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Immediate Scientific Response to the 2008 Wells, Nevada, Earthquake

by

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ABSTRACT

The 2008 magnitude 6 Wells, Nevada, earthquake provided an opportunity to study the effects of a moderate-magnitude Basin and Range Province (BRP) earthquake and initiated a multifaceted response from Nevada and Utah geological surveys and universities. We report the procedures, results, and implications of our scientific response to the earthquake, focusing on our search for primary (fault-related) and secondary (shaking-related) geologic effects and activation of an earthquake clearinghouse Web site. We found no evidence for primary (or sympathetic) surface faulting on known Quaternary-active fault zones within about 20 km of the earthquake epicenter. We did find limited evidence for secondary effects, consisting of isolated rock-falls north and south of Wells and disturbed snow deposits in the epicentral area. We did not find evidence for liquefaction in a river floodplain immediately north of Wells, possibly as a result of unsaturated and partly frozen near-surface soil conditions. The areal extent of the most significant secondary effects, combined with structural damage in Wells, defines a 280 km^2 minimum area of strongest seismic shaking that corresponds well with ground-surface-deformation interferograms and is consistent with a moderate-magnitude earthquake.

Based on our response to the Wells earthquake, we recognize several ways to improve future earthquake response efforts, including maintaining regular contact with the emergency operations center, focusing on areas of significant structural damage given poor or conflicting earthquake information, and using remote-sensing software to guide field investigations and interpret topography and land use. In regard to future earthquake clearinghouse Web sites, we recommend that clearly defined criteria address their purpose, threshold for activation, content, location, and management.

Although the Wells earthquake did not rupture the ground surface or cause widespread geologic effects, it did generate strong seismic shaking that caused significant structural damage in Wells, Nevada. Moderate-magnitude earthquakes are an important seismic-hazard component in the BRP, and provide opportunities to advance our knowledge of the seismogenic behavior of BRP faults (including slow-slip-rate faults) and improve the quality and coordination of scientific responses to future earthquakes.

INTRODUCTION

The 2008 magnitude 6 Wells, Nevada, earthquake occurred 9 km northeast of Wells in rural northeastern Nevada in the early morning of February 21, 2008 (figure 1). The earthquake was felt throughout eastern Nevada, southern Idaho, and northwestern Utah (including the Wasatch Front region of Utah), and initiated the quick response of both state and federal scientific and emergency-management agencies. Within hours of the event, Nevada and Utah state emergency operations centers were activated and coordinated; seismic details of the mainshock and aftershocks were available through the Nevada Seismological Laboratory (NSL) and U.S. Geological Survey (USGS) National Earthquake Information Center; and geologists from Nevada Bureau of Mines and Geology (NBMG), Utah Geological Survey (UGS), and University of Nevada, Reno (UNR) Center for Neotectonic Studies were field-checking known Quaternary faults. Within days of the event, a UGS technical clearinghouse Web site organized early earthquake information; shortly thereafter an NBMG earthquake portal (NBMG, 2008) provided a comprehensive central location for maps, photographs, preliminary damage reports, and reconnaissance field reports; and seismologists from the University of Utah Seismograph Stations (UUSS), NSL, and USGS had deployed temporary seismic instrument arrays.

