Annual Report Vol. 40 (2017)

Paleoseismic study of the Northern Teton Fault, Wyoming

Glenn D. Thackray[1*] and Mark Zellman[2]

1 Department of Geosciences, Idaho State University, Pocatello, ID
2 BGC Engineering Inc., Denver, CO
* Author for correspondence: thacglen@isu.edu

Abstract We investigated the earthquake history of the northern portion of the Teton fault by excavating two trenches across a fault scarp near the eastern shore of Jackson Lake, near Steamboat Mountain. We identified the primary stratigraphy of the trenches, logged the trenches in detail, and collected samples for dating analyses. The trenches exposed faulted glacial sediments and overlying hillslope colluvium and alluvial sediments. Interpretation of the trench stratigraphy is ongoing. Samples are currently being analyzed using radiocarbon and luminescence dating techniques to determine the ages of the sediments and constrain the timing of fault rupture. We hosted several visitors at the trench site, including professionals and students, and introduced two interns to the process of fault trenching and documentation.

Introduction

In July 2017, we conducted a paleoseismic trench investigation of the northern portion of the Teton fault near the northeastern shore of Jackson Lake at the Steamboat Mountain site (Figure 1). This study was performed to improve knowledge of the large-magnitude, surface-rupturing earthquake history of the Teton fault to better understand the seismic hazard it presents to the surrounding region. Herein, we discuss the motivation for the fault-trench study and document preliminary results and ongoing analyses.

The Teton fault is the major seismogenic, range-bounding normal fault on the eastern flank of the Teton Range (Smith et al., 1993; O'Connell et al., 2003; Petersen et al., 2014). The fault dips east beneath the Jackson Hole basin, has an estimated vertical slip rate of ~0.2–2 mm/yr (White et al., 2009), and is included as a seismic source in the U.S. Geological Survey (USGS) National Seismic Hazard Maps (NHSMs Petersen et al., 2014). The fault is expressed by prominent scarps that vertically offset glacial and deglacial surfaces near the base of the range. Thackray and Staley (2017) measured offsets of deglacial surfaces and sediments south of Jackson Lake, and used a ~15 ka BP time of deglaciation (Licciardi and Pierce, 2008; Licciardi et al., 2014) to estimate an average postglacial vertical slip rate of 0.9 mm/yr.

Several questions remain regarding the late Pleistocene and Holocene surface-faulting earthquake history of the Teton fault. This is in part due to the fault being located almost completely within the Grand Teton National Park boundary and generally in remote and rugged terrain. Prior to this study and our previous trenching study at Leigh Lake (Zellman et al., 2016*b*), the known fault earthquake history was based on results from a single paleoseismic trench at Granite Creek and possible liquefaction features observed near the northern part of Jackson Lake (Figure 1). At the Granite Creek site, Byrd (1995) interpreted two Holocene surface-faulting events: one at about 7.9 ka and a broadly constrained second event between about 7.0 and 4.8 ka. Pierce and Good (1992) used evidence of shoreline subsidence, flooded delta deposits, and possible liquefaction features to infer two faulting events near the northern part of Jackson Lake with estimated ages of ~4 ka and ~1.6 ka. These features imply strong ground shaking caused by a nearby fault, but because they are only secondary (shaking-related) features, they cannot be uniquely tied to movement of the Teton fault. Similarly, Larsen et al. (2016) presented possible evidence of a Holocene shaking-related sediment horizon in Jenny Lake. We aim to clarify the fault rupture history by trenching the previously understudied central and northern portions of the fault. Our 2016 trenches at Leigh Lake (Zellman et al., 2016*b*) exposed the fault and allowed construction of a chronology of the most recent fault motion.

