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Quaternary Faults in the 2008 Wells Earthquake Area

by

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ABSTRACT

The 2008 Wells M_w 6.0 earthquake occurred in an area of low seismic hazard, relative to most of Nevada. Several faults in the epicentral area offset Quaternary deposits by modest amounts, but the earthquake did not occur on a mapped fault. The surface projection of the inferred rupture plane, based on aftershock alignment, extends from the interior of the southern Snake Mountains across the frontal fault zone on the east side of the range, suggesting the earthquake occurred along one of several northeast-striking cross faults that segment the distributed, east-dipping range-front fault zone. The earthquake fault may also be part of a northern projection of the Clover Hill fault to the south. In western Town Creek Flat, a vegetation lineament and possible small scarp (about 0.5 m high) along the eastern Snake Mountains fault both cross an alluvial surface of late Quaternary age, suggesting that at least one surface-rupturing earthquake has occurred there in the recent geologic past. Examination of several faults in the epicentral area revealed no evidence of surface displacement or ground cracking, consistent with seismic evidence that indicates the rupture died out below the ground surface. There are subtle geomorphic features in the vicinity of the inferred surface projection of the rupture plane, but no clear evidence of a Quaternary fault. Thus, the Wells earthquake was a damaging background earthquake, the kind of earthquake that could occur anywhere in Nevada.

2008 WELLS EARTHQUAKE

The 2008 Wells M_w 6.0 earthquake was centered in the west-central part of Town Creek Flat, a 15-km-long by 9-km-wide, triangular-shaped basin just northeast of Wells (figures 1 and 2). Town Creek Flat is bounded by Quaternary faults on two sides: to the northeast, the Windermere Hills are bounded by a short, but fairly conspicuous range-front fault; and to the west, the southern end of the Snake Mountains are bounded by a distributed fault zone with discontinuous expression of Quaternary activity. To the south, the Wood Hills are not bounded by Quaternary faults.

The earthquake caused damage to more than half of the buildings in Wells, particularly in the historical district where there was a concentration of unreinforced masonry buildings. Seventeen buildings had major damage, and 10% to 15% of all chimneys were damaged. The cost of the earthquake is estimated to be about $10.5 million, a major impact on the community.

QUATERNARY FAULTS IN THE WELLS REGION

Quaternary fault activity in northeast Nevada is lower than throughout most of the state, but nonetheless there are several Quaternary faults within 50 km of Wells (figure 1). The most recent surface ruptures on these faults range in age from Holocene to middle Quaternary, but most of the faults have not been studied in detail.

There are three major Quaternary faults immediately south of Wells: the Ruby Mountains fault system; the eastern East Humboldt Range fault; and the Independence Valley fault zone. North of Wells, mapped Quaternary faults include the western Snake Mountains fault zone, the eastern Snake Mountains fault, faults within the Windermere Hills, and faults on the margins of Thousand Springs Valley and northern Marys River Valley. The more prominent of these faults are briefly discussed below.

The most prominent and the longest of the regional faults is the northeast-striking Ruby Mountains fault system, which bounds the northwest side of the Ruby Mountains and the southeast sides of Starr, Lamoille, Pleasant, and Huntington Valleys; the system has northwest-side-down normal displacement. Geomorphic evidence for this fault includes fault scarps, graben, faceted range fronts, and springs. The system is about 115 km long, but can be divided into three main sections that may be independently seismogenic. Wesnousky and Willoughby (2003) interpreted the most recent earthquake on the northern part of the system to have occurred between about 4,800 and 7,600 years ago and to have offset the surface vertically by 1 to 2.5 m.

The eastern East Humboldt Range fault bounds the east side of the East Humboldt Range for about 44 km, and appears to curve and intersect the northern end of the Ruby Mountains fault system. The eastern East Humboldt Range fault is an east-side-down normal fault that strikes north to north-northwest, except at its north end where it curves to the northwest. The fault is expressed by oversteepened slopes, inflections in ridges and slopes, spring alignments, highly eroded range-front facets, and sparse fault scarps. Although the fault has not been studied in detail, Dohrenwend and others (1991) indicate an early- to middle-Pleistocene age for much of the fault, and they show some fault scarps at the fault's southern end to be latest Pleistocene in age. To the north, the much smaller Clover Hill fault discussed above is a parallel normal fault that lies about 5 km east of the eastern East Humboldt Range fault.

