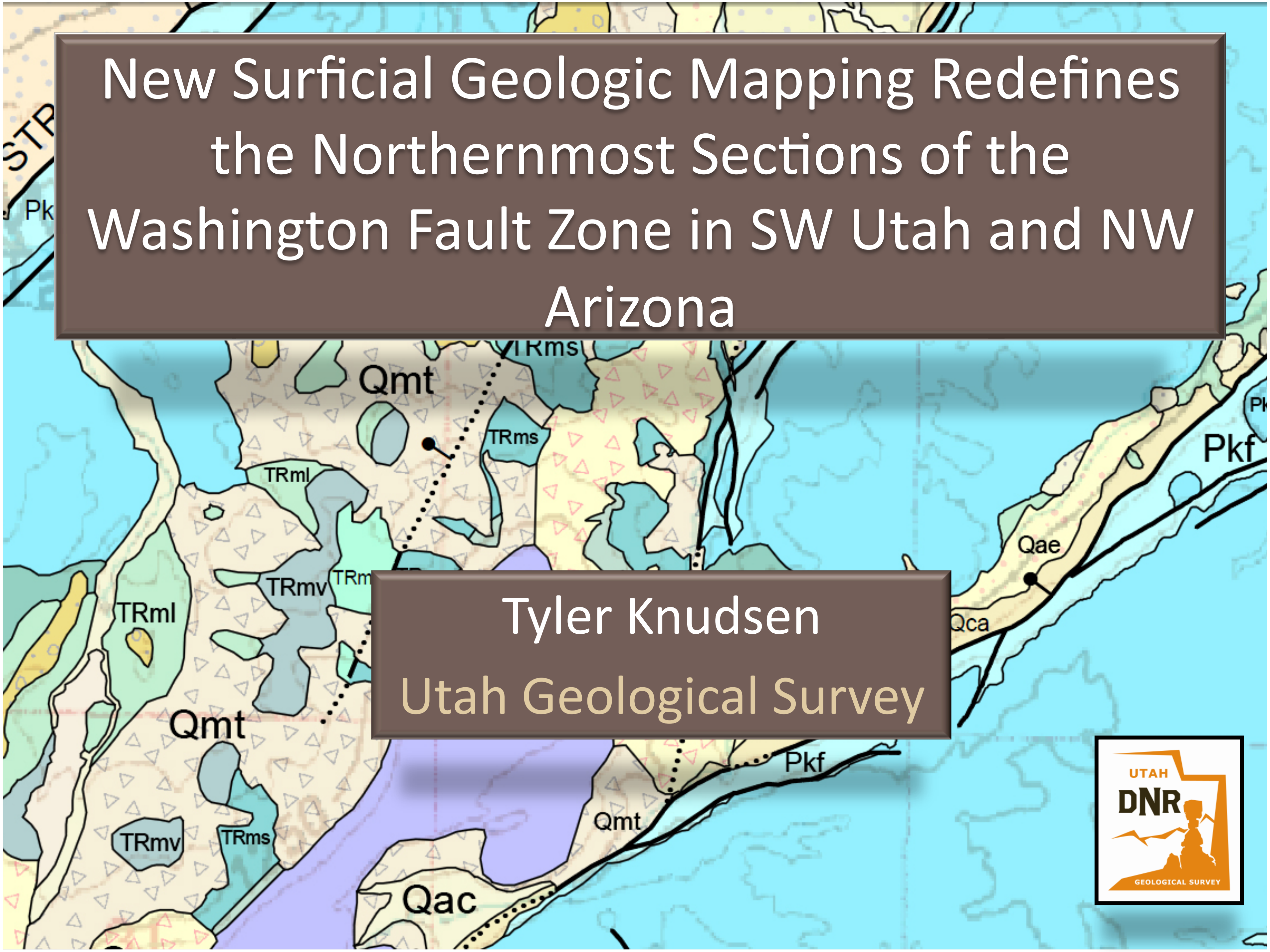
# Summary

- Very powerful tool – many different uses.
- Still learning how to use the software – we have just scratched the surface of what is capable with Agisoft.
- Speeds up trenching projects drastically by reducing down time waiting for trench logs to be completed.
- Can be used with minimal training

# New Surficial Geologic Mapping Redefines the Northernmost Sections of the Washington Fault Zone in SW Utah and NW Arizona

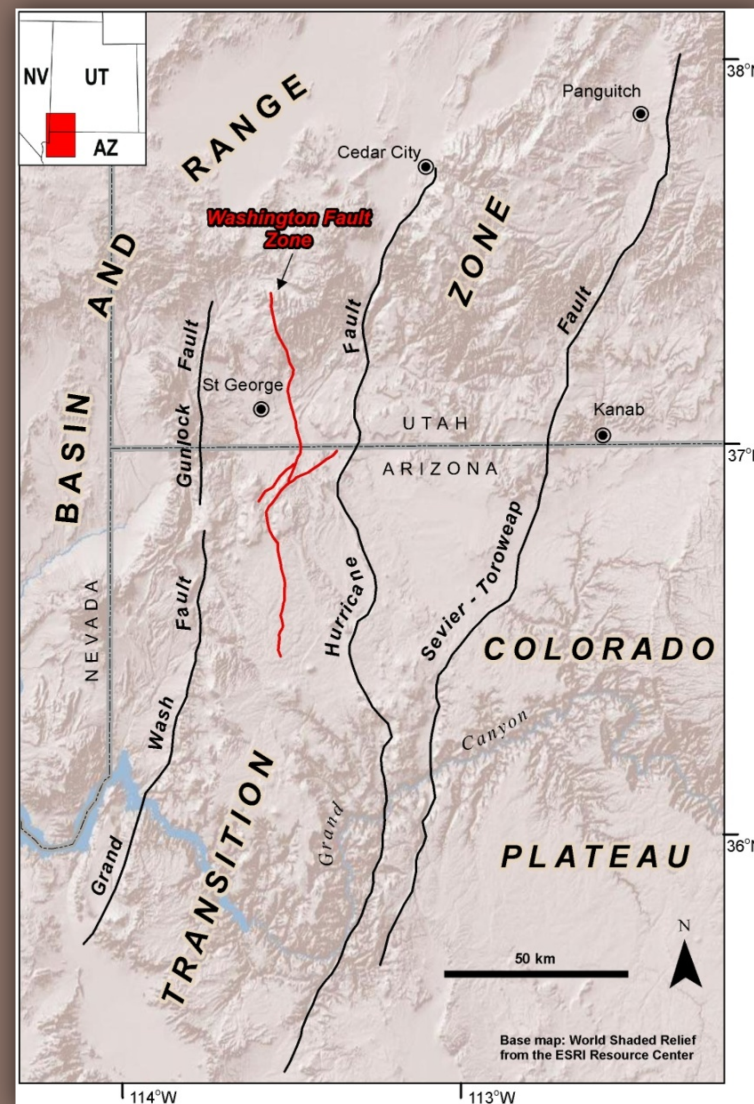

Tyler Knudsen

Utah Geological Survey

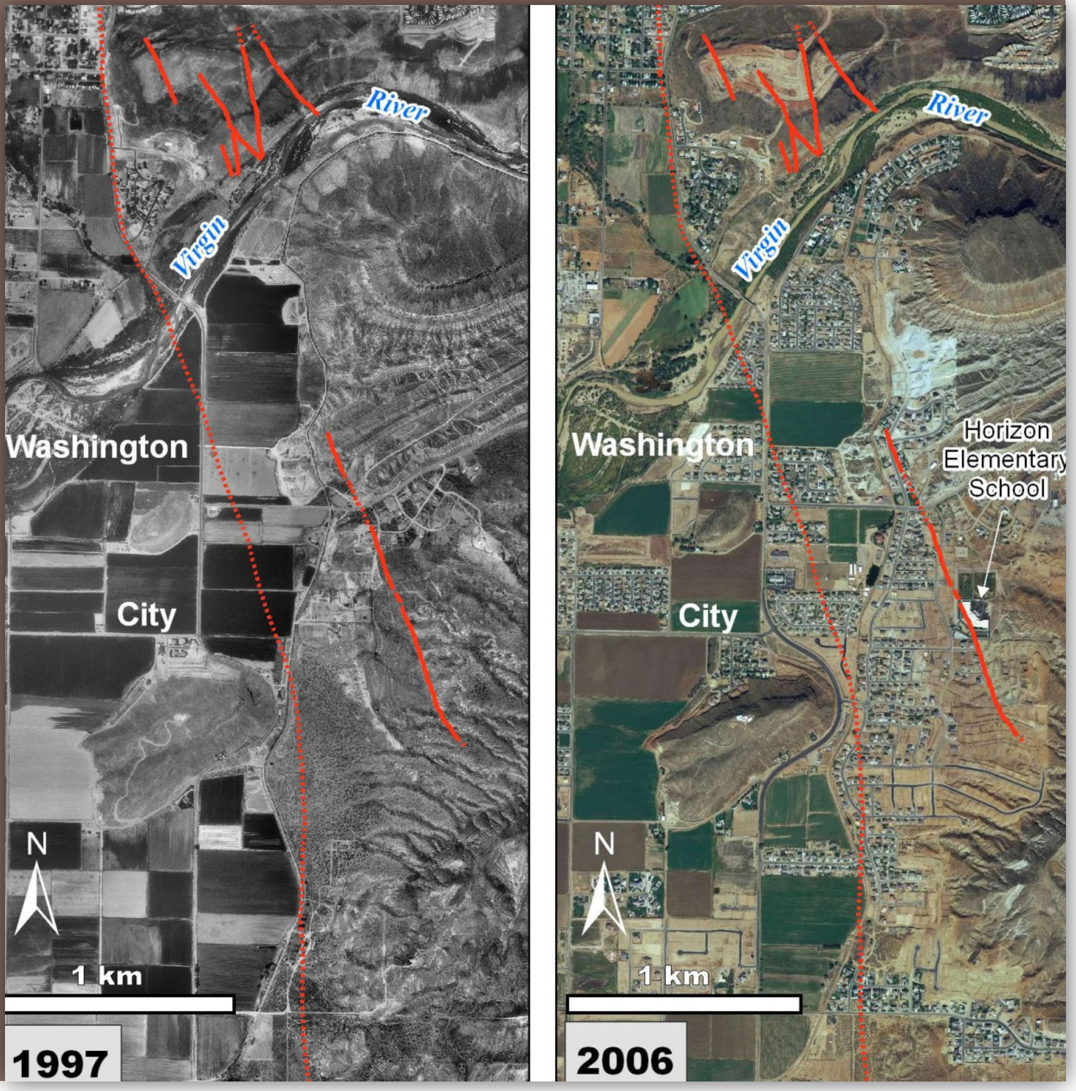
# Washington Fault Zone

- Within transition zone
- Extends into Utah & Arizona
- ~~75~~ 97 km long
- Maximum displacement of ~700 m just south of UT-AZ border



# Why Study the Washington Fault?

- Traverses heavily populated St. George Basin
- Only cursory study in 80s & 90s
- Moved to near top of UQFPWG's priority list in 2008
- NEHRP funding to complete & publish:
  - Detailed geologic mapping
  - Trenching
  - Basalt sampling



# Washington Fault

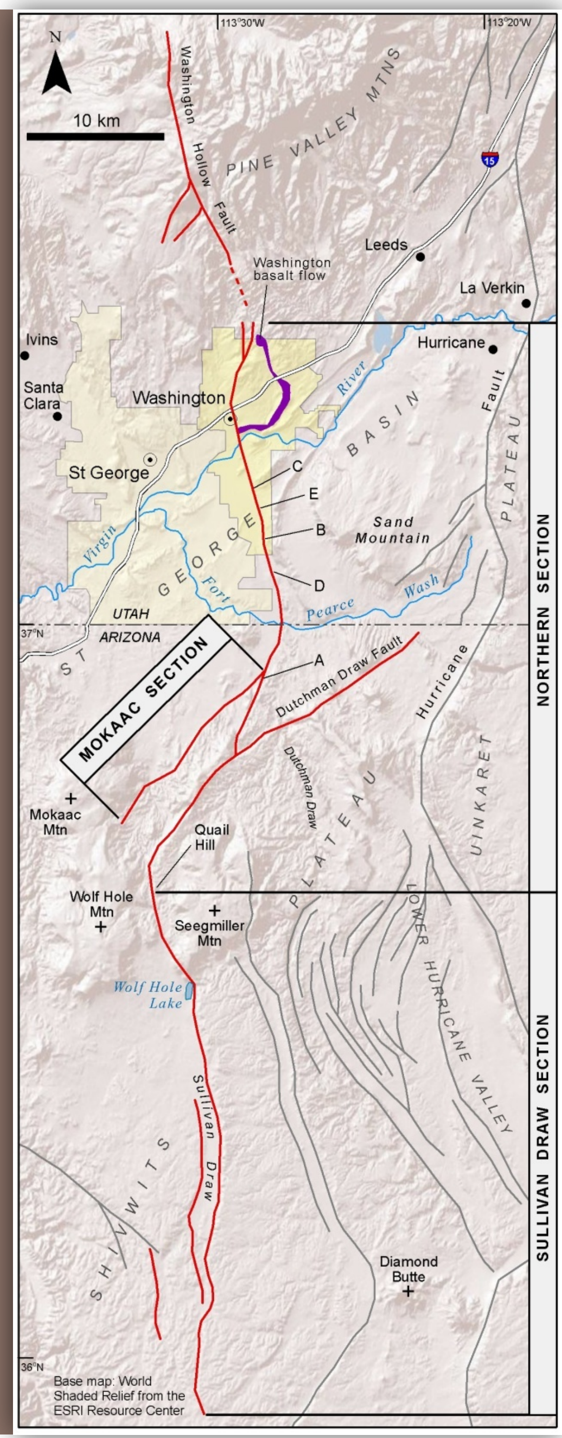
- Divided into three sections by AZ Survey
  1. Sullivan Draw (36 km)
  2. Northern (39 km)
  3. Mokaac (16 km)

# Mapping Goals

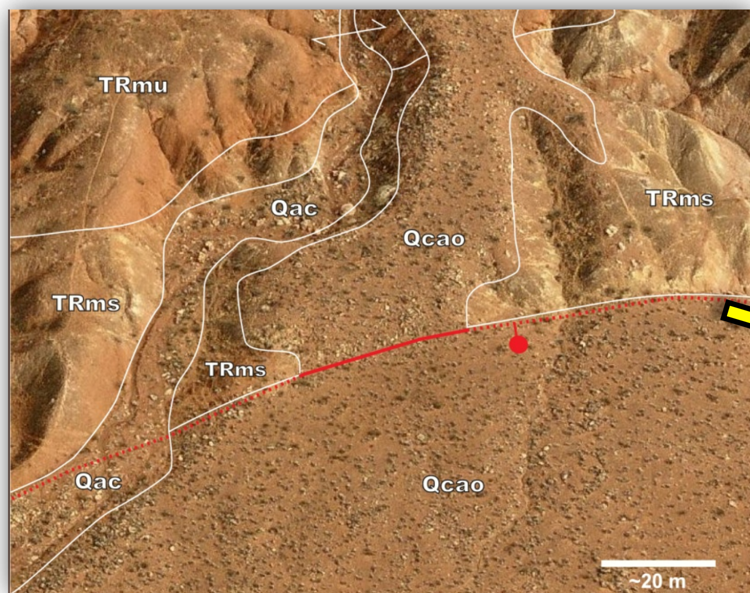
- Refine fault-section model
- Identify suitable trench site(s)

# Methods

- Compile parts of 12 7.5' quads (Hayden, Biek, Willis in UT and Billingsley in AZ)
- Air-photo and field mapping at 1:24k

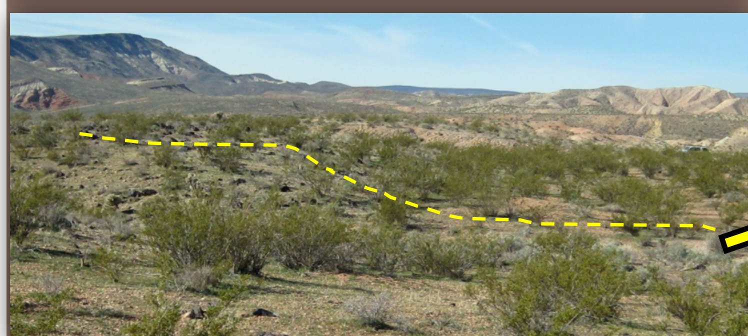


# Scarps on late Pleistocene-Holocene fans

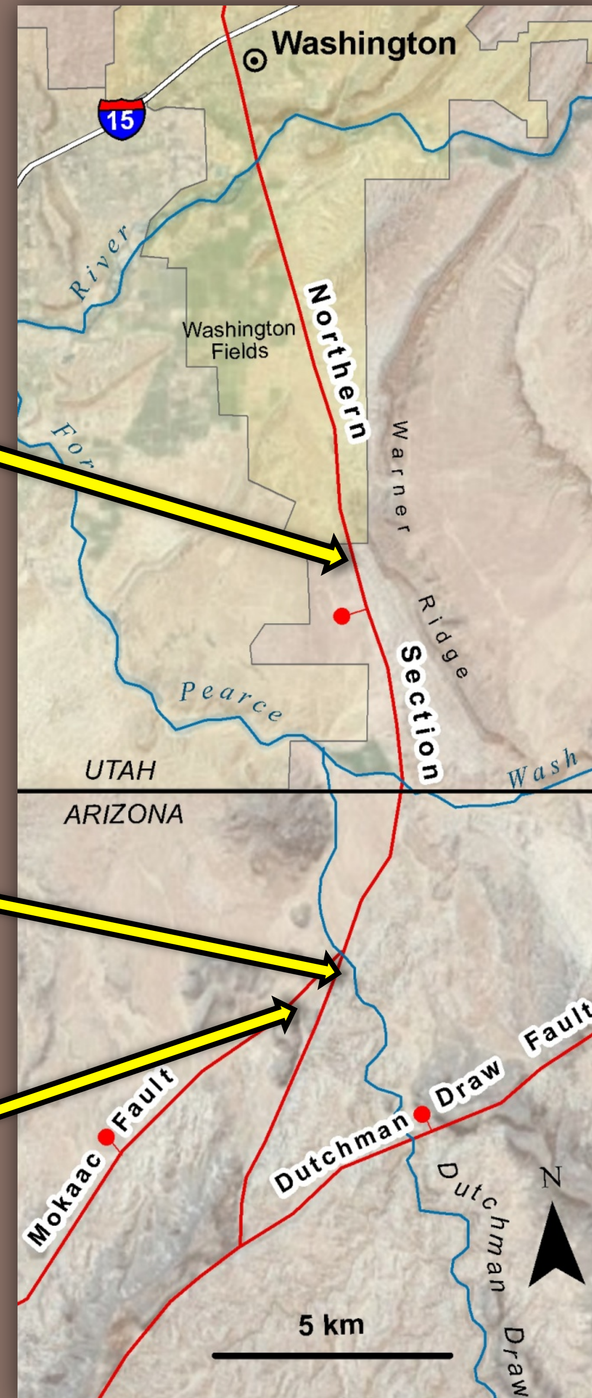



Warner Ridge
Anderson & Christenson, 1989
(bedrock-cored)

Dutchman Draw
Trenched by UGS

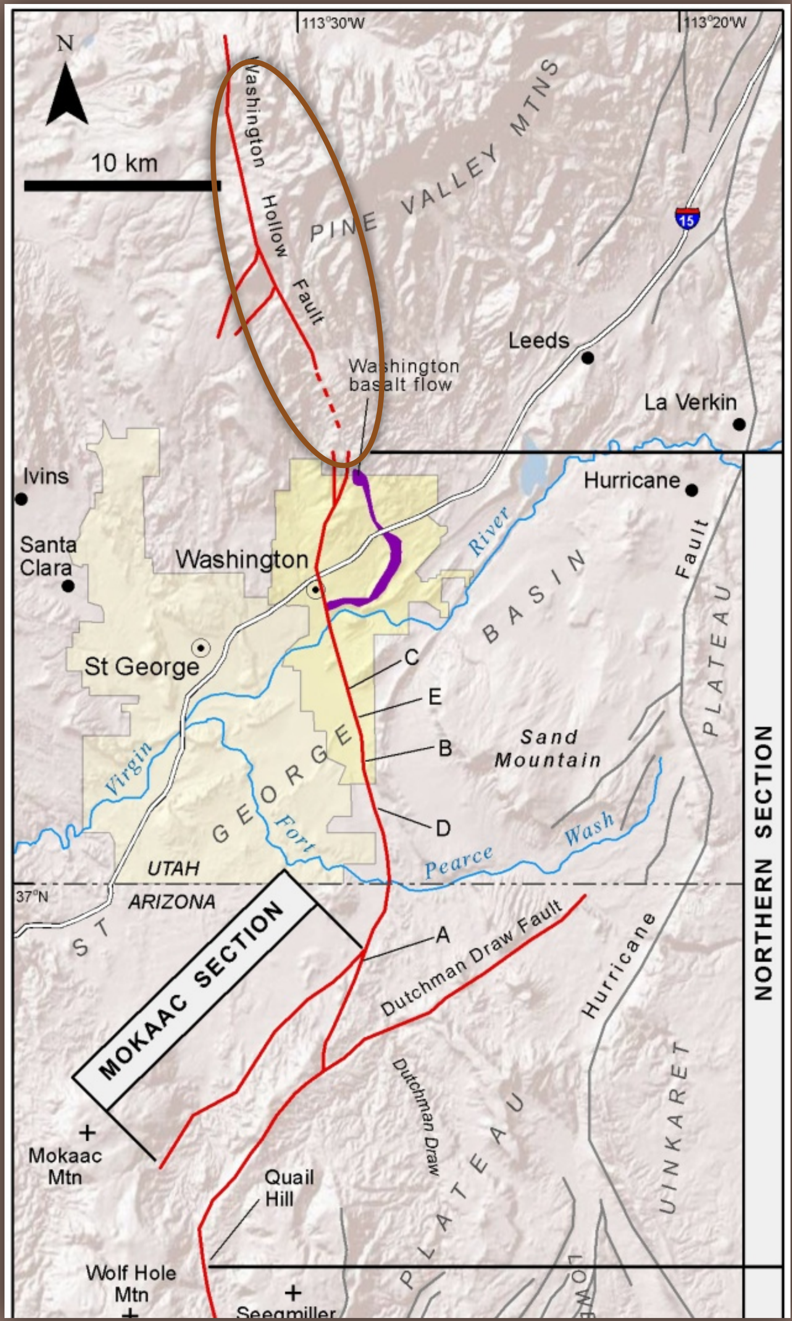


Splay of Mokaac fault



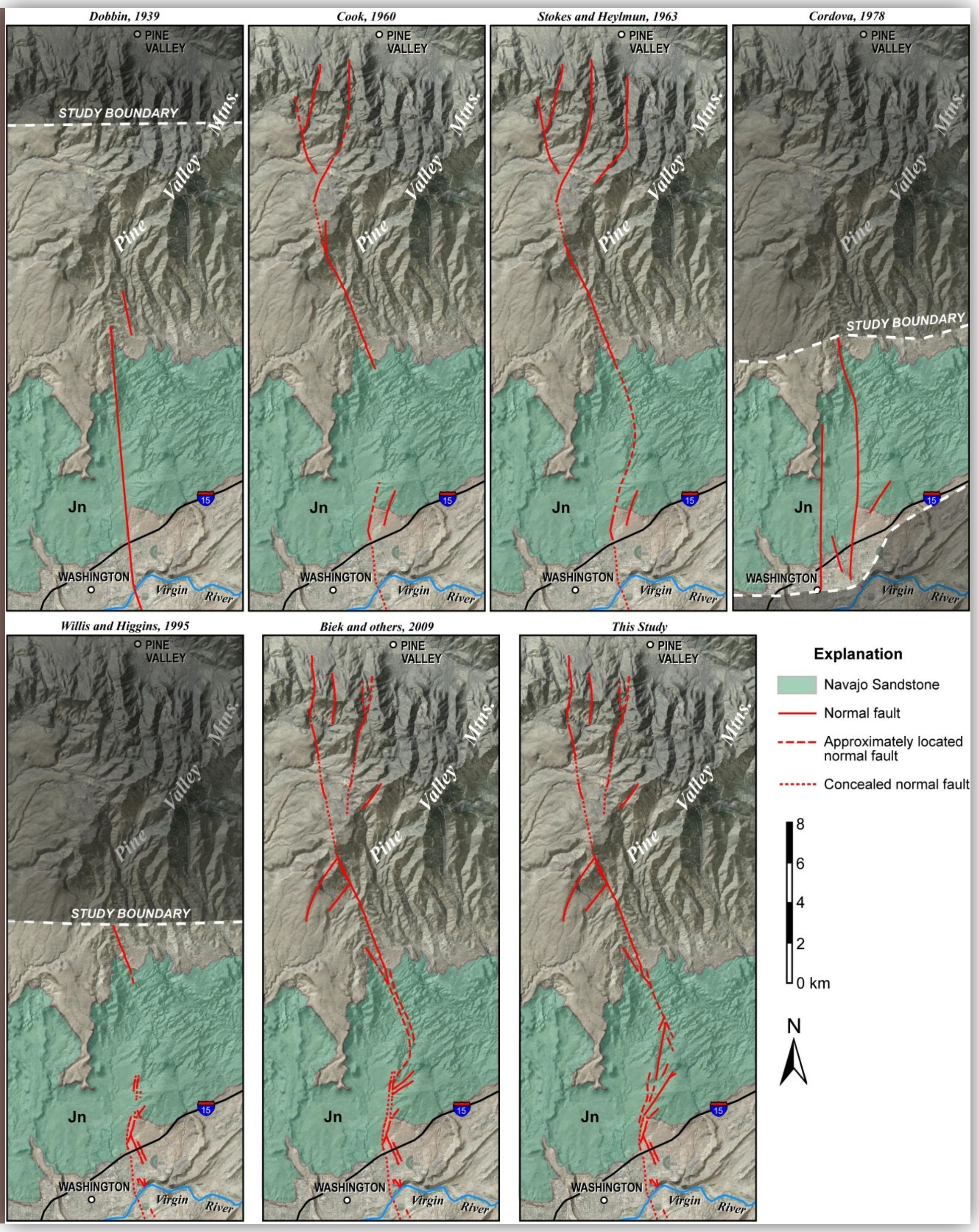
# Washington Hollow Fault—a Northern Extension of the Washington Fault?