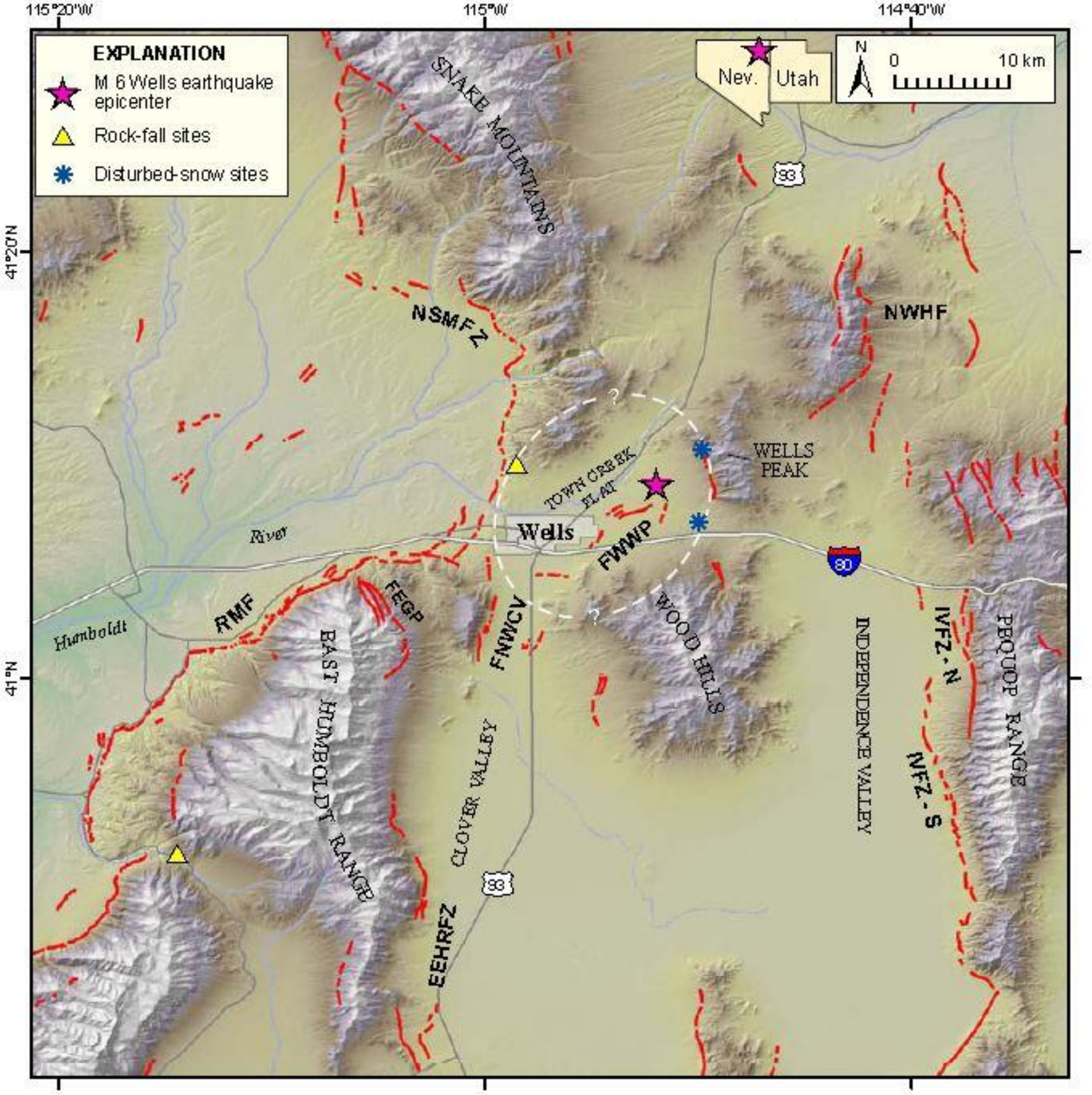

Figure 1. Quaternary faults of the Wells, Nevada, region. White dashed area is minimum extent of strongest seismic shaking (see text for discussion). FWWP - unnamed faults west of Wells Peak, FNWCV - unnamed faults northwest of Clover Valley, FEGP - faults east of Greys Peak, NSMFZ - northern Snake Mountains fault zone, RMF - Ruby Mountains fault, IVFZ – Independence Valley fault zone - northern (N) and southern (S) sections, EEHRFZ – eastern East Humboldt Range fault zone, and NWHF - northern Windermere Hills fault (U.S. Geological Survey, 2008b).

The Wells earthquake provided an opportunity to study the effects of a Basin and Range Province (BRP) normal-faulting earthquake in an area of relatively low earthquake activity. Investigating moderate-magnitude (M 5-6) earthquakes is important because: (1) Surface faulting associated with such events is generally minor and ephemeral, typically beyond the limits of conventional paleoseismic studies (e.g., trenching), and consequently, poorly understood; (2) Shaking-related geologic effects such as liquefaction can be both widespread and damaging (e.g., UUSS, 2008); and (3) Moderate events represent the middle ground between less frequent, large-magnitude surface-faulting earthquakes (M >6.5) and more frequent, small-magnitude events (M<5), and are thus an important component of regional seismic hazard. Studying moderate-magnitude earthquakes and their geologic effects is critical to improving our understanding of how BRP normal faults behave seismogenically (especially those having low rates of activity).

The Wells earthquake occurred on a previously unknown and apparently very-low-slip-rate fault. Mainshock and aftershock data outline a northeast-oriented normal fault dipping southeast below Town Creek Flat (Smith, *et. al*., this volume) with an up-dip projection about 5 km northwest of the epicenter. No geomorphic signature (e.g., fault scarps or a steep range front) is associated with the structure (Ramelli and dePolo, this volume). We (NBMG, UGS, and UNR) initiated an immediate field-based scientific response to the event to improve our odds of observing primary or secondary earthquake features. A quick response was vital because we anticipated only small, ephemeral geologic features (e.g., ground cracks), and inclement weather (snowfall) forecast for the evening following the earthquake threatened to obscure any geologic effects. In this report, we describe our immediate earthquake response efforts, summarize geologic effects based on our field observations, and consider ways to improve coordinated responses to future BRP earthquakes.

EARTHQUAKE RESPONSE

Our scientific response to the Wells earthquake took place on February 21–28, 2008, and included field investigations to search for primary and secondary geologic effects and establishing a technical earthquake clearinghouse Web site to make information about the event readily available. Emergency-response efforts, structural-damage assessments, and seismological studies were also important parts of the Wells earthquake response, but are not discussed here.