The Independence Valley fault zone lies along the east side of Independence Valley and the west side of the Pequop Mountains. It is a 54-km-long, north-striking, west-side-down normal fault. Piedmont fault scarps a little west of the range front extend along much of the zone's length. Wesnousky and others (2005) identified a paleoearthquake offset of about 2.9 m on this fault zone, and they estimated the time of the most recent earthquake to be about 40,000 years ago based on fault-scarp morphology.

The Thousand Springs Valley fault zone, about 44 km north of Wells, shows evidence of multiple, mid-to-late Quaternary surface-rupturing earthquakes. The fault zone bounds the east side of the Granite Range for about 37 km, and has southeast-side-down normal displacement. Where the southern part of this fault strikes away from the range front into the piedmont, there is a single-event fault scarp with a 2-m vertical offset of a late Pleistocene fan surface. A nearby middle Pleistocene fan surface is offset vertically > 15 m (dePolo, 1991, unpublished field work).

In summary, faults in the Wells region occasionally produce surface-rupturing earthquakes, but for a given fault, such earthquakes are typically separated by periods of tens of thousands to hundreds of thousands of years.

QUATERNARY FAULTS IN THE WELLS AREA

Several faults in the Wells area (figure 2) have geomorphic expressions that indicate limited Quaternary activity. Most of these faults were mapped by previous workers (Slemmons, 1964; Dohrenwend and others, 1991; Sawyer and Oswald, 1998), although we identified significant extensions of two of these faults during this study.

Eastern Snake Mountains fault

About 30 km north of Town Creek Flat, the Snake Mountains are bounded on the east by a generally north-striking, east-side-down distributed fault zone (the eastern Snake Mountains fault, No. 1576, of Sawyer and Oswald [1998]). During this study, we identified discontinuous expression of Quaternary activity along the southern part of the range, and infer that this is an extension of the eastern Snake Mountains fault, more than doubling the fault's previously mapped length.

For descriptive purposes, the eastern Snake Mountains fault is subdivided here into three sections separated by northeast-striking cross faults (figure 3). The northern part of the approximately 35-km-long Thousand Springs Valley section displays the most conspicuous evidence of Quaternary activity, but activity is much less obvious along the southern part of the section. The Bishop Creek and Town Creek sections are each about 12 km long, and have subtle, distributed expressions of Quaternary activity identified during this study.

The Town Creek section is a distributed fault zone that includes range-front faults, short, subtle piedmont scarps, and a prominent spring alignment in alluvium; it also contains the 2008 Wells earthquake fault (figures 2, 3). Contrary to the overall northerly strike of the eastern Snake Mountains fault, the Town Creek section strikes to the northeast and we interpret it to be a connector fault that transfers displacement between the frontal faults bounding the east sides of the Snake Mountains and the East Humboldt Range. Clover Hill, relatively small mountains that lie within the right step between these two frontal fault systems, is bounded on the east by a small, north-striking fault, the Clover Hill fault. At its northern end, the Clover Hill fault changes to a northeast strike and projects into the interior of the Snake Mountains, approximately aligning with the inferred surface projection of the 2008 Wells earthquake (Henry and Colgan, this volume). Low-sun-angle aerial photographs taken in 1982 reveal a short (about 0.7 km long) vegetation lineament along the Town Creek section that crosses an alluvial fan of probable Holocene age (figure 4). Field examination revealed a small scarp (about 0.5 m high) along the northern part of the lineament (figure 5), suggesting that at least one Holocene surface-rupturing earthquake has occurred along this part of the fault. A scarp is not obvious elsewhere along the lineament, but greater incision of the fan surface to the west supports a small amount of surface offset or warping. Further study, including fault trenching, would be needed to conclusively determine whether the fault ruptured during the Holocene. This fault trace and the group of faults striking north toward the Snake Mountains range front (figure 2) have the best developed geomorphic expression of Quaternary activity among the distributed faults that make up the Town Creek section.

The 2008 Wells earthquake produced normal, down-to-the-southeast displacement (Smith and others, this volume). The causative fault is parallel to and synthetic with the frontal fault zone, and it can be considered a secondary fault of a distributed system.

