OPINION

"This is the Right Place"

We welcome you to the 2013 Annual Meeting of the Seismological Society of America in Salt Lake City. On 24 July 1847, when Mormon pioneers first viewed the Salt Lake Valley, Brigham Young famously pronounced, "This is the right place"—the place of destiny and refuge they had been seeking. By the time of Young's death in 1877, Mormon pioneers had extensively colonized most of what we now recognize as Utah's main seismic belt, notably along the Wasatch Front, the western escarpment of the Wasatch Range that forms the eastern topographic boundary of the Basin and Range Province (Fig. 1). This contrast in geology and geography signals active tectonic forces inexorably at work.

In his classic letter to *The Salt Lake Daily Tribune* in September 1883, G. K. Gilbert, then a senior geologist with the newly formed U.S. Geological Survey, warned local residents about the implications of observable fault scarps along the western base of the Wasatch Range—large surface-rupturing earthquakes had occurred before Mormon settlement and more would occur in the future. The main actor in this drama of course is the 380-km-long Wasatch fault zone, which extends from central Utah to southernmost Idaho. The modern Wasatch Front urban corridor, which follows the valleys on the Wasatch fault's hanging wall between Brigham City and Nephi, is home to nearly 80% of Utah's population of 2.8 million. Adding to this circumstance of "lots of eggs in one basket," more than 75% of Utah's economy is concentrated along the Wasatch Front in Utah's four largest counties, literally astride the five central and most active segments of the Wasatch fault (Fig. 2).

The last SSA Annual Meeting in Salt Lake City was in 1983, just at the beginning of a five-year program of focused studies on Utah's Wasatch Front region under the National Earthquake Hazards Reduction Program (NEHRP; see Gori and Hays, 2000). Since then, there has been gratifying progress in addressing the earthquake threat in Utah, but daunting challenges remain—as in most earthquake-prone metropolitan areas of the United States.

The Wasatch Front faces a dual earthquake threat from infrequent, large (**M** 6.5–7.5) surface-faulting earthquakes on mapped faults, such as the Wasatch fault, and from more frequent moderate-size (**M** ~ 5.5–6.5) earthquakes that do not cause surface faulting. Since about 1850, only eight moderate-size but damaging earthquakes have occurred in the Wasatch Front area, and only two earthquakes greater than **M** 6 have occurred in the Utah region: the 1901 **M** 6.5 Richfield and the 1934 **M** 6.6 Hansel Valley earthquakes (Arabasz *et al.*, 1992). The Hansel Valley earthquake produced Utah's only instance of historic surface-fault rupture. In contrast, paleoseismic studies of the five most-active central segments of the Wasatch fault (10 segments are now recognized faultwide; Machette *et al.*, 1992; Fig. 2) have revealed evidence of numerous large surface-faulting earthquakes in the latest Pleistocene and Holocene. While the Wasatch fault is the most important fault in the Wasatch Front, numerous other active faults can generate large earthquakes that result in strong ground shaking and other earthquake hazards.

As one of the best studied intraplate faults in the world, the Wasatch fault has played a prominent role in the development and advancement of earthquake geology and paleoseismology. G. K. Gilbert recognized that the fault scarps he observed at the base of the prominent Wasatch Range were evidence of incremental fault movement during earthquakes. Although Gilbert's pioneering ideas took decades to gain acceptance, they eventually led to focused paleoseismic studies of prehistoric earthquakes on the Wasatch fault. Early trench studies in the late 1970s and 1980s focused on finding evidence of Holocene earthquakes (e.g., Swan *et al.*, 1980), which formed the basis for models of fault segmentation and earthquake recurrence (Schwartz and Coppersmith, 1984; Machette *et al.*, 1992). More than three decades and 25 detailed paleoseismic studies later, we have substantially improved our understanding of the timing, recurrence, and displacement of the latest Pleistocene and Holocene surface-faulting earthquakes on the five central segments (Fig. 2) and refined models of rupture extent and fault segmentation (see reviews, for example, by Lund [2005] and DuRoss [2008]). At least 22 large earthquakes have ruptured

▲ **Figure 1.** View of the Wasatch Mountains and Wasatch fault zone at the base of the range front in Salt Lake City. (Photo courtesy of Utah Facilities Magazine.)

