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Magnitude Values Used for M≥6 Earthquakes in *Earthquakes in Nevada: 1840s to 2010,* NBMG Map 179

by

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Nevada earthquakes with magnitudes ≥6 were reevaluated for the new earthquake epicenter map of Nevada (dePolo and dePolo, 2012). This report briefly reviews these magnitudes and highlights differences between this compilation and the most recent study of Nevada earthquakes by Pancha et al. (2006). In order to facilitate an understanding of the magnitudes for these events and where they came from, a historical magnitude table is presented (table 1). This table shows values from different catalogs and historical magnitude estimates for these earthquakes. The new map was standardized to moment magnitude for the larger earthquakes and used historically-estimated magnitudes where moment magnitudes were not available. Although two California earthquakes that caused damage in Nevada are listed in gray, the rest of the California earthquakes are not included in the table. Toppozada et al. (2000) was generally used for the magnitude values of the other California events. Toppozada et al. (2000) have revisited earlier magnitude versus intensity area estimates made by Toppozada et al. (1981) and increased several of these earlier magnitude estimates. These appear to be more appropriate magnitude values for these events, based on near-field effects. These new values were used in dePolo and dePolo (2012).

In the 2012 compilation, there are 23 earthquakes of magnitude ≥6 in Nevada history (155 years), three with magnitudes ≥7 and 20 with magnitudes from 6 to 6.9.

SPECIFIC HISTORICAL EARTHQUAKES

Pancha et al. (2006) most recently assigned preferred magnitudes to Nevada earthquakes, and many of these values were used. The following discussions describe the situations where there are differences in preferred value assignments compared to that in Pancha et al. (2006).

Two non-Nevada earthquakes that caused damage in Nevada or had tremendous damage potential to Nevada—the 1872 Owens Valley, California earthquake and the 1966 Boca Valley, California earthquake—are included in gray; these events are important to Nevada even though they occurred just outside its borders.

In the pre-1900 part of the catalog, local magnitude estimates based on intensity areas from Toppozada et al. (2000) were used. For events in the early part of the 20th century, magnitudes were taken from Slemmons et al. (1965) and the University of Nevada, Reno Seismological Laboratory catalog. Since 1915, many of the large earthquake magnitudes were taken from individual earthquake and regional earthquake studies. Magnitudes shown in Table 1 under "This Study" are the final preferred values used in the map.

1857, 1860, and 1868 western Nevada earthquakes

These three events were reanalyzed by Toppozada et al. (2000), and newer magnitude values were adopted for each: M6.3, M6.5, and M6.0, respectively. These values replaced magnitudes from Toppozada et al. (1981).

1869b Virginia City earthquakes

Originally named the Olinghouse earthquakes by Sanders and Slemmons (1979) and later the Virginia Range earthquake by dePolo et al. (2003), this event has been slightly renamed based on the location with the most damage caused by the event: Virginia City. Pancha et al. (2006) use a magnitude (M 5.5) developed by dePolo et al. (2003). This magnitude was derived by using a preliminary analysis of the intensity data and a technique originally developed by Bakun and Wentworth (1997). Unfortunately, the magnitude determination was experimental, and it is premature to use it without further development of the local coefficients for these equations. New magnitude estimates were made by Toppozada et al. (2000) for these earthquakes and were adopted (MLa 6.4 and 6.2 for the two largest events).

1887 Carson City earthquake

This earthquake was reanalyzed by Toppozada et al. (2000), and their newer magnitude value was adopted: M6.5. The previous value resulted from Toppozada et al. (1981).