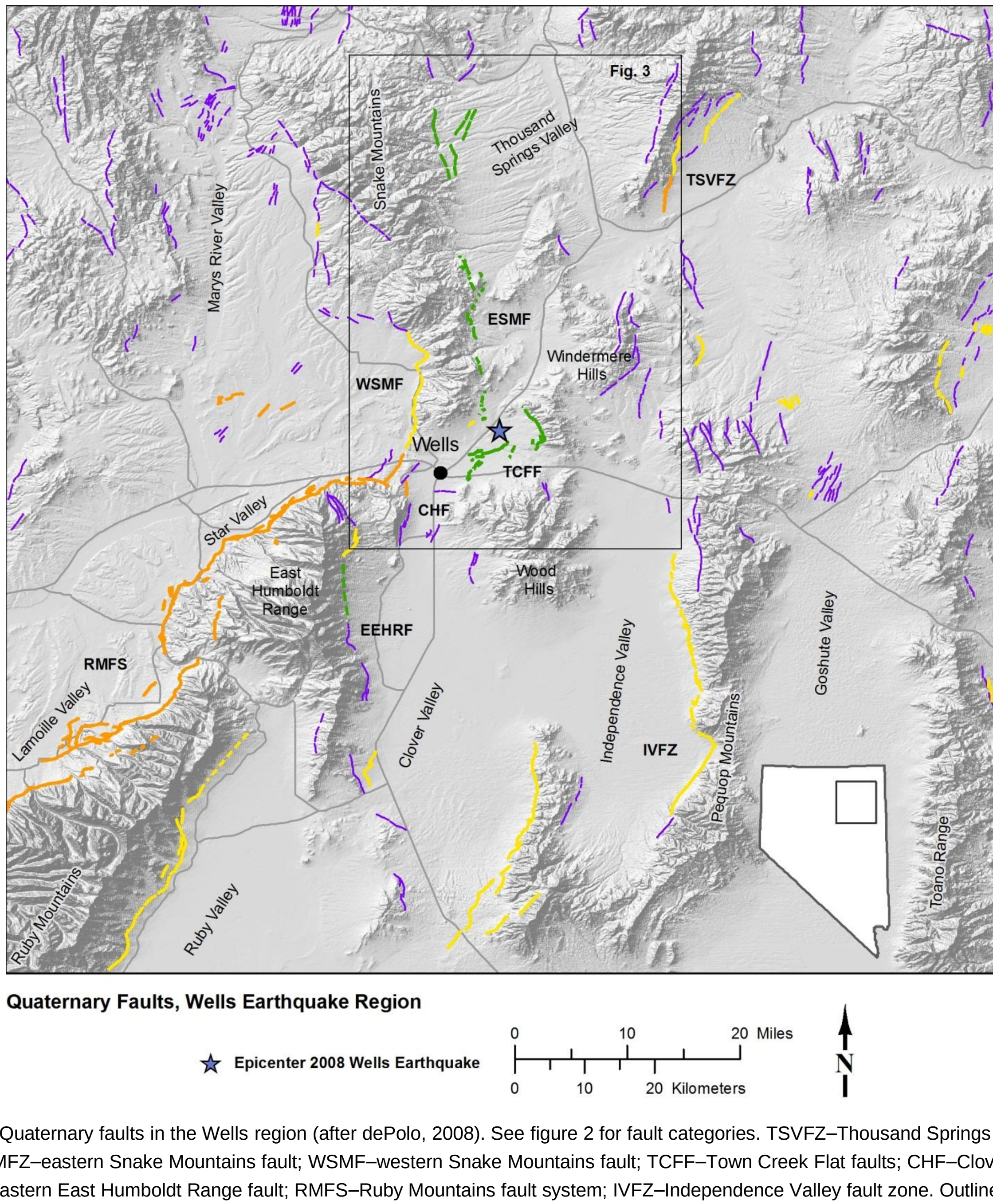

Figure 1. Quaternary faults in the Wells region (after dePolo, 2008). See figure 2 for fault categories. TSVFZ–Thousand Springs Valley fault zone; ESMFZ–eastern Snake Mountains fault; WSMF–western Snake Mountains fault; TCFF–Town Creek Flat faults; CHF–Clover Hill fault; EEHRF–eastern East Humboldt Range fault; RMFS–Ruby Mountains fault system; IVFZ–Independence Valley fault zone. Outline of figure 3 is approximate.