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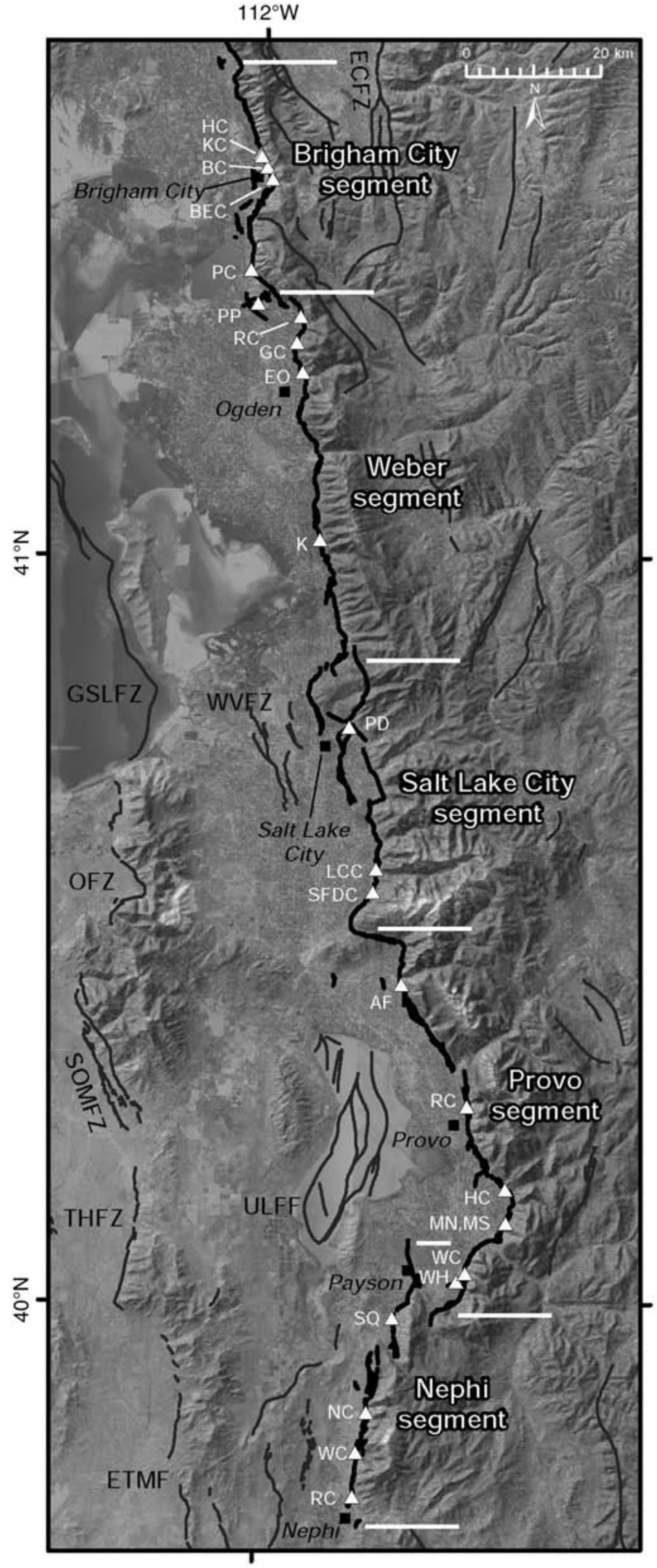
the five central fault segments in the past ~6000 years (Fig. 3), yielding mean closed earthquake recurrence intervals of about 900–1300 years for individual segments or a composite recurrence interval of about 300 years for the central segments combined. The most recent large earthquake occurred about 300 years ago on the Nephi segment. Together, paleoseismic data for the Wasatch fault provide important information for forecasting earthquake probabilities in the Wasatch Front region (Wong *et al.*, 2011). Although our understanding of the Wasatch fault has advanced significantly since the first trench was excavated in 1978, important questions remain regarding fault segmentation, subsurface dip, and the temporal and spatial variability of earthquake recurrence.