1903 Wonder earthquake

Slemmons et al. (1959) conducted historical research demonstrating that an earthquake with surface rupture occurred near Wonder, Nevada in the fall of 1903. Rogers et al. (1991) assigned a magnitude 6.5 to this earthquake based on the reported surface rupture length, 19 km, deduced by Slemmons et al (1959), but the apparent lack of felt reports elsewhere in Nevada indicates that this magnitude is likely too large. The surface rupture was put together by Slemmons et al. (1959) using multiple accounts. F.C. Schrader's 1911 observations along the northern part of the rupture have the highest confidence of relating to the earthquake. Schrader noted "pronounced earthquake disturbance, which produced among other fractures a north-south rift or fissure 3 miles or more in extent" (Slemmons et al., 1959). Slemmons et al. (1959) documented additional recollections in the 1950s indicating a southern extension of this rupture. The 1903 surface breaks were re-ruptured by the 1954 Fairview Peak earthquake, complicating the recognition of these older ruptures. The assumption was made by Slemmons et al. (1959) that the 1903 event was the only big event mentioned during this time period; therefore, all reported surface effects are related to that event. However, there may be other factors that can cause relatively long surface ruptures, such as shallow faulting, triggered surface slip, and after-slip.

The 1903 earthquake was not felt in Fallon (~50 km to the west), Austin, or Wadsworth (Slemmons et al., 1959). These observations strongly question whether this event was as large as a magnitude 6.5. For comparison the M_L 6.1 foreshock of the 1915 Pleasant Valley earthquake (east of Lovelock, Nevada) was distinctly felt in Reno, a distance of over 200 km (Slemmons et al., 1965). The 1903 event appears to have only local effects, which would limit the size to a magnitude 6 or less. Thus, this event is assigned a magnitude 6.

1915 Pleasant Valley earthquake

The 1915 Pleasant Valley earthquake is the largest earthquake in the Nevada historical record, with the largest surface displacement, one of the longest surface ruptures, and one of the largest felt areas. Surface-wave magnitudes range from 7.6 to 7.8. Two studies reevaluated the surface-wave magnitude. Lienkaemper (1984) calculated an M_s of 7.6 using Gutenberg-Richter notepad information; and Abe and Noguchi (1983) also reevaluated the magnitude and calculated an M_s of 7.7. Doser and Smith (1989) estimated a moment magnitude of 6.9, but this is likely low, because the body wave modeling of limited number of seismograms from the 1915 event may not have identified all the subevents that occurred (Doser, 1988; Doser pers. comm., 1988). The USGS (e.g., Stover and Coffman, 1993) reported an M_s of 7.7 (from Abe and Noguchi, 1983) and a geologic moment magnitude of 7.14, which is attributed to Wallace (1984); the later value has commonly been rounded to 7.1. The moment magnitude attributed to Wallace (1984) is close to his estimate, but not exact; Wallace (1984) assigned an M_w 7.2 to the 1915 earthquake, and a moment derived from the surface rupture of 6.1 x 10^{25} dyne-cm (this converts to a moment magnitude of 7.16 using the Hanks and Kanamori (1979) moment magnitude formula of $M_w = 2/3 \log Mo - 10.7$ (which Wallace refers to). Wallace (1984) used the following parameters in his moment calculation; a length of 59 km, an average displacement of 2.03 m, a down-dip width of 17 km (considering a 15 km depth and a dip of 60°), and a shear modulus of 3 x 10^{11} dynes/cm^2. Caskey et al. (1996) also calculated a seismic moment for the 1915 earthquake based