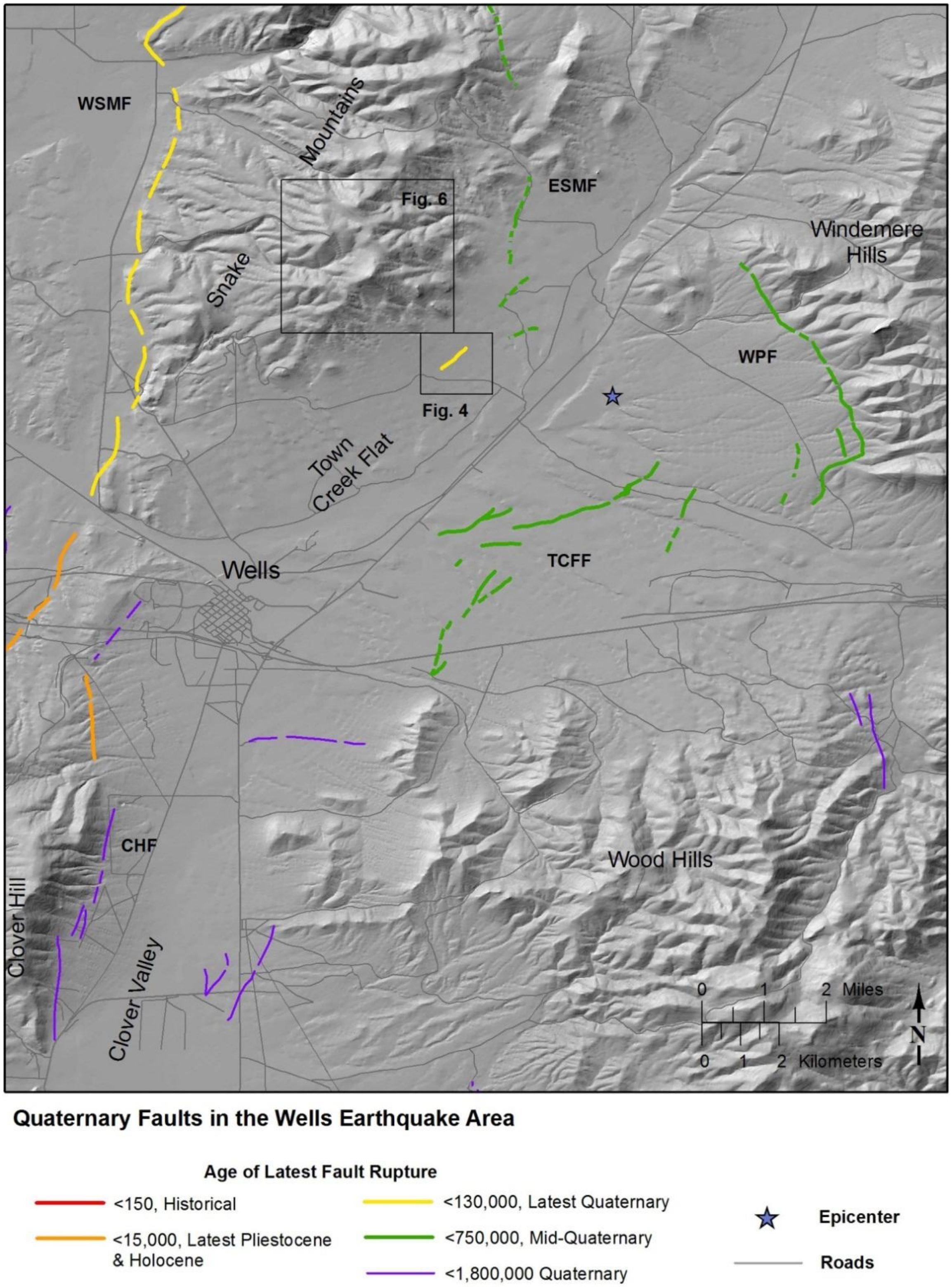

Figure 2. Shaded relief map of the Wells area showing Quaternary faults (after dePolo, 2008), the epicenter of the 2008 Wells M_w 6.0 earthquake, and outlines of figures 4 and 6. WSMF-western Snake Mountains fault; ESMF-eastern Snake Mountains fault; WPF-Wells Peak fault; TCFF-Town Creek Flat faults; CHF-Clover Hill fault.

