Paleoseismic Investigation of Earthquake Hazard and Long-term Movement History of the Hurricane Fault, Southwestern Utah and Northwestern Arizona
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INVESTIGATIONS UNDERTAKEN

The Utah Geological Survey (UGS) and Arizona Geological Survey (AZGS) are cooperating on a study of the Hurricane fault in southwestern Utah and northwestern Arizona. The Hurricane fault is a large, active, west-dipping normal fault within the structural and seismic transition between the Colorado Plateau and Basin and Range physiographic provinces. The UGS investigated the paleoseismicity and long-term slip history of the northern portion of the fault (proposed Ash Creek and Anderson Junction segments) in Utah (figure 1). The AZGS studied the proposed Shivwitz segment to better understand the geologic controls of earthquake rupture on the Hurricane fault in Arizona.

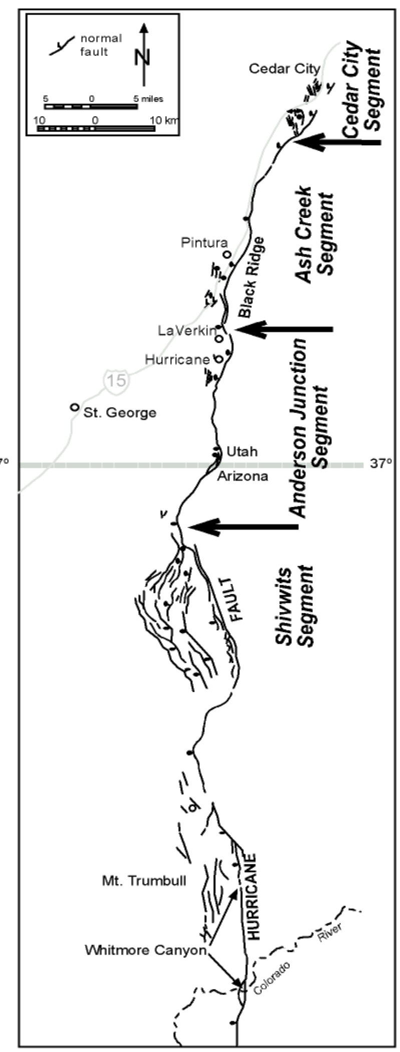

Figure 1. The Hurricane fault and proposed fault segments.

Utah Geological Survey Investigation

Trenching

On the Ash Creek segment (Stewart and Taylor, 1996; figure 2) fault scarps are formed on unconsolidated deposits at six locations (Pearthree and others, 1998). The UGS preferred the Murie Creek site for a trenching; however, that site is on private property and was not available for study. We then selected the scarp at Shurtz Creek (figure 2) for trenching. We originally rejected Shurtz Creek because we felt that large boulders on the ground surface there might extend into the subsurface. When trenching commenced, we quickly encountered buried boulders that limited the trench depth to less than 1.5 meters and prevented exposing the fault zone. Moving to a third site was rejected because we had already selected what we considered to be the two sites with the best chance of providing useful paleoseismic data and because of access problems at the other locations.

Dating Stream Alluvium and Alluvial-Fan Deposits

Lacking a viable trench site, our efforts focused on dating unfaulted young stream alluvium where it overlies the fault zone at the Middleton and Bauer sites (figure 2) and faulted young alluvial-fan sediments at Murie Creek. We believed that dating these deposits would provide limiting ages for the timing of the most recent surface-faulting earthquake (MRE) at the north end of the fault. Stream cuts exposed the sediments of interest. We prepared geologic maps of the sites and made detailed descriptions of soil profiles at each location. Utah State University analyzed bulk samples from the soil-profile horizons for grain-size distribution and total carbonate content. Paleo Research Laboratories processed bulk samples from select stratigraphic intervals and identified the organic matter present. We submitted detrital charcoal from each site to Beta Analytic, Inc. for accelerator mass spectrometry radiocarbon dating.

