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Seismicity and Seismic Hazard of Northeastern Nevada

by

John G. Anderson
Nevada Seismological Laboratory
University of Nevada, Reno

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ABSTRACT

The February 21, 2008, Wells earthquake (M_W=6.0) occurred in a region of northeastern Nevada where the seismicity has historically been low relative to western Nevada. In a region of area of approximately10^5 km^2 of northeastern Nevada, based rates of smaller earthquakes in the region prior to 2008, earthquakes of M_W=6.0 or larger are expected with a rate of about 0.01 per year. The probability of the once-a-century earthquake in northeastern Nevada occurring close to a city also seems small given our current state of knowledge, but the occurrence of this event is reasonably consistent with the U.S. Geological Survey National Hazard Map hazard curve for Wells.

The seismic hazard in Wells is comparable to the hazard in Las Vegas. Thus the Wells earthquake is a reminder that the potential for significant earthquakes is present every place in Nevada, and not just in the parts of the state with relatively high rates of seismicity.

INTRODUCTION

The February 21, 2008, Wells earthquake (M_W=6.0, Global CMT catalog) is important to study for many reasons. It occurred in the interior of the western United States, in a region dominated by normal and strike-slip earthquakes. Table 1 lists earthquakes in this region from the Global CMT catalog, which was initiated in 1976. The most recent normal faulting events of comparable size occurred in 1993. From the scientific viewpoint, advances in instrumentation since that time provide the opportunity to study the event in much greater detail. This opportunity was enhanced because the earthquake occurred in an easily accessible location.

Interest in the Wells earthquake is enhanced because the location was almost directly below the city of Wells, Nevada (pop. 1346 in 2000, according to 2000 U.S. Census). Thus the earthquake calls particular attention to the seismic hazards throughout the region. The purpose of this article is to provide a general introduction to the seismic hazard of northeastern Nevada, with an emphasis on Wells. A second purpose is to place the hazards in Wells in the context of the seismic hazards in the rest of Nevada.

SEISMICITY

Figure 1 shows a map of earthquakes, with magnitude 4.0 or greater, in the western United States. East of the active area associated with the San Andreas Fault of California, the most prominent feature of the seismic activity in figure 1 is the zone of earthquakes along the eastern side of the Sierra Nevada, in the California-Nevada border region and in western Nevada. Another feature of figure 1, although less prominent, is the “Intermountain Seismic Belt” which extends northerly from southern Utah into Montana. Northeastern Nevada, located between these two zones, shows a lower level of scattered seismicity. Still, northeastern Nevada has had more seismic activity than other large western regions, such as eastern Washington and Oregon, the Snake River Plain, or the Colorado Plateau.

Earthquakes in the Nevada Seismological Laboratory catalog with magnitude greater than 4.0 are shown in figure 2. A prominent feature on this map is the north-south “Central Nevada Seismic Belt”. Four earthquakes with magnitude 7.0 or larger have occurred in this seismic zone between 1915 and 1954. Since then, seismic activity in that zone has been decreasing gradually over time.

Table 1. Earthquakes with M_W >5.9 in the western interior of the United States, 1976–2009, from the Global CMT Project[1] catalog (http://www.globalcmt.org/CMTsearch.html)