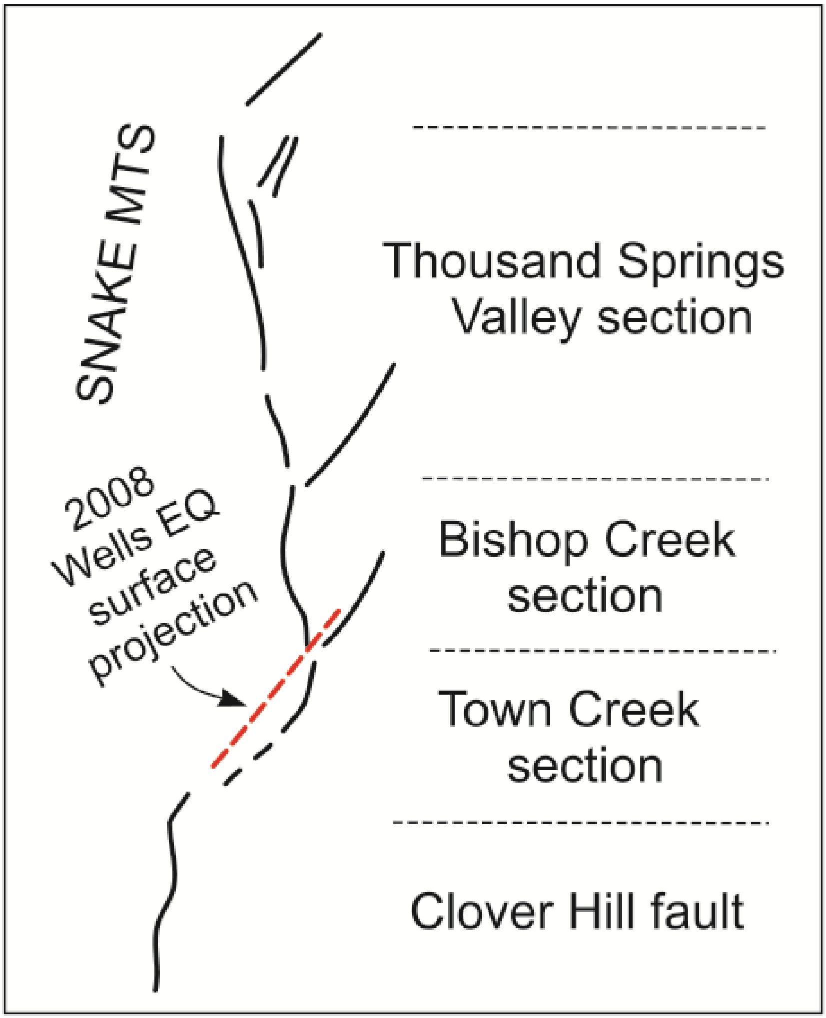

Figure 3. Sections of the eastern Snake Mountains fault described in text. The 2008 Wells earthquake occurred along a northeast-striking cross-fault that likely connects the eastern Snake Mountains and Clover Hill faults.

Wells Peak fault and Town Creek Flat faults

Sawyer and Oswald (1998) referred to the Wells Peak fault and Town Creek Flat faults collectively as "Unnamed fault west of Wells Peak, No. 1581". Here, we discuss these faults separately due to their contrasting orientations and geomorphic positions, but they may comprise a single complex fault zone.

The Wells Peak fault is a northwest-striking, west-side-down, range-front fault bounding the southwest side of the Windermere Hills (figure 2). The fault is generally expressed as a distinct bedrock-alluvium contact. It has a subdued expression, and locally has subtle scarps in alluvium. Based on subdued range-front morphology, we infer that this fault extends farther to the northwest than previously mapped.

The Town Creek Flat faults, not to be confused with the Town Creek section of the East Snake Mountains fault, form a distributed zone of intrabasin faults that generally strike northeast or north-northeast, have small northwest-side-down displacement, and are commonly accentuated by vegetation lineaments. These faults were mapped by previous workers (Dohrenwend and others, 1991; Sawyer and Oswald, 1998), although we identified a slight extension farther to the north along the westernmost trace. The Town Creek Flat faults dip toward the earthquake epicenter, although their actual dip angles are unknown. These faults likely intersect the causative earthquake fault, but aftershock distribution indicates the earthquake occurred on a southeast-dipping fault.

Scarps in alluvial deposits along both the Wells Peak and Town Creek Flat faults have very subdued expressions, and middle Quaternary deposits are offset by modest amounts, indicating low rates of surface-faulting activity.

Clover Hill fault

The Clover Hill fault is a short range-bounding fault (about 10 km long) with subdued expression of Quaternary activity. Quaternary alluvium is juxtaposed against bedrock along much of the range front (Sawyer and others, 2000). The fault generally lacks obvious scarps, but there are some small broad scarps at the northern end of the fault, which forms a contact between Tertiary sediments and Quaternary alluvium. Henry and Colgan (this volume) propose that the Clover Hill fault continues to the northeast into the Snake Mountains, and that this extension was the source of the 2008 Wells earthquake.

The Clover Hill fault approximately aligns with the Town Creek section of the eastern Snake Mountains fault, and the Town Creek section can be considered a distributed right step between range-front faults on the east sides of the East Humboldt Range and Snake Mountains. Henry and Colgan (this volume) did not map an extension of the Clover Hill fault within the surface geology of the Snake Mountains.

