Source fault evaluation of the 1994 Draney Peak earthquake sequence, Caribou County Idaho

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Abstract

The Draney Peak Earthquake sequence occurred in southeastern Idaho February 3, 1994 approximately 100 miles east of Pocatello Idaho. It included two initial earthquakes of 5.7 and 4.5 magnitude producing normal fault focal mechanisms. On March 4, 2013 a magnitude 4.0 earthquake occurred in the same area indicating that the region continues to be seismically active. Previous researchers suggest the 1994 events occurred on the Star Valley fault in Wyoming 17 km east of the hypocenter. The hypocenter depth is ~4.5 km (Brumbaugh, 2001). Using basic trigonometric principles and constraining the dip of the fault to 45 to 60°, the responsible fault should lie approximately 4.5 to 2.6 km from the epicenter. Based on this analysis we hypothesize that the earthquakes occurred on the Meade thrust fault rather than the Star Valley fault. To test the hypothesis, we created a map in ArcGIS using Digital Elevation Models (DEMs) to determine elements indicative of a fault including horizontal offset and linear features. In addition we are using ERS-1 Synthetic Aperture Radar (SAR) images to create an interferogram of the surface deformation. The results will likely highlight localized vertical displacement caused by the earthquake and show whether surface deformation is consistent with movement on the Star Valley fault or extensional reactivation of the Meade thrust fault. The earthquakes and the Meade thrust fault lie within the extensional Basin and Range province in the western United states. The Draney Peak earthquakes may be an instance of reactivation of a Sevier-age thrust fault. Understanding fault reactivation as tectonic stresses shift from compression to extension can increase the ability to predict seismic hazards in the Intermountain West.