Western Interior Earthquakes, 1976-2009												
Year	Month	Day	Hour	Minute	Second	Lat	Long	Depth	Moment	MW	Region/Name	Mechanism
1980	5	25	16	33	53.1	37.49	-119.15	10.1	2.43E+25	6.19	Mammoth Lakes	Strike-slip
1980	5	25	19	44	58.5	37.17	-119.35	15.0	8.30E+24	5.88	Mammoth Lakes	Strike-slip
1983	10	28	14	6	22.5	44.35	-113.98	13.7	3.12E+26	6.93	Borah Peak	Normal
1986	7	21	14	42	33.9	37.53	-118.82	15.0	2.65E+25	6.22	Chalfant	Normal
1992	4	23	4	50	29.5	34.07	-116.52	15.0	2.11E+25	6.15	Joshua Tree	Strike-slip
1992	6	28	11	57	53.0	34.65	-116.65	15.0	1.06E+27	7.28	Landers	Strike-slip
1992	6	28	15	5	39.6	34.27	-117.24	15.0	6.78E+25	6.49	Big Bear	Strike-slip
1993	5	17	23	20	53.9	36.68	-118.10	15.0	1.83E+25	6.11	Eureka Valley	Normal
1993	9	21	3	29	0.6	42.12	-121.92	15.0	1.09E+25	5.96	Klamath Falls	Normal
1994	9	12	12	23	47.4	38.74	-119.75	15.0	8.41E+24	5.88	Double Spring Flat	Strike-slip
1999	10	16	9	46	59.2	34.71	-116.27	15.0	8.46E+25	6.55	Hector Mine	Strike-slip
2008	2	21	14	16	10.0	41.16	-114.85	13.5	1.35E+25	6.02	Wells	Normal

[1] Times and locations are for the centroid of the earthquake, which is generally different from the epicenter.

As in figure 1, figure 2 shows distinctly lower seismicity in the northeastern part of Nevada than the western part of the state. The Wells earthquake, shown in figure 2, is the largest historical event in northeastern Nevada.

Figure 3 shows seismicity of northeastern Nevada, from the Nevada Seismological Laboratory catalog. All located earthquakes through November, 2009, are shown on this map. It should be noted that this is an area with intense mining activity, so there is the possibility that some of the events shown on this map, particularly at lower magnitudes, may be mine blasts that have been misidentified as earthquakes. Figure 3 shows broadly scattered earthquakes throughout the region, although there does appear to be a gradient in the scattered background earthquakes, from higher activity in the southwest to lower activity in the northeast. Other than that large-scale trend, there are no distinctive activity patterns that define, for instance, active faults. The sparse instrumentation in the region causes both great difficulty in identification of blasts and poorly constrained event locations. Increased seismic monitoring would be very helpful for improved understanding of the seismic hazards of northeastern Nevada.

Figure 4 shows Gutenberg-Richter curves for the western interior region studied by Pancha and others (2006) and for northeastern Nevada (figure 3). The curve for the western interior region is based on the catalog compiled by Pancha and others (2006), and includes aftershocks. The magnitude scales are not uniform between the two curves, as described in the caption. Pancha and others (2006) attempted to obtain the magnitude for each earthquake most closely approximating the moment magnitude, and concluded that for the region as a whole, the historical occurrence rates of the largest earthquakes ($M_W \geq 7$) are approximately consistent with the overall geodetic deformation rate of the region. The northeastern Nevada data is from the Nevada Seismological Laboratory catalog (www.seismo.unr.edu, 12/6/2008). Although the Wells earthquake and its aftershocks are available in that catalog, the Gutenberg-Richter curves for this region were determined using only the catalog through the end of 2007. The magnitude 6.0 earthquake on the northeastern Nevada curve is poorly constrained. It occurred on Nov. 12, 1872, and is located on the boundary of the region (39 ^{o} N, 117 ^{o} W). Between magnitudes 5.0 and 6.0, the data (but not the fit lines) on figure 4 form roughly parallel curves separated by a factor of about 30.

Figure 4 shows that in the western interior region as a whole, M_1, the magnitude that is equaled or exceeded on average once per year, is 5.5. Magnitude 6 or larger earthquakes have occurred on average at a rate of about 0.35 per year, or about once every 3 years. The occurrence of 12 earthquakes (table 1) since 1976 is roughly consistent with this rate. The Gutenberg-Richter curve for the northeastern Nevada region has $M_1 = 3.7$, and extrapolates to a rate of 0.01 earthquakes per year with $M \geq 6$. That is also roughly consistent with the observed activity: one instrumentally observed earthquake of magnitude ≥6.0 (Wells) in the approximately 90 years of local instrumental recordings of Nevada earthquakes.