Field Investigation

The purpose of our field investigations was to (1) look for primary or secondary surface faulting or ground cracking associated with mapped Quaternary faults; (2) document any geologic evidence of strong ground shaking such as liquefaction, ground cracks, rock falls, landslides, and shattered ground; and (3) provide geologic information to emergency-response teams as necessary. In general, our investigations revealed no ground-surface deformation associated with the Wells earthquake and very little geologic evidence for strong ground shaking. We attribute the lack of geologic effects to the moderate magnitude and depth (7 km) of the earthquake. Additionally, our field observations were limited by conflicting initial epicentral location information and seasonal issues (frozen soil, snow cover, and poor road conditions).

Due to limited road access and a large field area that contained eight separate Quaternary fault systems within 30 km of Wells (figure 1), our field response was by necessity limited to a reconnaissance investigation. Access to the epicentral area (northeastern Town Creek Flat; figure 1) was limited to U.S. Highway 93 (figure 1); however, about a week following our initial investigation, we completed cross-country ski tours both east and west of the epicenter. Outside of the epicentral region, we investigated Quaternary faults where crossed by paved or gravel roads. A typical stop involved both driving and walking across a scarp; walking along a scarp for a short distance if possible; and taking field notes, photographs, and location data with a hand-held Global Positioning System (GPS) unit. Where access was limited, we drove as close to the mapped fault traces (or range front) as possible and scanned the fault areas with binoculars for evidence of ground disturbance (e.g., exposed soil, rock falls, or landslides). Field teams maintained mobile-phone contact to share observations and revise field strategies.

We used Google^{TM} Earth, an Internet-based mapping application that integrates aerial photography, satellite imagery, and topography with layers (e.g., geographic features, rivers, roads, and population centers), to help guide our field investigations. Google Earth requires an Internet connection, which we were able to acquire wirelessly in parts of Wells. In terms of earthquake response, Google Earth is a powerful tool that can (1) plot real-time seismic data (USGS, 2008a) and mapped Quaternary fault traces (USGS, 2008b); (2) highlight fault-related lineaments, scarps, and range fronts in both developed and undeveloped areas; (3) provide maps, as well as local geographic features, for emergency and scientific responders; and (4) map field locations and attach descriptions and geolocated digital photographs (e.g., EERI, 2008), draw polygons, and export files compatible with Google Maps.