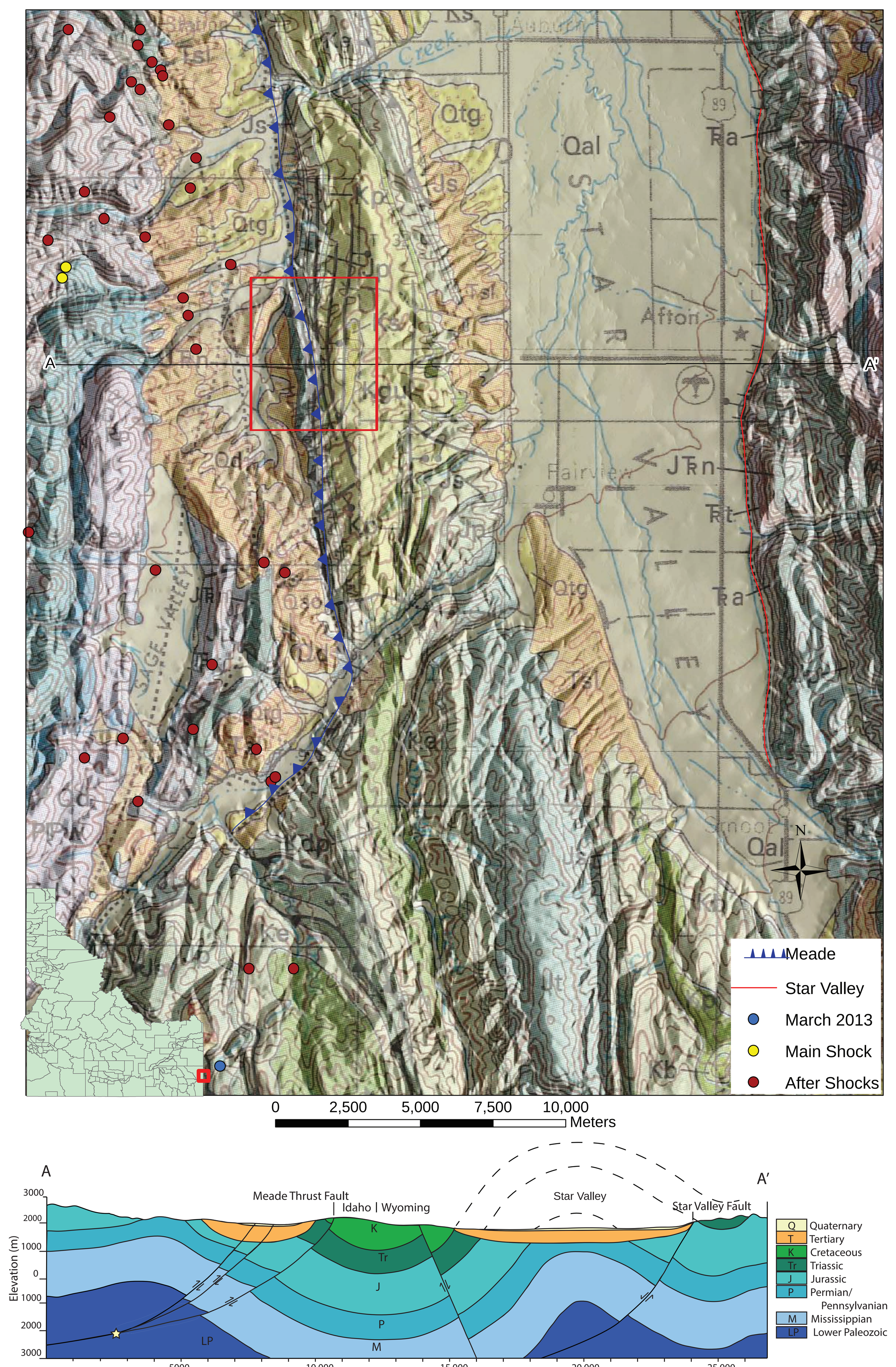

Figure 1 Geology. The study area is located in southeastern Idaho on the Idaho-Wyoming border in the Webster Range. The cross section shows the units grouped by age, the important faults in the area, and the epicenter location and depth. The geologic map (Oriel et al., 1980) shows the Meade thrust and Star Valley faults in relation to epicenter location.

Geometric Analysis

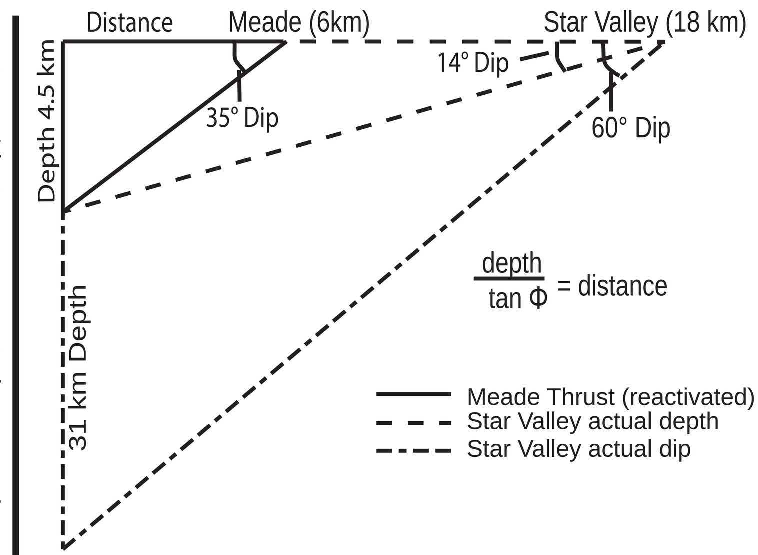

Figure 2. Geometry. Using the depth and the angle of dip the distance of the fault from the epicenter was determined using trigonometry. The solid lines indicate the values for the Meade thrust fault as the source fault for a hypocentral depth of 4.5 km (Brumbraugh, 2001). The angle of dip is ~35 degrees which is reasonable for a normal fault rupture on a pre-existing fault (Anderson, 1951). The dashed lines are based on the Star Valley fault as the source fault. The upper dashed line is based on the actual hypocentral depth of the earthquake; it has a dip of 14º which is unrealistic for normal fault rupture. The lower dashed line is based on a realistic dip for a normal fault rupture; but it projects to a hypocentral rupture depth of 31 km, far below the actual depth. From this analysis we hypothesized that reactivation of the Meade thrust or a fault near the Meade thrust is the more likely source fault of the Draney Peak earthquakes.