- Aligned with Washington fault
- Similar geometry
  - Both are west-dipping
  - Both are NNW-striking



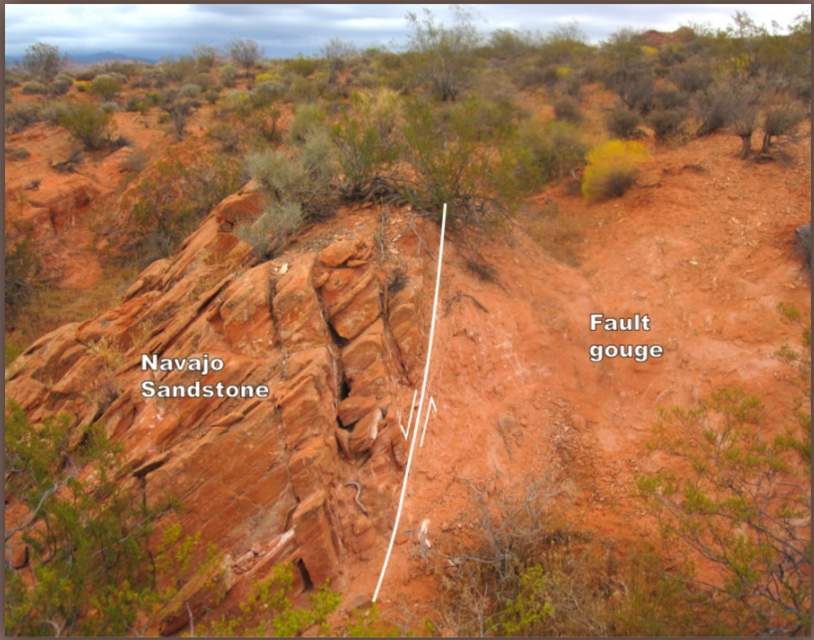
# Washington Hollow Fault

- Has been previously mapped as either a separate fault or an extension of the Washington fault



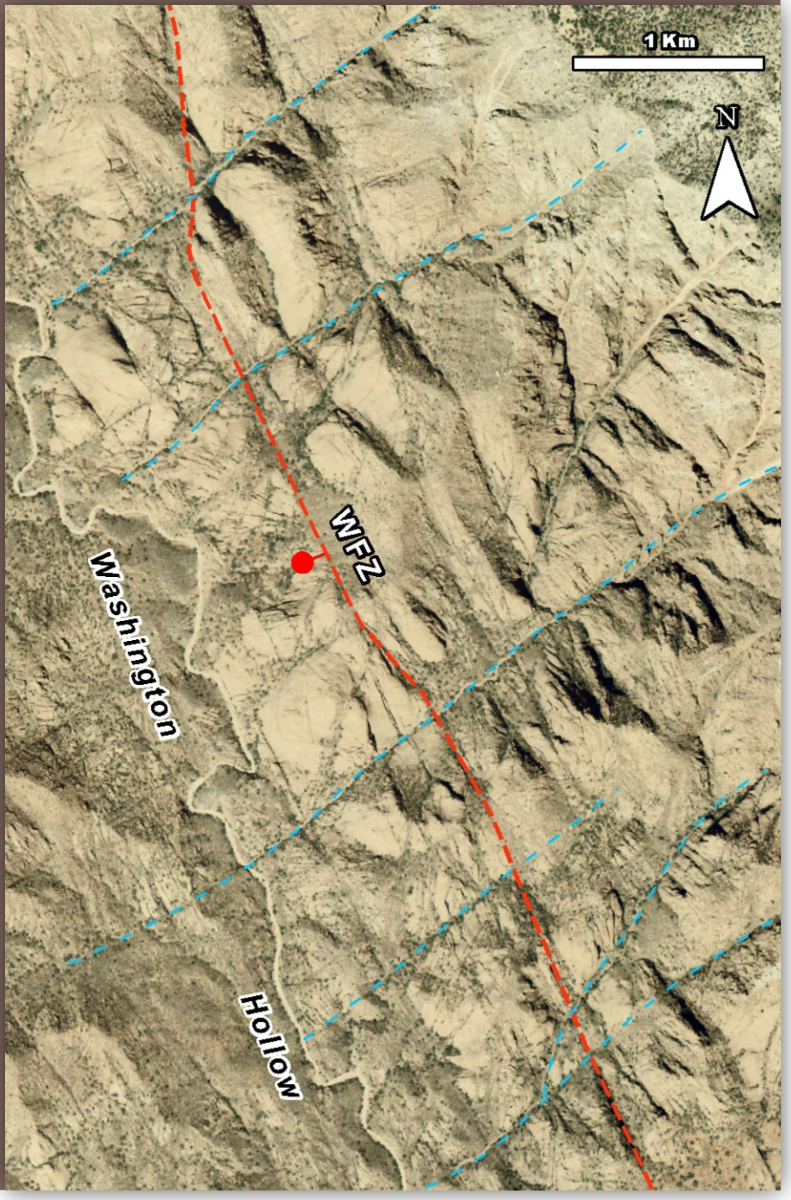
# WHF Most Likely is Part of the Washington Fault

- Evidence for a through-going fault
  - Brecciation zones
  - gouge zones
  - Minor-displacement faulting




# Washington Hollow Section

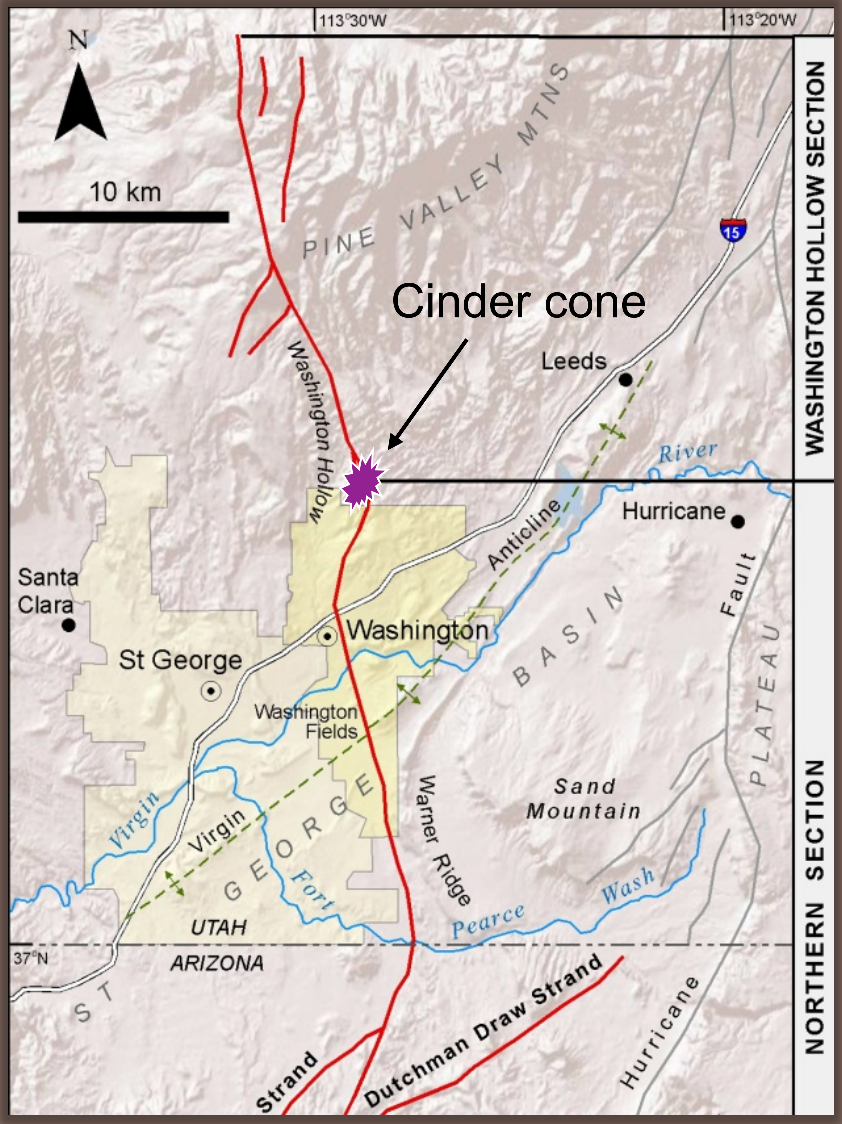
- Thoroughgoing structure appears to be relatively minor
- Does not displace Cretaceous-age joint set (dashed blue lines)
- Limited net vertical displacement



# Washington Hollow Section

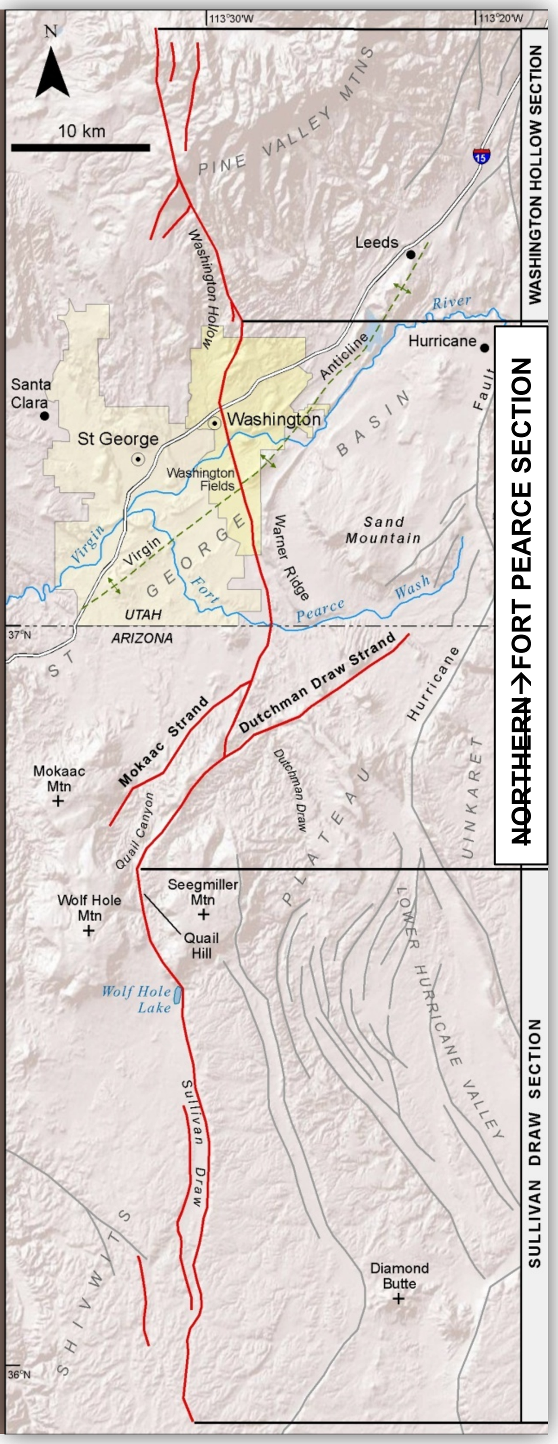
- Boundary placed near Washington flow cinder cone
  - 45$^{o}$ change in strike
  - Increased structural complexity
  - Decreased net displacement

- Newly defined Washington Hollow section is 22 km long



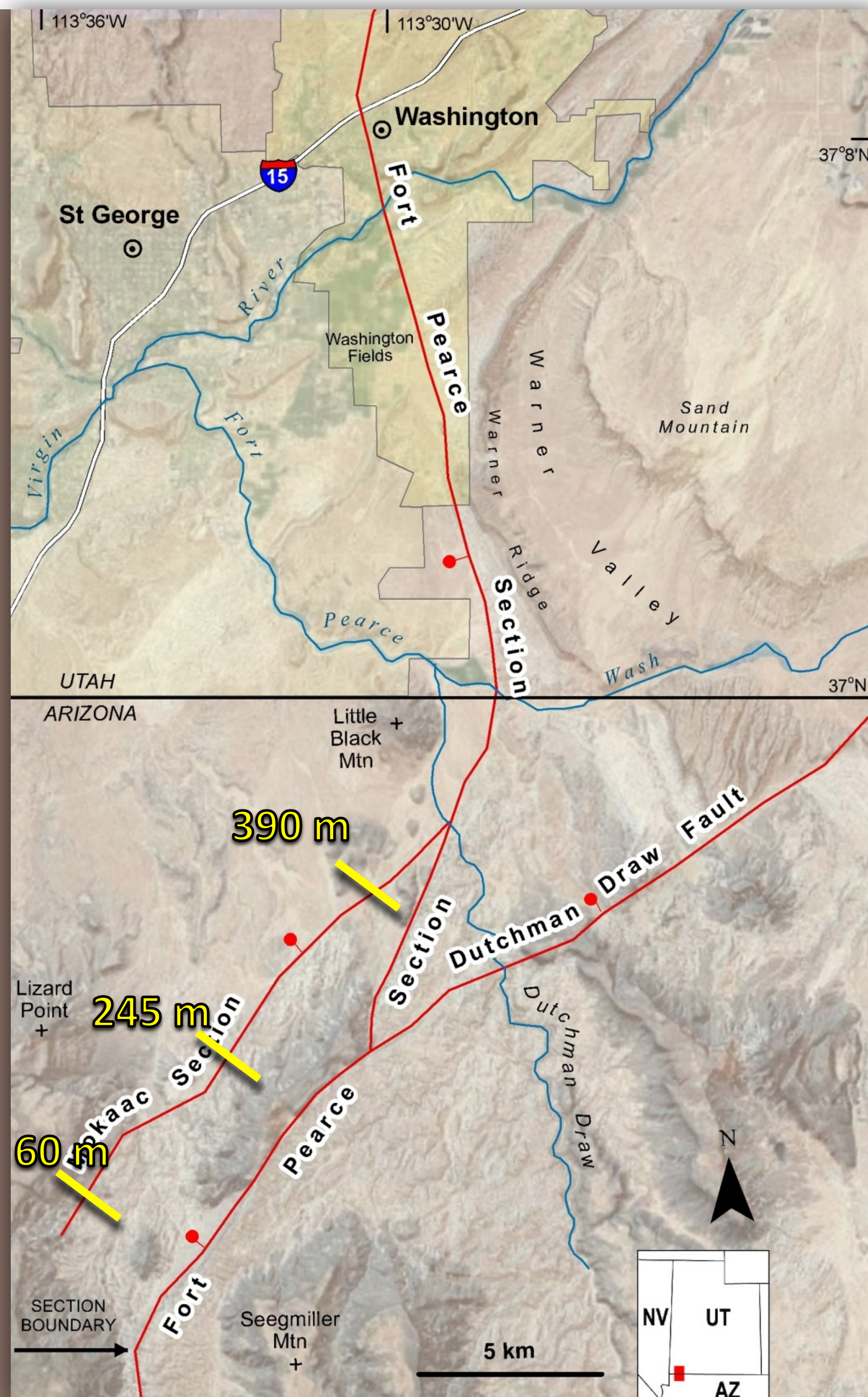
# Fort Pearce Section

- Northern section is no longer the northernmost section
- Renamed the Fort Pearce section (37 km long)



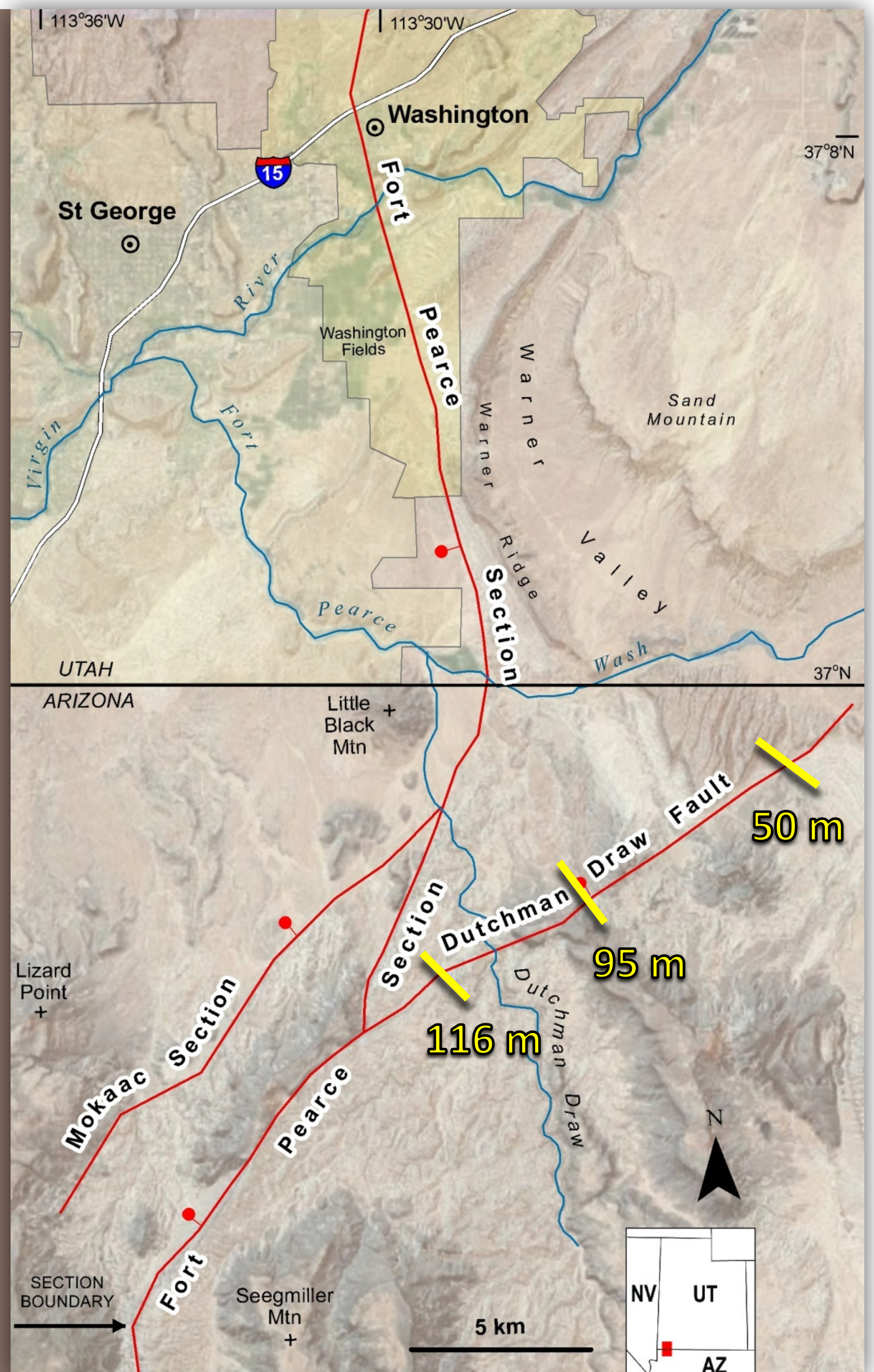
# Mokaac Section(?)