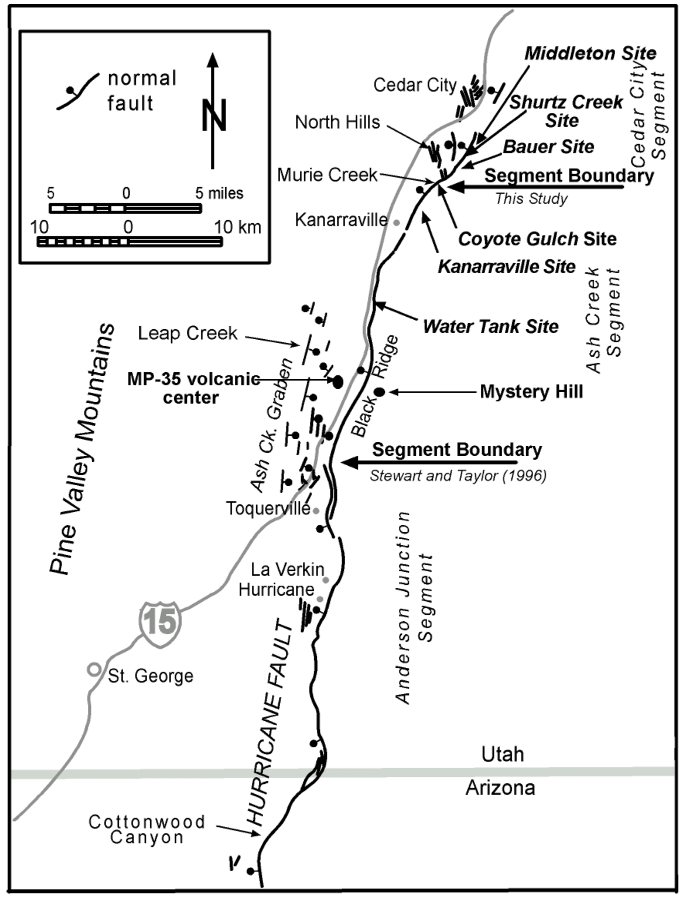

Figure 2. Hurricane fault in southwestern Utah showing sites with scarps formed on unconsolidated deposits. The Ash creek graben and MP-35 and

Developing Long-term Fault-slip Data from Displaced Basalt Flows

We used geochemical, paleomagnetic, and petrologic data to correlate displaced basalt flows across the Hurricane fault and to determine the amount of backtilting toward the fault for net-slip calculations. We submitted samples of the displaced basalts to the New Mexico Geochronology Research Laboratory for $^{40}Ar/^{39}Ar$ radiometric dating to determine the time period over which the slip occurred.

Paleomagnetic analysis: Differences in the orientation of the remanent magnetic vector between basalts in the hanging wall and footwall of the Hurricane fault provide a measure of the backtilting of the hanging wall toward the fault. Once the extent of the backtilting is known, the effects of near-field deformation can be accounted for in slip-rate calculations for the fault. We analyzed the paleomagnetic characteristics of basalt samples from 42 sites along the Utah portion of the fault.

Geochemical and petrologic analysis: We collected more than 70 samples for geochemical and petrologic examination along the Hurricane fault in Utah, most at locations coordinated with the paleomagnetic sampling program. We sent the samples to the Washington State University GeoAnalytical Laboratory for major, minor, and trace element x-ray fluorescence spectroscopy analysis.

^{40}Ar/^{39}Ar age determinations: We submitted three basalt samples for ^{40}Ar/^{39}Ar age determinations. Two samples are from key locations along the Hurricane fault where geochemical and topographic affinities indicated the basalt flows on either side of the fault can be correlated with a high degree of certainty. The third sample is from the basalt remanent in Cedar Canyon above Coal Creek on the footwall of the Hurricane fault (figure 2). We chose to date this flow because it rests directly on paleo-Coal Creek stream sediments approximately 335 meters directly above the present Coal Creek stream bed. Coal Creek flows westward to Cedar Valley and crosses the Hurricane fault at the mouth of Cedar Canyon. The rate of downcutting since the basalt remnant was emplaced serves as a proxy slip rate for the Hurricane fault.

Arizona Geological Survey Investigation

The AZGS investigated the late Quaternary behavior of the Shivwitz section (figure 1) of the Hurricane fault, which is south of the Arizona-Utah border and north of the Colorado River (Pearthree and others, 1998). Studies to characterize the late Quaternary rupture history of the Shivwitz segment of the Hurricane fault included: geologic and geomorphic mapping, scarp profiling, trenching, and geochemical correlation and dating of a displaced basalt flow.

RESULTS

Utah Geological Survey Investigation

Summary of Study Results

Results of this UGS study show that:

1. Long-term slip rates on the Hurricane fault in Utah range from 0.44 to 0.57 mm/yr and generally increase from south to north.
2. Although long-term slip-rate data are sparse, increases in slip rate appear to be incremental across a previously suspected fault segment boundary at South Black Ridge between the proposed Anderson Junction and Ash Creek segments. The data are also permissive, but not necessarily supportive, of a seismogenic boundary farther north at Murie Creek.
3. Slip rates determined from displaced late Pleistocene and Holocene alluvial and colluvial deposits are lower (<0.01 - 0.3 mm/yr) than the long-term rates and show that slip on the Hurricane fault has slowed in more recent geologic time. This decrease in activity helps explain the sparse distribution of young fault scarps on unconsolidated deposits at the base of the high, steep Hurricane Cliffs in Utah. This slowing may have begun more than 350,000 years ago as evidenced by the 0.21 mm/yr slip rate determined from the displaced basalt flow at Pah Tempe Hot Springs.
4. Faulted late Holocene alluvial-fan deposits at Coyote Gulch on the Ash Creek segment near Murie Creek, and the absence of evidence for young faulting north of that point, argues for a third fault segment in Utah with a segment boundary likely at the right bend in the fault near Murie Creek. We have named this new northern segment the Cedar City segment (figures 1and 2).
5. The MRE on the Anderson Junction segment occurred in the early to middle Holocene (Pearthree and others, 1998). The MRE on the Ash Creek segment occurred in the late Holocene sometime after 1,260 cal. B.P. Timing of the MRE on the proposed Cedar City segment is prior to 1,530 cal B.P., and the absence of young scarps on the Cedar City segment argues for a considerable period of time since the last surface-faulting earthquake.

6. The most recent surface-faulting earthquakes on the Ash Creek and Anderson Junction segments are different in time, demonstrating that the two adjacent segments are independently seismogenic. Because both MREs occurred in the Holocene, both segments are active and considered capable of generating future large earthquakes.
7. A decrease in slip rate from the middle to late Quaternary along the Hurricane fault translates into longer recurrence intervals between surface-faulting earthquakes. The average recurrence interval for such earthquakes on the Hurricane fault in Utah is presently measured in several thousand to possibly more than ten thousand years.
8. Based on 2.75 meters of single-event displacement at Coyote Gulch, the MRE on the Ash Creek segment had an estimated moment magnitude of M 6.9-7.1.
9. Based on an estimated segment length of 20 kilometers, the Cedar City segment is capable of producing M 6.6 events.

Arizona Geological Survey Investigation

Studies to characterize the rupture history of the Shivwitz segment of the Hurricane fault (figure 1) included: geologic and geomorphic mapping, scarp profiling, trenching, and geochemical correlation and dating of a displaced basalt flow. Mapping showed that Quaternary units displaced by the fault include the Moriah Knoll basalt (figure 3) and late Pleistocene to early Holocene (?) alluvial and colluvial deposits. Slip-rate estimates from scarp profiles and carbonate-rind-thickness surface-age estimates range from 0.03 to 0.61 mm/yr. In contrast to results in Utah, slip rates on the Shivwitz segment are generally higher when determined using younger geomorphic surfaces. The reasons for this are not fully understood, but possible sources of slip-rate error include uncertainty in the age of displaced surfaces and underestimation of net slip due to burial of the hanging-wall surface by younger deposits.

The trench was excavated on a large alluvial fan that is an estimated 15,000-33,000 years old near Moriah Knoll (figure 3). The scarp is 4.5 meters high, shows little evidence of erosion, and represents multiple surface-faulting events. Stratigraphy in the trench consisted of debris-flow deposits in the footwall, and fault-scarp colluvium, fissure-fill deposits, slope-wash deposits, and a likely fluvial gravel deposit in the hanging wall. Two distinct colluvial-wedge deposits provide evidence for two surface-faulting earthquakes. No stratigraphic units in the trench correlate across the fault. Secondary geologic relations indicate that total slip for the two events is 4.33 to 4.66 meters. Retro-deformation analysis suggests that the MRE produced about 2.5 meters of vertical displacement. Detrital charcoal recovered from fissure-fill material below the MRE colluvial wedge had an age of 9,300 +1070, -430 cal B.P., which is considered close to the maximum age for the MRE.

Geochemical data show that the Moriah Knoll flow is correlative across the fault, and a new $^{40}Ar/^{39}Ar$ date establishes the age of the basalt at 0.83 ± 0.06 Ma. The flow is displaced about 200 meters, resulting in a long-term slip rate for the Shivwitz segment of 0.24 mm/yr.

A MRE single-event maximum surface displacement of 2.5 meters along the southern Shivwitz segment gives an estimated moment magnitude of 7-7.1. Using an estimated segment length of 57 kilometers, the Shivwitz segment is capable of producing M 6.8-7 events.