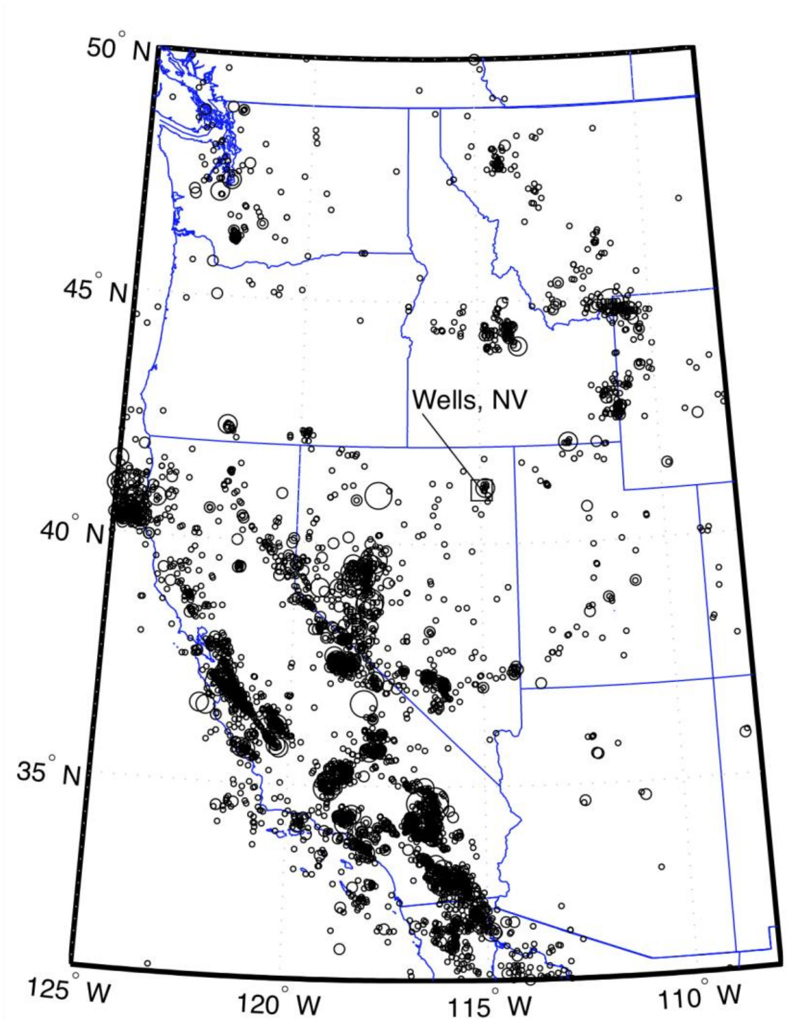

Figure 1. Western U.S. Seismicity (from Advanced National Seismic System catalog, http://www.ncedc.org/cnss/, accessed Nov. 2009), supplemented by the catalog of Pancha and others (2006) for earthquakes with M_W>7. Earthquakes with magnitudes of 4.0 or greater are shown. Magnitudes in the ANSS catalog are generally local magnitudes or coda magnitudes.