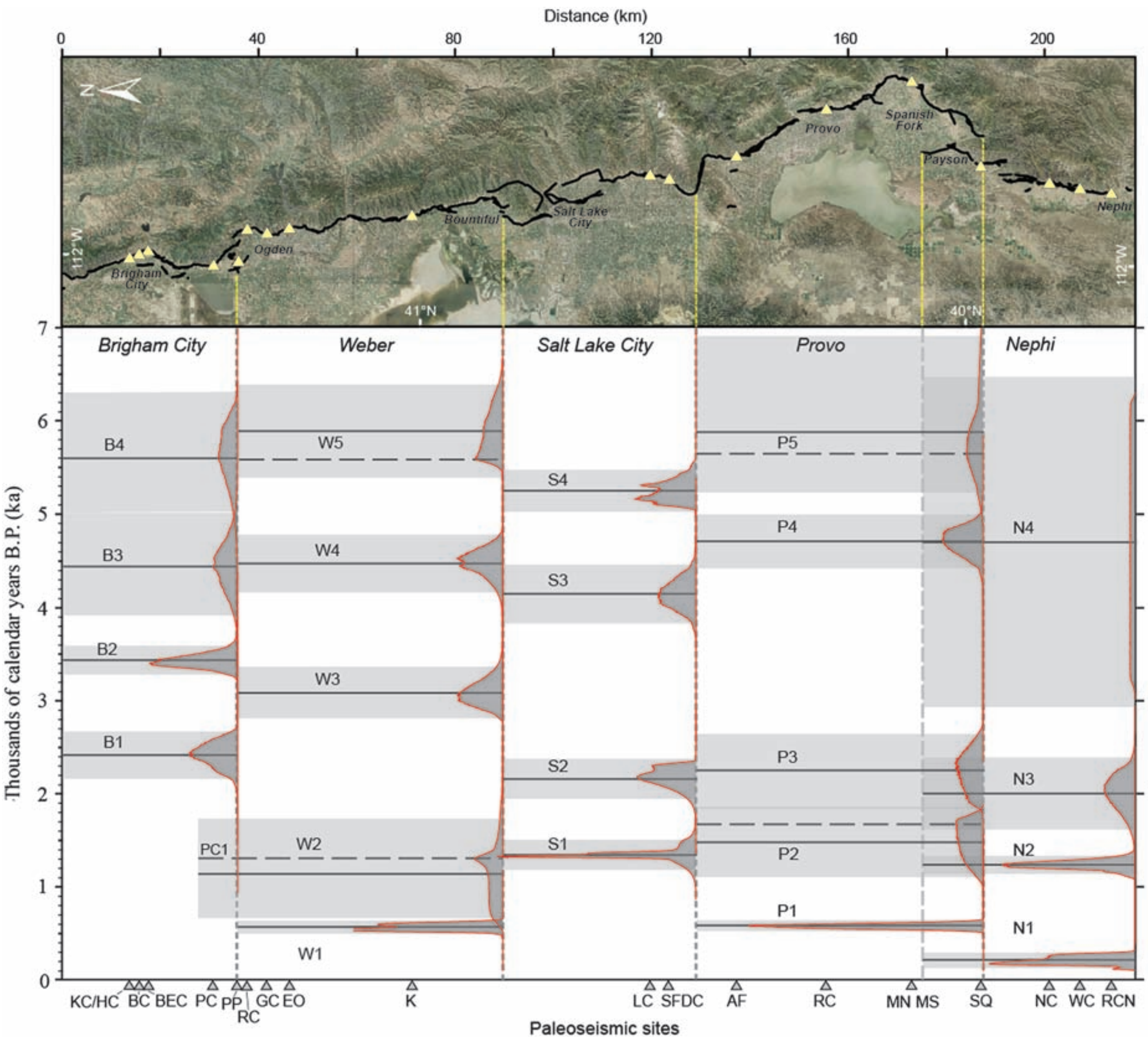
Almost all major Utah population centers are in one of several basins adjacent to the Wasatch fault, such as the Salt Lake basin. The most significant factors that will impact strong earthquake ground shaking from large earthquakes on the Wasatch fault and other faults in the region are rupture direction effects and the presence of soft soils and sedimentary basins. Enhanced ground shaking can result from all three factors, as illustrated by recent 3D numerical simulations of ground motions (0–10 Hz) from **M** 7 surface-rupturing earthquakes along the Salt Lake City segment of the Wasatch fault by Roten *et al.* (2011, 2012). Significant features of the predicted ground motions from their six different rupture scenarios include a strong sensitivity to the rupture propagation direction, large nonlinear soils effects, and average peak horizontal ground accelerations ranging from 0.3 to $>0.6\,g$ over the eastern two-thirds of the Salt Lake Valley. The predicted ground motions are in reasonably good agreement with empirical ground-motion prediction models. Surface faulting, liquefaction, seismically induced landslides, and tectonic subsidence are also hazards that will likely accompany a large earthquake in the Wasatch Front (e.g., Solomon *et al.*, 2004).