Summary

Quaternary faults had been mapped in the Wells area prior to the 2008 earthquake (Slemmons, 1964; Dohrenwend and others, 1991; Sawyer and Oswald, 1998), and we identified additional faults and extensions of mapped faults during this study. The 2008 Wells earthquake occurred along an unmapped fault that projects to the surface within the interior of the Snake Mountains (Smith and others, this volume) in an area that lacks obvious expression of Quaternary activity. We infer that the earthquake fault is part of a northeast-striking cross fault that segments the eastern Snake Mountains fault, and is a connector fault between the principal east-facing range-front faults. The best surface expression of Quaternary activity along the Town Creek section is on the piedmont just east of the range front, where subtle scarps, vegetation lineaments, and a prominent spring alignment form a zone oblique to the range front. Henry and Colgan (this volume) interpret the Clover Hill fault as projecting to the north into the Snake Mountains, where it may be a blind fault that was the source of the 2008 Wells earthquake.

FIELD-CHECKING FOR EARTHQUAKE SURFACE RUPTURE

At the time of the 2008 Wells earthquake, snow cover hindered the search for surface expression of the event (e.g., DuRoss and others, this volume). Nonetheless, field crews from the Utah Geological Survey and the Center for Neotectonic Studies at the University of Nevada, Reno deployed the day of the earthquake, looking for evidence of surface rupture and collateral effects, such as landslides, rock falls, and liquefaction; these studies are documented in DuRoss and others (this volume). The Utah Geological Survey group spot-inspected the Independence Valley fault zone, the Clover Hill fault, and the Town Creek Flat faults. The Center for Neotectonic Studies group examined the eastern East Humboldt Range and Ruby Mountains faults. Seven days after the event, the second author of this paper examined the Wells Peak fault on cross-country skis, and about a month later walked snow-free dirt roads crossing the southern end of the earthquake's surface projection.

In late spring, when snow had melted, analyses of seismicity and interferometric synthetic aperture radar (InSAR) interferometry gave a better understanding of the source structure and nature of surface deformation associated with the earthquake (Smith and others, this volume; and Bell, this volume, respectively). Guided by these results, we examined several faults in the epicentral area, including: 1) the young scarp in western Town Creek Flat (figures 4 and 5); 2) most of the Town Creek Flat faults; and 3) much of the area across and around the northern part of the surface projection of the earthquake, including a thrust fault mapped by Thorman and others (2003), which has an orientation consistent with the earthquake source. None of these investigations identified cracking or surface displacement related to the Wells earthquake. Minor ground cracking (up to a few mm) cannot be precluded because such features could have healed under the prevailing wet conditions at the time of the earthquake, but displacements of more than a few cm can be confidently ruled out.

Geomorphic Expression along the Surface Projection of the Wells Earthquake

Most of the surface projection of the 2008 Wells earthquake, based on relocated aftershocks, can be confidently located within the Snake Mountains (Smith and others, this volume). Aftershock location control using portable seismic stations is within a couple hundred meters for shallower aftershocks and aftershocks in more easterly directions, but is less well constrained for deeper aftershocks or aftershocks in more westerly directions (Ken Smith, 2010, personal communication). One assumption made in this projection is that the fault plane does not significantly steepen at shallow depths. Normal faults commonly do steepen near the surface, but the amount and depth of steepening required for the earthquake to project to the range front rather than into the mountain range itself appear unreasonable.