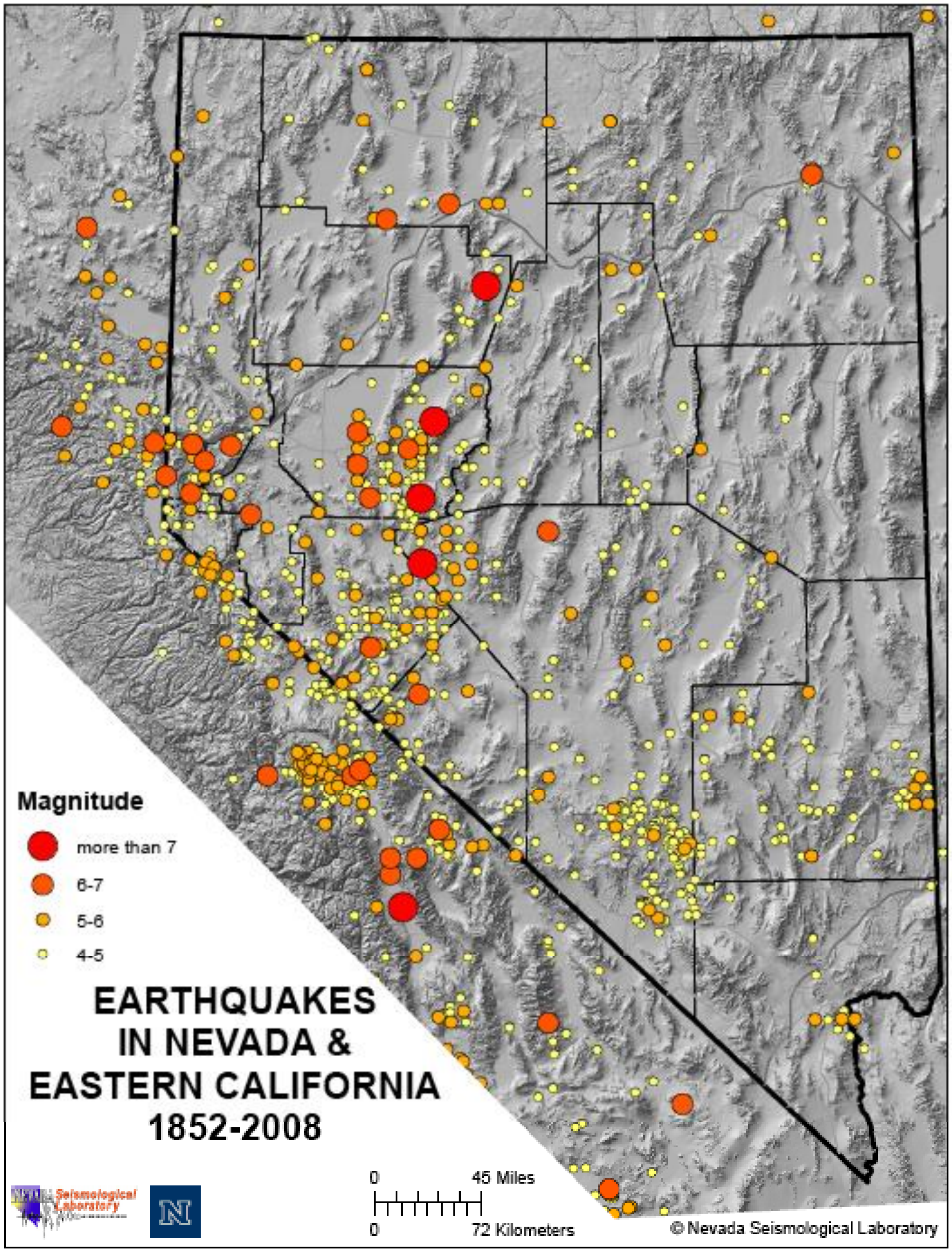

Figure 2. Earthquakes in and near Nevada, with magnitude 4.0 and larger through 2008, from the online catalog of the Nevada Seismological Laboratory (www.seismo.unr.edu, last accessed Nov. 2009). Earthquakes with $M_W \geq 7.0$ (as compiled by Pancha and others, 2006) are shown with red. From north to south, these events occurred in 1915, 1954, 1954, 1932, and 1872.