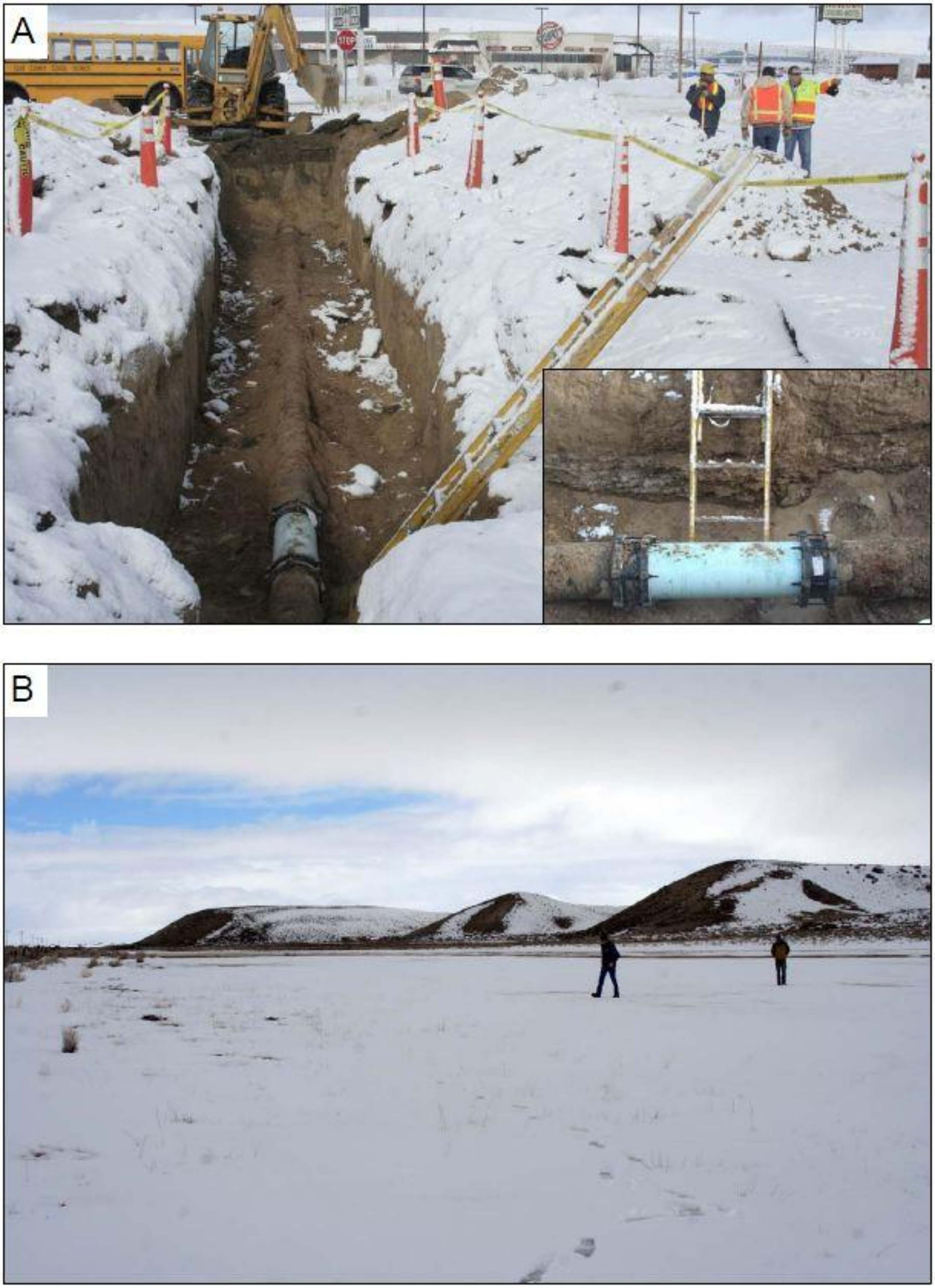

Figure 2. Investigation of (A) a water main damaged in the Wells earthquake (pipe is about 25 cm in diameter; inset shows repaired section), and (B) the partly frozen flood plain of the Humboldt River north of Wells. Neither site contained geologic evidence for strong seismic shaking; photographs taken February 22, 2008.

Primary Geologic Effects

Our field investigations did not reveal primary geologic evidence for the Wells earthquake, such as surface faulting or ground cracking. Our initial investigation (afternoon of February 21) focused on Quaternary fault scarps of the Independence Valley fault zone (IVFZ) along the eastern margin of Independence Valley, about 30 km east of Wells (figure 1). Early reports placed the earthquake epicenter in the northwestern part of Independence Valley; however, later reports correctly relocated the epicenter to the northwest part of Town Creek Flat. We traveled to within about 1.5 km of the northern segment of the IVFZ, but were unable to reach the mapped fault scarps. We investigated scarps along the southern section of the IVFZ (figure 1), where crossed by an unimproved dirt road, but did not find evidence for surface faulting, ground movement, or road damage.

Later in the afternoon of February 21 and on February 22, we focused our efforts in the Wells (Town Creek Flat) area. Access in the epicentral region was very limited due to snow-covered and impassible roads and we were unable to visit the sites of photolineaments in eastern Town Creek Flat, immediately southwest of the epicenter (unnamed faults west of Wells Peak [FWWP]; figure 1). We were able to inspect the western base of Wells Peak (east of epicenter, also part of FWWP; figure 1), but found no ground cracks or displacement. We also crossed the projected traces of the FWWP in southern Town Creek Flat and an unnamed fault zone in northwest Clover Valley (south of Wells; figure 1), but did not observe scarps associated with these faults. We completed a northwest-oriented transect (on skis) in the hills northwest of Wells, crossing the up-dip projection of a southeast-dipping fault-plane solution (Dreger and Ford, 2008), but did not find evidence for ground deformation. We also investigated the surface traces of the eastern part of the East Humboldt Range fault zone, northern part of the Ruby Mountains fault, and southern part of the northern Snake Mountains fault zone (figure 1), but did not observe evidence for surface rupturing or sympathetic cracking. In general, we were able to visit scarps associated with these fault zones only where crossed by gravel roads.

Secondary Geologic Effects

On February 22 we searched for shaking-related geologic effects in and near Wells. We found limited evidence for rock falls north and south of Wells, but did not observe any geologic features in Wells that could be confidently associated with the earthquake. We also investigated fractured and collapsed snow deposits in the epicentral area.

In Wells, we searched for geologic evidence of strong ground shaking, such as ground deformation or liquefaction. We observed a repaired water main that had been damaged during the earthquake (figure 2a); however, the exposed, approximately 25-centimeter-diameter pipe showed no horizontal or vertical offset. Sediments exposed in the trench walls showed no signs of liquefaction or displacement and the surrounding area showed no evidence for ground cracks or liquefaction features; however, snow cover limited our investigation. We also investigated the Wells airport and volunteer fire station areas after receiving reports of possible “ground swales,” but observed no evidence for surface deformation clearly associated with the Wells earthquake.

The Humboldt River, immediately north of Wells, provided a likely location for liquefaction features. We traversed parts of a wide, snow-covered, and mostly dry flood plain, but did not find evidence for liquefaction or ground deformation (e.g., sand blows or ground cracks). We also looked for liquefaction features northwest of Wells, where surface water was flowing and the banks and marsh areas were mostly covered by snow and ice (figure 2b). We did not observe evidence for liquefaction or lateral spreading along stream banks. We did not investigate the Humboldt River or Town Creek northeast of Wells due to impassible road conditions.

About 9 km west-northwest of the Wells earthquake epicenter, in the southern Oxley Peak area (southernmost Snake Mountains; figure 1), M. Meremonte (U.S. Geological Survey, written communication, 2008) reported rock falls that occurred during (or shortly after) the Wells earthquake. At the site, numerous cobbles and boulders, including an approximately 2-m-high by 3-m-wide boulder (figure 3a), were dislodged from an exposed ridge of Miocene sedimentary and volcanic rocks that dips 25° southwest (Thorman and others, 2003). Based on M. Meremonte’s account and the unit description of Thorman and others (2003), the source rock was likely interbedded volcanic tuff, fluvially reworked tuff, and conglomerate.