- 16 km long
- Vertical displacement greatest at junction with Fort Pearce section
- No obvious rupture barrier with Fort Pearce section
- More likely to rupture sympathetically with Fort Pearce section
- Best described as a **strand** of the Fort Pearce section



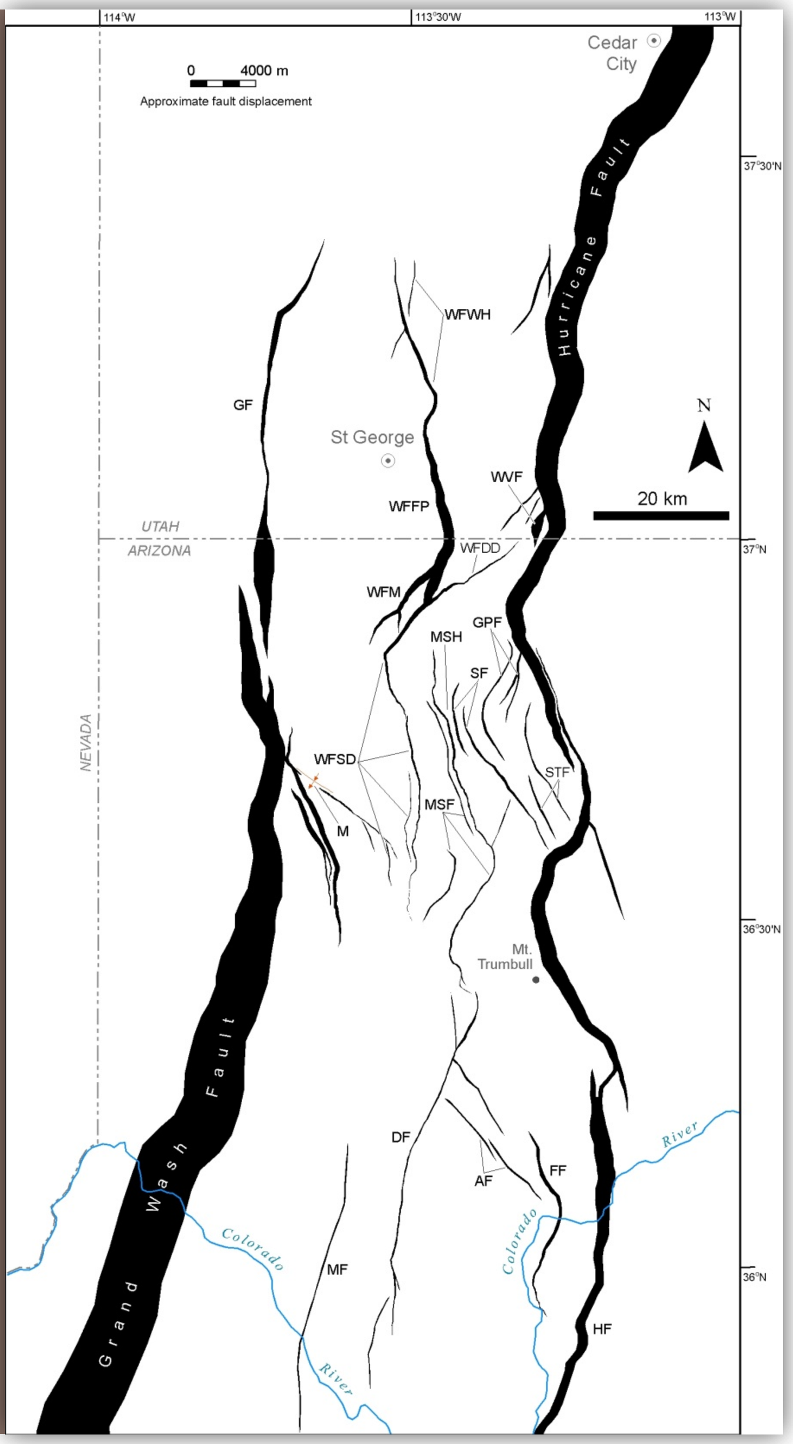
# Dutchman Draw Fault

- 16 km long
- Vertical displacement greatest at junction with Fort Pearce section
- No obvious rupture barrier with Fort Pearce section
- More likely to rupture sympathetically with Fort Pearce section
- Best described as a **strand** of the Fort Pearce section



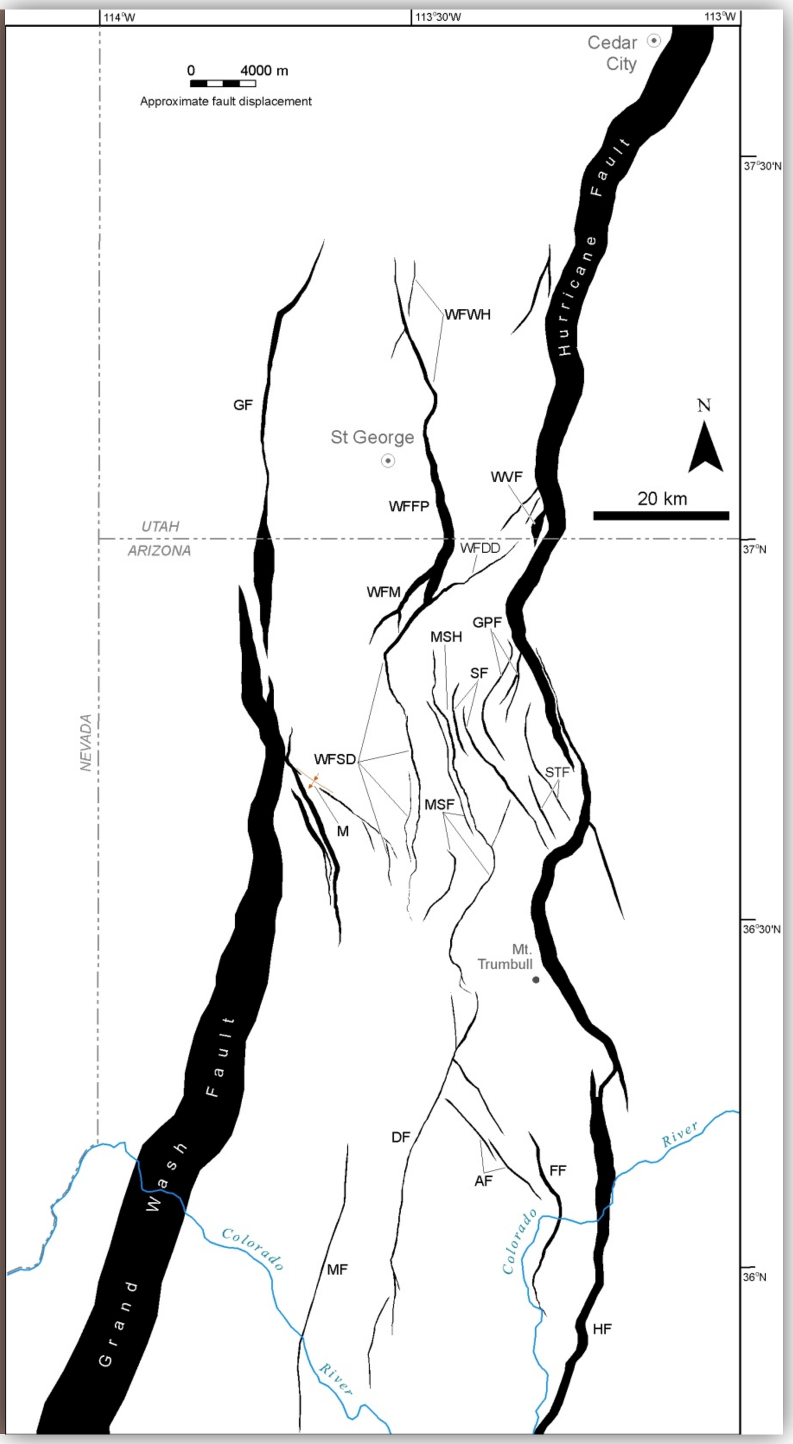
# Regional Relations in Transition Zone

- Map patterns:
  - Intersecting
  - Branching
  - En echelon
  - Rhombic
  - Salients & reentrants at similar latitudes
- Similar activity rates
  - All faults displace Quaternary alluvium
- Structurally linked?



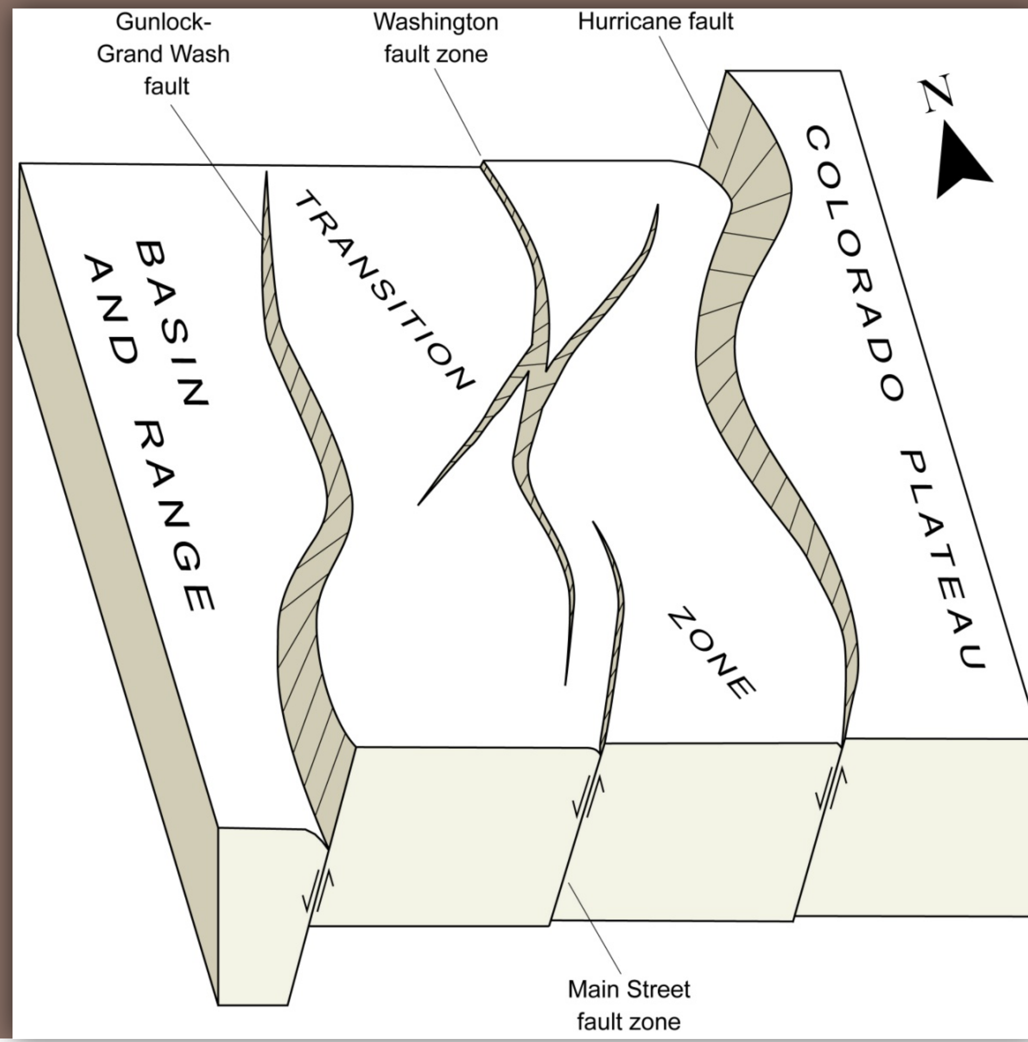
# Displacement Transfer Zone or Regional Relay Ramp (?)
(Schramm, 1994)

- Similar geometries
- Slip on Grand Wash and Hurricane faults increases in opposite directions
- All faults displace Quaternary units
- Limited Earthquake record indicates WF, GWF, HF are all seismically active



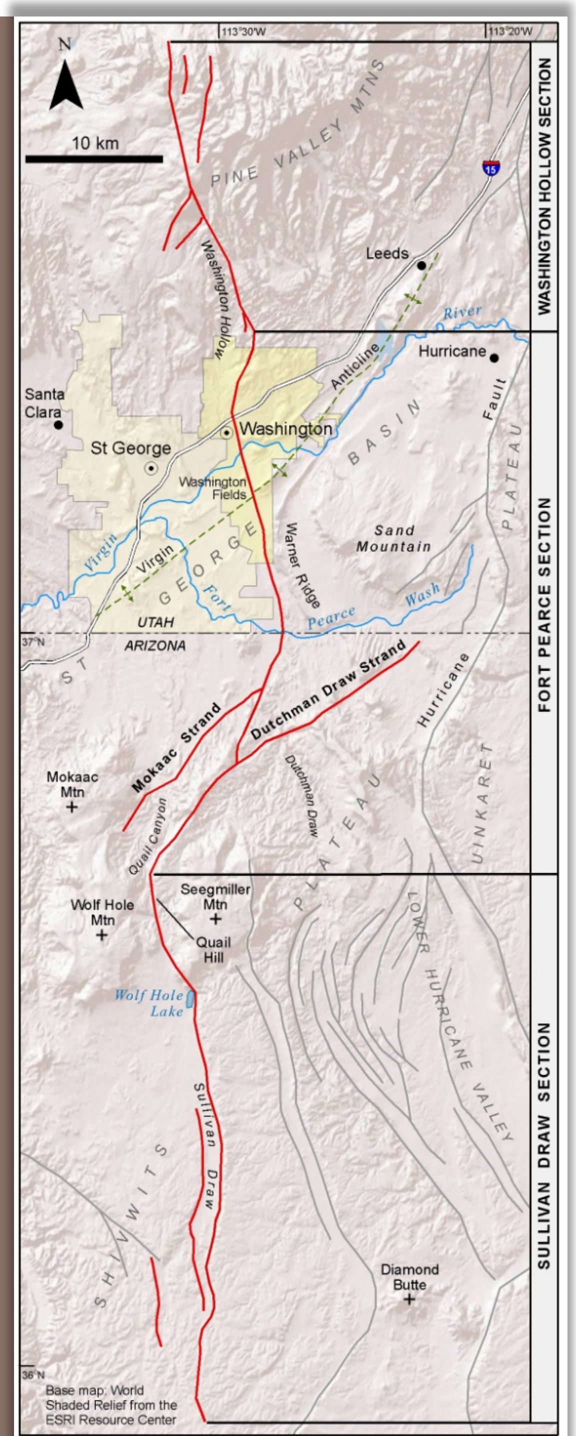
# Regional Transfer Zone (Relay Ramp)

- Grand Wash fault initiates in Miocene
- Locus of extension shifts east, Hurricane fault initiates in Pliocene
- Strain in intervening block creates Washington fault zone
- More data/analyses necessary to evaluate existence of a master detachment



# Summary

- High erosion rates
  - Fault-line scarps
  - Few scarps on unconsolidated units
- Washington Hollow fault is part of the Washington fault zone→ Washington Hollow section (22 km long)
- Northern section renamed the Fort Pearce section (37 km long)
- Mokaac section and Dutchman Draw fault are redefined as major strands of the Fort Pearce section
- Faults in the transition zone may be structurally linked as a regional transfer system

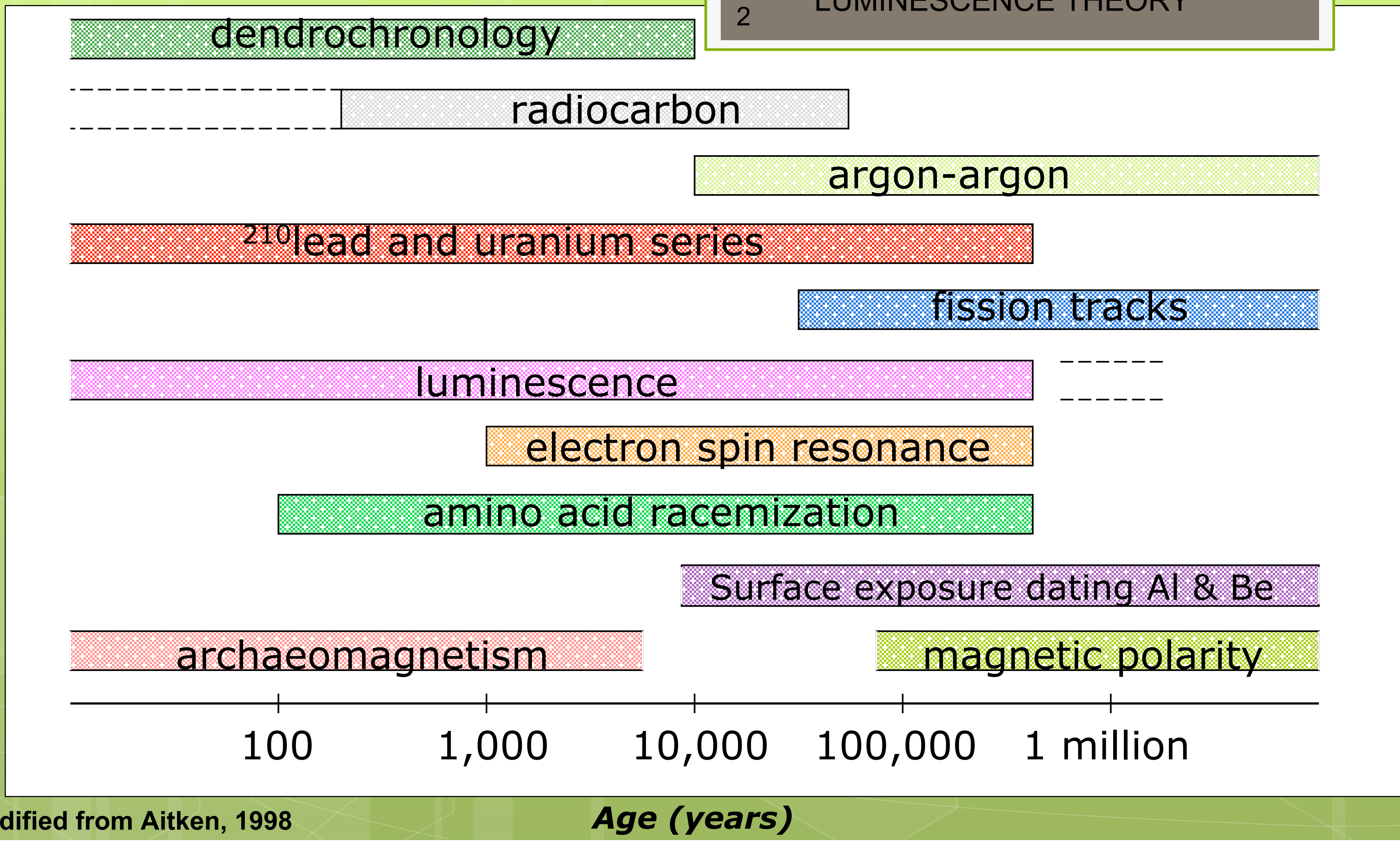


# USER GUIDE FOR LUMINESCENCE SAMPLING IN PALEOSEISMIC CONTEXTS

*Shannon Mahan, USGS, Denver*
*Harrison Gray, USGS, Denver*
*Michelle Nelson, Utah State University*
*Tammy Rittenour, Utah State University*

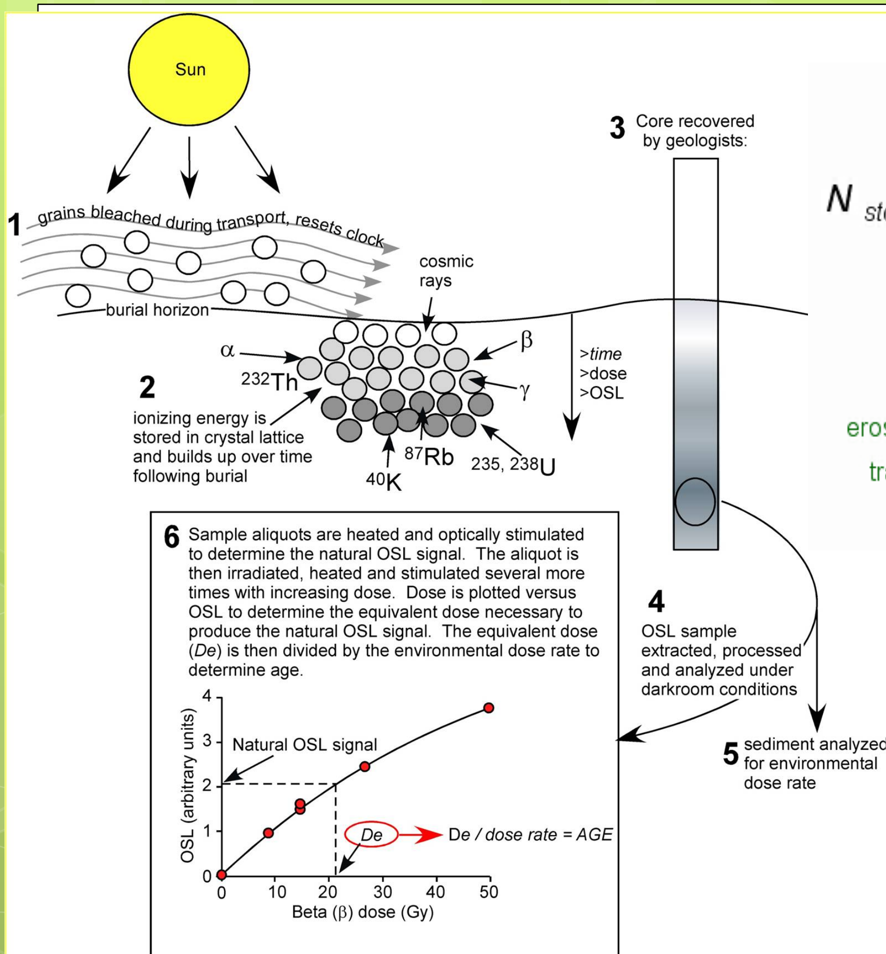
*BRPSHSIII Workshop*

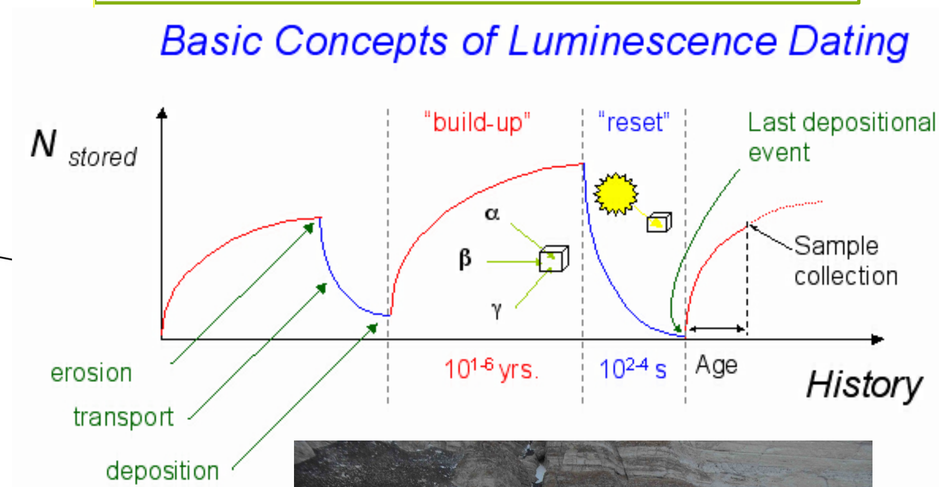
*Essential background information for sampling in fault trenches and for understanding your OSL data*