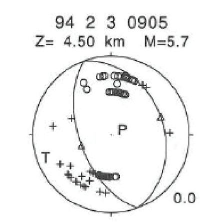

Figure 3. Focal Mechanisms. Focal mechanisms show the Draney Peak earthquake resulted from normal fault movement (Brumbaugh 2001).

InSAR

Synthetic aperature radar (SAR) data is generated by transmitting radiowaves from an antennae fixed to a satellite reflected off a target (the ground) and collected by a receiver. The known outgoing phase (Fig. 4a) is compared to the return phase to calculate the distance to the ground (Fig. 4b). When multiple SAR images are stacked on top of each other the change in distance can be calculated to produce an image called an interferogram. Interferograms can be used to detect subtle changes in topography caused by tectonic deformation (Simons et al., 1999). We created an interferogram of the Draney Peak area by stacking October 11, 1993 and July 26, 1995 images using ROI_PAC software (Fig. 5) (Rosen et al., 2004). The yellow to red colors indicate ground surface that moved towards the satellite; the blue color indicates land surface that moved away from the satellite. In the area of the Meade thrust fault the image suggests normal fault movement.

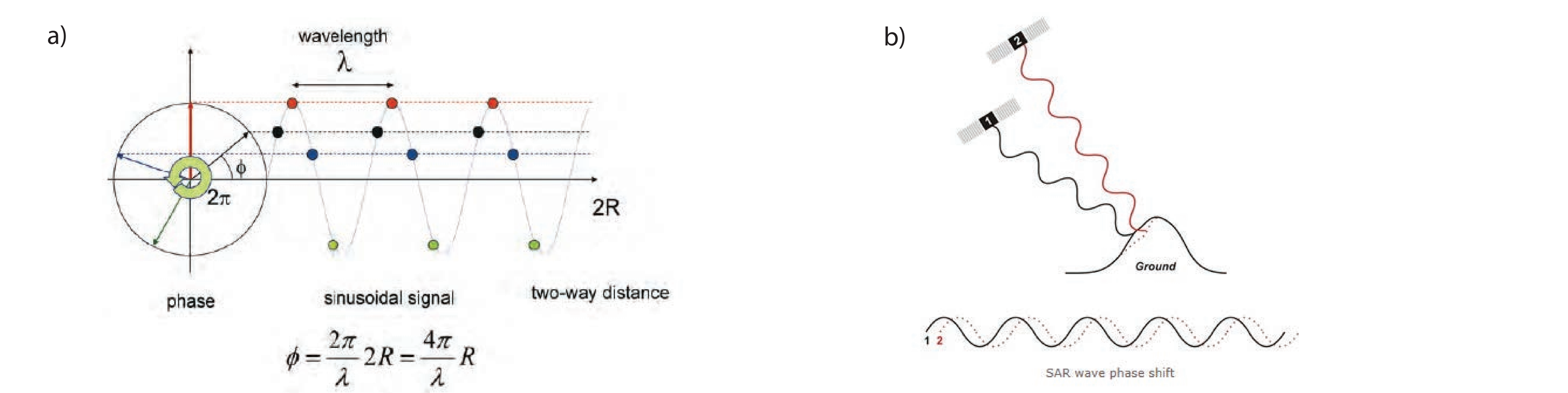

Figure 4. SAR explanations. a) A SAR phase is calculated using the distance the wave traveled, the wavelength and the cyclical nature of the phase (Ferretti et al., 2007). b) A shift in the phase can be calculated between 2 SAR images, measured from the same satellite position at different times. The phase differencing produces an interferogram of the change in elevation (CGG 2013).