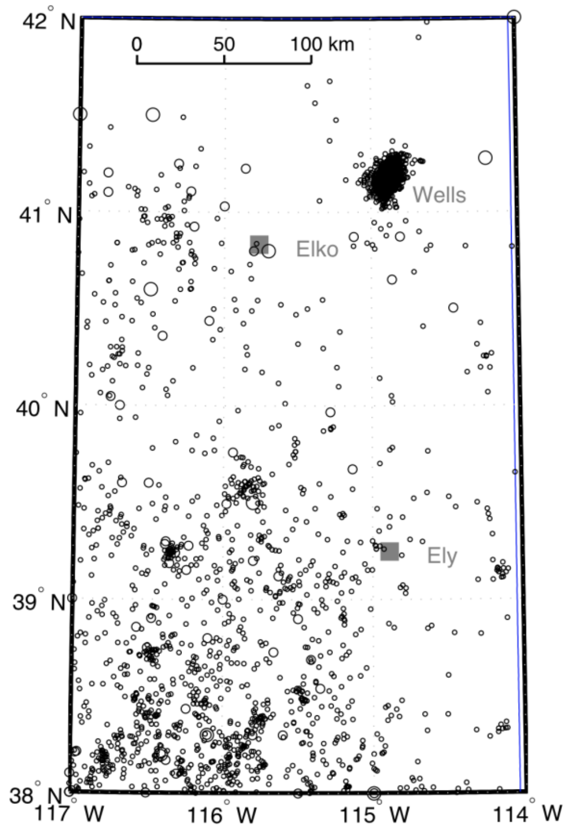

Figure 3. Seismicity of northeastern Nevada. This map shows all events in the Nevada Seismological Laboratory catalog, 1852-November 2008.

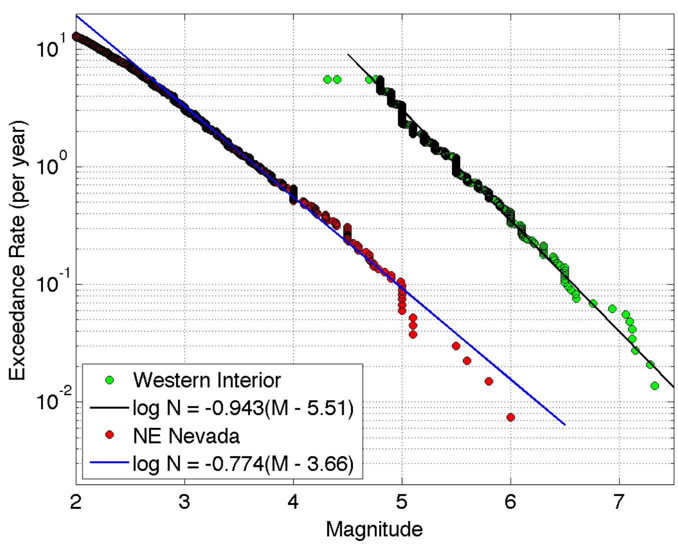

Figure 4. Gutenberg-Richter curves for northeastern Nevada (figure 3) and for the Western Interior (WI) Region. In the equations in the legend, N is the number of earthquakes per year with magnitude of M or greater. The WI catalog, described by Pancha and others (2006), is complete through 1999, and the NEN catalog is intentionally truncated at the end of 2007, prior to the Wells earthquake. The WI region is the region studied by Pancha and others (2006); it extends from 34° - 47° N, and from 110°W on the eastern side to the Sierra Nevada and Cascade mountain ranges on the west. The NEN region, shown in figure 3, is bounded by 38°N-42°N, 114°W-117°W, giving an area of approximately 10^5 km^2, which is about 9% of the area of WI. The WI catalog used moment magnitude, M_W. The NEN catalog is nominally local magnitude, ML, but is best regarded as having a mixture of magnitudes, as some are determined from coda duration and the early catalog is developed from felt reports. The Gutenberg-Richter relation for the NEN region is determined by least-squares fitting to the 100 largest earthquakes on the plot. For the WI region, all points on the plot are included in the fit.