About 45 km southwest of the Wells earthquake epicenter, we observed minor rock falls along the Secret Pass road in the East Humboldt Range (figures 1 and 3b). The rock falls typically consisted of one to four boulders generally having maximum dimensions of 20 to 30 cm. At one location, we observed two small rock-fall debris cones deposited on snow. We infer that seismic shaking from the Wells earthquake caused the rock falls as they were deposited on snow that fell a few days prior to the earthquake.

In response to news reports of rock falls (and road closure) on U.S. Highway 93 north of Wells, we traveled north on the highway for approximately 75 km. We observed steep road cuts and exposed bedrock near Contact, Nevada, but found no evidence of road-cut failures, rock falls, or other strong ground-shaking effects.

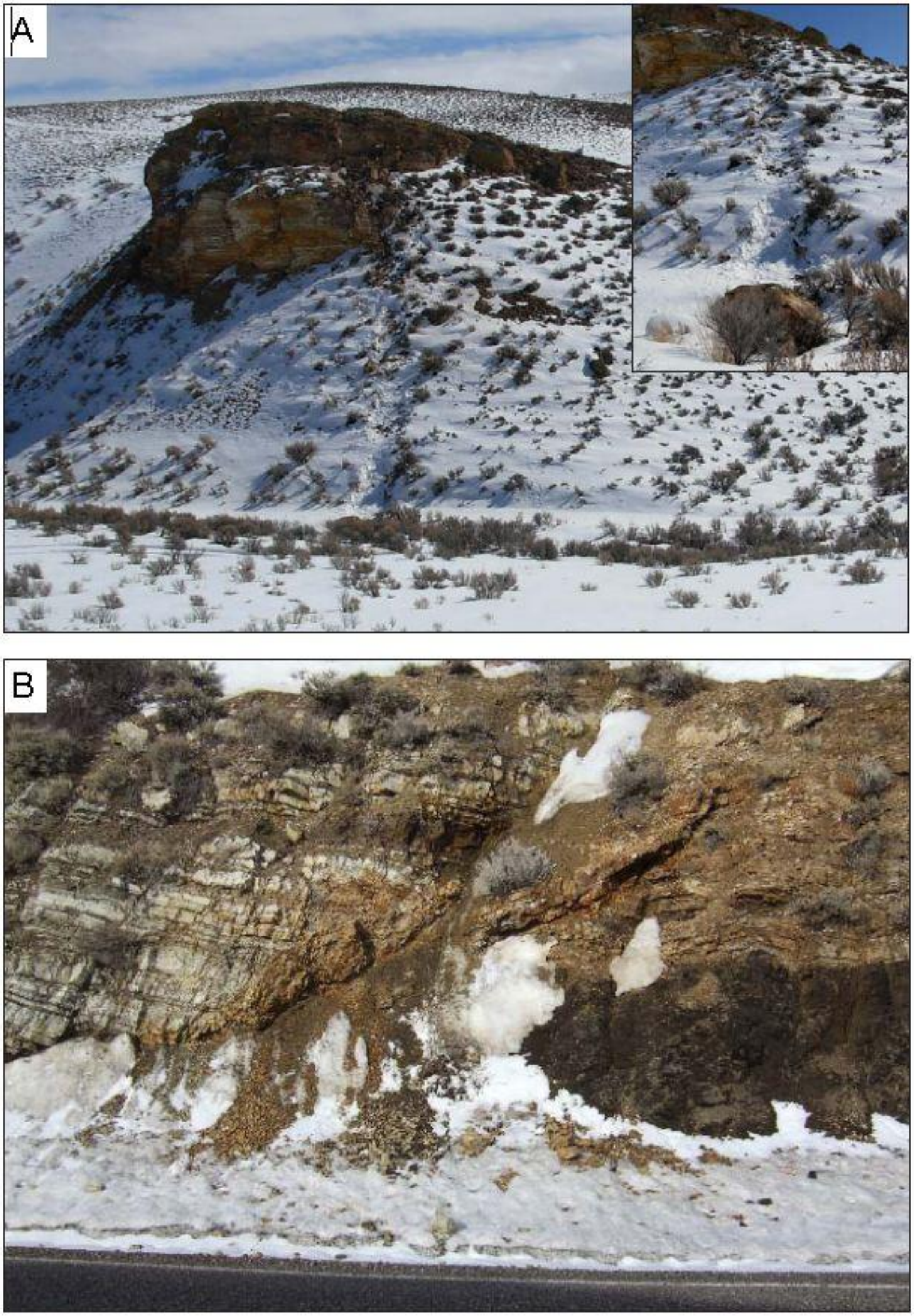

Figure 3. Rock falls related to the Wells earthquake, showing (A) dislodged boulder (approximately 2 m high and 3 m wide) north of Wells (courtesy of M. Meremonte, U.S. Geological Survey); view is to the southeast; and (B) cobbles and boulders southwest of Wells along Secret Pass road in the East Humboldt Range. Photographs taken February 23 (A) and 22 (B), 2008.