Modified from Aitken, 1998

# LUMINESCENCE THEORY

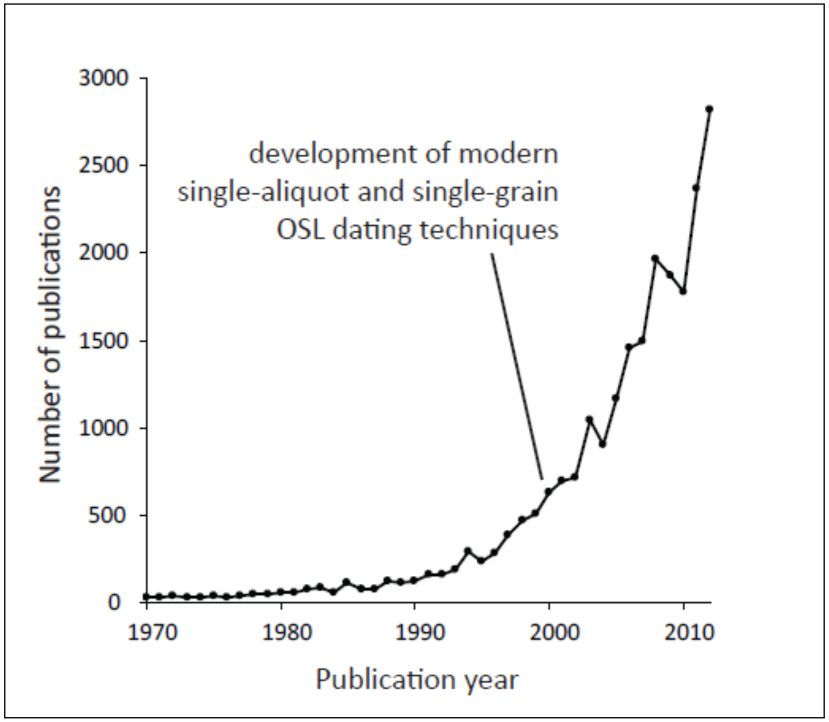


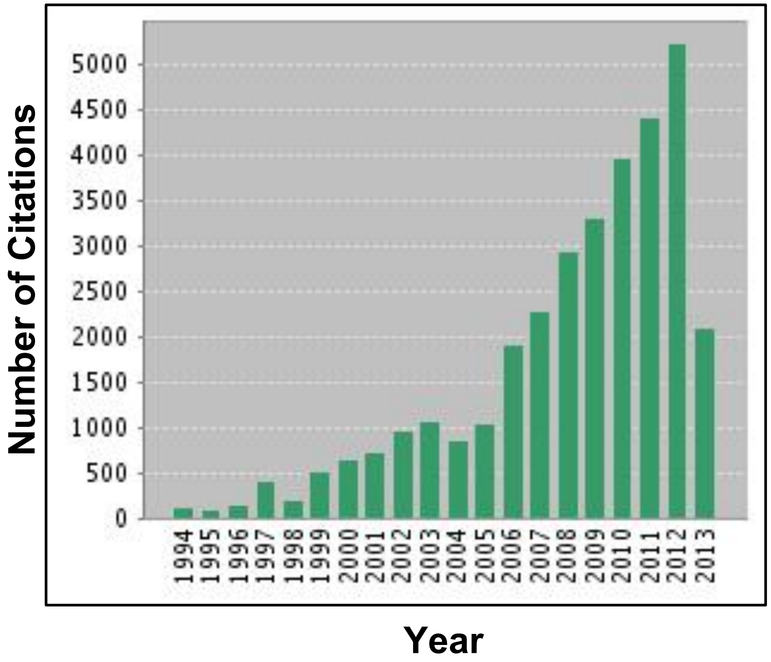




# CITATIONS OF OSL LITERATURE

**Graphs generated from Web of Science on 08/05/13 and 10/25/14**

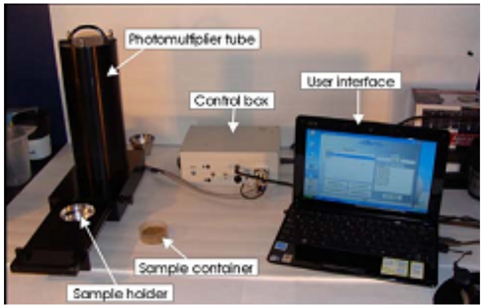
**Published Studies Using OSL Dating**



# FAQ from Reviewers and Users

1. What units can be sampled in the trench?
2. What methods of sampling are best?
3. What are the problems in quartz OSL dating?
4. What are the problems in K-spar IRSL dating?
5. What new techniques are in use?
6. What's the resolution of OSL? (will errors get smaller)?
7. Are there calibration standards for OSL in the lab?
8. I have a table of data and I don't know what it means, how do I figure it out?
9. What models are used to obtain OSL ages?
10. What is a probability plot or a radial plot?



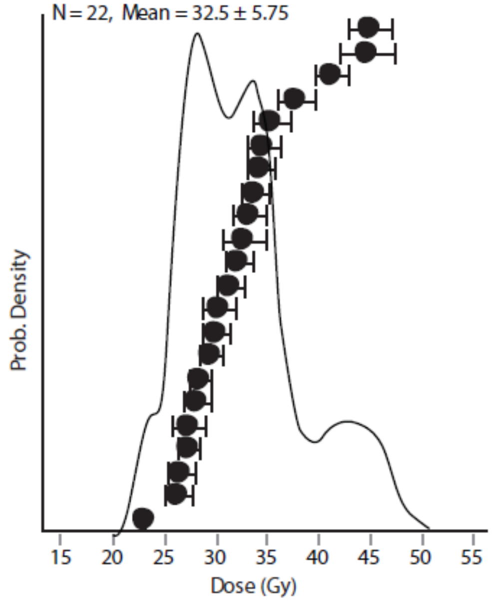




Fig. 4. Probability plot for sample LORV-26, which shows that there are four distributions of $D_E$. Two peaks have a high density and other two peaks are smaller. The first small peak is a low dose and includes 1 alliquot, and the other smaller peak is a high dose and includes 4 aliquots. The high dose peak may have partially bleached component, which would produce and overestimation of age. To minimise the effects of outliers from the main population, samples ages were estimated using weighted mean statistics.

# Sampling tools (and fools)

You know you are in trouble when your main analytical tools are: your brain, a rock hammer, and a shovel. Or are you…..

# Trench Sampling-you can't change it



First, the target unit must contain quartz and/or potassium feldspar in either the fine to very-fine sand range (250-63 µm grain size). Alternatively, the target unit can contain silt (~ 5-10 µm).

# 8 Trench Sampling-you can't change it


Second, the target sediment must have had sufficient exposure to sunlight before sediment burial such that any prior luminescence signal was depleted. The incomplete removal of a previous signal causes the apparent luminescence age to overestimate the depositional age. This process, called "partial bleaching," is analogous to inheritance in the cosmogenic system or inherited age in radiocarbon.

# TRADITIONAL OSL SAMPLING


| Collection method: | Tube collection |
|---|---|
| Target material: | ☒ Non-cemented sand or silt beds<br>☒ Interbedded sandy lenses in coarse-grained matrix |
| Equivalent dose ($D_E$) sample container: | 1. Sharpened opaque PVC or steel tubes with a plug inserted into the sharpened end to keep sediment compacted. 1.5-3" (3-8 cm) in diameter and 8" (20 cm) long, size may be dependent on target unit. |
| Field equipment for $D_E$ and $D_R$ collection: | 2. A pounding cap or block of wood (wider diameter than the tube) and sledge hammer that can be used to pound against the tube.<br><br>3. Hand trowel for excavation, duct tape and/or rubber end caps for sealing ends of tube, and permanent marker for labeling. |
| Dose rate ($D_R$) sample container: | 4. Gallon-sized zip-locking bag to contain bulk sediment sample surrounding the tube. |
| Water content sample container: | 5. Airtight container or zip-locking bags for water content sample. |
| Cosmogenic contribution: | 6. Tape measure for depth below landform surface. GPS for latitude, longitude, and elevation. |

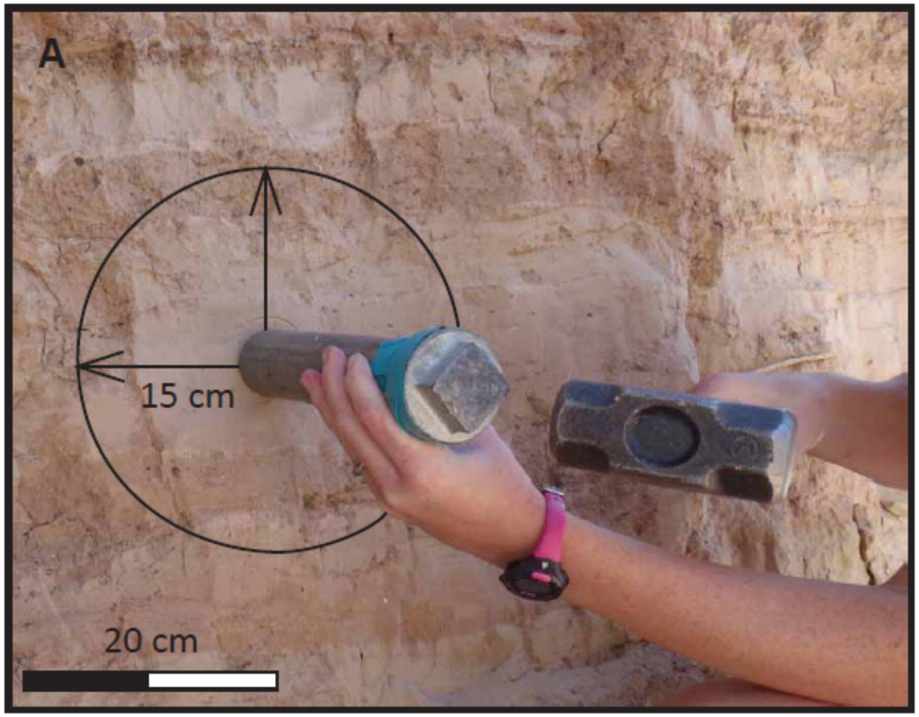
# OUTSIDE THE BOX SAMPLING


| Collection method: | Block collection |
|---|---|
| Target material: | ☒ Well-cemented or indurated sediments |
| Equivalent dose ($D_E$) sample container: | 1. Large, plastic zip-locking bag or other material to cover and seal the block. |
| Field equipment for $D_E$ and $D_R$ collection: | 2. Field knife or other hand tool for carving a block of indurated sediment out of the outcrop.<br><br>3. Duct-tape and tinfoil to secure and wrap the block and permanent marker for labeling. Black or silver spray paint (if desired). Do not use red or orange spray paint as it is not visible in the dark lab. |
| Dose rate ($D_R$) sample container: | 4. N/A, this will be extracted from the outer (exposed) portion of the block. |
| Water content sample container: | 5. N/A, this will be extracted from the outer (exposed) portion of the block. |
| Cosmogenic contribution: | 6. Tape measure for depth below landform surface. GPS for latitude, longitude, and elevation. |

# OUTSIDE THE BOX SAMPLING


| Collection method: | Canister collection |
|---|---|
| Target material: | ☒ Coarse-grained sediments absent of sandy lenses but with silty or sandy matrix<br>☒ Moderately-cemented sediments |
| Equivalent dose ($D_E$) sample container: | 1. Light-tight container or bag for holding sample. |
| Field equipment for $D_E$ and $D_R$ collection: | 2. Opaque blankets or tarps if collecting during daylight. Headlamp with red filter if collecting at night. Hand trowel or field shovel for removing exposed material and for filling canister.<br><br>3. Duct tape and tinfoil for sealing canister, and permanent marker for labeling |
| Dose rate ($D_R$) sample container: | 4. Gallon-sized zip-locking bag to contain bulk sediment sample surrounding the $D_E$ sampling area. |
| Water content sample container: | 5. Airtight container or zip-locking bags for water content sample. |
| Cosmogenic contribution: | 6. Tape measure for depth below landform surface. GPS for latitude, longitude, and elevation. |

# THE IMPORTANCE OF WATER AND DOSE RATES




The #1 problem in determining an accurate dose rate is accessing the long-term moisture content of the sediment and getting the full spectrum of sediment around the OSL sample.

The #2 problem is determining whether there was disequilibrium in the U:Th decay chain at any point due to water flow, sediment disintegration, or soil formation processes (i.e. leaching of feldspars).

**Quaternary Geochronology 2 (1-4) (2007), p. 117-124**

# Information required for publication of luminescence ages

**Equivalent Dose Information:**

1. Analyzing laboratory
2. Mineral type and grain-size analyzed
3. Unique sample number and/or laboratory number
4. Method used for DE determination (e.g. single-aliquot regenerative-dose (SAR))
5. Specifics related to sample analysis (e.g. instrumentation, preheat temperatures)
6. Number of analyzed and accepted aliquots/grains
7. Size of aliquot (diameter of region coated with sand or if single grain analysis)
8. Equivalent Dose value and error
9. Method used for age calculation (e.g. mean, central age model, minimum age model)
10. Luminescence age and error

**Dose-rate Information:**

1. Method of dose-rate measurement (e.g. ICP-MS, gamma spectrometry)
2. Concentrations of radio-elements (U, Th, K) or dose-rate contribution from each
3. Method of conversion of radio-elemental concentrations to dose-rate
4. Sample depth and cosmic dose rate value and method of calculation
5. Water content value
6. Total Dose Rate value and error

# 14 Quartz and feldspar differences

| Quartz | | K-Feldspar | |
|---|---|---|---|
| **Advantage** | **Disadvantage** | **Advantage** | **Disadvantage** |
| **Highly resistant to weathering** | Relatively low luminescence intensity; some quartz samples do not emit measurable OSL | **Luminescence saturates at a higher radiation dose than quartz** | Weathers more readily from the environment than does quartz |
| **Luminescence bleaches more rapidly in sunlight than feldspar** | Luminescence saturated at lower radiation doses compared to that emitted from feldspar | **Luminescence intensity may be orders of magnitude higher than quartz** | Suffers from anomalous fading and each sample must be tested and corrected for this |
| **Does not appear to suffer from anomalous fading** | Thermal transfer can be higher in quartz than in feldspar | **IRSL can be stimulated preferentially in quartz-feldspar mixtures** | Difficult or impossible to correct for sensitivity change in regenerative dose data when using SAR |
| **Can produce large and consistent data sets** | Sensitivity of quartz due to temperature of crystallization & number of cycles of erosion | | |

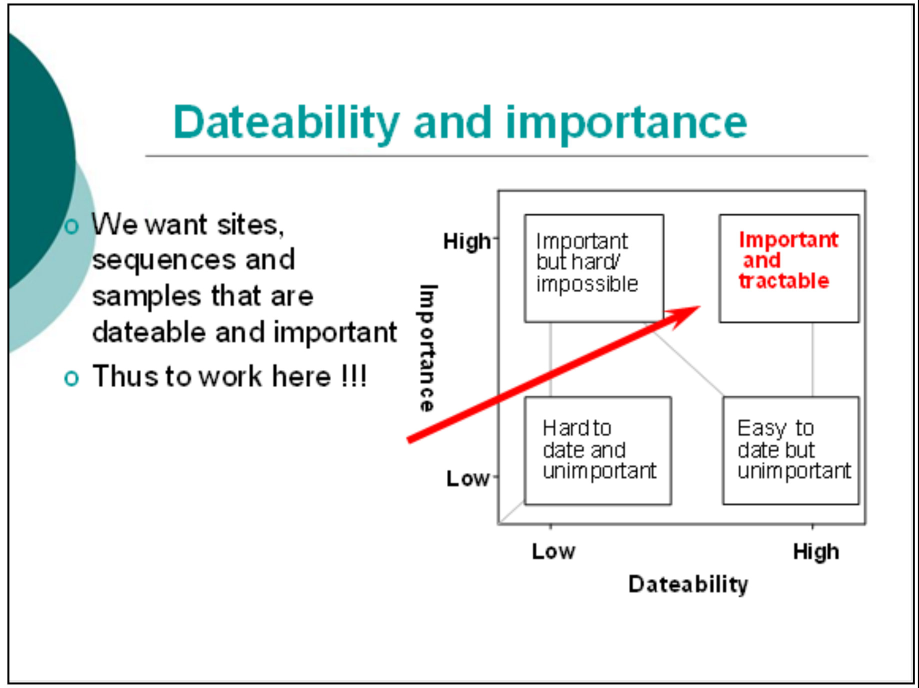
**From Lian, Encyclopedia of Quaternary Science, 2007.**

# Errors on luminescence ages

**Lower limit determined by detection sensitivity and dose rate data**

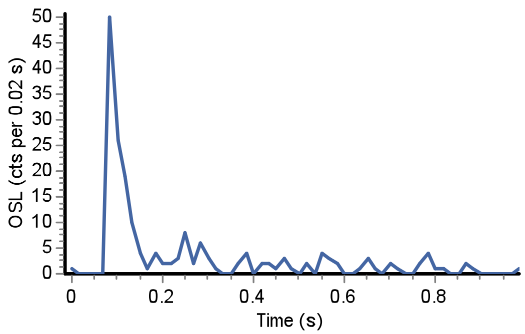
**Upper limit is dependent on source geology (high K, U, and Th means saturation is reached sooner) and stability characteristics of the sample**

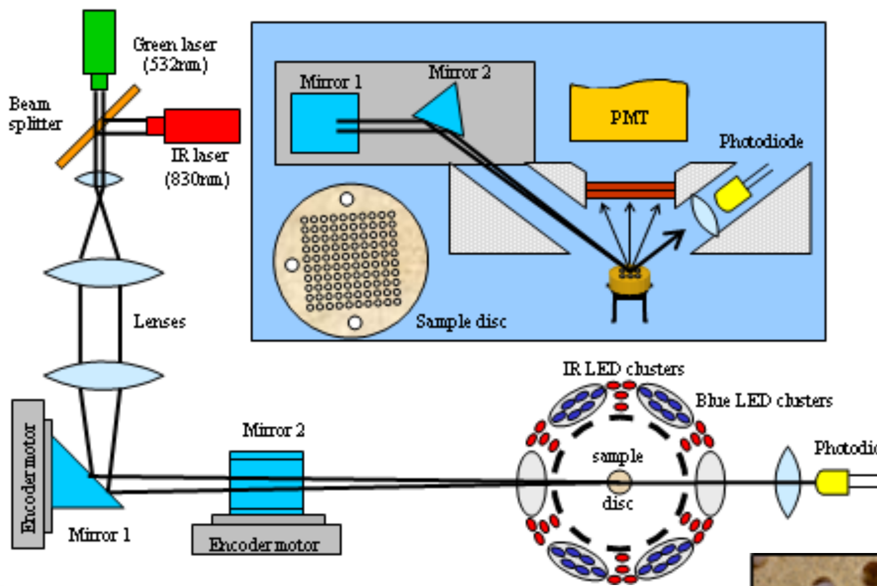
Some sources of error that are difficult to avoid include conversion from concentration data to dose rate (estimated at ~3%), absolute calibration of concentration measurements (~3%), beta source calibration (~2%), and beta attenuation factor (~2%). These estimated values are of course approximate, **but it should be clear that it is difficult to obtain a luminescence age with an overall or combined standard uncertainty of much less than 5%.**



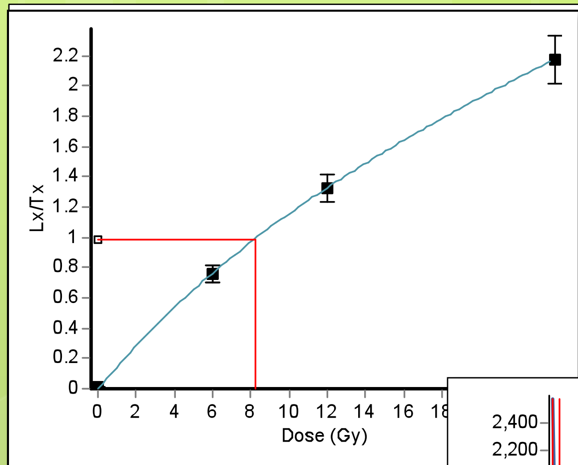

**Thanks to David Sanderson, LED11 for permission to use his concept.**

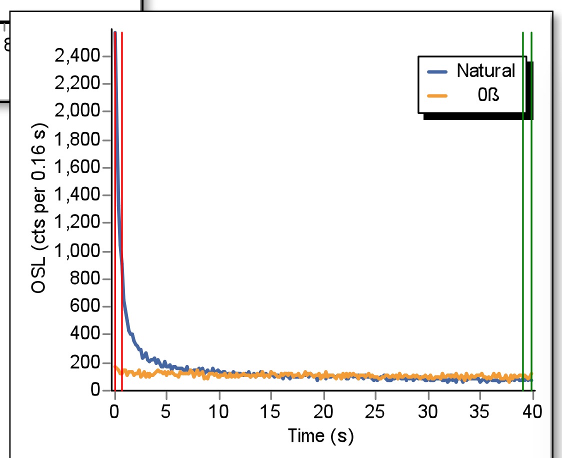
# Techniques in Use-Single Grain Laser




# Techniques in Use-Continuous Wave single aliquot

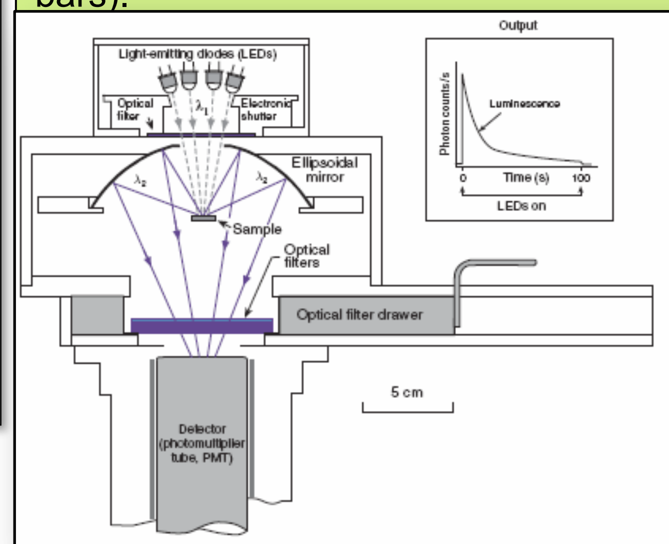



## Continuous-Wave OSL

The OSL equivalent dose data is taken from the initial part of the first 0.5 sec. (red bars).

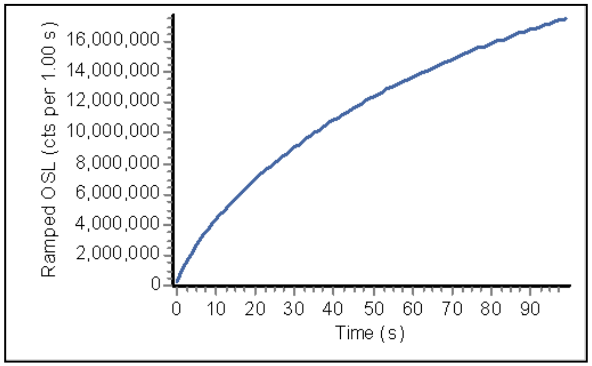
The background adjustment is taken from the last second of the 40 seconds of measurement (green bars).