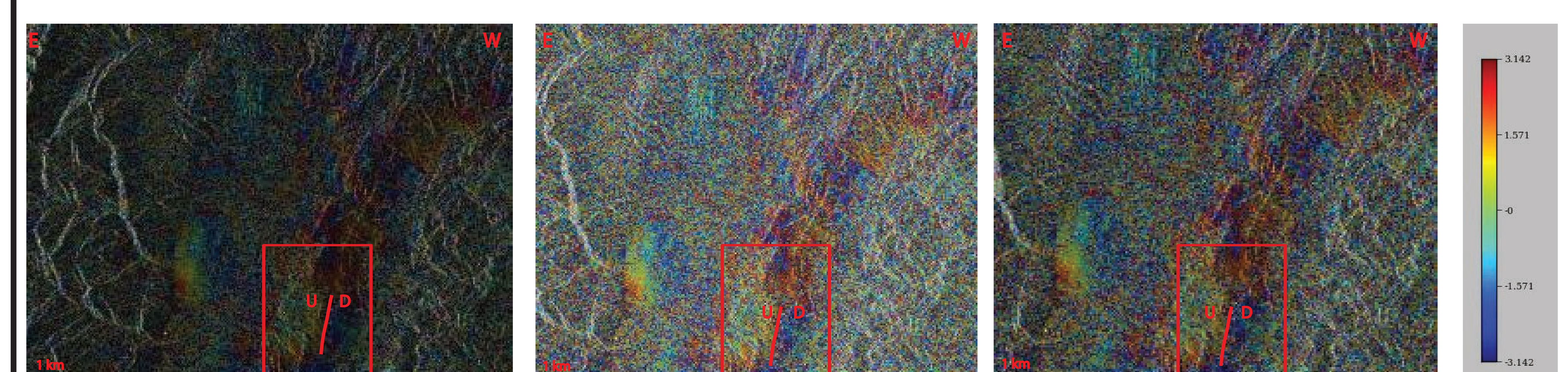

Figure 5. Interferograms. Interferograms of the Draney Peak area showing slight changes in elevation between October 1993 and July 1995. The elevation changes associated with the color changes marked by the red line suggest movement along a normal fault. (InSAR images produced using ROI_PAC software, Rosen et al., 2004). The red box is 6 km wide.