We found limited evidence for shaking-related disturbance of snow deposits in the epicentral region. About 4 km northeast of the epicenter, near the northern terminus of the FWWP (figure 1), we found sloughed snow on steep south-, east-, and west-facing hillslopes. Numerous small fractures, spaced 10 to about 50 cm apart (figure 4a) in snow 4 to 30 cm thick, were present on most of the hillslopes. The fractures were concentrated in the upper parts of the slopes, suggesting that the snow deposits failed and moved slightly. We also observed a failed deposit of wind-blown snow along a north-facing railroad cut slope about 5 km southeast of the epicenter (figure 4b). We did not observe any other sloughed-snow features in or outside of the epicentral area, and thus interpret these features as evidence of relatively strong seismic shaking.

Summary of Geologic Effects

In general, we found no evidence for primary (or sympathetic) fault rupture and very limited evidence for secondary (shaking related) features. Our initial investigation spanned the day of the earthquake and the day after, but was limited by impassible road conditions and snowfall the night following the earthquake. Later investigations on skis focused on the epicentral area. Based on our observations, we infer that:

- Mapped Quaternary faults within about 20 km of the Wells earthquake epicenter did not rupture primarily or sympathetically, although we had limited access to scarps associated with each fault zone.
- Secondary geologic effects related to the Wells earthquake include isolated rock falls north of Wells (Oxley Peak area) and south of Wells along the Secret Pass road (East Humboldt Range). Disturbed snow deposits northeast and southeast of the epicenter possibly indicate relatively strong seismic shaking.
- The lack of liquefaction features in Humboldt River flood-plain deposits may be the result of unsaturated and partly frozen near-surface soil conditions. Frozen soil may have prevented formation of secondary geologic features in other areas as well.
- Limited geologic effects from the Wells earthquake may be attributed to the moderate magnitude and depth (7 km) of the earthquake. Our ability to observe these affects was limited by poor initial epicentral location information, poor road conditions, and snow cover.

Earthquake Clearinghouse Web Site

An earthquake clearinghouse Web site organizes and makes available earthquake response information, conveys information to investigators and the public, and tracks field investigations (after Solomon, 2001). At the request of the NBMG, the UGS established a preliminary technical clearinghouse Web site to make information on the Wells earthquake available to the scientific community. Immediately following the earthquake, the UGS added information on event magnitude, depth, and epicenter location, and USGS ShakeMap plots to a UGS earthquake clearinghouse Web site template created for earthquake planning exercises in Utah (Solomon, 2001). Following approval by the NBMG, the Web site went online on February 22, the day after the Wells earthquake. For three days following the event, the UGS maintained and updated the site by adding temporary seismic instrumentation location maps, preliminary field data, and links to news articles. The NBMG Wells Earthquake Portal (NBMG, 2008) replaced the UGS technical clearinghouse less than a week following the event.

The UGS clearinghouse Web site had a flexible design that allowed for changes and non-standard file formats. For example, after publishing the Web site online, the UGS used Web-based forms and basic HTML programming to create free-form entries for inputs like aeromagnetic data and non-word processor (e.g., Adobe PDF) files. In addition, the UGS site allowed for remote updates from off-site locations.

Due to the sparse earthquake-related geologic effects from the Wells earthquake and the limited UGS earthquake response, the UGS clearinghouse Web site template was not fully tested. Downloadable response forms (from Solomon, 2001) were available, but largely unused. The forms allow responders to provide complete and consistent information on geologic effects such as surface fault rupture, liquefaction, and other geologic hazards (e.g., landslides). In addition, the UGS clearinghouse Web site template allows the input of digital photographs, video, and interactive maps, but these capabilities were not fully used.