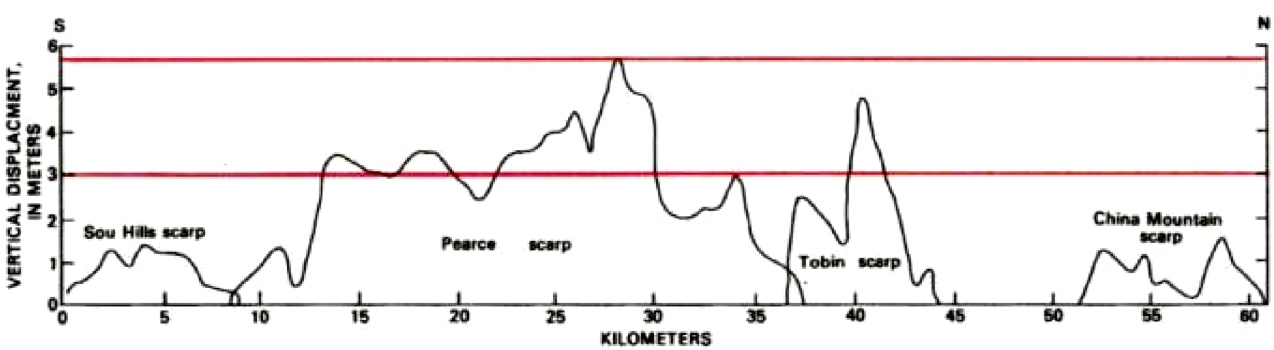

Figure 1. Displacement curve for the 1915 Pleasant Valley earthquake from Wallace (1984). The lower red line is an average displacement of 3 m that resulted in an M_w 7.3 (dePolo, unpublished), and the upper red line indicates the maximum displacement. The 3 m is a visual mode of displacement from the most representative sections of the surface rupture.

on the surface rupture, which used slightly different parameters than Wallace (1984), but arrived at the same moment magnitude estimate of 7.2. Caskey et al. (1996) maximized the displacement value to 5.8 m (compared with their 1.9 m average displacement value) and the resulting moment magnitude estimate was 7.5. Pancha et al. (2006) used a geologic moment-magnitude estimate of M_w 7.15 calculated by Wells and Coppersmith (1994).

dePolo et al. (2000) also used the surface rupture to recalculate the seismic moment of the 1915 earthquake. This estimate used a seismogenic depth of 16 km and a dip of 60° for calculating fault width, and the 59 km length of fault rupture from Wallace (1984). The moment magnitudes of 7.1 and 7.2 seemed too small compared to the instrumental magnitudes, and there was a 1- to 2-m right-lateral offset along the Pearce and Tobin scarps (Wallace, 1984, plate 1; D.B. Slemmons, 2011, pers. Comm.) that has not been accounted for in these calculations. dePolo et al. (2000) used a modal displacement in the Pearce scarp to calibrate an overall average displacement for the earthquake. Wallace (1984) noted that the Pearce section was likely the most representative of the fault at depth. This rupture has a rough plateau in displacement around 3 m, and is 3 m or greater over about half of its length (see surface rupture figure). The Tobin scarp also exceeds 3 m in the central part, and when the displacement along its southern part is added to the overlapping tail of the Pearce scarp, it is also about 3 m. Taken together, this means about 3 m offset occurred along about half of the rupture. The maximum displacement, 5.8 m, is nearly twice this value. Thus, a 3 m value was used for the 1915 average displacement, which yielded a seismic moment of 9.56×10^{26} dyne-cm and corresponded to a moment magnitude of 7.3 (7.29 rounded up) using Hanks and Kanamori's (1979) relationship. Considering an additional 1–2 m right-lateral component, the net displacement would be 3.2–3.6 m and the estimate would be a more robust magnitude of 7.3.

An alternative to the magnitude 7.3 estimate is a maximum-moment calculation of magnitude 7.5 by Caskey et al (1996). They noted that the instrumental magnitudes of most large Basin and Range Province earthquakes compare better to the maximum moment magnitudes calculated from surface ruptures and cited Thatcher and Bonilla (1989) as an example of a study that found that maximum displacements also correlated better with geodetic displacements measured from earthquakes. Additionally, Wallace (1984) noted that if an intraplate relationship of magnitude versus moment was used, $M = 2/3 \log Mo - 10.46$ (Singh and Havskov, 1980), a moment magnitude of 7.4 was obtained using his fault parameters.

A moment magnitude of 7.3 or 7.5 appears to better represent the 1915 earthquake than magnitude 7.1 and decreases the fairly large gap between the geologic moment magnitude and the instrumental magnitude. The M_w of 7.3 was adopted to account for the large vertical displacements over the two main sections of the surface rupture and a right-lateral component recognized along those segments.

1934 Excelsior Mountain earthquake

Doser and Smith's (1989) M_w 6.1 value was adopted for the Excelsior Mountains earthquake. This was 0.1 magnitude units above the 6.0 used by Pancha et al. (2006), which was an average of moment magnitude values presented in Doser and Smith (1989).