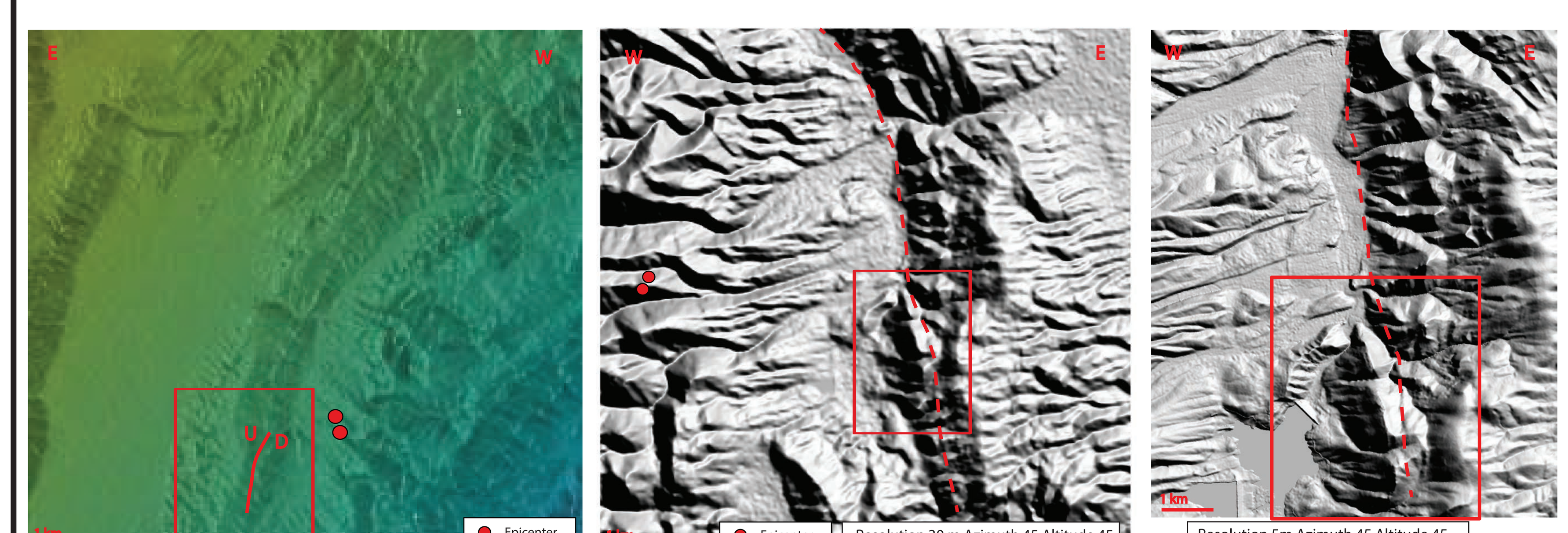

Figure 6. Lidar compared to Insar. The colored image is the DEM created with the interferogram. It is "backwards" because the the satellite was moving in a descending orbit. We located the region of potential fault movement found with the interferogram on this image and used topographic details to locate the possible active fault on high and low resolution DEMs. The red box is 6 km wide on the Insar image and 4 km wide for the DEMs.

Tectonic Indices

Mountain front sinuosity is a tectonic index calculated to help determine the potential for tectonic activity in an area. This index is a ratio between the curvilinear length of a mountain front (Lmf) and the length of the straight line mountain front (Ls) (Fig. 7)(Keller et al., 2002). A value between 1 and 1.6 indicates a potential for active tectonics. Along the mountain front near the Meade thrust fault the Lmf of segment A is 6673 m and the Ls is 6321 m resulting in a mountaint front sinuosity of 1.05. The Lmf of segment B is 5901m and the Ls is 5567 m resulting in a mountian front sinuosity of 1.06.