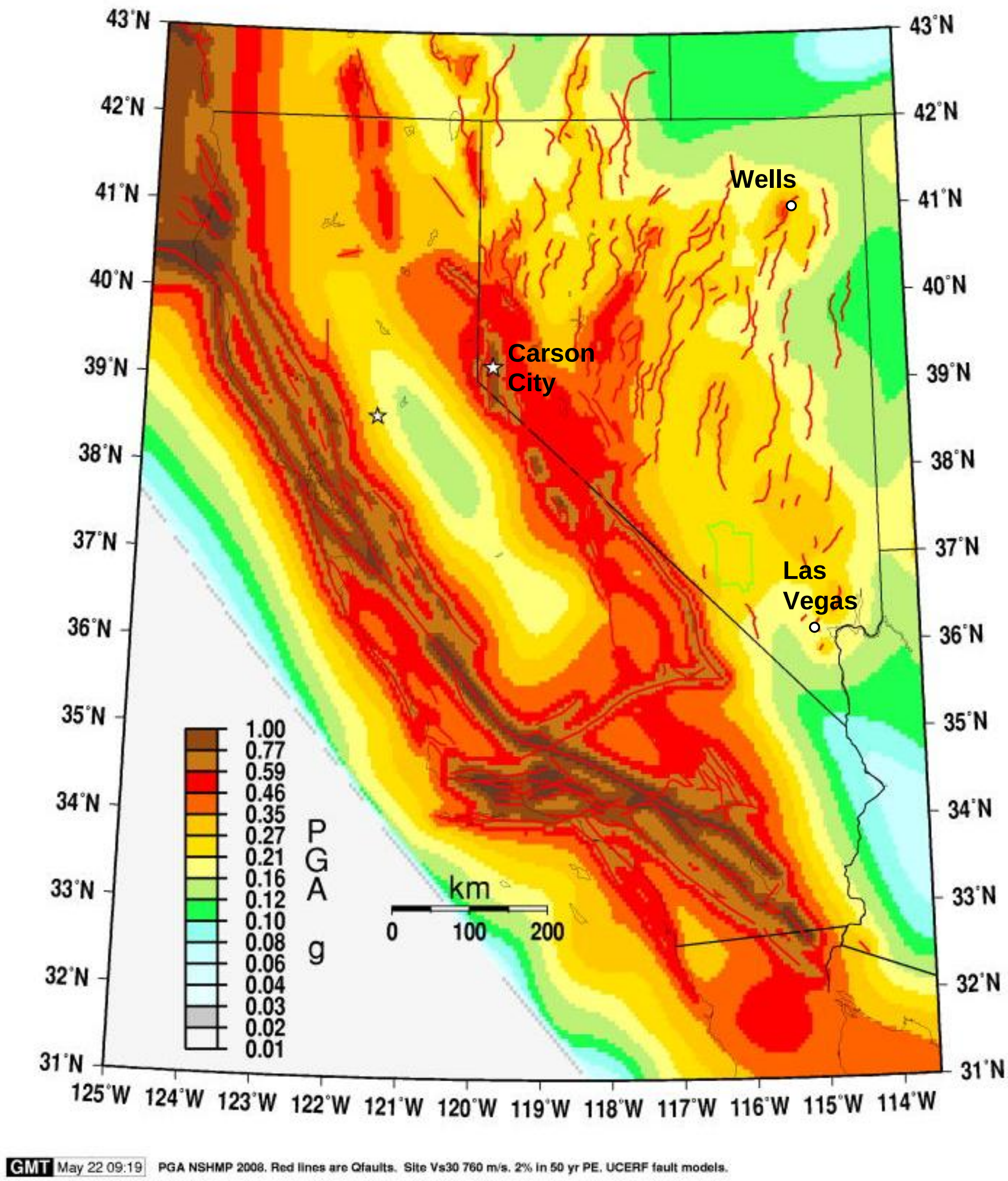

Figure 5. The 2008 national hazard map (Petersen and others, 2008; http://earthquake.usgs.gov/hazards/, last accessed November, 200948), showing peak acceleration with a probability of 2% in 50 years in California and Nevada.

GEOLOGICAL AND GEOPHYSICAL CONTEXT OF NORTHEASTERN NEVADA SEISMICITY

Figure 2 shows that the topography of Nevada is dominated by north- to northeast-trending mountain ranges that result from east-west lateral spreading of the crust. Thatcher and others (1999) and Kreemer and others (2009) observe that spreading directly using global positioning system measurements. These papers show that along an east-west profile, the region around northeastern Nevada is moving to the west relative to eastern Utah. To the east, the main gradient in deformation rate occurs at the Wasatch fault in the Intermountain Seismic Belt. They find little measurable internal deformation in northeastern Nevada. The low seismicity of northeastern Nevada is consistent with a significantly smaller deformation rate than the rate in the seismicity zones to the east and west. The presence of relatively low rates of seismicity is an indication that some geodetic deformation must be occurring in this region even though it may take more instrumentation and a few more years of measurements to determine the strain rates accurately. The paleoseismic record is also consistent with the observed low rates of deformation and earthquake activity (Wesnousky and others, 2005). The direction of deformation seen on the GPS data is generally consistent with the topography of the region.