1954c Stillwater earthquake

Pancha et al. (2006) adopted a moment magnitude generated by Mason (1996) from the surface rupture. This value of M_w 6.76 was rounded to M_w 6.8 and was used in the new map.

1954d Fairview Peak earthquake

The rounded off magnitude of 7.1 from Pancha et al. (2006) was used. If a visual average displacement of 2 m is used for the Fairview fault in the calculation of seismic moment and moment magnitude (Caskey et al., 2004), it raised the seismic moment magnitude estimate from the surface rupture from 7.0 to 7.1. It should be noted, however, that D.B. Slemmons (2011 pers. comm.) favored a magnitude 7.2, concluding that some of the southern ruptures and displacements were no longer preserved and might represent more moment release than has been accounted for.

1954e Dixie Valley earthquake

The seismic moment magnitude estimate of M_w 6.9 based on surface rupture by Caskey et al. (1996) was used. Pancha et al. (2006) adopted a M_w 7.057 value from Doser and Smith (1989).

1966 Caliente earthquake

Magnitude estimates range from 5.0 to 6.1 for the August 16, 1966 Caliente earthquake. Stover and Coffman (1993) reported this event as having an M_L of 5.6 and an M_w of 5.3; this M_L is from the University of Utah Seismograph Stations and is a revision of their original M_L 5.9 based on a thesis by Beck (1970). Early magnitude estimates cluster around magnitude 6 (Pasadena, M_L 6; Berkeley, M_L 5.7–6.1; UNR, M_L 6; U. of Utah, M_L 5.9). Two days after the event the local newspaper, *The Pioche Record*, even announced a "seismometer reading of six on the Richter scale." The higher Berkeley magnitude was likely adopted by von Hake and Cloud (1968) for the USCGS *United States Earthquakes, 1966*, which reports a magnitude 6.1 for the event. Seismic moments are estimated for the August 16th earthquake by Doser and Smith (1982), 1.1×10^{24} dyne-cm (M_w 5.3), and by Wallace et al. (1983), 4.1×10^{24} dyne-cm (M_w 5.7). The

August 16th event has a reasonably robust local magnitude of 6. For a moment magnitude, the M_w 5.7 deduced from Wallace et al. (1983) was used because their study inverted two sets of waveforms and came up with a nearly identical seismic moment and it was closer to the local magnitude. Pancha et al. (2006) preferred the M_w 5.3 of Doser and Smith (1982; 1989).

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Table 1. A comparison of earthquake magnitudes from Nevada's major historical earthquakes (and two other earthquakes that caused damage in Nevada).