Our paleoseismic investigations at the Leigh Lake (Zellman et al., 2016*a*) and Steamboat Mountain (this study) sites were conducted to improve understanding of the earthquake history of the Teton fault. Our research is motivated by several questions:

1. Do fault displacement and slip rate vary spatially and (or) temporally?
2. What is the recurrence time between large earthquakes on the fault?
3. When did the most recent earthquake occur?
4. How much of the fault breaks in large earthquakes? That is, is the fault segmented?
5. Why are faulted offsets of the Steamboat Mountain glacial and alluvial sediments small compared to those of other scarps in deglacial surfaces of similar age?

To address these questions, we excavated two trenches across a 1-3-m-high fault scarp near Steamboat Mountain.

Steamboat Mountain site

The study site topography has developed in Mesozoic sedimentary and Tertiary volcanic bedrock, overlain by glacial and alluvial deposits (Love et al., 1992). The trenches were excavated in a unique location where the Teton fault cuts a glacial and alluvial surface, ca. 0.4 km east of the northern shore of Jackson Lake (Figures 1 and 2). The site lies near the western edge of a deeply incised surface, primary cut into

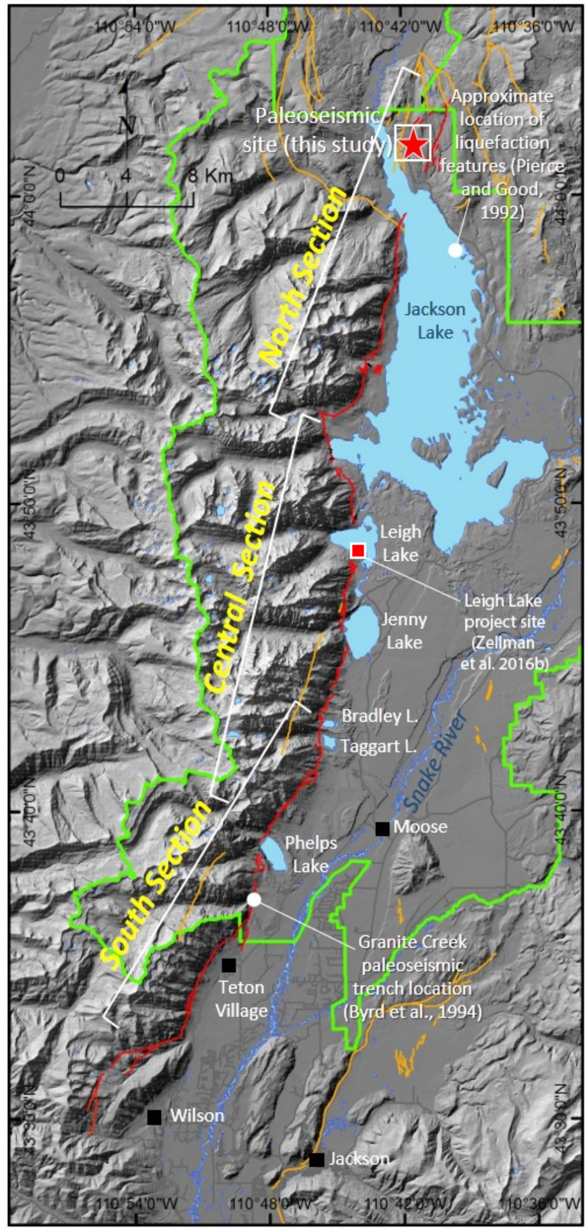

Figure 1. Location map showing the Steamboat Mountain project site (red star) on the northern portion of the east-dipping Teton fault (red; other faults in the region shown in orange). Approximate location of Pierce and Good (1992) possible paleoliquefaction features is shown, as are the locations of Byrd (1995) and Zellman et al. (2016*b*) paleoseismic trench sites; approximate fault section boundaries (yellow labels) from O'Connell et al. (2003). The Grand Teton National Park (GTNP) boundary shown in green. White box shows location of Figure 2. Basemap is hillshade map generated using digital topographic data from U.S. Geological Survey (2016)