SEISMIC HAZARD

Figure 5 shows the 2008 probabilistic seismic hazard map for California and Nevada, as developed by Petersen and others (2008). Reports on earlier U.S. Geological Survey national hazard maps (e.g. Frankel and others, 2002) give more details on the construction of the map. Consistent with the seismicity map, this map shows that the hazard is higher in western Nevada and near the eastern side of the Sierra Nevada than it is in northeastern Nevada. One difference from what one might note from figure 2 is that the hazard is shown as higher immediately to the east of the Sierra Nevada than in the central Nevada seismic zone. The evidence in support of this result includes the following: 1) higher geodetic deformation close to the Sierra Nevada, 2) while seismicity has declined in central Nevada since the mid 1950s, it has continued at a steady rate in the zone east of the Sierra Nevada, and 3) the faults close to the Sierra Nevada have higher activity rates.

Eastern Nevada is shown on figure 5 to have a hazard that is substantially lower than western Nevada, but the hazard in eastern Nevada is not zero. There is an important lesson for the development of the hazard maps in this observation. Perusal of the work of Frankel and others (2002) shows that the hazard in western Nevada is in part a consequence of input based on observations of repeat times of large earthquakes on discrete, well-studied faults. A second major contribution in western Nevada is from shear zones that are intended to increase the earthquake occurrence rates to levels closer to those expected from the rapid geodetic deformation rates. In eastern Nevada, because there are few well-studied faults, the input to the national maps includes a large background earthquake source zone. The Wells earthquake affirms the value of including background earthquake zones in the hazard model.

A useful way to compare the hazard in different locations is to compare hazard curves instead of contours on the map. This is done on figure 6, which shows the hazard curves for peak horizontal acceleration for Wells, Carson City, and Las Vegas. Hazard curves can be visualized as the outcome of an experiment in which ground motion is recorded at a site for a very long time (e.g. over 10,000 years), and the frequency with which different amplitudes of ground motions are exceeded are compiled and plotted. The contours at a fixed annual probability in the national maps are used as input for seismic design.

According to figure 6, ground motions at all amplitudes that can occur in Carson City can also occur in Wells or Las Vegas, but they occur less frequently. The basic physics of earthquakes in the less active areas is no different than in the more active areas. Thus for a site at equal distances from an active fault, the ground motion is expected to be about the same regardless of where in Nevada the fault is located. The difference, represented by lower hazard curves, is that the strong motions occur less frequently. The decision to use the hazard values at a constant level ($4*10^{-4}$ per year) as a control for design of structures is the result of an recognition that there is a correlation between greater seismic safety and greater construction costs, and a decision by code-agencies that for average construction it is not cost-effective to build for less probable seismic events.

Based on the results in figures 4-6, the probability of the earthquake in Wells can be roughly estimated. The probability of this earthquake occurring someplace in northeastern Nevada is approximately 10^{-2} per year. If the strongly-shaken area had a radius of about 18 km, the area was about 10^3 km^2, or approximately 1% of northeastern Nevada. Multiplying by the earthquake rate, then, the probability of strong shaking is approximately 10^{-4} per year. According to reports of some heavy furniture being moved during the earthquake, the shaking may have approached approximately 0.5g (50% of gravity), which is given an annual probability of approximately 10^{-4} per year in figure 6. Thus an order-of-magnitude calculation is able to confirm that the U.S. Geological Survey probabilistic seismic hazard analysis is giving reasonable results.

DISCUSSION

The Wells earthquake occurred in a part of Nevada with low, but non-zero, earthquake hazard. Its occurrence affirms the decision made, in development of the national hazard maps, to use background seismicity zones as an integral part of the description of the earthquake hazard for the national hazard maps.