Year	Slemmons et al. (1965)	UNR Catalog	Lienkaemper (Ms) (1984)	Toppozada et al. (1981) (Mla)/(2000)	Doser and Smith (Mw) (1989)	Stover and Coffman (1993)	Geologic Moment (Mw)	Pancha et al. (2006)	Others	This study
1840s?	-	-	-	-	-	-	-	-		-
1852?	-	-	-	-	-	-	-	-		-
1857	-	-	-	6.0/6.3		6.00MLa	-	6		6.3* MLa
1860	7.-	7	-	6.3/6.5		6.30MLa	-	6.3		6.5* MLa
1868	6.-	6	-	5.8//6.0		5.80MLa	-	5.8		6.0* MLa
1869a	-	6.7	-	6.1/6.4		6.10MLa	-	6.1	6.7MLa[1]	6.4* MLa
1869b	-	6.1	-	5.9/6.2		5.90MLa	-	5.6		6.2* MLa
1872*	-	-	-	7.8/7.4		7.75Mw	7.5-7.7[2]	7.58		7.6 Mw
1872	6	-	-	-		6.00MLa[21]	-	6		6? MLa
1887	-	6.3	-	6.3/6.5		6.30MLa	-	6.3		6.5* MLa
1903	-	-	-	-		-	-	6.5	6.53	6* MLa
1910	-	6.1	-	-		-	-	6.1	6.33	6.1 ML
1914	6.-	6	-	/5.6		6.00ML	-	6		6 ML
1914	6.4	6.4	-	/6.0		6.40ML	-	6.4		6.4 ML
1915a	-	6.1	-	-		-	-	6.1		6.1 ML
1915	7.8, 7.5MLa	7.8	7.61	-	6.9	7.7Ms[4], 7.14Mw[5]	7.2-7.5[6], 7.3[7]	7.15	7.3Mb[8]	7.3* Mwg
1932	7.2	7.2	-	-	6.8	7.2Ms[9]	7.1[10]	7.1		7.1 Mwg
1933	5.9w	6	-	/6.1	-	6.1Ms[9]	-	6		6 ML
1934	6.3w	6.3	-	-	6.1	6.5Ms[11]	-	6		6.1* Mw
1948	6.0	6.0	-	/6.0	-	6.00ML	-	6	5.8-6.0MLa[12]	6 ML
1954a	6.8	6.8	6.34	-	6.1	6.80ML	6.3max[13]	6.2		6.2 Mw
1954b	6.0	6.0	-	-	5.9	6.00ML	6.0max[13]	6.1		6.1 Mw
1954c	6.8	6.8	6.95	-	6.5	6.80ML	6.9max[13]	6.76		6.8* Mwg
1954d	7.3	7.3	7.24	-	7.2	7.2ML[14], 7.25Mw[15]	7.0[16]	7.12	7.1Ms[11], 6.9Mb[8]	7.1* Mwg
1954e	6.9	6.9	-	-	6.7	7.1ML[14], 6.90Mw[17]	6.9[16]	7.06		6.9* Mwg
1959a	6.3, 5.9MLa	6.3	-	-	5.7	6.30ML[14]	-	5.71		5.7* Mw
1959b	6.3, 6.1MLa	6.3	-	-	5.6	6.10ML[14]	-	5.55		5.6* Mw
1966		6	-	-	5.3	5.60ML[18], 5.31Mw[19]	-	5.3		5.7* Mw
1966*		6	-	/6.0	5.9	6.00ML[14], 5.90Mw[20]	-	5.9		5.9 Mw
2008		6.0 Mw	-	-	-	-	-	-		6.0 Mw

Earthquakes located in California that caused damage in Nevada are in gray type; * = value different from Pancha and others (2006).
w = Univ. of Nevada Wiechert seismometer magnitude; MLa = local magnitude derived using Modified Mercalli Intensity area. Mwg = moment magnitude from surface rupture.

Table Footnotes:

1 Local earthquake magnitude estimate by Sanders and Slemmons (1979), based on maximum intensity area.
2 Moment magnitude estimates made based on the surface rupture by Beanland and Clark (1994).
3 "Maximum" magnitude from Rogers and others (1991).
4 Surface-wave magnitude by Abe and Noguchi (1983).
5 Moment magnitude based on the surface rupture by Wallace (1984).
6 Moment magnitude based on the surface rupture by Caskey and others (2004).
7 Moment magnitude based on the surface rupture by dePolo and others (2000).
8 Body-wave magnitude by Abe (1981).
9 Surface-wave magnitude by Gutenberg and Richter (1954).
10 Moment magnitude based on the surface rupture by Bell and others (1999).
11 Surface-wave magnitude from Richter (1958).
12 Local magnitude correlation to Modified Mercalli Intensity areas (Toppozada, 1975).
13 Moment magnitude based on surface rupture by Caskey and others (2004).
14 Local magnitude from U.C. Berkeley Seismograph Stations.
15 Moment magnitude from Hanks and others (1975).
16 Moment magnitude from Caskey and others (2004).
17 Moment magnitude from Scholz and others (1986).
18 Local magnitude from the Univ. of Utah catalog; note this follows Beck's 1970 thesis.
19 Moment magnitude from Doser and Smith (1982).
20 Moment magnitude from Kanamori and Anderson (1975).
21 Local magnitude based on intensity area by Ellsworth (1990).