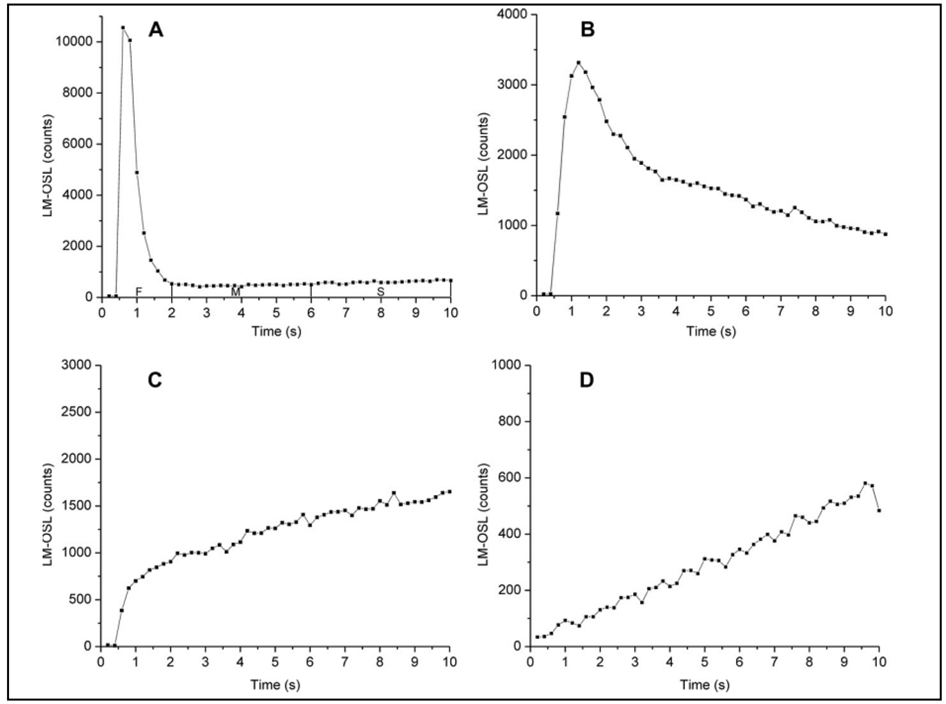



<u>OSL: (can be performed at any elevated temperature)</u>

- Blue (470 nm) LED stimulation: 50 mW/cm$^2$
- Infrared (870 nm) LED stimulation: 145 mW/cm$^2$

# Techniques in Linear Modulation

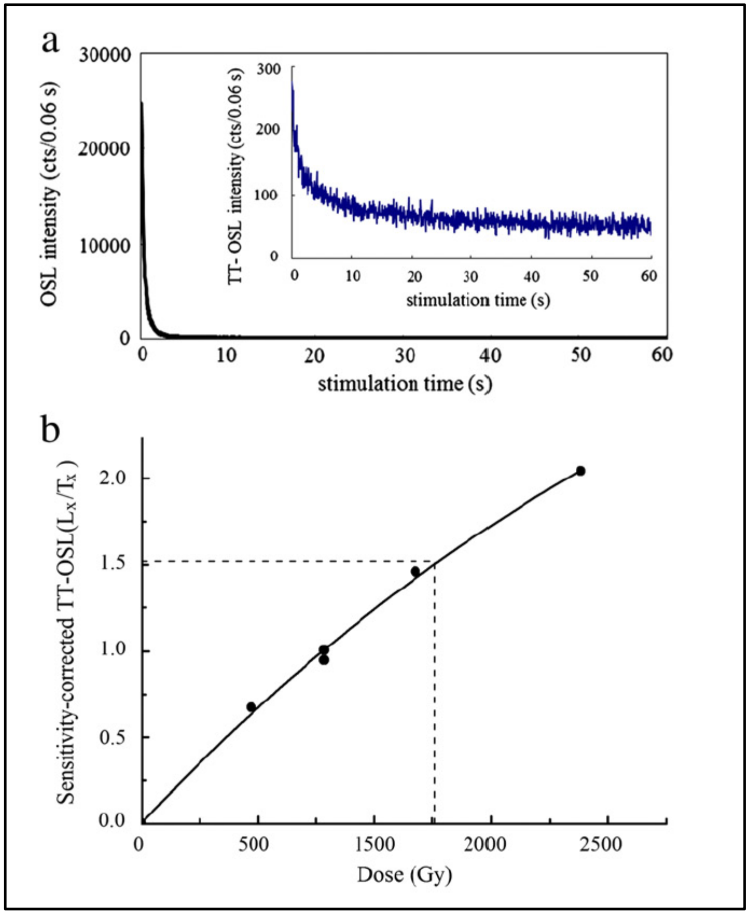



Used when quartz (or desired mineral) has components that can't be separated—the LED's or laser are slowly ramped up. Used for assessing OSL components (e.g. fast, slow, medium).

**Quaternary Geochronology 6 (2011), p. 261-272.**

## 19 Thermal Transfer OSL-Equivalent Dose




**Advantages:**

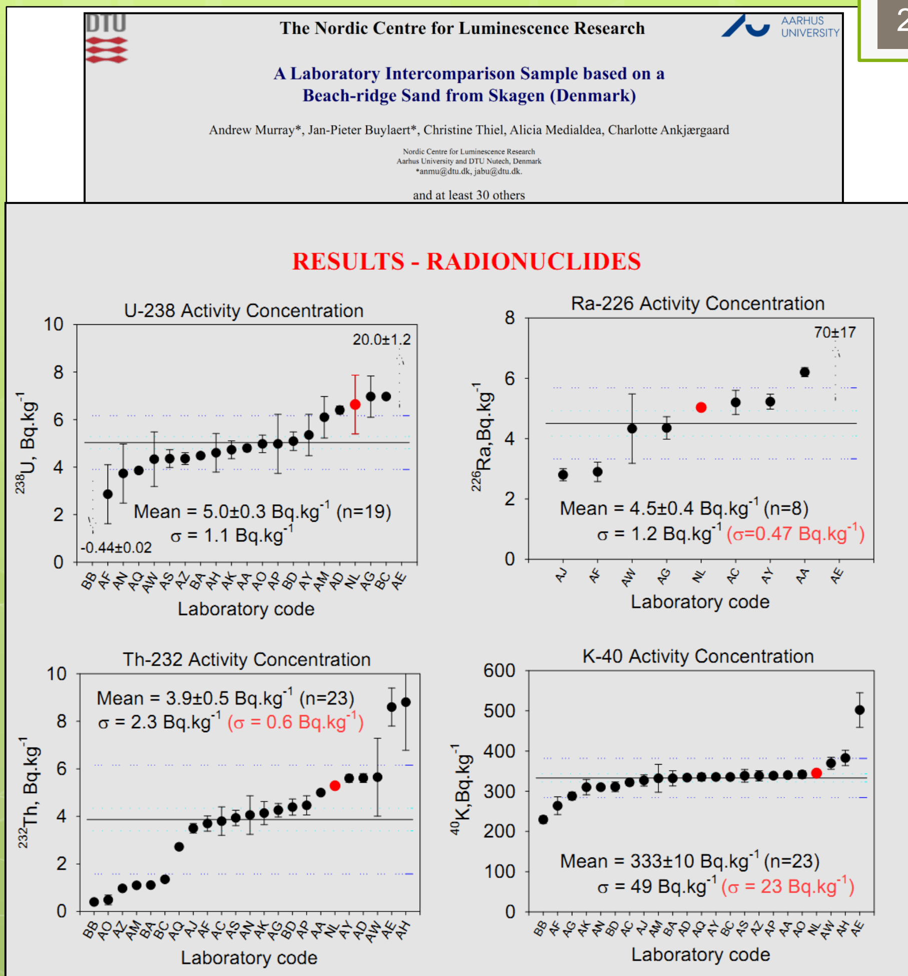
1. Access of deep traps using quartz thermal-transfer OSL (TT-OSL) and preliminary assessments by numerous workers are highly encouraging providing preliminary age estimates in the range of 40,000 to 1 million years.
2. Does not require the use of additional machines or equipment.
3. Signals >900 Grays can be measured.

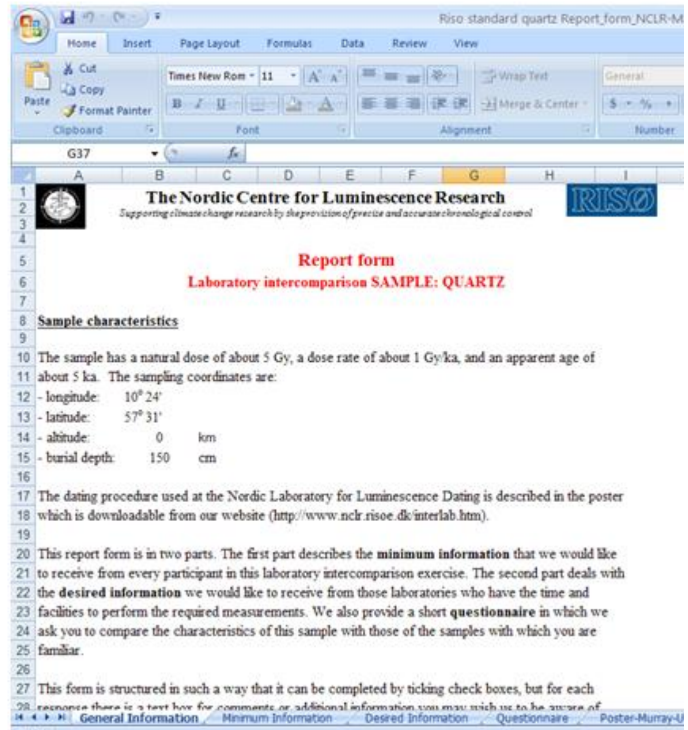
**Disadvantages:**

1. Each aliquot or single grains requires long bleaching times (300 seconds or more) for each regeneration; thus analysis times are likely to be 12-24 hours per aliquot (grains take 10-15 hours).
2. Sensitivity of the aliquots is increased and therefore the sample should be bright (and fast) for the regular component of OSL.
3. At signals of <50 Gy shows underestimates.

**Quaternary Research 79 (2013), p. 168-174. Radiation Measurements 42 (2009), p. 380-391.**

# 20 Riso Labs Calibration Quartz-$D_R$ Results



The Nordic Centre for Luminescence Research

RISØ

**Report form**

**Laboratory intercomparison SAMPLE: QUARTZ**

**Sample characteristics**

The sample has a natural dose of about 5 Gy, a dose rate of about 1 Gy/ka, and an apparent age of about 5 ka. The sampling coordinates are:

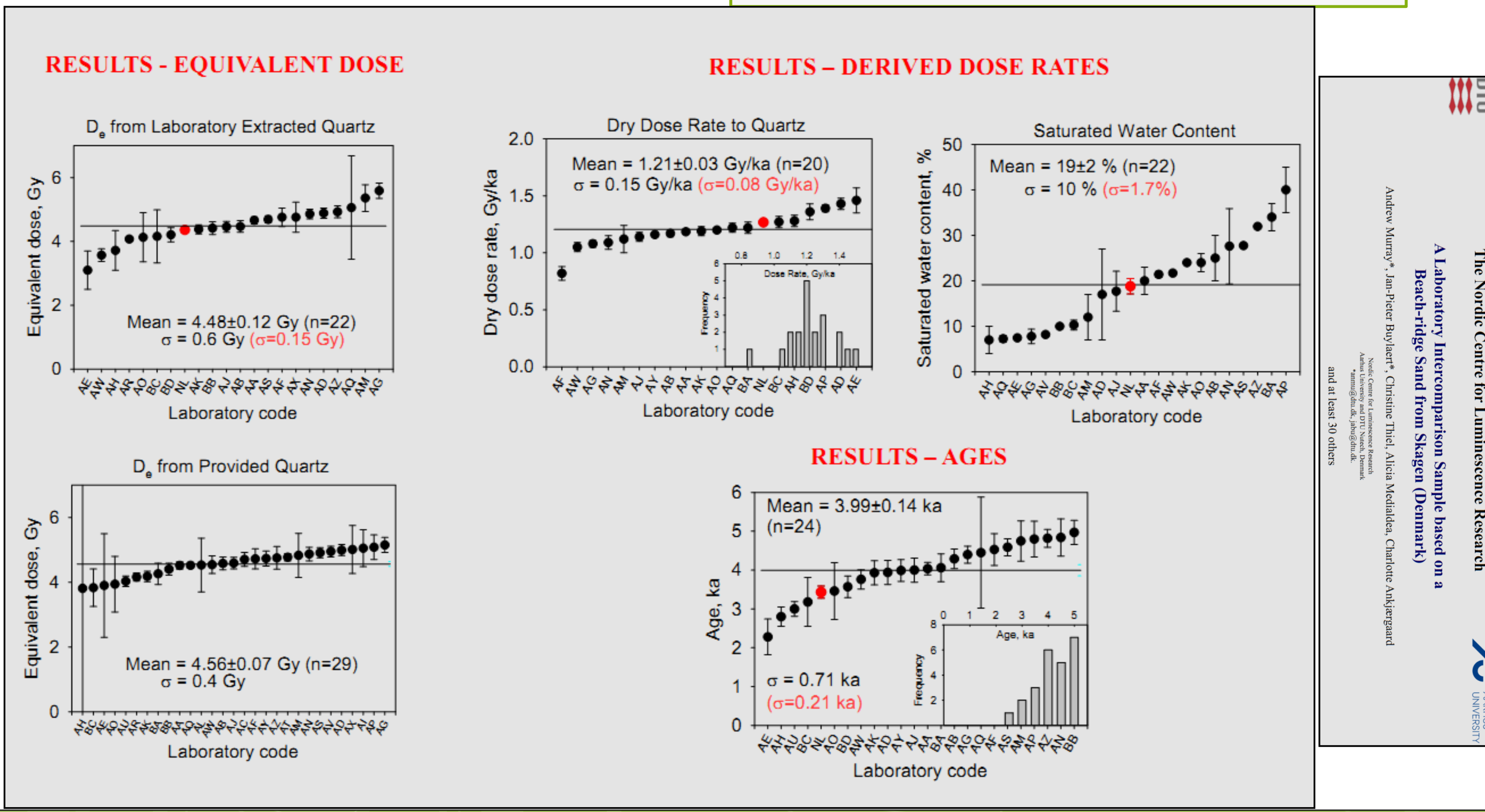
- longitude: 10° 24'
- latitude: 57° 31'
- altitude: 0 km
- burial depth: 150 cm

The dating procedure used at the Nordic Laboratory for Luminescence Dating is described in the poster which is downloadable from our website (http://www.nclr.risoe.dk/interlab.htm).

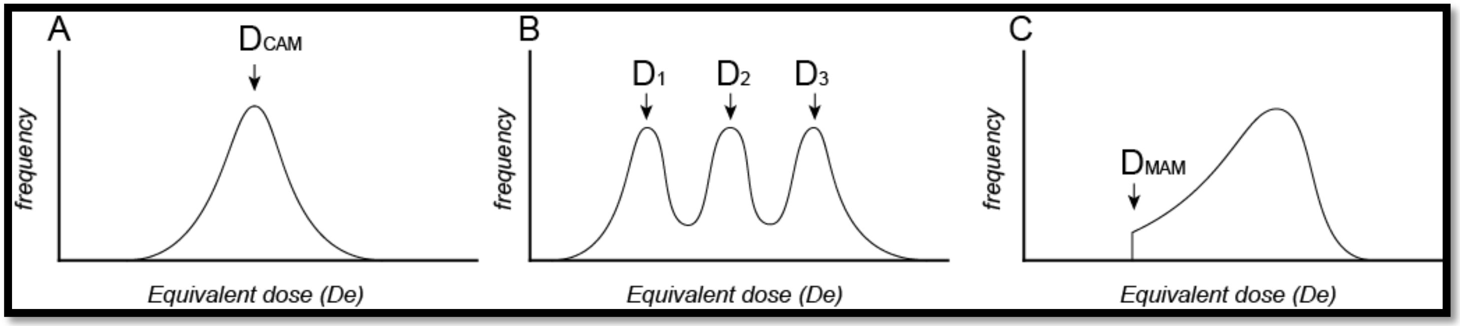
This report form is in two parts. The first part describes the **minimum information** that we would like to receive from every participant in this laboratory intercomparison exercise. The second part deals with the **desired information** we would like to receive from those laboratories who have the time and facilities to perform the required measurements. We also provide a short **questionnaire** in which we ask you to compare the characteristics of this sample with those of the samples with which you are familiar.

This form is structured in such a way that it can be completed by ticking check boxes, but for each

# 21 Riso Labs Quartz Calibration-$D_E$ Results



# Equivalent dose distributions




**Schematic Equivalent Dose Distributions and correct use of appropriate age model**

A) Example of an originally well-bleached sample with a single age population. The label and arrow ($D_{CAM}$) demonstrate the application of the Central Age Model (CAM) which computes a weighted mean at the peak of the normal distribution.

B) Example of a sample with various age populations possibly introduced by various bleaching histories or post-depositional mixing. This situation is appropriate for the Finite Mixing Model (FMM) which can statistically identify each age population (D1, D2, D3).

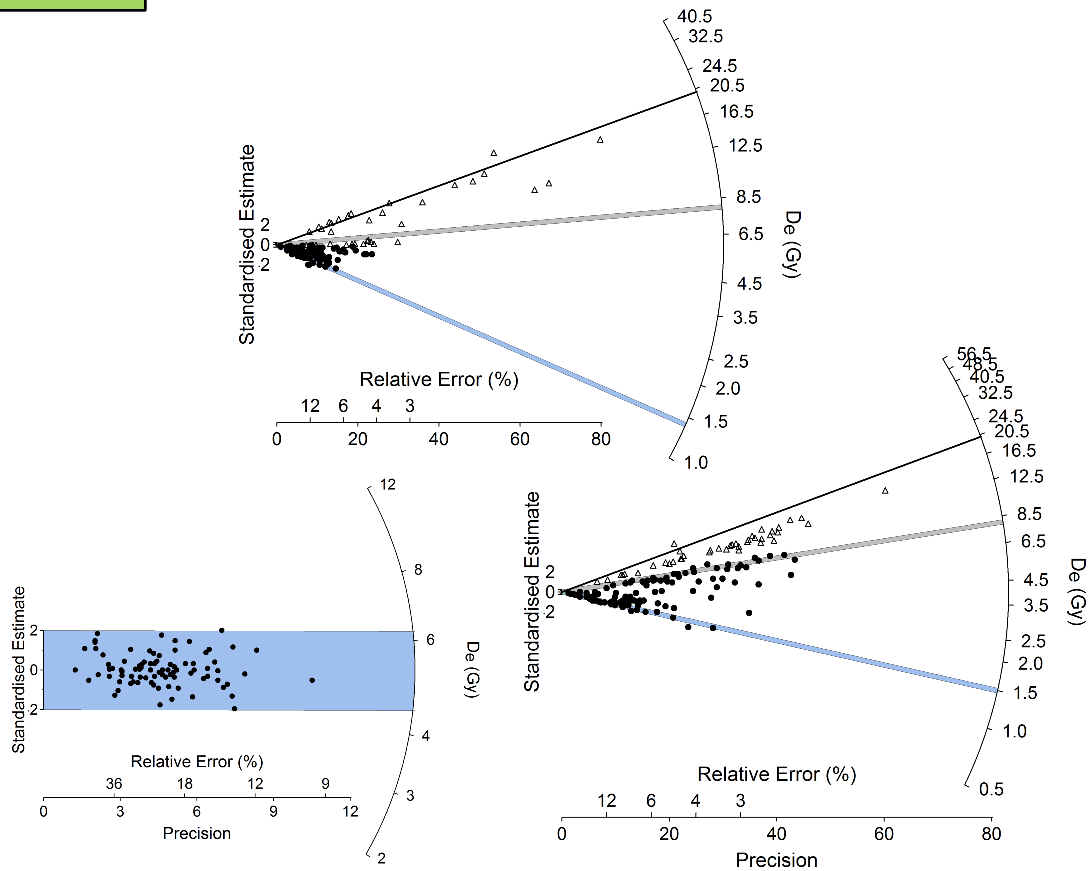
C) Schematic example of a partially-bleached sample where insufficient sunlight exposure removed the signal of only a few select grains. Label and arrow ($D_{MAM}$) indicate population isolated by the Minimum Age Model (MAM). *Adapted from Duller (2008).*

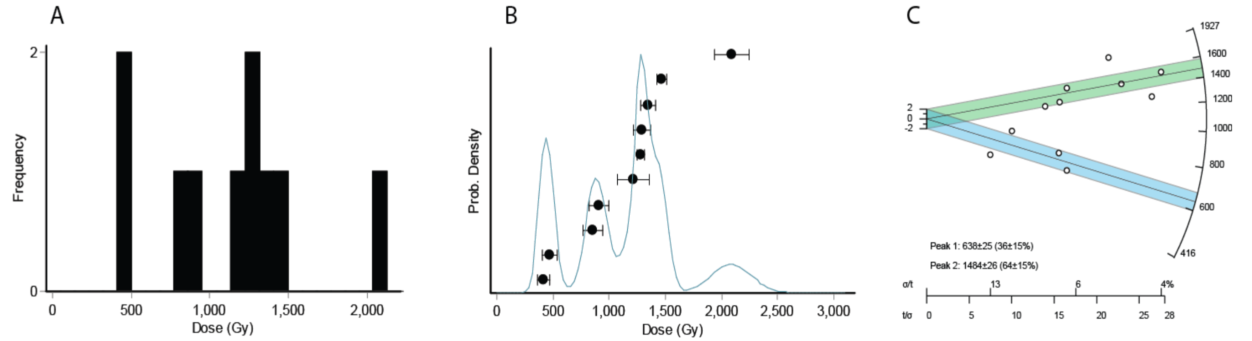
**From forthcoming BRPSHSIII proceedings paper**

# Equivalent dose distributions II

**Quaternary Geochronology 11 (2012), 1-27.**

❖Scatter or "overdispersion" is defined as σd, the relative spread in De remaining **after taking measurement uncertainties into account.**
❖In practical terms it is usually accessed or measured by taking the average/standard deviation.
❖A "good" overdispersion is considered anything <20%. Moderate is 25-45% and "bad" is >50%.
❖Some colluvial and alluvial samples have overdispersion that range from 50-150%.






**Examples of graphical representations of luminescence data**

A) histogram

B) weighted histogram produced by *Luminescence Analyst v. 4.1* (Duller, 2007);

C) radial plot generated using *Radialplotter v. 7.1* (Vermeesch, 2009).

D) See text for discussion of advantages and disadvantages associated with each plot type.