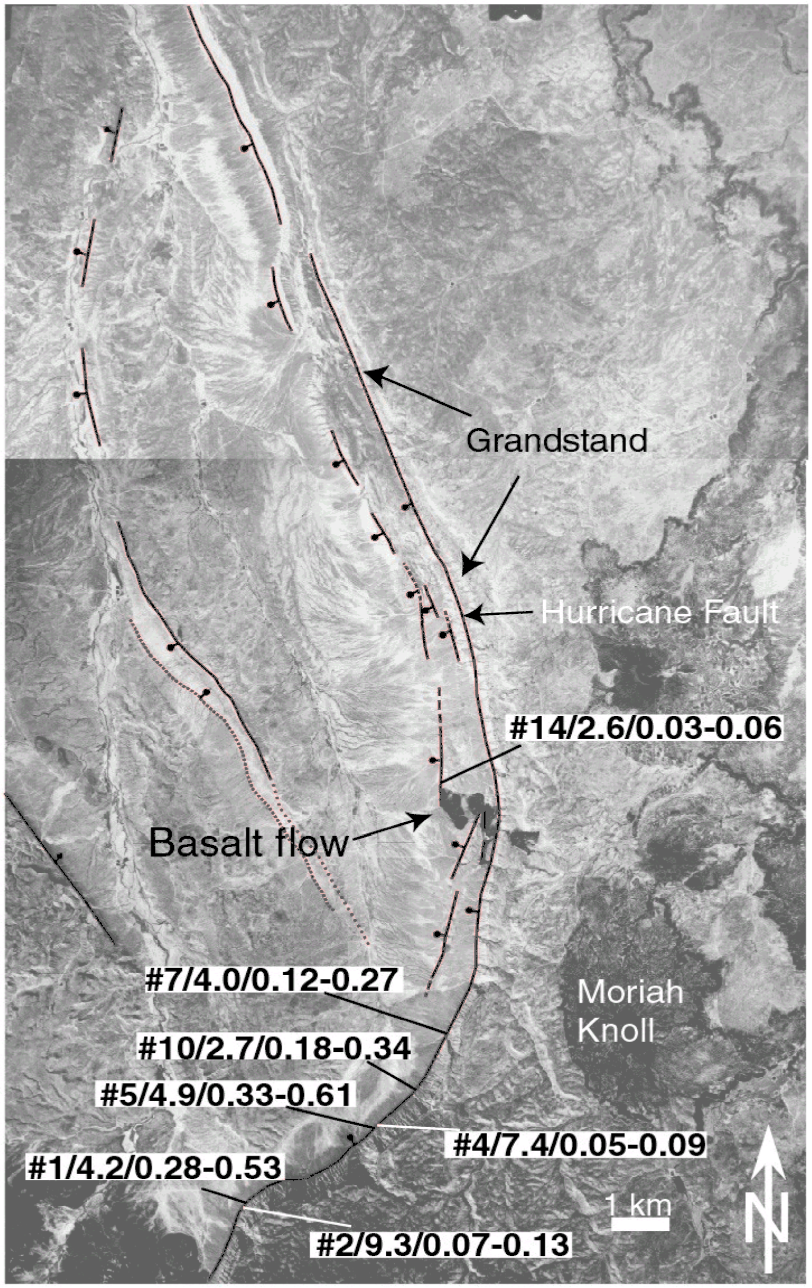

Figure 3. Mosaic of NASA high-altitude aerial photography of the Shivwitz section of the Hurricane fault zone showing profile locations and numbers, scarp heights in meters, and slip rates in mm/yr. The trench is at profile #7. Faults are dashed where approximate or inferred and dotted where concealed. The fault strands were taken from Billingsly (1994a and 1994b).

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REPORTS PUBLISHED

Preliminary results of this investigation were presented at the Geological Society of America Annual Meeting in Reno, Nevada on November 16, 2000, and at the Seismological Society of America Annual Meeting in March, 2001. The final technical report for this NEHRP-funded study, *Paleoseismic Investigation of Earthquake Hazard and Long-Term Movement History of the Hurricane Fault, Southwestern Utah and Northwestern Arizona,* was submitted to the U.S. Geological Survey Office of Acquisition and Federal Assistance on July 31, 2001.

AVAILABILITY OF INFORMATION

Contact William R. Lund at (435) 865-8126, lund@suu.edu for information regarding the data generated for this project.

NON-TECHNICAL PROJECT SUMMARY

We evaluated earthquake hazard on the Hurricane fault in Utah and Arizona. In Utah we dated unfaulted stream deposits and faulted alluvial-fan sediments to bracket the timing of the most recent surface-faulting earthquake. We studied the chemical and magnetic characteristics of basalts displaced by the fault, and dated the flows that could be correlated across the fault to develop a long-term slip history for the fault. In Arizona, we surveyed fault-scarp profiles and used soil development on alluvial-fan surfaces to estimate fault slip rates. We trenched a multiple-event scarp, on which the most recent earthquake occurred 9,300 years ago.