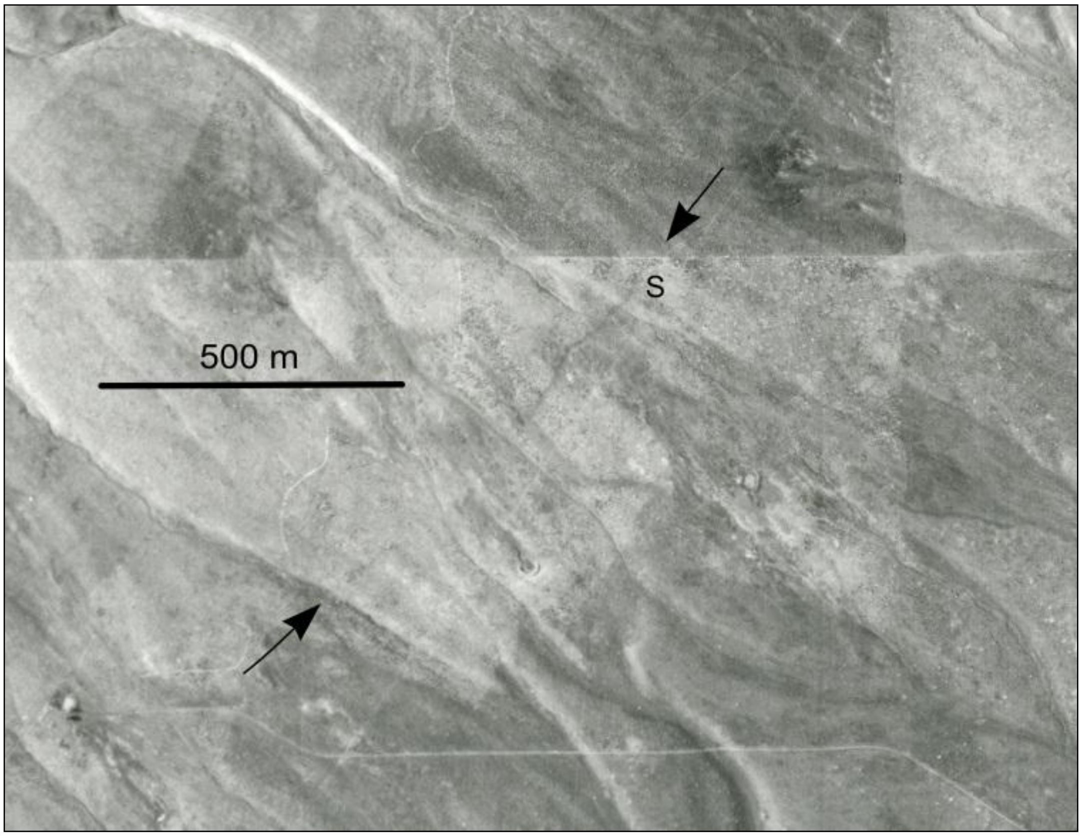

Figure 4. Air photo of vegetation lineament and young scarp on the west side of Town Creek Flat (location shown on figure 2). “S” indicates the location of the photo in figure 5.

Figure 5. Photo of young scarp (at “S” in above air photo). *Photo by C. dePolo*.

The inferred surface projection of the earthquake does not coincide with obvious geomorphic features related to Quaternary faulting, although there are lineaments on the flank of Oxley Peak that are roughly coincident with and subparallel to the fault projection, including a short (about 3 km long) alignment of northwest- and southeast-facing scarps of unknown origin, linear swales, deflected drainages, and a ridge-top depression (figure 6). However, this alignment does not coincide with a mapped bedrock fault (c.f., Henry and Colgan, this volume), and erosional surfaces that cross this alignment have minimal possible offset, indicating little, if any, late Quaternary activity.