# Data Table

| Sample ID | % Water content[a] | K (%)[b] | U (ppm)[b] | Th (ppm)[b] | Cosmic dose (Gy/ka)[c] | Total Dose Rate (Gy/ ka) | Equivalent Dose (Gy) | n[d] | Scatter[e] | Age (ka)[f] |
|---|---|---|---|---|---|---|---|---|---|---|
| ***Sample 1*** | 1 (32) | 3.89 ± 0.05 | 3.50 ± 0.18 | 28.8 ± 0.39 | 0.24 ± 0.02 | 7.16 ± 0.08 | 423 ± 70.1 | 21 (30) | 45 | 59 ± 10 |
| ***Sample 2*** | 7 (38) | 4.07 ± 0.04 | 4.23 ± 0.14 | 30.9 ± 0.41 | 0.23 ± 0.02 | 7.16 ± 0.07 | 657 ± 34.2 | 25 (30) | 41 | 66 ± 7 |

[a]Field moisture, with figures in parentheses indicating the complete sample saturation %. Ages calculated using field moisture values.

[b]Analyses obtained using laboratory Gamma Spectrometry (high resolution Ge detector).

[c]Cosmic doses and attenuation with depth were calculated using the methods of Prescott and Hutton (1994). See text for details.

[d]Number of replicated equivalent dose (De) estimates used to calculate the mean. Figures in parentheses indicate total number of measurements made including failed runs with unusable data.

[e]Defined as "over-dispersion" of the De values in %. Obtained by taking the average over the std deviation. Values >35% are considered to be poorly bleached sediments.

[f]Dose rate and age for fine-grained 250-180 microns quartz. Exponential fit used on equivalent dose, errors to one sigma, ages and errors rounded. Equivalent dose populations used for ages based on Minimum Age Model (MAM) values.

# Equivalent Dose Models

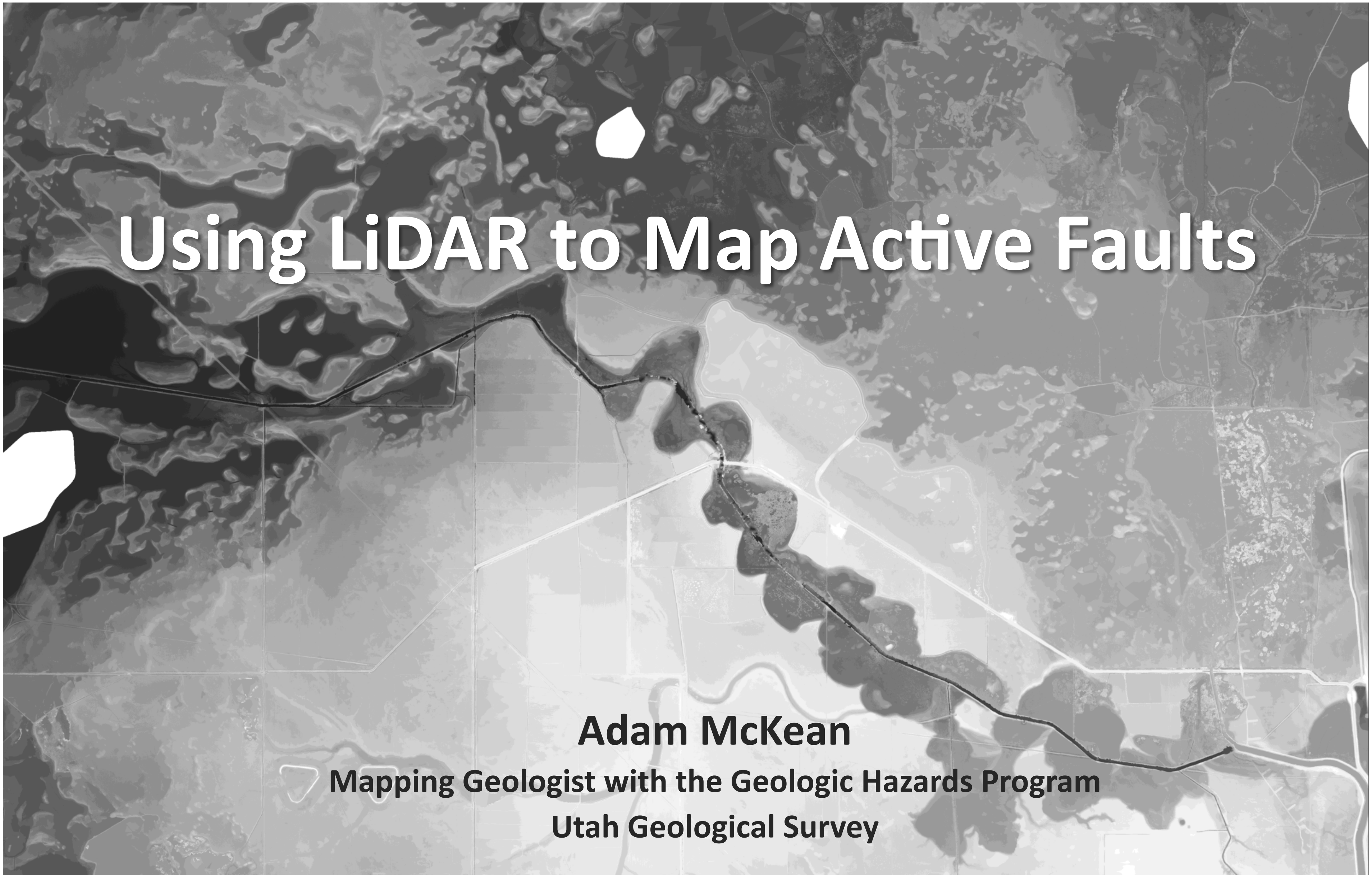
| Model: | Used for: | Abused for: |
| --- | --- | --- |
| Common Age (1 parameter) | Most straightforward; well bleached, not post-depositionally mixed | If positively skewed, gives poor estimate, fits limited samples |
| Central Age-CAM | Large dispersions where the measured De is not consistent within error of measurements; 15~25% overdispersion parameter | Everything to do with trying to reduce error; can give unrealistic error precision |
| Minimum Age-MAM (4 and 3 parameters) | Fluvial or alluvial deposits, true values for the equivalent dose are drawn from a truncated normal distribution | Skewing and kurtosis are important to know in detail |
| Maximum Age | Grains fully bleached at deposition and then mixed with younger intrusive grains; occurs rarely | Limited applications |
| Finite mixture-FMM | When the sample contains several discrete grain populations (bioturbation and bleached or with additional partial bleach variety) | Generally not to be applied to multi-grain aliquots |

Quaternary Geochronology 11 (2012), p. 1-27

# Conclusions

1. The successful application of luminescence dating is first and foremost dependent on collecting suitable samples.
2. It is critical to collect samples for water content shortly after trenching a site and to provide an estimation of average meteorological, climate, and ground water conditions at the site for accurate dose rate measurement.
3. Because paleoseismic investigations occur in a variety of geomorphic settings, there is no specific set of guidelines for each trench and each site should be analyzed on a case-by-case basis.
4. A main strength of the OSL technique for paleoseismology is that it allows great versatility in selecting sampling horizons, especially in depositional settings that lack significant organic deposits.
5. When submitting samples, include as much information as possible such as trench logs, stratigraphic context, and photos as significant amounts of information are present in a luminescence equivalent dose dataset.
6. The use of a portable gamma spectrometer during the OSL sampling process in fault trenches greatly aids in the selection of the most probable elemental concentration to be paired with the OSL and can help avoid locations with disequilibria or extreme compositional heterogeneity.

**From forthcoming BRPSHSIII proceedings paper: Gray, Mahan, Nelson and Rittenour-2015**



# Using LiDAR to Map Active Faults

**Adam McKean**

**Mapping Geologist with the Geologic Hazards Program**

**Utah Geological Survey**

UTAH DNR GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY

geology.utah.gov

# Common LiDAR data and derivatives

## Point Cloud

LAS or ASCII file format

- Laser file format

## Raster Surface Grid

DSM

- Digital surface model
- All laser point returns

DEM/DTM

- Digital elevation model
- Bare-earth return
- Removing points from non-terrain features (vegetation, cars, and structures)

## Other file types

- Topographic contours
- Triangular irregular networks (TIN)
- Terrain surface model

# Software

## LAS data

- LAS dataset
- Mosaic dataset
- Terrain dataset

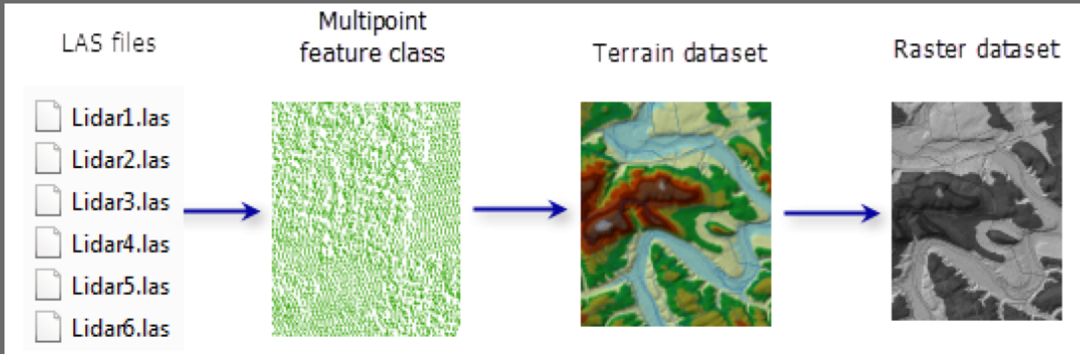
## Raster Surface Grid

- Raster dataset
- Mosaic raster dataset
- Raster catalog

ESRI has numerous "how to resources" for LiDAR datasets

## Products

- Elevation shaded raster
  - e.g. Atlas shade
- Hill shade
- Slope shade
- Contours
- Slope direction
- Gradient shade
- Profile tools
- Triangular irregular networks (TIN)




*Import LAS workflow through multipoints into a geodatabase based terrain dataset. Data courtesy of Mecklenburg County GIS.*

Figure from http://resources.arcgis.com

# Software

Global Mapper

## LAS data

- LAS point cloud

## Raster Surface Grid

- Raster data

Global Mapper automatically mosaics the data for use in point or raster form

Accepts most data types
Very user friendly

## Products

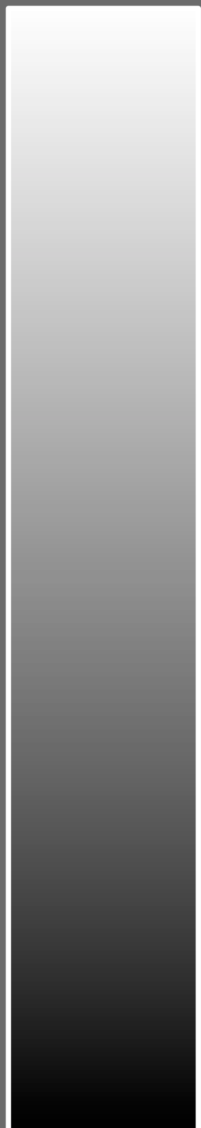
- Elevation shaded raster
  - e.g. Atlas shade
- Hill shade
- Slope shade
- Contours
- Slope direction
- Gradient shade
- Profile tools

## Other software (free)

- FugroViewer
- Fusion
- CloudCompare (LAS)

# Elevation Shaded DEM

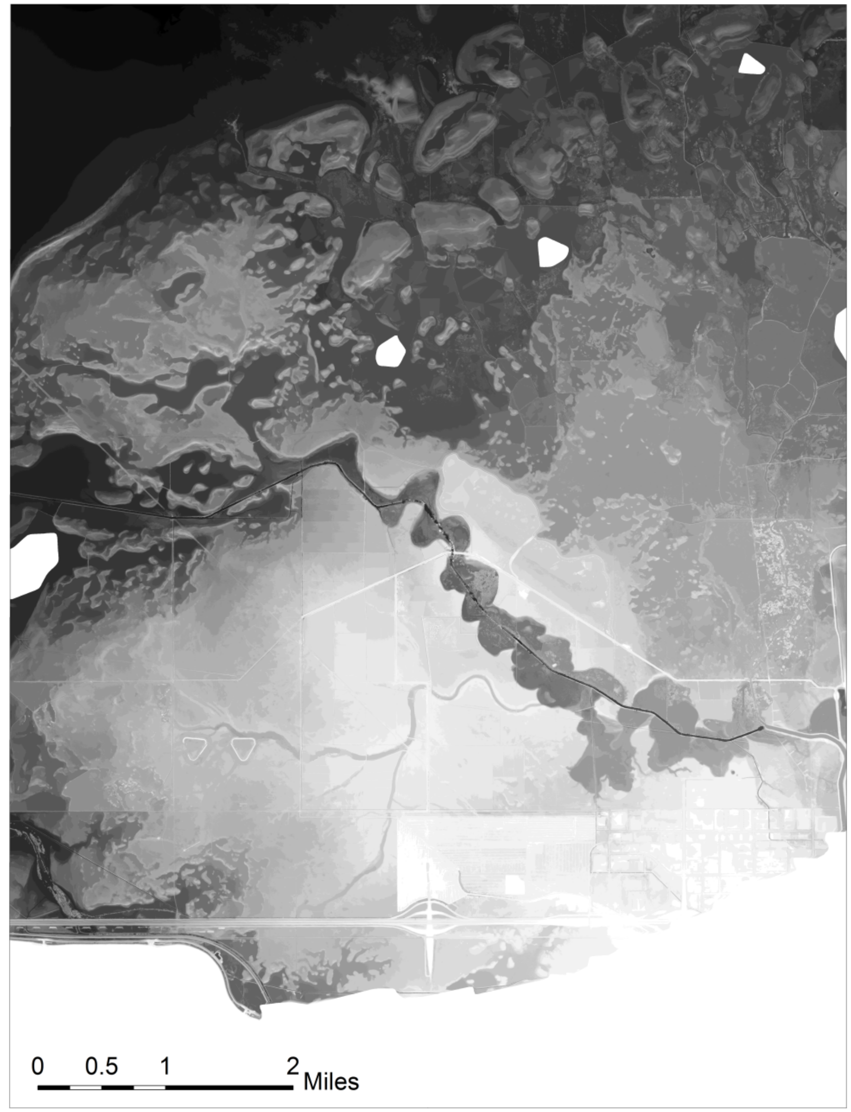
## Elevation



1279 m

1289 m

1 m LiDAR, 2011
Elevation shaded DEM

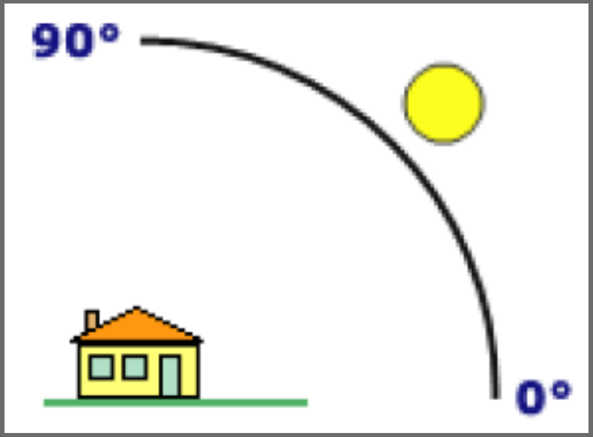


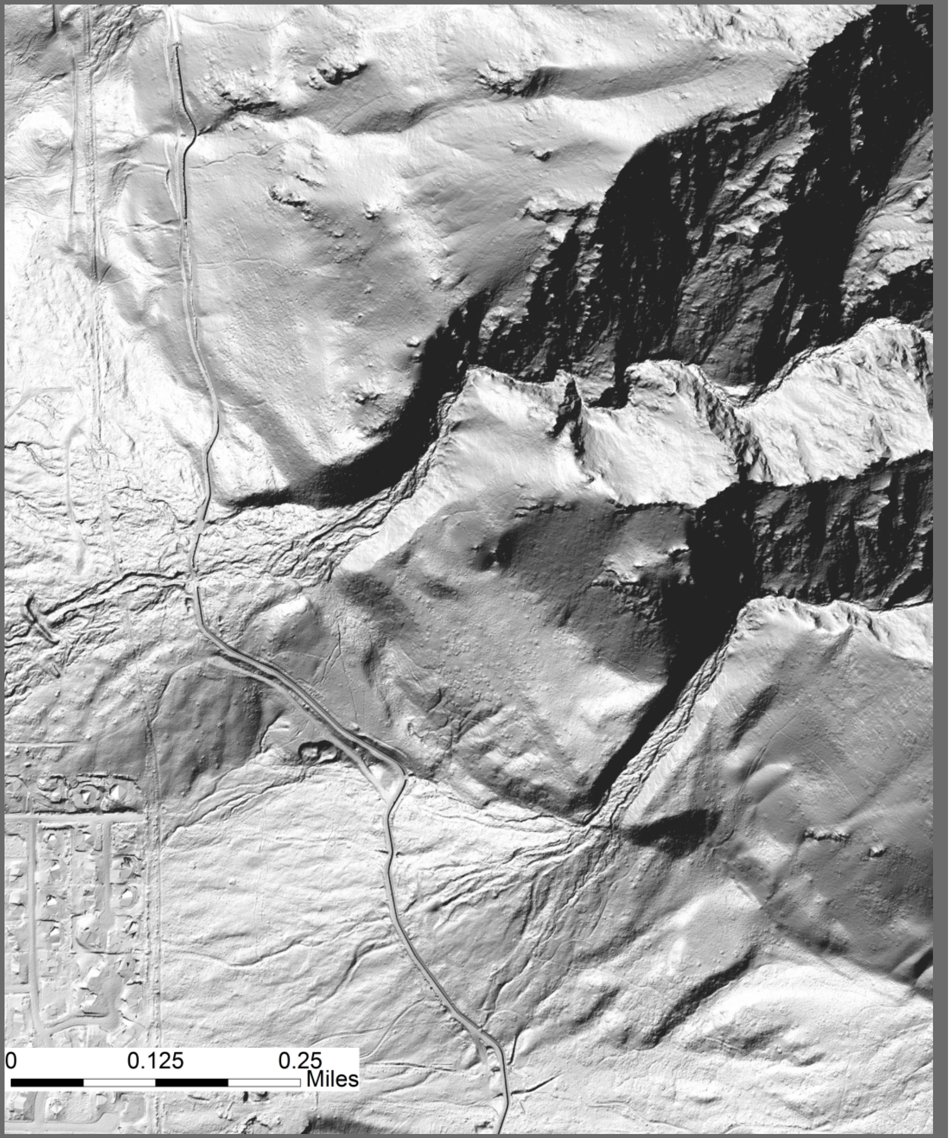
# Hill Shade

0.5 m LiDAR, 2013
45-315 hill shade

## Azimuth = 315°


## Altitude = 45°



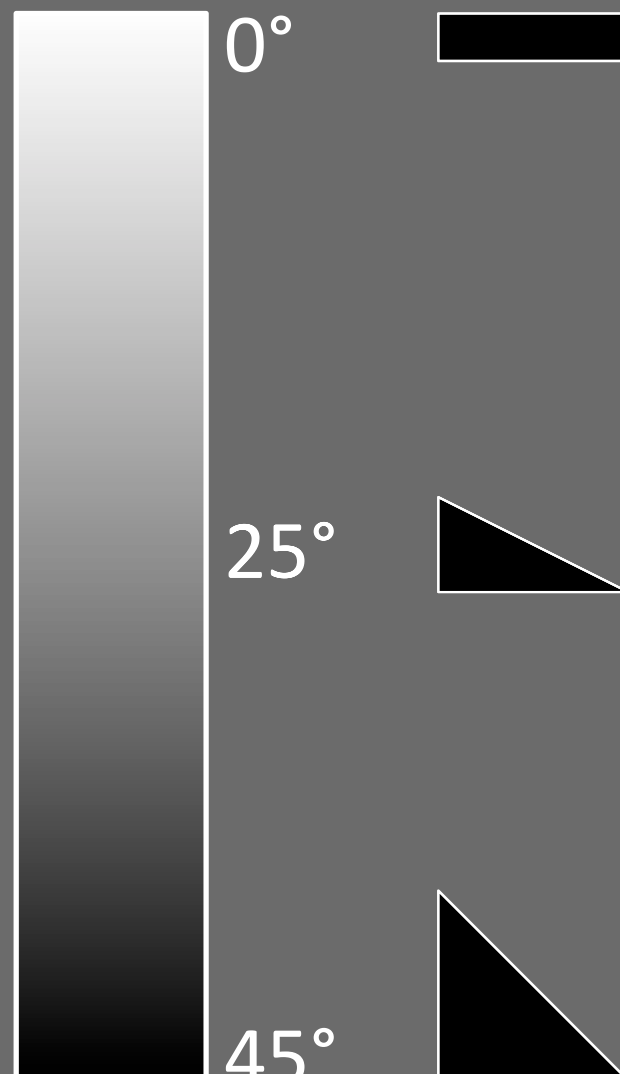




Figures from http://help.arcgis.com

# Slope shade

0.5 m LiDAR, 2013
0-45 slope shade


## Slope Angle



# What to look for

## Finding faults

- Faults are typically expressed as scarps or linear features that:
  - Cross cut topography
  - Offset streams
  - Offset geologic units
  - Form linear depressions or grabens
- Non faults also make linear features, like:
  - Canals, ditches, trails
  - Vegetation
  - Stream or landslides escarpments
  - Shorelines
  - Strike ridges or other resistant bedrock