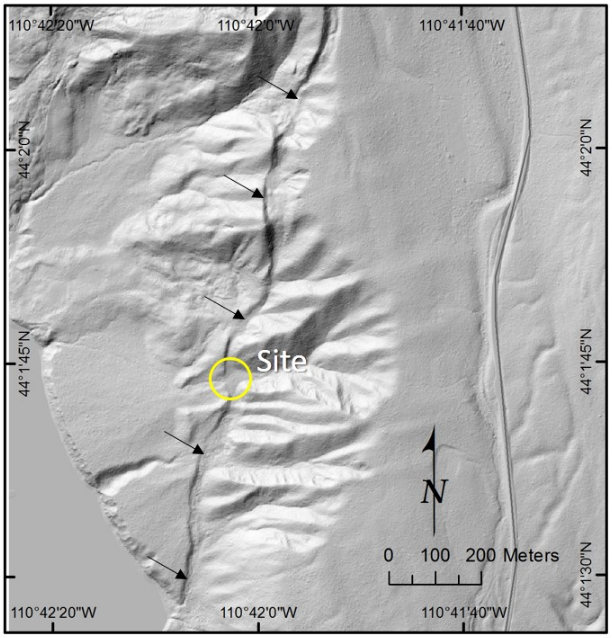

Figure 2. The Steamboat Mountain study site, showing the east-dipping Teton fault scarp (black arrows). The yellow circle shows the location of the paleoseismic trenches. Elevation data (slopeshade map) from 2104 Grand Teton National Park lidar data.

rhyolite volcanic rock of the Yellowstone volcanic sequence (Love et al., 1992).

The site is located within the main inferred path of the Jackson Hole lobe of the Yellowstone ice cap (Pierce and Good, 1992; Licciardi et al., 2014). The glacial surface and sediments have not been directly dated, but can be inferred to be younger than 16.97±0.63 ka, based on extensive dating of ice-cap sourced glacial landforms near the southern end of Jackson Lake (Licciardi and Pierce, 2008; Licciardi et al., 2014). In this report, we use 17 ka as an approximate age for the surface.

The site lies within the course of an ephemeral stream draining the incised surface (Figure 2). More specifically, the site lies in the transition between steep, erosional reaches and alluvial reaches, within the transition zone to the alluvial fan that stretches to the eastern shore of Jackson Lake. At the trench site, the east-dipping Teton fault has displaced the surface of a west-sloping alluvial fan, forming an uphill (east-facing) fault scarp. We chose the site because of the likelihood that the trench would expose alluvial sediments.

Figure 3. Trench A, which exposed the Teton fault across a low scarp (<1.5 m). View is to the west-southwest.

The scarp at the site is 1-3 m high, in contrast to the 5–13-m-high scarps that offset surfaces of Pinedale-age glacial sediments elsewhere on the Teton fault. The lower scarp height likely results from more recent stream erosion, partial scarp burial by stream sediments, and shifting of the main stream course.

Methods

We excavated two trenches across the single fault scarp at the Steamboat Mountain study site (Figure 2). The first site (Trench A) was selected where the scarp is well defined and less than ~2 m high. Trench A (Figure 3) was excavated with an orientation of 70° and measured 7 m long, 1 m wide, and 1–2.1 m deep. Trench B (Figure 4) was excavated across the same scarp, ca. 20 m to the south of Trench A. Trench B was oriented 70° and measured 6 m long, 1 m wide, and 1–1.5 m deep. We created orthophoto mosaics for the north and south walls of trenches A and B using Agisoft Photoscan software and following the methods of Reitman et al. (2015). We recorded primary stratigraphic units and structures exposed in the trenches on acetate sheets overlying the orthophotos.

A total of 37 samples were collected for sediment dating to establish estimated ages of stratigraphic

Figure 4. Trench B, which exposed the Teton fault on the lower slope of a 3.5 m high scarp. View is to the east-northeast. South wall (left) exposes well stratified, charcoal-rich sequence of alluvial sediments and paleosols.

units and the timing of past surface-faulting events. Four optically stimulated luminescence (OSL) samples and 17 radiocarbon samples were collected from Trench A, and four OSL and 12 radiocarbon samples were collected from Trench B. The orientation of the trenches and strike and dip of fractures and faults were measured with Brunton pocket transits calibrated to a declination of 11°35' E, and the "right hand rule" was applied to all attitude measurements.