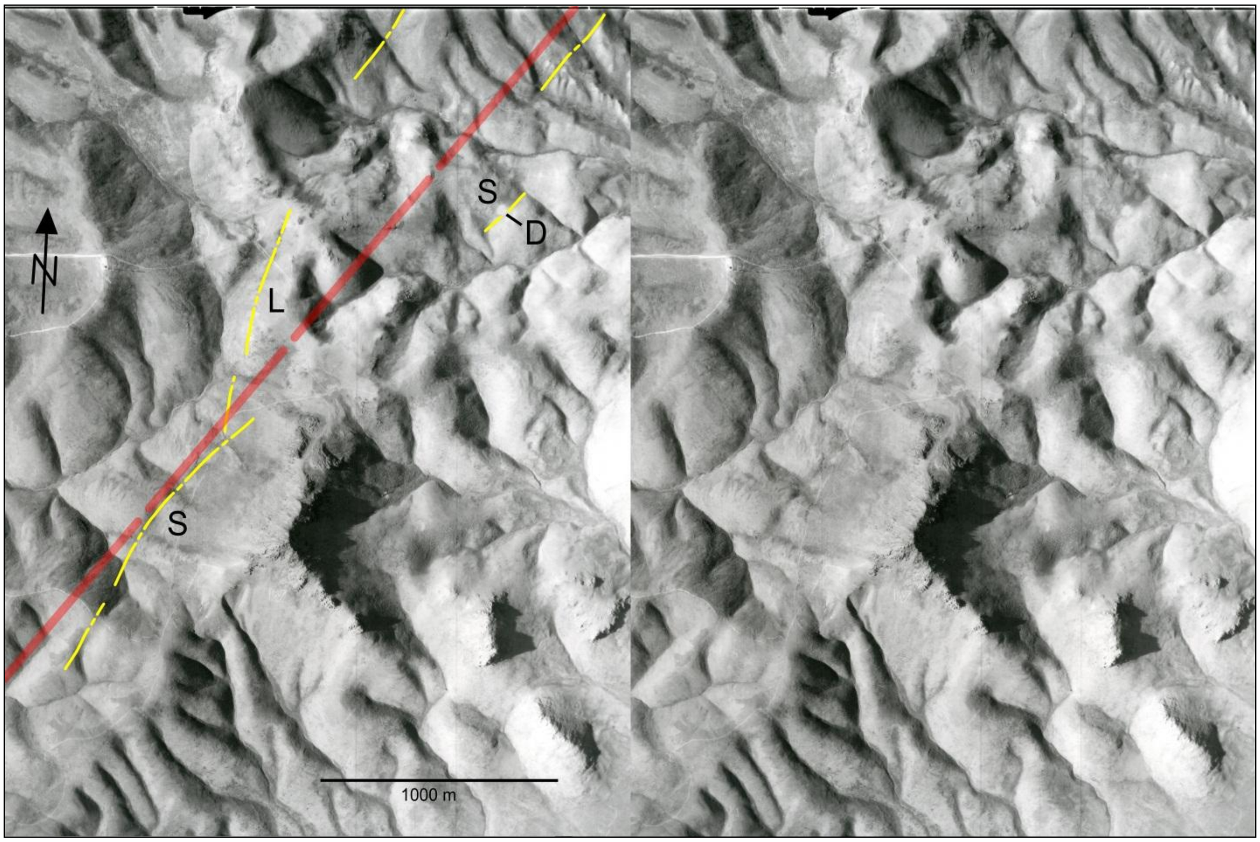

Figure 6: Aerial photograph of selected lineaments near the surface projection of the 2008 Wells earthquake. Location shown on figure 2. On the right, the same photo is shown without markup for comparison. Lineaments shown in yellow; approximate surface projection of the earthquake rupture plane shown in red. S=scarp of unknown origin (S on lower side); L= tonal lineament; D= ridge top depression.

BACKGROUND EARTHQUAKE

The 2008 Wells earthquake was a background earthquake: that is, an earthquake that does not cause surface rupture and is thus not preserved in the geologic record, making it impossible to detect similar prehistoric events (dePolo, 1994). Such earthquakes have occurred in sufficient historical numbers that they are usually represented in seismic-hazard analyses as blanket statistical levels of ground motion, or “floors” in hazard–in other words, background earthquakes are considered capable of causing a certain level of shaking anywhere within a defined area (c.f., Petersen and others, this volume). The largest historical background earthquakes in the Basin and Range Province are around magnitude 6.5 (dePolo, 1994). The Wells earthquake demonstrates how damaging background earthquakes can be when they occur close to a community, and reinforces the appropriateness of considering background earthquakes in seismic-hazard analyses.

CONCLUSIONS

The 2008 Wells M_w 6.0 earthquake occurred along a northeast-striking fault that crosses and segments the eastern Snake Mountains fault, and is a connector fault between principal east-facing range front faults. The rupture largely overlaps with the eastern Snake Mountains fault, and alternatively could be considered a secondary footwall strand of that distributed zone. The rupture also aligns with the northeastward projection of the Clover Hill fault.

Prior to the 2008 Wells earthquake, Quaternary activity along the southern part of the eastern Snake Mountains fault had not been recognized, but the fault was known to have late Quaternary activity along the Thousand Springs Valley section about 30 km to the north. During this study, we identified geomorphic expression of Quaternary activity along the Town Creek and Bishop Creek sections of the eastern Snake Mountains fault, including short, subdued scarps in alluvium, spring alignments, and vegetation/tonal lineaments. The small offsets and limited geomorphic expression indicate the fault here has a low rate of activity, but nonetheless reflect the likely occurrence of larger earthquakes in the geologically recent past.

The surface projection of the Wells earthquake does not coincide with a mapped fault or any obvious expression of a Quaternary fault. There are lineaments and other geomorphic features within the Snake Mountains that are close to the inferred surface projection of the earthquake, but these features are subtle, discontinuous, and equivocal in origin. Further detailed field studies are required to resolve whether these features are related to Quaternary fault activity.

Background earthquakes, similar to the Wells earthquake, can occur in Nevada on mapped or unmapped faults, and along faults that lack clear evidence of Quaternary activity. The damaging Wells earthquake supports the importance of considering background earthquakes in seismic-hazard analyses and of adopting and enforcing seismic building codes throughout the state, regardless of historical earthquake activity.

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