Geodetic data show a concentration of strain along the eastern margin of the Basin and Range Province in the Wasatch Front region, with about 3 mm/yr of east-west extension occurring over a 100- to 200-km-wide zone (Hammond and Thatcher, 2004; Chang *et al.*, 2006; Velasco *et al.*, 2010). This extension rate is two or three times the vertical component of the slip rate on the five central, most-active segments of the Wasatch fault (Lund, 2005; Fig. 2). The amount of the horizontal extension rate that can be explained by strain accumulation on the Wasatch fault depends on both the mechanism of strain accumulation and the subsurface fault geometry, both of which are poorly known.

Since the 1983–1988 NEHRP initiative, paleoseismic studies of the Wasatch fault and modeling of future earthquake ground shaking in the region are among some of the significant advances that have been made in Wasatch Front earthquake-hazards research. Major contributions have collectively been made by scientists and engineers from the U.S. Geological Survey (USGS), the Utah Geological Survey (UGS), the University of Utah and other universities in Utah, and Utah's engineering community. Key roles have also been played by researchers outside of Utah. They include participants in multidisciplinary working groups that have been meeting annually since 2003,



▲ **Figure 2.** Five central segments of the Wasatch fault zone (heavy black lines) and other Quaternary faults in the Wasatch Front region (thin black lines). The white bars indicate the segment boundaries, and the triangles indicate paleoseismic trenching sites (DuRoss, 2008).



▲ **Figure 3.** Holocene chronology of surface-faulting earthquakes on the five central segments of the Wasatch fault (relative to 1950). Red lines indicate earthquake-timing probability density functions; horizontal and dashed black lines show mean and modal earthquake times, respectively.

under the auspices of the UGS and USGS, to coordinate local studies of Quaternary faulting, earthquake ground-shaking modeling, and liquefaction potential (a working group on earthquake-induced landslides was active from 2003 to 2005). A currently active Working Group on Utah Earthquake Probabilities (Wong *et al.*, 2011) has met nine times since 2010.

Of seismological interest, since 1983 there has been a major expansion and modernization of statewide seismic monitoring in Utah, with particular focus on the Wasatch Front urban corridor. Thanks chiefly to the development and local implementation of the Advanced National Seismic System (ANSS)—and also to extensive state support—the number of seismic stations operating within Utah and its immediate borders has grown from 52 (nearly all short-period) stations in 1983 to 216 (including 33 regional broadband stations and 114 urban strong-motion stations). In partnership with ANSS, the University of Utah Seismograph Stations (UUSS) plays the lead role in seismic monitoring of Utah and neighboring parts of the Intermountain seismic belt. The UUSS operates and maintains a 214-station regional and urban seismic network extending from southern Utah to Yellowstone Park in northwestern Wyoming and records and analyzes data from a total of 269 stations. UUSS also has seismically hardened, state-of-the-art facilities for network operations and earthquake-information services. As part of a continuity-of-operations plan, all UUSS data are redundantly recorded at a hot site in Richfield, Utah (225 km south of Salt Lake City), from which they are transmitted to the USGS National Earthquake Information Center.

An effective state earthquake program in Utah was forged in the mid-1980s, underpinned from the start by a strong partnership between the UGS, UUSS, and the Utah Division of Emergency Management (UDEM). Expanding the partnership to Utah's earthquake engineering community successfully led to the creation of the Utah Seismic Safety Commission (USSC), established by the Utah State Legislature in 1994. An uncommonly high level of earthquake awareness and preparedness in

Utah has been achieved by earthquake-safety advocates, with the involvement of concerned community and business leaders. The news media, disaster-preparedness inclinations inherent in Utah's Mormon culture, and earthquake-conscious émigrés from California have all greatly helped the cause. Hundreds of millions of dollars have been invested in seismically upgrading, among others things, highway systems, industrial and public-works facilities, a sizeable number of K-12 and university buildings, and key government buildings, including the Utah State Capitol. Alas, a large legacy building stock of unreinforced masonry buildings, aggravated by the state's delayed adoption of seismic building codes until the mid-1970s, is a major part of Utah's earthquake vulnerability.