Preliminary Results

As expected, the trenches expose apparent glacial and alluvial sediments. The up-scarp (western) end of Trench A exposed stratified gravel, diamicton, and sand, while the down-scarp (eastern) end exposed stratified alluvial sediments and paleosols.

Figure 5. Photograph of a portion of the south trench wall in Trench A. Sloping contact marked by displaced gravel clasts separates well-stratified sediment interpreted as glacial sediment (right) from less-well stratified alluvial sediments and paleosols (left).

Those sediments are separated by an east-sloping unconformity (strike 335° dip 67° E), marked by gravel clasts and by colluvial diamicton (Figure 5). In Trench B, the up-scarp end exposes less well-stratified (glacial?) sediments and colluvial diamicton, while the down-scarp end exposes a well-stratified, charcoal-rich sequence of alluvial sediments and paleosols (Figure 4).

Geochronology

We sampled buried soil horizons, sedimentary units, and colluvial diamictons for radiocarbon and OSL dating. Analysis of the OSL samples will be completed by the USGS Luminescence Laboratory. Radiocarbon samples are currently undergoing examination to identify charcoal from short-lived plant species (e.g., alder, rose and other shrubs), which are better suited for accurate radiocarbon dating as opposed to charcoal derived from long-lived trees such as lodgepole and limber pine. Lawrence Livermore National Laboratory or Woods Hole Oceanographic Institution will analyze the radiocarbon samples. The results will constrain the ages of the fault offset and surface disturbance events.

Interpretation and Conclusions

Preliminary interpretations suggest that both trenches exposed the fault zone, and that our radiocarbon and OSL samples will constrain the timing of fault rupture. Interpretation of trench logs and sediment descriptions is ongoing.

Outreach and Collaboration

Our Steamboat Mountain trench investigation was a collaborative effort between the USGS, Fugro Consultants, and ISU. Our field crew included two USGS interns, Nicole Cholewinski and Tyler Reyes, and one ISU employee, Nicholas Patton, all of whom gained experience in fault trenching and sediment dating techniques.

During the week-long period that the trenches were open, we hosted approximately 24 visitors. Sixteen students and four instructors from the University of Michigan's geology summer field course examined the trenches to learn about trench interpretation techniques and the development of paleoseismic records (Figure 6). Jeanne Godaire, Ralph Klinger, and intern Kris Hornsby from the U.S. Bureau of Reclamation, who are also conducting research on the fault history of the region, visited the site and provided feedback on the paleoseismic trenchs. Darren Larsen, a geologist at Occidental College researching earthquake records in Teton lake sediments, also visited the trench to examine the sediments and discuss implications for the earthquake history.

Results of this trenching project will be combined with those of our previous project at Leigh Lake and with those of a larger USGS-led trench project, completed at Jackson Hole Ski Resort in September of 2017, to develop a more robust record of surface-rupturing earthquakes on the Teton Fault.

Figure 6. Photograph of Trench A during a visit by students and instructors from the University of Michigan geology field course.

Acknowledgements

This research was funded by the University of Wyoming, National Park Service Research Station small grants program, Idaho State University, USGS, and Fugro Consultants, Inc. and BGC Engineering. Chris DuRoss and Rich Briggs of the USGS made integral contributions to the planning, implementation, and interpretation of the trenching project. Tyler Reyes (USGS), Nicole Cholewinski (USGS), and Nick Patton (ISU) helped move tons of sediment, assisted with other aspects of this paleoseismic investigation, and maintained excellent humor. We also thank Elizabeth Barrett and Breelyn Van Fleet of the U.S. National Park Service for their invaluable assistance with permitting and archaeological site clearance. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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