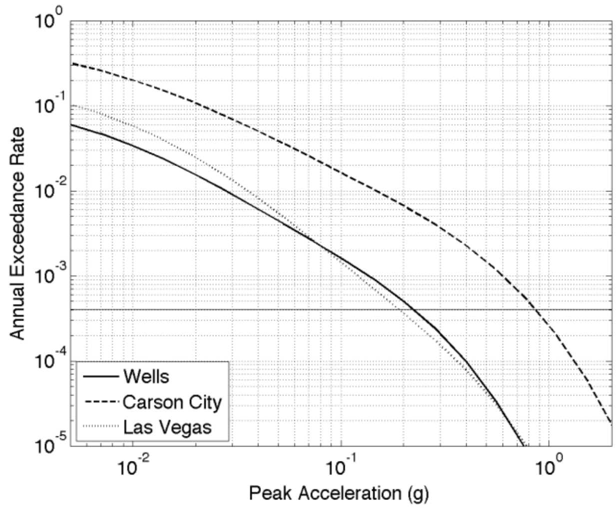

Figure 6. Hazard curves for Wells, Carson City, and Las Vegas. These curves are obtained from the U.S. Geological Survey National Seismic Hazard Map web site (http://earthquake.usgs.gov/hazards/products/conterminous/2008/data/, accessed Nov. 20, 2009). The national maps are created by calculating hazard curves for a grid of points on the map, and then contouring values obtained for a uniform probability of exceedance. The map in figure 5 was calculated for an annual probability of 2% in 50 years, which corresponds to an annual exceedance rate of $4 * 10^{-4}$ per year (shown by a light solid line).

According to figure 6, the hazard in Wells is significantly lower than it is in western Nevada, and particularly in Reno and Carson City. This is a reminder that the parts of Nevada that are mapped with relatively low seismic hazards should still take that hazard seriously. This lesson is particularly important for Las Vegas, since the seismic hazard there is a little larger than it is in Wells. As in the hazard model for Wells, an important contribution to the hazard at Las Vegas is earthquakes from low-rate sources modeled as part of a background seismicity zone.

Finally, for western Nevada, figure 2, and studies of active faults (e.g. Wesnousky and others, 2005) show clearly that the historical seismicity justifies the higher hazard in western Nevada, as shown in figures 5 and 6. For these regions of higher hazard, also, the Wells earthquake is a reminder of the potential for severe shaking and of the need for earthquake preparedness.

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REFERENCES

Frankel, A.D., Petersen, M.D., Mueller, C.S., Haller, K.M., Wheeler, R.L., Leyendecker, E.V., Wesson, R.L., Harmsen, S.C., Cramer, C.H., Perkins, D.M., Rukstales, K.S., 2002, Documentation for the 2002 update of the National Seismic Hazard Maps: U.S. Geological Survey Open-File Report 2002–420, 39 p.

Kreemer, C., Blewitt, G., and Hammond, W.C., 2009, Geodetic constraints on contemporary deformation in the northern Walker Lane: 2. Velocity and strain rate tensor analysis, *in* Oldow, J.S., and Cashman, P.H., eds., Late Cenozoic Structure and Evolution of the Great Basin–Sierra Nevada Transition: Geological Society of America Special Paper 447, p. 17–31, doi: 10.1130/2009.2447(02).

Pancha, A., Anderson, J.G., and Kreemer, C., 2006, Comparison of Seismic and Geodetic Scalar Moment Rates across the Basin and Range Province: Bulletin of the Seismological Society of America, v. 96, p. 11–32.

Petersen, M.D. and others, 2008, United States National Seismic Hazard Maps: U. S. Geological Survey Fact Sheet 2008-3017, 4 p.

Thatcher, W., Foulger, G.R. , Julian, B.R., Svarc, J., Quilty, E., and Bawden, G.W., 1999, Present-day deformation across the Basin and Range Province, Western United States: Science, v. 283, p.1714–1718.

Wesnousky, S. G., Barron, A. D., Briggs, R.W., Caskey, S.J., Kumar, S., and Owen, L., 2005, Paleoseismic transect across the northern Great Basin: Journal of Geophysical Research, v. 110, 25 p., B05408, doi:10.1029/2004JB003283.