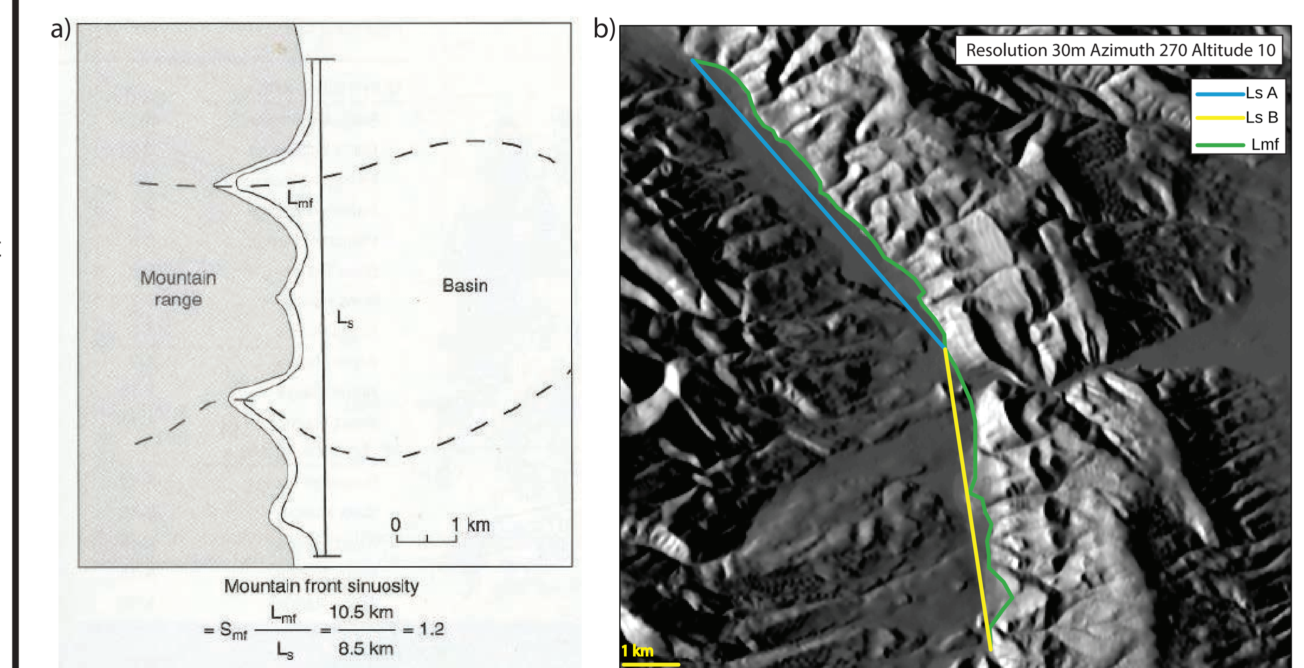

Figure 7. Mountain Front Sinuosity. a) Lmf measured the actual distance along the front of the mountain. Ls measures a straight line with the same starting and ending points as Lmf. Mountain front sinuosity is determined by dividing Lmf by Ls (Keller et al., 2002). b) Lmf and Ls measured in the Draney Peak area along the Meade thrust fault.

Profile Analysis

Topographic profiles were gathered across a high resolution digital elevation model (DEM). The profiles indicate a possible the location of the reactivated fault based on topography. We created a series profiles along the area of deformation within the red box (Fig. 8) and looked for patterns in the profiles. The trend we noticed suggests that in the north (white profile) the fault is along the east side of Sage Valley. The green and blue profiles show a distinct hill and valley complex through which the fault may pass. The hill and valley complex diminish across the orange and yellow profiles possibly indicating that the fault has shifted back towards Sage Valley.