G. K. Gilbert possessed a keen appreciation of earthquake risk. In his letter to the *Salt Lake Daily Tribune*, he stated that, following a large earthquake on the Wasatch fault, the surviving citizens of Salt Lake City "will have sorrowfully rebuilt of wood," a material he considered more resistant to earthquake forces based on observations of the damage to buildings in Lone Pine, California, resulting from the 1872 Owens Valley earthquake (Gilbert, 1884). Asked what the citizens of Salt Lake City were going to do about his warning, he answered "probably nothing." Gilbert considered it unlikely that the city's inhabitants would "abandon brick and stone and adobe (in today's parlance, unreinforced masonry [URM]), and build their new houses of wood." He further concluded that even if they did rebuild the city of wood, it would only increase the danger of fire which, "in the long run destroys more property than earthquakes" (Gilbert, 1884).

In Salt Lake City we will again convene a Town Hall meeting for the public on Wednesday evening, April 17. The meeting will be held on the same day as the Great Utah ShakeOut exercise.

Time has proven Gilbert's forecast of the public's response to his warning regarding the city's building stock correct. Analyses performed by the UDEM and Federal Emergency Management Agency (FEMA) using the loss-estimation software HAZUS have provided estimates of the impacts a large earthquake will have on the Wasatch Front today. The HAZUS analysis estimates that if an **M** 7 earthquake were to rupture the Salt Lake City segment of the Wasatch fault, the number of deaths would run into the thousands and building-related economic losses would be about $32 billion. One of the biggest problems in the Wasatch Front area is the large number of URM structures in urban areas (yes, some still exist), buildings that Gilbert warned us about all those many years ago. As many as 130,000–150,000 URMs exist in the Wasatch Front, and severe losses in a large earthquake would undoubtedly result from collapse and damage to these buildings (e.g., FEMA/UDEM, 2012).

Another concern is the vulnerability of schools to the effects of a large earthquake. Many of Utah's approximately 1,000 K-12 school buildings are seismically vulnerable. School safety has been a focus of USSC. In a pilot project, 128 public and charter school buildings were assessed for seismic safety using a rapid visual screening method. Sixty percent of the schools appeared to be vulnerable to damage and possibly collapse. Recognizing this problem, the USSC and the Structural Engineers Association of Utah have been working to get bills passed in the Utah State Legislature to thoroughly evaluate all 1000 schools. The most recent bill did not pass in 2012; however, Governor Gary Herbert did include a line item in his proposed 2013–2014 budget earmarked specifically for school building earthquake inspections that may bring a more favorable consideration during the 2013 legislative session.

These challenges are nothing new. There are numerous communities like Salt Lake City throughout the United States, and hundreds of millions of people live in seismically vulnerable buildings all over the world. The 2011 SSA annual meeting was held in Memphis, Tennessee, which also has a large building stock of URMs and vulnerable schools. How can the SSA help with earthquake safety here in the United States and globally? Admittedly, we are a research-focused organization known for our technical publications, but consider our recently refreshed mission statement:

> *The Seismological Society of America (SSA) is an international scientific society devoted to the advancement of seismology and the understanding of earthquakes for the benefit of society.*

With this statement of purpose, SSA's members are committed to make a difference individually and collectively.

One example of effective collaboration was the recent publication of the booklet *Putting Down Roots in Earthquake Country—Your Handbook for Earthquakes in Utah*, which has been distributed extensively statewide. This effort was spearheaded by several SSA members at the University of Utah and Utah Geological Survey. Additionally, the Working Group on Utah Earthquake Probabilities, whose participants are all SSA members, will be releasing their forecast this year for large earthquakes in the Wasatch Front (Wong *et al.*, 2011).

In Salt Lake City, we will again convene a Town Hall meeting for the public on Wednesday evening, April 17. The meeting will be held on the same day as the Great Utah ShakeOut exercise, and a number of exercise participants are expected to attend. This is the fourth Town Hall meeting that has been organized as part of the annual SSA meeting. The purpose of the Town Hall meetings is to help local residents become more aware of (1) what scientific research tells us about earthquake hazards in the cities and regions where they live, (2) the vulnerabilities of their surrounding built environment, and (3) what measures are being taken or can be taken to increase earthquake safety and reduce future losses. We hope that such Town Hall meetings will motivate individuals and, better yet, decision-makers to take action and make informed choices. Finally, we urge all SSA members to use their knowledge, skills, and experience to make a difference in earthquake-risk reduction—locally, nationally, and worldwide.