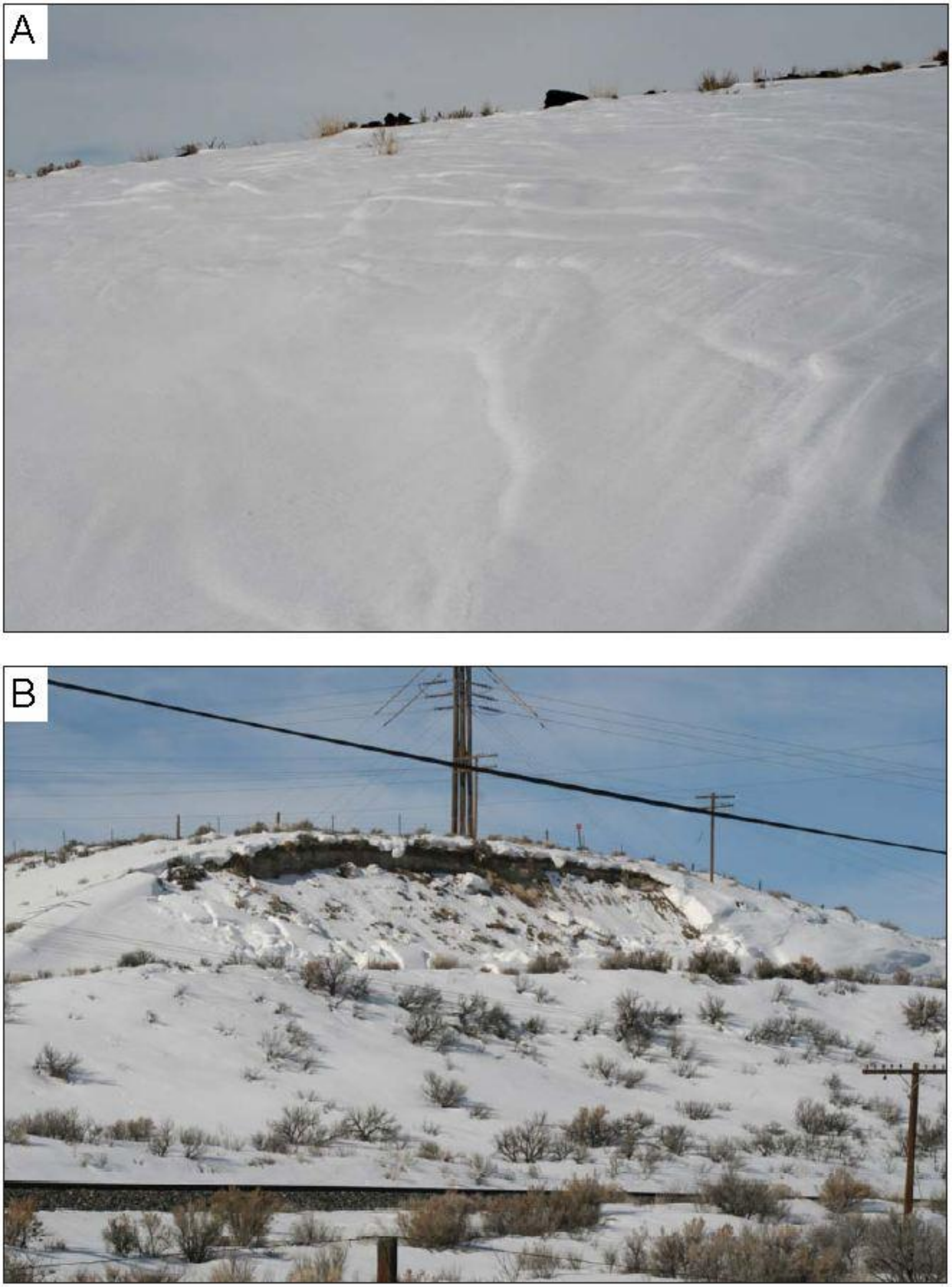

Figure 4. Snow disturbed in the Wells earthquake, showing (A) fractures, spaced about 10 to 50 cm apart, on a hillslope northeast of the epicienter; and (B) a failed deposit of wind-blown snow along a north-facing railroad cut slope southeast of the epicenter. Photographs taken February 27 (A) and 28 (B), 2008.

DISCUSSION

Geologic Effects

Geologic effects associated with the Wells earthquake are consistent with an earthquake of moderate magnitude (M 5–6). The ground surface did not rupture in the earthquake, consistent with the approximate magnitude 6.5 threshold for surface faulting in the BRP, and significant secondary features were confined to the epicentral area. Although our investigations were limited by time, access, and adverse weather conditions, it is unlikely that we missed a significant number of secondary features. Further investigation after the snow melted by Ramelli and dePolo (this volume) did not find any surface fractures related to the earthquake as well.

The areal extent of the most significant secondary effects related to the Wells earthquake delineates a minimum area of strongest seismic shaking (figure 1). The area encompasses isolated rock falls and disrupted snow deposits within about 10 km of the epicenter as well as structural damage in Wells, and is likely oriented northeast-southwest based on aftershock and fault-plane-solution data (Dreger and Ford, 2008; Smith, 2008). The strongest seismic shaking affected a minimum area of about 280 km^2, which corresponds to an earthquake of magnitude 5–6 using a correlation between landslide distribution and historical earthquake magnitude (Keefer, 1984). The area of strongest seismic shaking corresponds well with the area of ground-surface deformation inferred from satellite data. Satellite radar interferograms, which include deformation between August 2007 and March 2008, show a northeast-oriented elliptical pattern of subsidence centered on the Wells earthquake epicenter (J. Bell, written communication, 2008; Bell, this volume).

Minor rock falls about 40-50 km southwest of the epicenter provide a reasonable maximum extent of more moderate seismic shaking (figure 1), and may represent the maximum extent of secondary features related to the Wells earthquake. This distance suggests an earthquake of magnitude 5.5-6.0, using a relation between the maximum distance of disrupted slides or falls from the fault-rupture zone and magnitude (Wilson and Keefer, 1985).

Lessons Learned

The scientific response to the Wells earthquake included NBMG, UGS, UNR, NSL, UUSS, and USGS geologists, seismologists, and Geographic Information Systems (GIS) specialists. Here we suggest ways to improve the immediate response to future moderate- to large-magnitude earthquakes in the BRP.