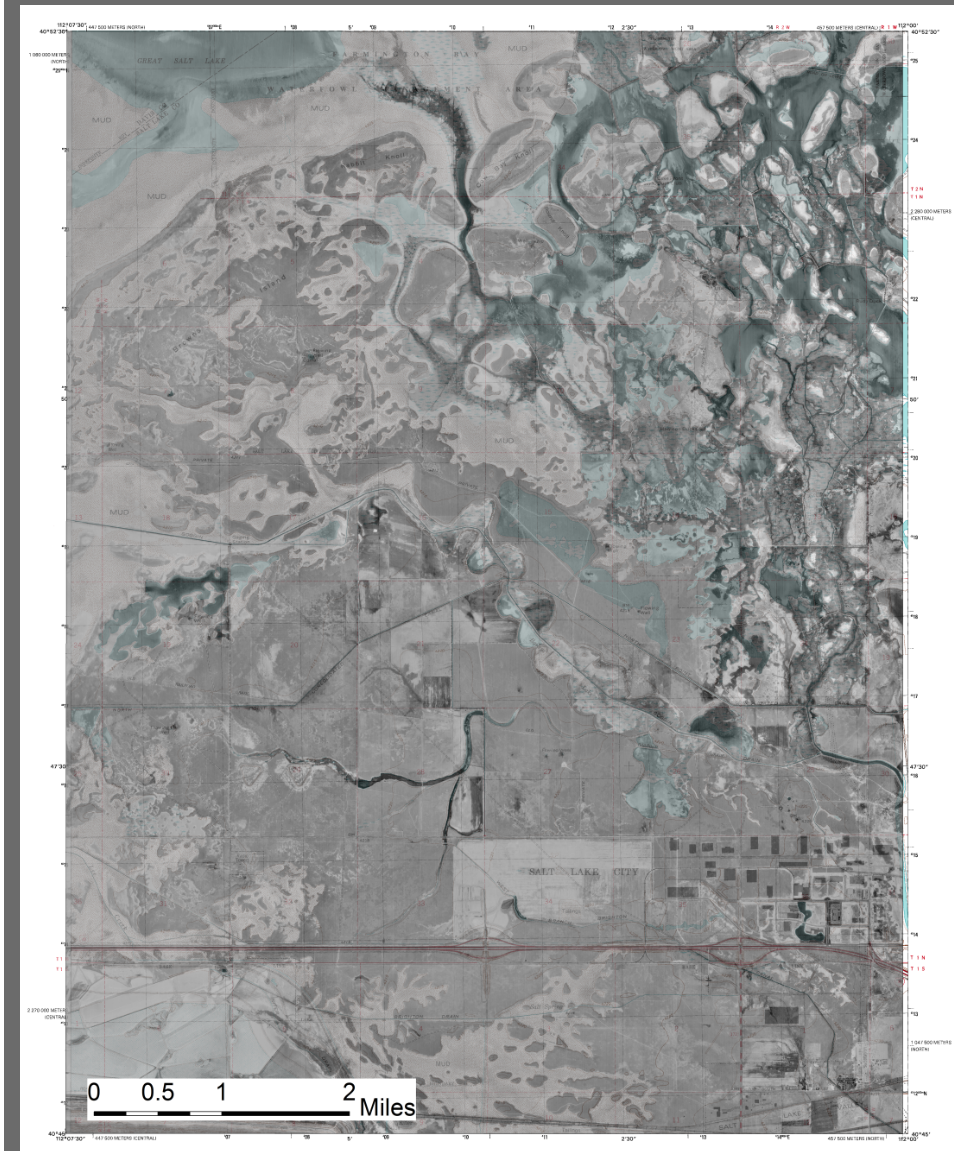
## Fieldwork is still needed

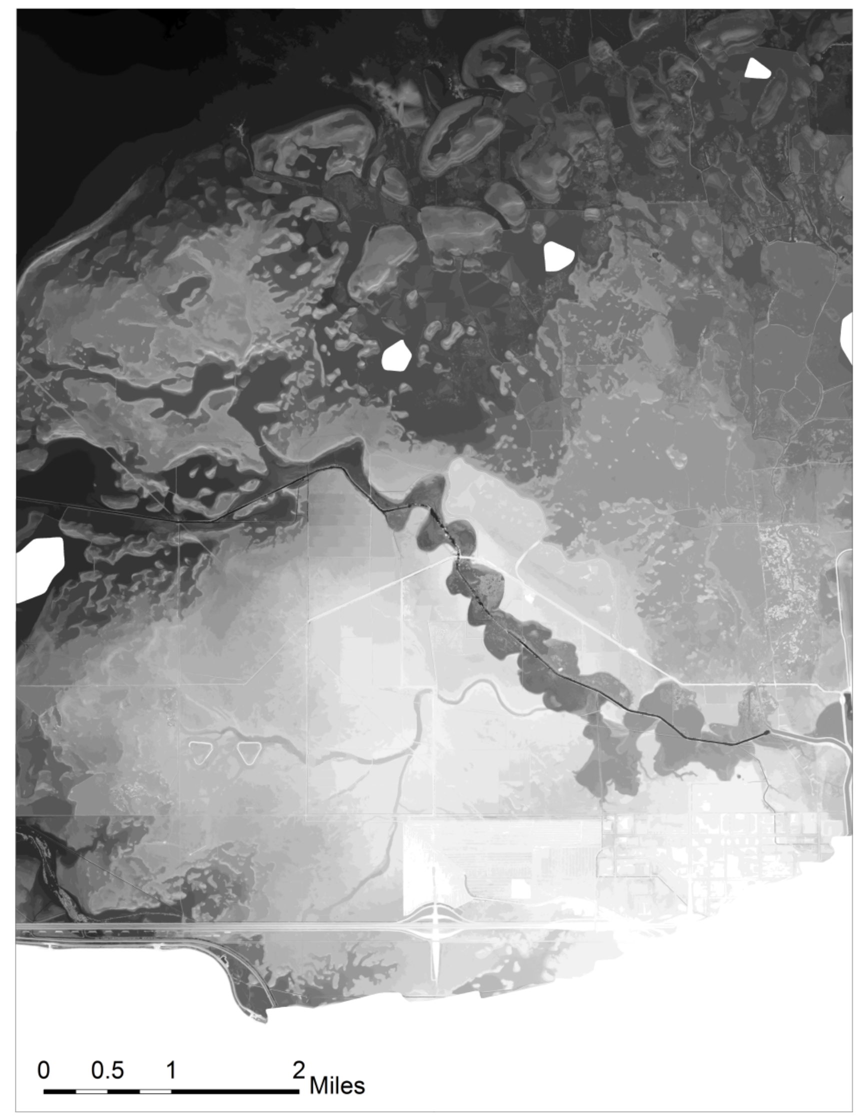
- LiDAR does not remove the need for field investigations
- I recommend:
  - If possible visit the field area before mapping to calibrate your eye to the features and geology of the study area
  - After mapping revisit the study area to field check the mapped faults and uncertain lineaments