REFERENCES

Arabasz, W. J., J. C. Pechmann, and E. D. Brown (1992). Observational seismology and the evaluation of earthquake hazards and risk in the Wasatch front area, Utah, in *Assessment of Regional Earthquake Hazards and Risk Along the Wasatch Front, Utah*, P. L. Gori and W. W. Hays (Editors), *U.S. Geol. Surv. Profess. Pap. 1500-A-J*, D1–D36.

Chang, W. L., R. B. Smith, C. M. Meertens, and R. A. Harris (2006). Contemporary deformation of the Wasatch fault, Utah, from GPS measurements with implications for interseismic fault behavior and earthquake hazard: Observations and kinematic analysis, *J. Geophys. Res.* **111**, B11405, doi: 10.1029/2006JB004326.

DuRoss, C. B. (2008). Holocene vertical displacement on the central segments of the Wasatch fault zone, Utah, *Bull. Seismol. Soc. Am.* **98,** 2918–2933.

Federal Emergency Management Agency (FEMA)/Utah Division of Emergency Management (UDEM) (2012). *Great Utah ShakeOut Earthquake Scenario HAZUS Earthquake Event Report*, Vol. 8, 14–15.

Gilbert, G. K. (1884). A theory of earthquakes of the Great Basin, with a practical application [from The Salt Lake Tribune of Sept. 20, 1883], *Am. J. Sci.* **27,** 4953.

Gori, P. L. and W. W. Hays (Editors) (2000). Assessment of regional earthquakes and risk along the Wasatch Front, Utah—Introduction, *U.S. Geol. Surv. Profess. Pap. 1500-K-R.*, 1–7.

Hammond, W. C., and W. Thatcher (2004). Contemporary tectonic deformation of the Basin and Range Province, western United States: 10 years of observation with the Global Positioning System, *J. Geophys. Res.* **109,** B08403, doi: 10.1029/2003JB002746.

Lund, W. R. (2005). Consensus preferred recurrence-interval and vertical slip-rate estimates—Review of Utah paleoseismic-trenching data by the Utah Quaternary Fault Parameters Working Group, *Utah Geol. Surv. Bull.* **134,** CD.

Machette, M. N., S. F. Personius, and A. R. Nelson (1992). Paleoseismology of the Wasatch fault zone—A summary of recent investigations, interpretations, and conclusions, in *Assessment of Regional Earthquake Hazards and Risk along the Wasatch Front, Utah*, P. L. Gori and W. W. Hays (Editors), *U.S. Geol. Surv. Profess. Pap. 1500 A-J*, A1–A71.

Roten, D., K. B. Olsen, and J. C. Pechmann (2012). 3D simulations of **M** 7 earthquakes on the Wasatch fault, Utah, Part II: Broadband (0–10 Hz) ground motions and nonlinear soil behavior, *Bull. Seismol. Soc. Am.* **102,** 2008–2030.

Roten, D., K. B. Olsen, J. C. Pechmann, V. M. Cruz-Atienza, and H. Magistrale (2011). 3D simulations of **M** 7 earthquakes on the Wasatch fault, Utah, Part I: Long-period (0–1 Hz) ground motion, *Bull. Seismol. Soc. Am.* **101,** 2045–2063.

Schwartz, D. P., and K. J. Coppersmith (1984). Fault behavior and characteristic earthquakes—Examples from the Wasatch and San Andreas fault zones, *J. Geophys. Res.* **89,** 5681–5698.

Solomon, B. J., N. Storey, I. Wong, W. Silva, N. Gregor, D. Wright, and G. McDonald (2004). Earthquake hazards scenario for a **M** 7 earthquake on the Salt Lake City segment of the Wasatch fault zone, Utah, *Utah Geol. Surv. Spec. Study 111DM, CD-ROM*, 59 pp.

Swan, F. H., III, D. P. Schwartz, and L. S. Cluff (1980). Recurrence of moderate to large magnitude earthquakes produced by surface faulting on the Wasatch fault zone, Utah, *Bull. Seismol. Soc. Am.* **70,** 1431–1462.

Velasco, M. S., R. A. Bennett, R. A. Johnson, and S. Hreinsdottir (2010). Subsurface fault geometries and crustal extension in the eastern Basin and Range Province, western U.S., *Tectonophysics* **488,** 131–142.

Wong, I., W. Lund, C. DuRoss, W. Arabasz, J. C. Pechmann, A. Crone, N. Luco, S. Personius, M. Peterson, S. Olig, and D. Schwartz (2011). The working group on Utah earthquake probabilities—Background and goals, *Seismol. Res. Lett.* **82,** 345–346.

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