Field Investigations

Communication is a critical component of a successful post-earthquake field investigation. Coordinating fieldwork to maximize the investigated area in a time-effective manner is important, and is accomplished by meeting at the local emergency command center. Registering with the command center is also important to (1) alert the incident commander to the presence and intent of the scientific field teams, (2) receive reports of possible geologic effects, (3) receive information on which areas to avoid, such as those that have ongoing emergency operations, (4) coordinate with other responding agencies (e.g., counties or local governments), and (5) provide geological information (and rumor control) to emergency response teams.

Field investigations in the critical period immediately after the Wells earthquake were hindered by the poor accuracy of the initial epicenter location. The poor location stemmed from the use of the USGS regional network stations, which had a coarser location than the NSL, which used stations from the Advanced National Seismic System (ANSS) instrument network (temporarily deployed in the northern BRP in 2008). In areas of poor seismic instrumentation, or when different (e.g., state versus federal) organizations provide conflicting earthquake locations, scientific response teams should focus on geologic areas surrounding the locations of most significant structural damage until the mainshock epicenter is accurately located. Following the Wells earthquake, response teams would have been better utilized north and south of Wells – near faults that are several kilometers, rather than tens of kilometers, from the area of most significant structural damage. Furthermore, we recommend that reporting agencies (e.g., the USGS) provide clear epicenter accuracy information, possibly rate epicenter locations based on the quality of the supporting seismic network, and develop a consensus location as soon as possible.

The scientific response to the Wells earthquake was greatly aided by Google Earth. Non-local investigators can use the service to familiarize themselves with the geography and Quaternary fault history of the region (when combined with data from the *Quaternary Fault and Fold Database of the United States*; USGS, 2008b), search for fault-related geomorphic features and lineaments, and interpret relative development in epicentral regions. Following the field investigation, Google Earth is useful for plotting and annotating field locations, geolocating photographs, and producing maps (and exportable data).

Earthquake Clearinghouse Web Site

A Web site is an important component of a post-earthquake information clearinghouse. Although detailed protocols exist for the activation, scope, purpose, and management of regular clearinghouse activities (California Office of Emergency Services, 1998; Solomon, 2001; Holzer and others, 2003), information for clearinghouse Web sites is limited. Following the Wells earthquake, the UGS managed the initial design and content of the clearinghouse Web site, but delayed its activation due to the time necessary to coordinate Utah and Nevada state agencies. Thus, we recommend that clearinghouse protocols include clear, written criteria that define the purpose, threshold for activation, content, location, and management of future earthquake clearinghouse Web sites. The criteria should address (1) how resources will be allocated and the Web site activated and managed when multiple jurisdictions are involved, (2) what preliminary technical data (epicenter maps and ShakeMap) and non-technical information (felt reports and news reports) will be included, and (3) how earthquake information will be reviewed and updated. Furthermore, we recommend a plan for backing up and (or) replicating the Web site on a separate server to ensure Web site continuity should the clearinghouse building, computer hardware, or communication links become damaged during aftershocks.

CONCLUSIONS

The magnitude 6 Wells earthquake generated few geologic effects, but provided important insight into earthquake hazards in the BRP. The event had a magnitude below the generally accepted threshold for BRP surface faulting (M 6.5) and would be considered a background (non-fault-specific) earthquake in regional seismic-hazard assessments (e.g., Peterson and others, 2008). However, the earthquake clearly deformed the ground surface (J. Bell, written communication, 2008) and resulted in strong seismic shaking over a minimum 280 km^2 area that caused significant structural damage in Wells, Nevada. A similar event in a more urbanized area such as Las Vegas or the Wasatch Front region of Utah would result in damage over a much larger area. Thus, an important conclusion drawn from the Wells earthquake is that although moderate-magnitude BRP earthquakes typically do not produce long-lived or widespread geologic features and therefore leave a limited geologic record of their occurrence, they do generate strong ground motions, and may be under-appreciated compared to less frequent larger magnitude events in BRP seismic-hazard analyses. For example, along the Wasatch Front, paleoseismic studies indicate that a magnitude 7 (approximately) earthquake has occurred on average every 300-350 years on one of the five central segments of the Wasatch fault zone (Machette and others, 1992; McCalpin and Nishenko, 1996; Lund, 2005). The potential for these large earthquakes is important, but should not diminish the attention paid to hazards due to more moderate-magnitude (M 6+) events, which have occurred on average every 50 years along the Wasatch Front, based on historical seismicity (Pechmann and Arabasz, 1995).

We may also use the Wells earthquake to highlight the significance of scientific responses to moderate-magnitude earthquakes. Rapid, thorough, and coordinated responses yield important information on the geology and seismology of the events and region, and help improve our preparedness for BRP earthquakes. Moderate-magnitude earthquakes also yield opportunities to (1) improve investigations of primary and secondary geologic features, (2) resolve the geometries and seismogenic capabilities of BRP faults (including slow-slip-rate faults), (3) revise and improve earthquake-hazard models, and (4) prepare local communities and governments for future earthquakes.

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