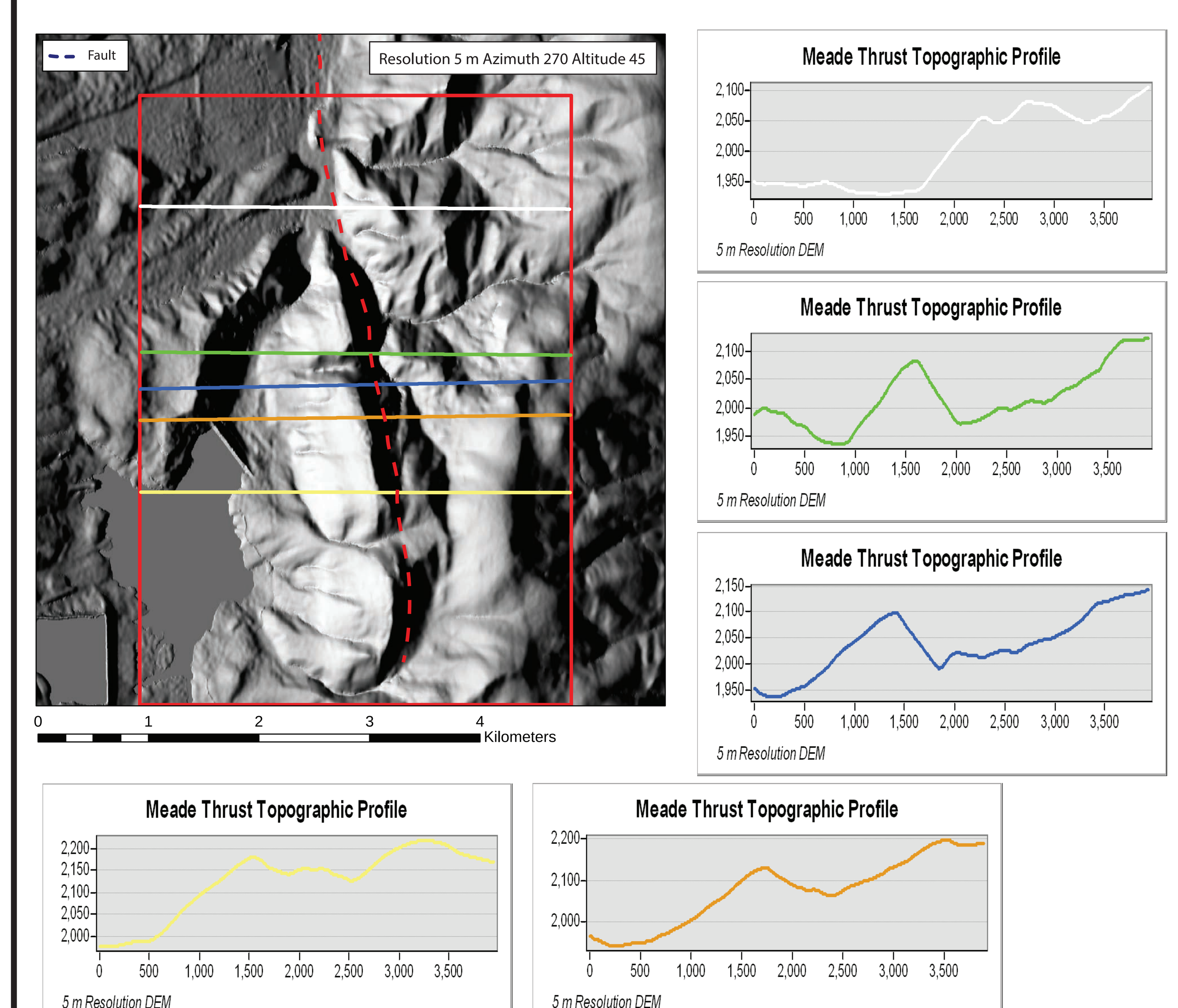

Figure 8. Meade thrust profiles. The profile graphs are graphs created using ArcGIS to analyze the location of the fault by looking for distinct changes in topography. These profiles show that the fault trends along on the east side of Sage Valley. The high resolution DEM shows the location of the profiles within the area of deformation.

Field Photos

Figure 9. Field Photos. (Left) a view of the fault along strike. (Right) a view of the fault from the front. It trends behind the hill in the foreground.

Conclusions

The 5.7 and 4.5 Draney Peak earthquakes were normal fault ruptures that occurred in southeastern Idaho in February of 1994. We suggest that the earthquakes occurred on an extensional reactivated segment of the Sevier-age Meade thrust fault rather than on the more distal Star Valley normal fault. An interferogram created by stacking pre- and post-rupture SAR images (October 11, 1993 and July 26, 1995) clearly suggests deformation along the western edge of Sage Valley. The resulting interferograms include significant noise which could be caused by changes in vegetation. The vegetation near the Meade thrust is sage brush and doesn't affect the results. The results show in the region of the Meade thrust fault that Sage Valley moved down and the ridge moved up indicating normal fault movement. The Star Valley fault also experienced elevation change but the movement in the valley was toward the satellite indicating uplift along the valley side of the fault; thus it is unlikely this elevation change was caused by the Draney Peak earthquakes. Rather it could be from a landslide, human development or other event that would increase the elevation at the mouth of a canyon. We analyzed the location of the fault identified in SAR data by comparing it to Lidar images which helped narrow the location of the surface deformation. Field analysis failed to locate any surface rupture in the area of the Meade thrust, as is expected for magnitude 5.9 and 5.7 ruptures.The InSAR analysis agrees with a geometric analysis of the hypocenters that place the fault ~6 km from the epicenter for a fault dipping ~ 35º. The results of our analysis suggest that the Draney Peak earthquake did not occur on the Star Valley fault; rather it likely occurred by extensional reactivation of the Meade thrust fault. Similar extensional reactivation in the Basin and Range province is reported by West (1993).

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Sources

High resolution DEM from InterMap; resold by Eastview.com serving the Academic Community

DEM from National Map viewer http://viewer.nationalmap.gov/viewer/

ERS 1 data from UNAVCO http://facility.unavco.org/data/sar/

ORD Orbit data provided by Walter Szeliga

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