# Shaded DEM

USGS 7.5-minute topographic map
1977 Salt Lake County imagery

1 m LiDAR, 2011
Raster shade DEM



# Shaded DEM

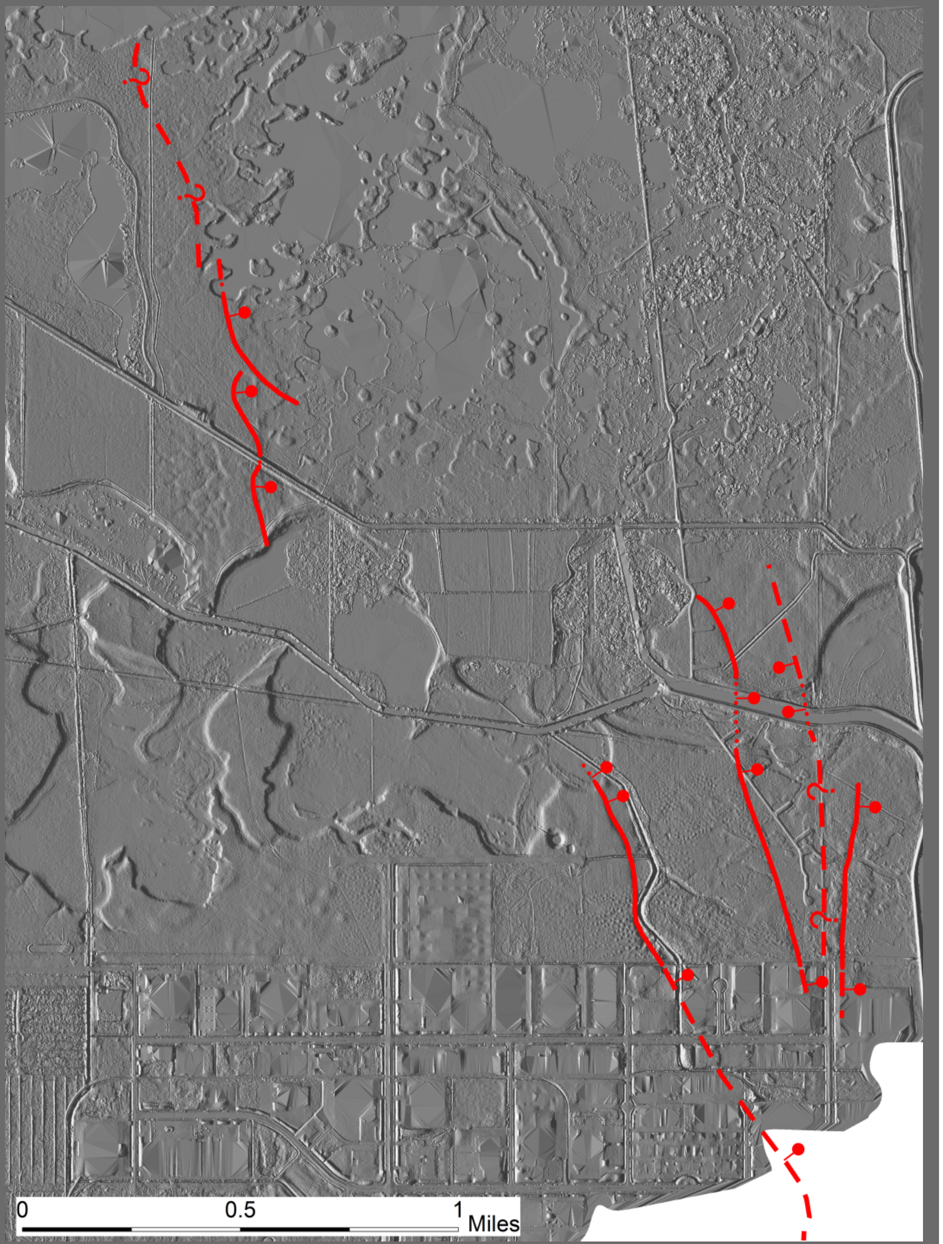
2012 HRO Color 6 inch

1 m LiDAR, 2011
Raster shade DEM


# Low angle hill shade

1 m LiDAR, 2011
Raster shade DEM

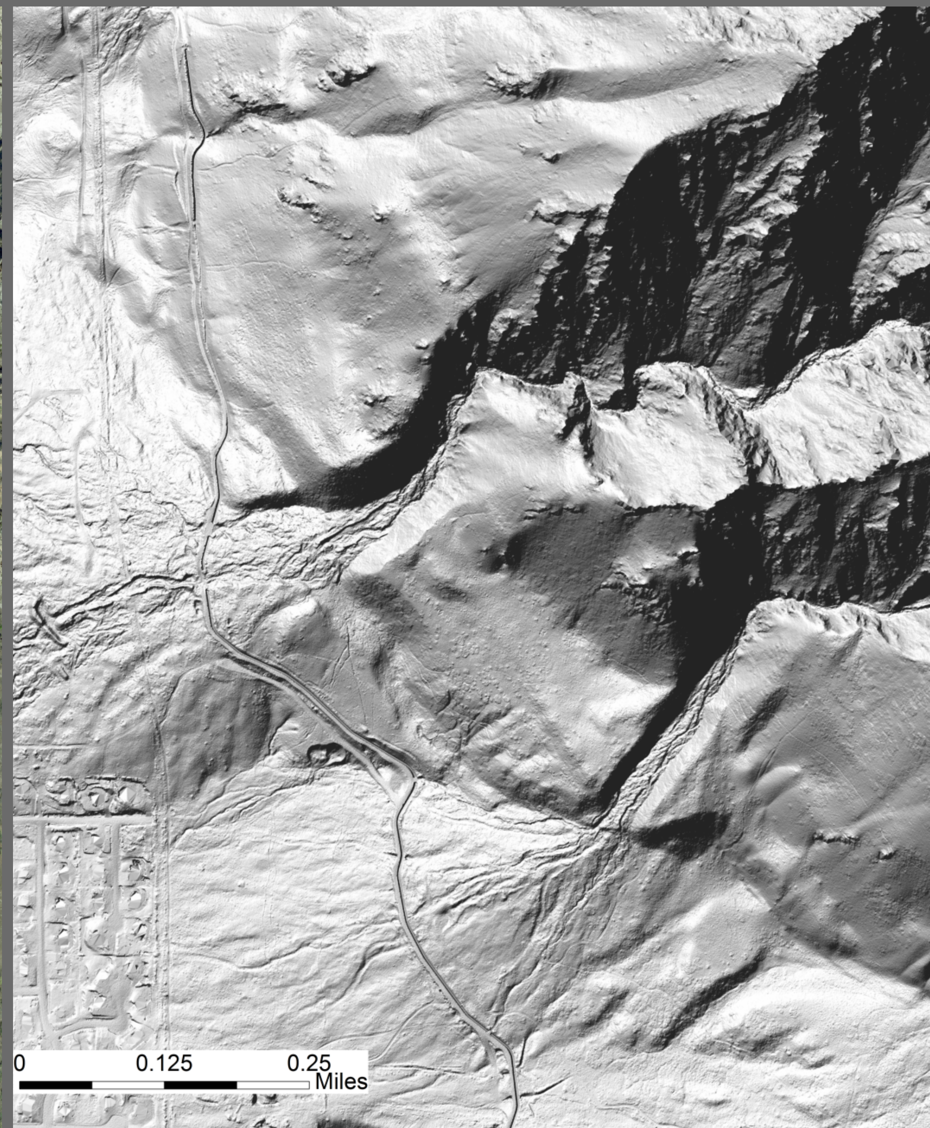

1 m LiDAR, 2011
20-270 hill shade



# Hill shade

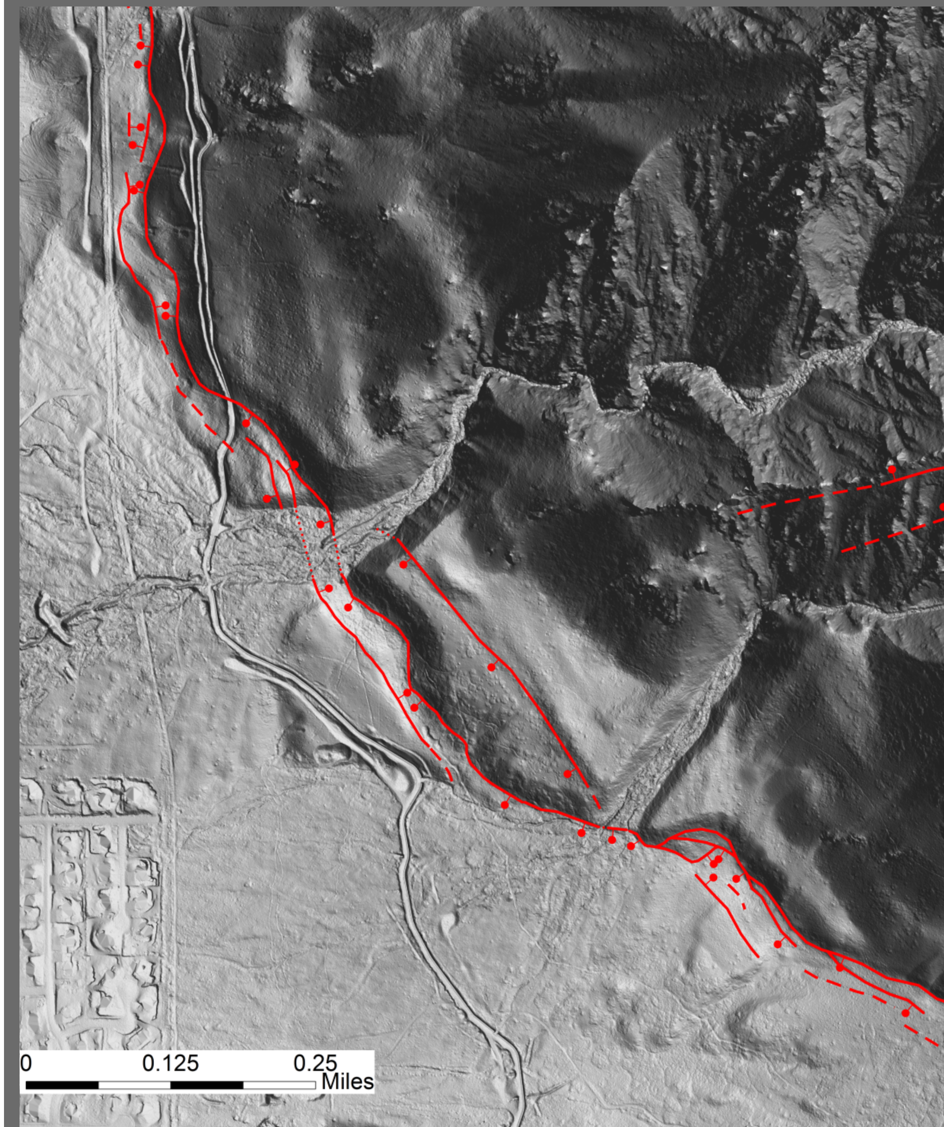
2009 HRO Color 1 foot


0.5 m LiDAR, 2013
45-315 hill shade

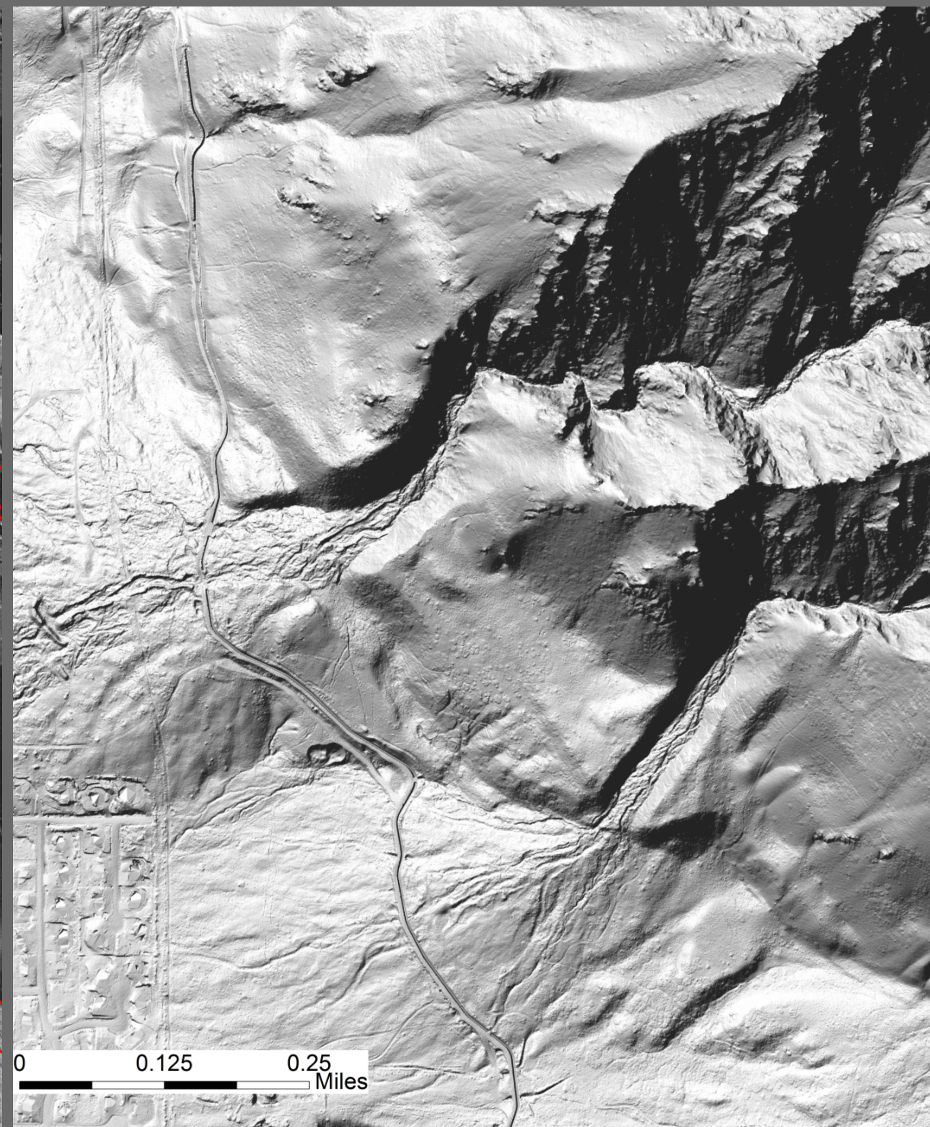


# Hill shade

0.5 m LiDAR, 2013
70-065 hill shade




0.5 m LiDAR, 2013
45-315 hill shade



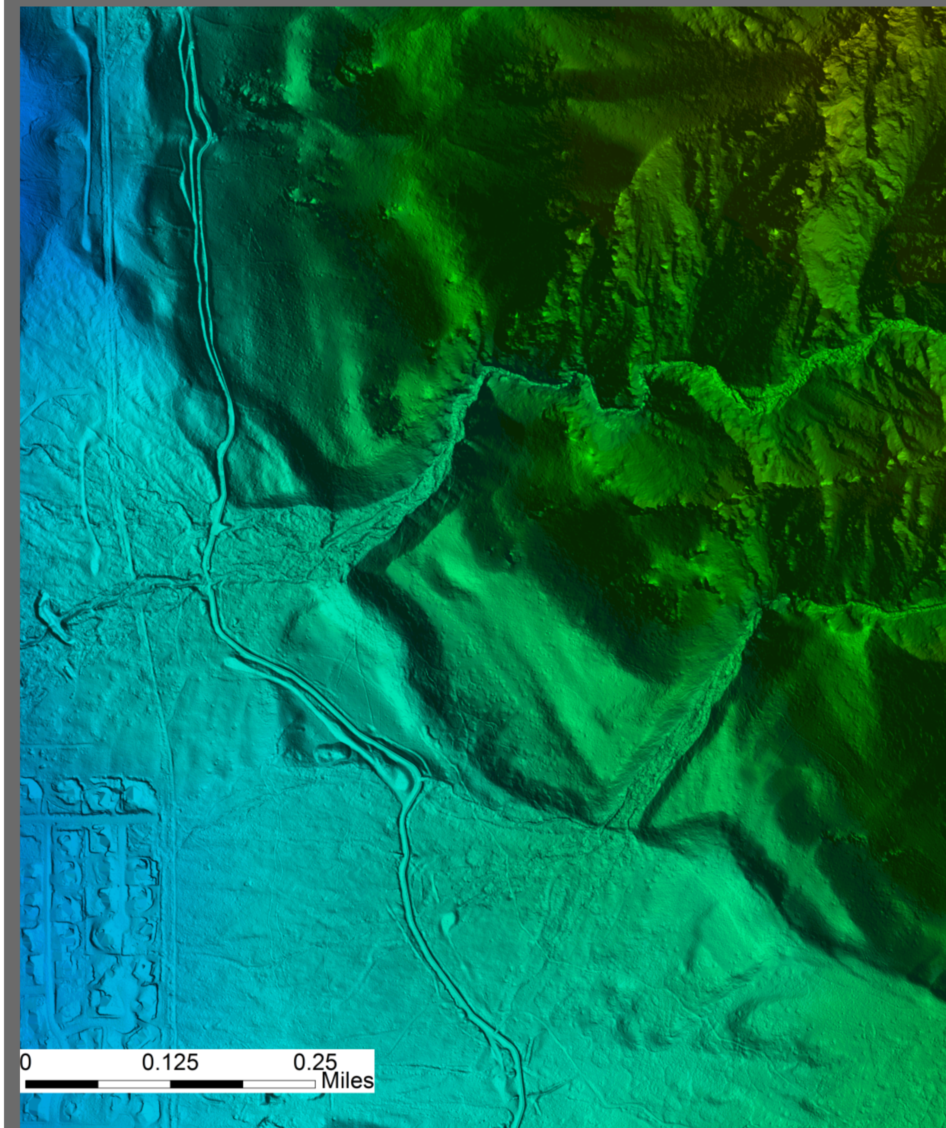
# Slope shade

0.5 m LiDAR, 2013
0-45 slope shade


0.5 m LiDAR, 2013
80-045 hill shade

# Atlas and hill shades

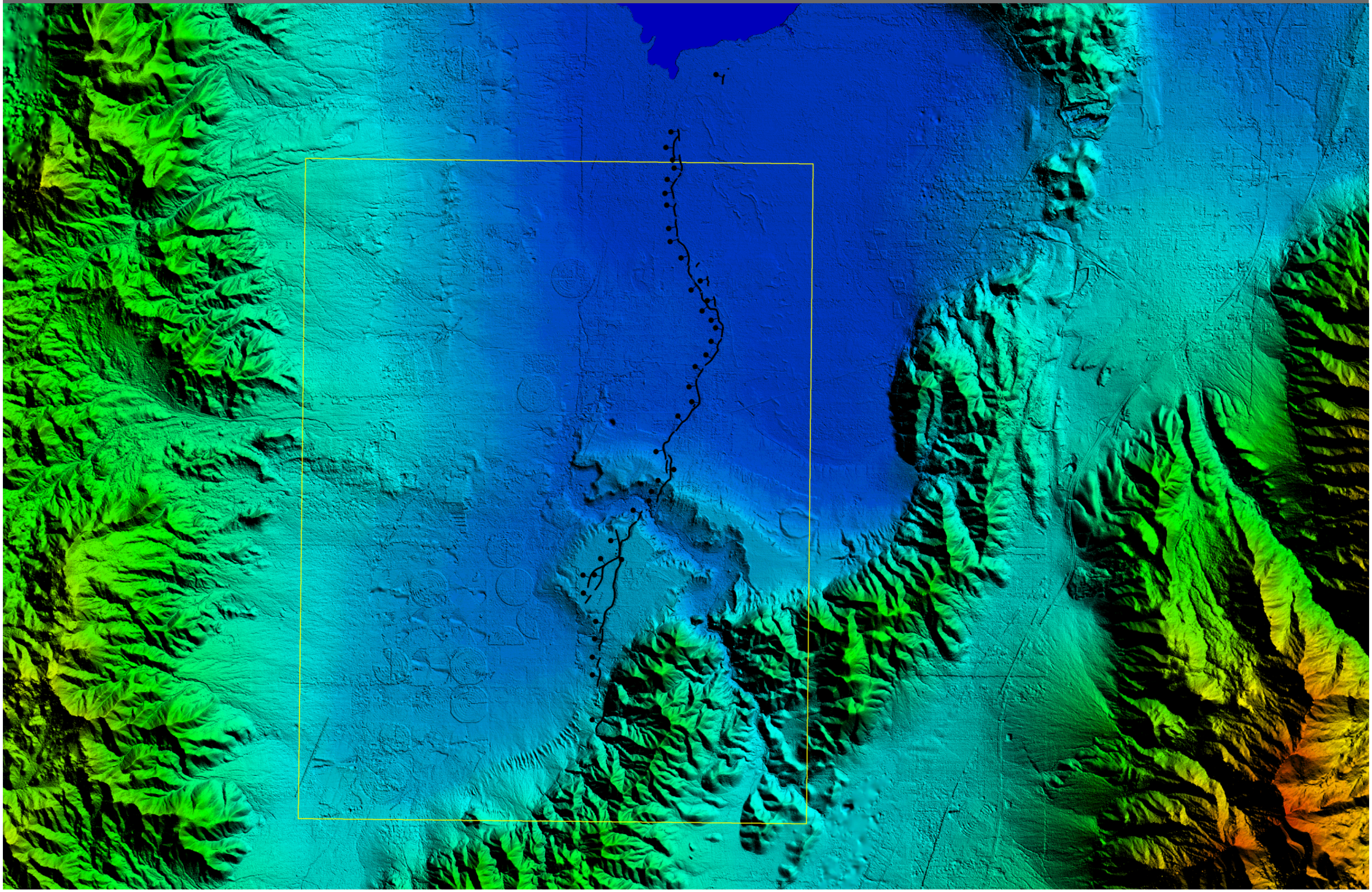
0.5 m LiDAR, 2013
70-065 hill shade and Atlas gradient shade




0.5 m LiDAR, 2013
80-045 hill shade

# Atlas and hill shades

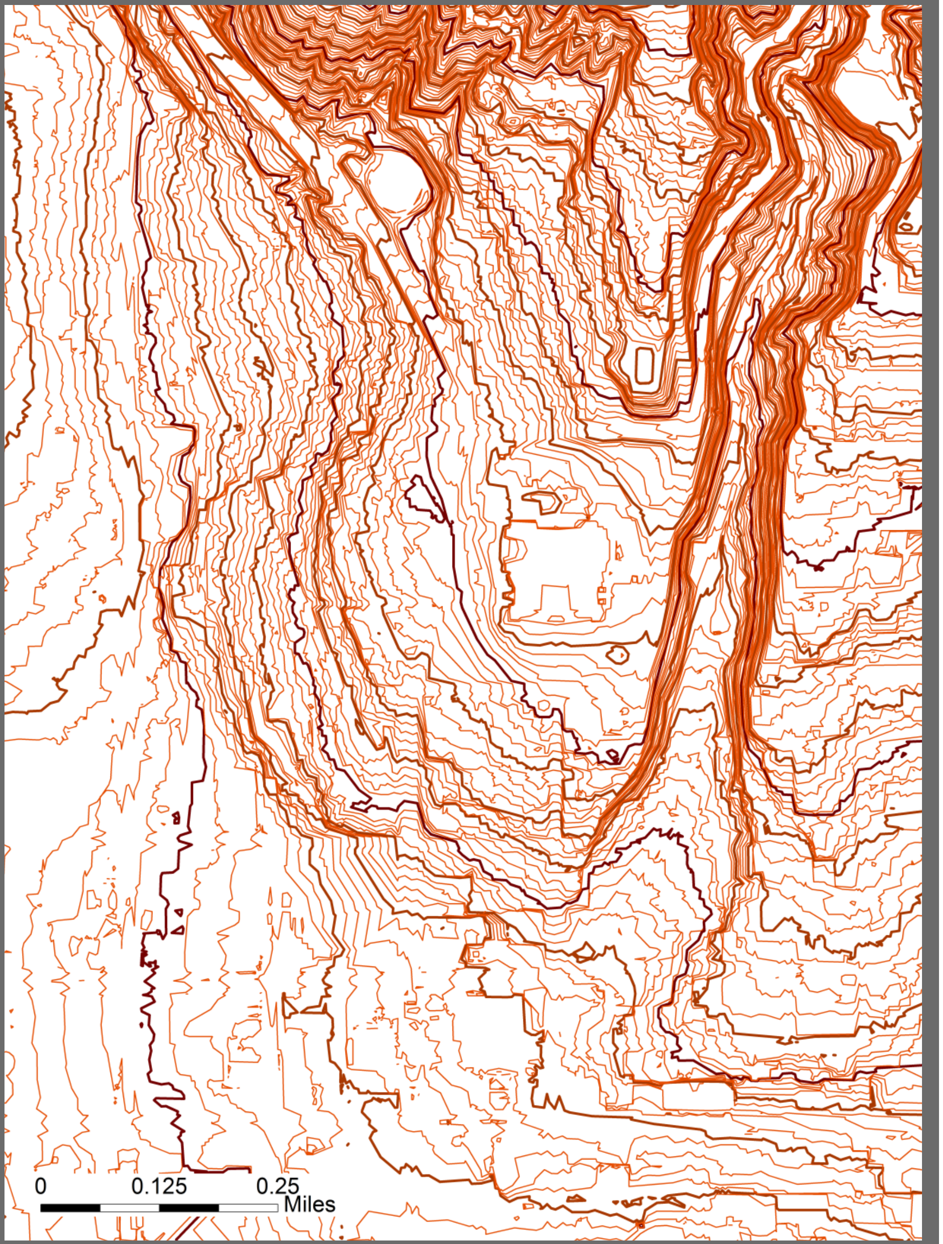
5 meter auto-correlated elevation model
Atlas gradient shade and hill shade



# Contours

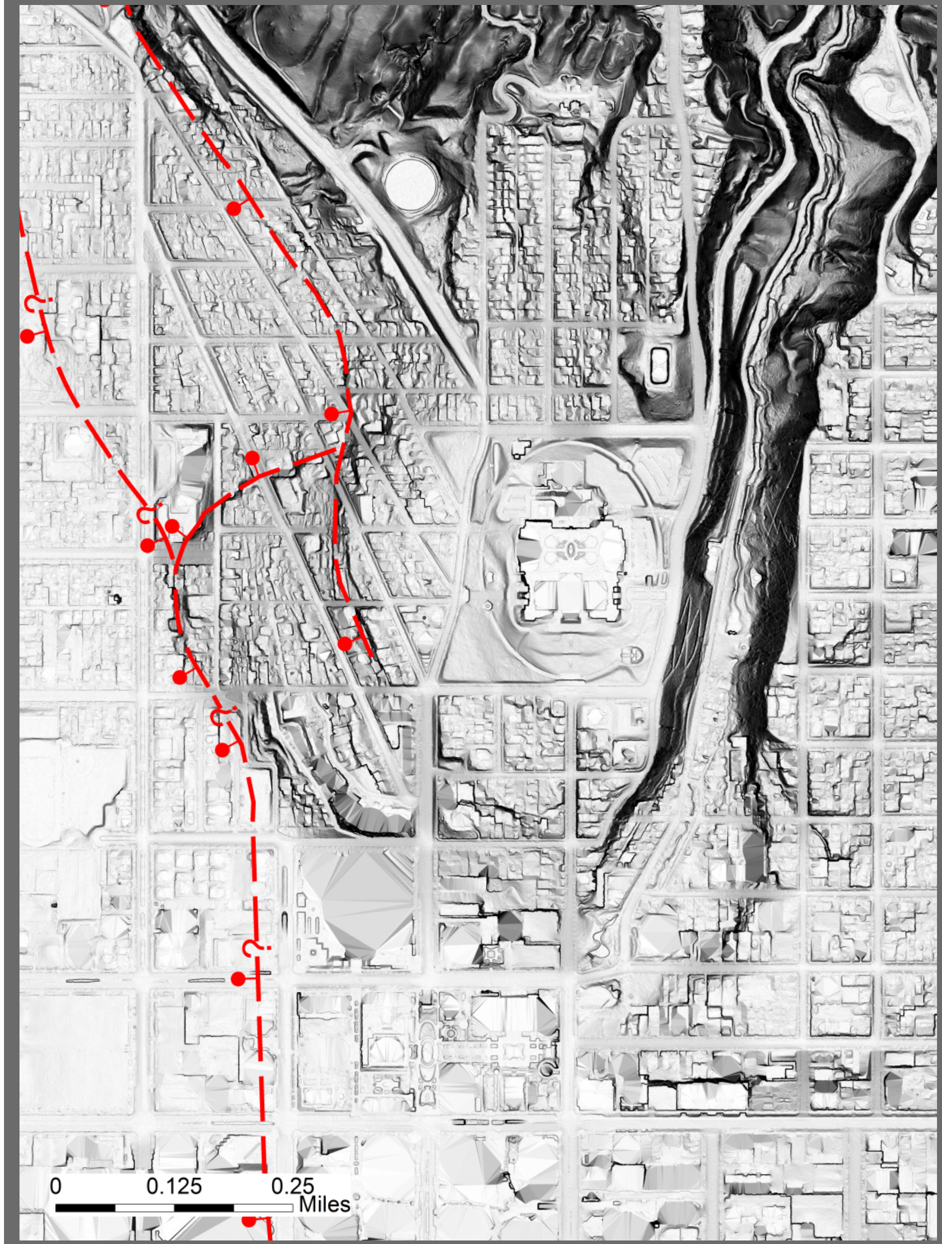
2011 NAIP

0.5 m LiDAR, 2014
5 foot contour

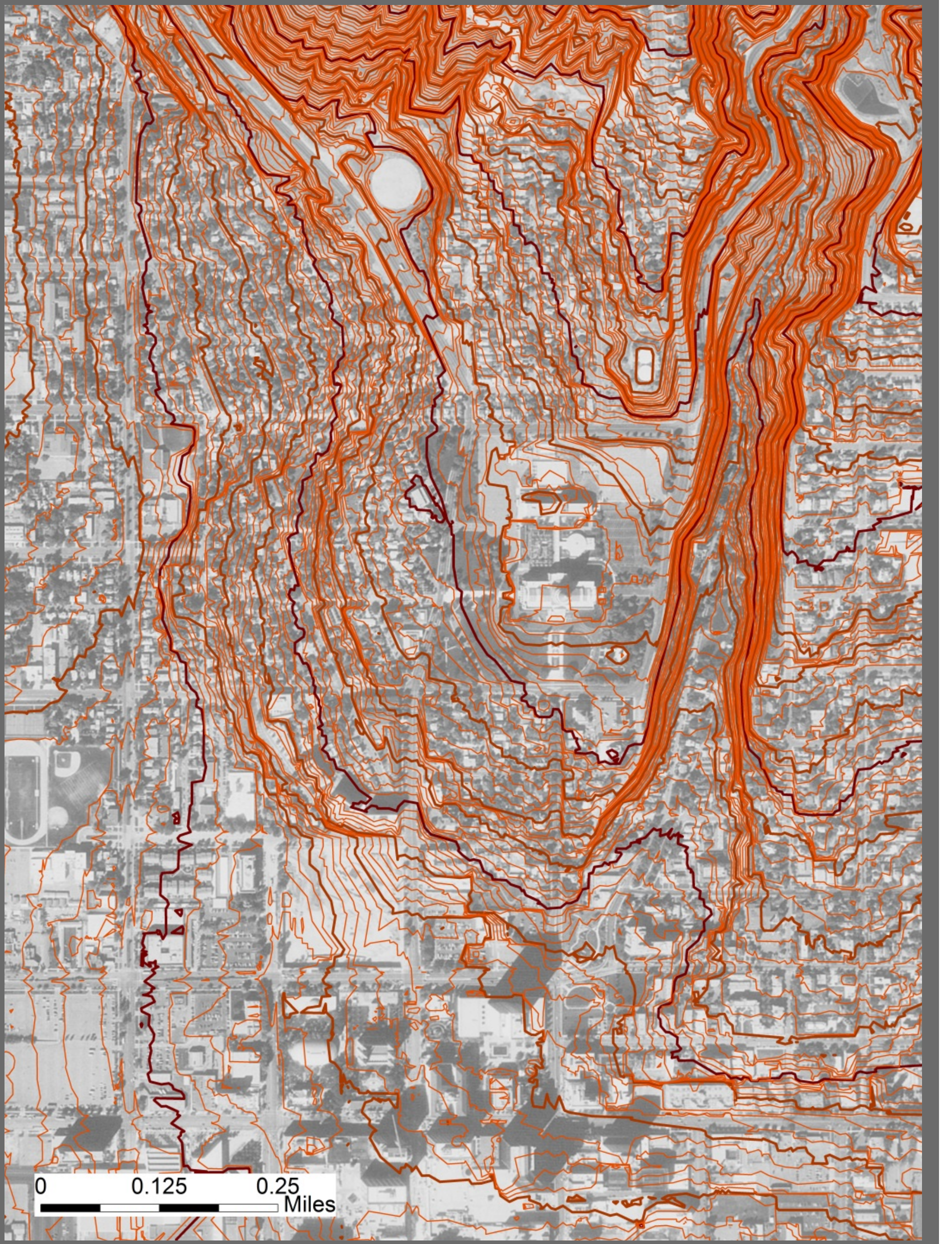



# Contours

0.5 m LiDAR, 2014
Slope shade



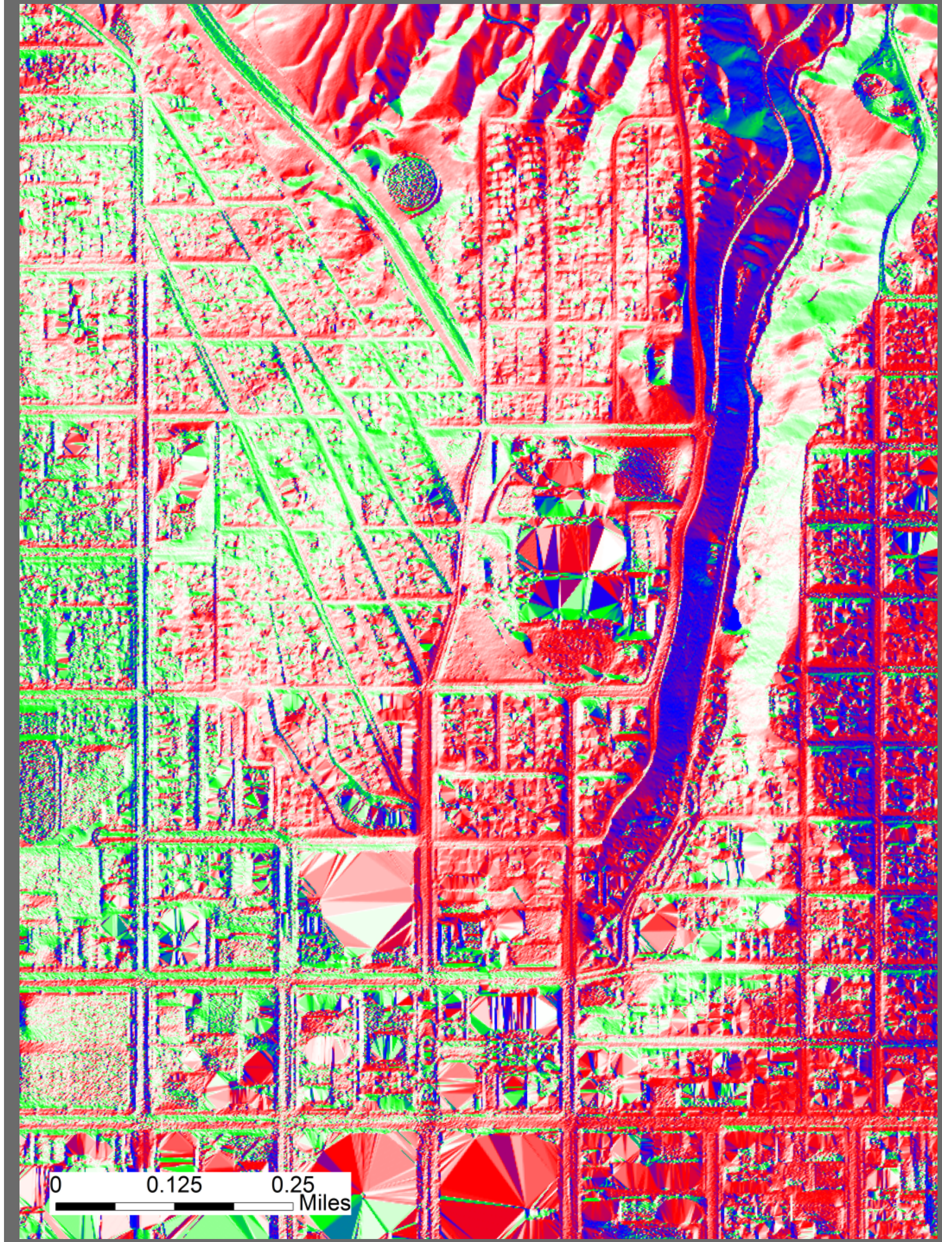

0.5 m LiDAR, 2014
5 foot contour



# Slope direction and gradient shades

2 m LiDAR, 2006

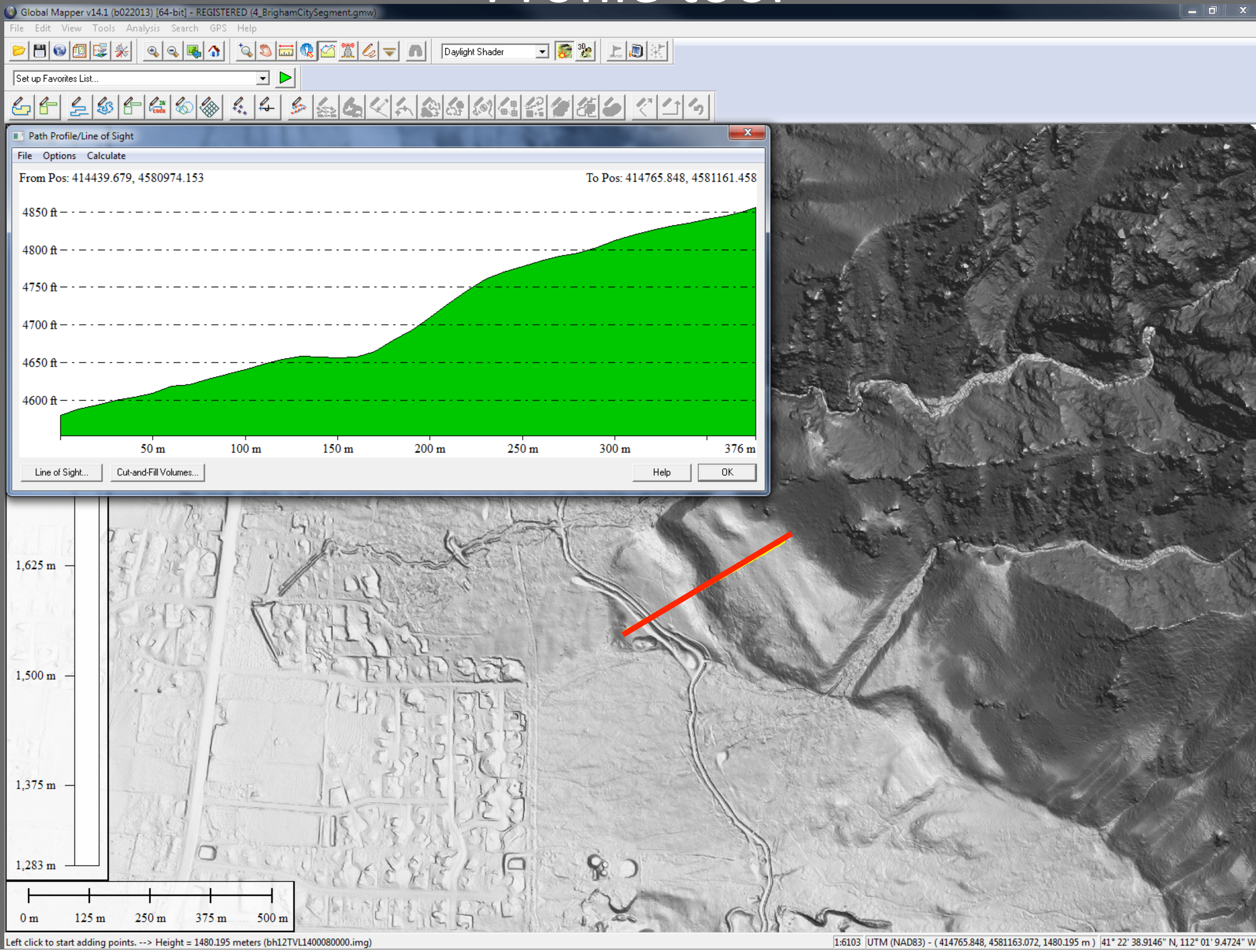
Slope direction shade




2 m LiDAR, 2006

Custom gradient shade

# Profile tool



Thank you