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# Revisiting the 1872 Owens Valley, California, Earthquake

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**Abstract** The 26 March 1872 Owens Valley earthquake is among the largest historical earthquakes in California. The felt area and maximum fault displacements have long been regarded as comparable to, if not greater than, those of the great San Andreas fault earthquakes of 1857 and 1906, but mapped surface ruptures of the latter two events were 2–3 times longer than that inferred for the 1872 rupture. The preferred magnitude estimate of the Owens Valley earthquake has thus been 7.4, based largely on the geological evidence. Reinterpreting macroseismic accounts of the Owens Valley earthquake, we infer generally lower intensity values than those estimated in earlier studies. Nonetheless, as recognized in the early twentieth century, the effects of this earthquake were still generally more dramatic at regional distances than the macroseismic effects from the 1906 earthquake, with light damage to masonry buildings at (nearest-fault) distances as large as 400 km. Macroseismic observations thus suggest a magnitude greater than that of the 1906 San Francisco earthquake, which appears to be at odds with geological observations. However, while the mapped rupture length of the Owens Valley earthquake is relatively low, the average slip was high. The surface rupture was also complex and extended over multiple fault segments. It was first mapped in detail over a century after the earthquake occurred, and recent evidence suggests it might have been longer than earlier studies indicated. Our preferred magnitude estimate is $M_w$ 7.8–7.9, values that we show are consistent with the geological observations. The results of our study suggest that either the Owens Valley earthquake was larger than the 1906 San Francisco earthquake or that, by virtue of source properties and/or propagation effects, it produced systematically higher ground motions at regional distances. The latter possibility implies that some large earthquakes in California will generate significantly larger ground motions than San Andreas fault events of comparable magnitude.

*Online Material:* Summary of macroseismic effects including assigned MMI for the 1872 event.

## Introduction: Historical Context

The 26 March 1872 Owens Valley earthquake is one of three historical events that generated perceptible shaking over the full, or nearly full, extent of the state of California. The felt extent of the earthquake is especially noteworthy given that the event occurred at approximately 2:30 in the morning, local time, a time when most people were soundly asleep. (The modern tungsten filament light bulb, which is inferred to have had a significant impact on sleep patterns [Coren, 1996] was not introduced until 1913.)

According to census figures, the population of California grew from under 100,000 at the start of the gold rush to 560,000 by 1870. By 1860, silver had been discovered in and around Owens Valley, and gold had been discovered farther north in and around Bodie, California (Piatt, 2003). Mining communities were quickly established in the region. The 1872 earthquake occurred within Inyo County, which had been established in 1866 (Chalfant, 1933). The population was sparse; in 1867, there were an estimated 500 voters (i.e., male citizens of any race, 21 years old and older) scattered between a half-dozen principle settlements (Chalfant, 1933). The total population of Lone Pine was estimated at 250–300 at the time of the earthquake (Whitney, 1872a). There were, however, scattered small settlements throughout the county, including mining settlements along the Sierra and Inyo ranges, and the town of Swansea, established in the late 1860s as a hub for smelting operations (Fig. 1). By 1880, the total population of the county was 2937 (U. S. Census Office, 1883). To the west of the Sierra Nevada, agricultural communities sprang up in the central valley soon after the gold rush began.

The Owens Valley earthquake caused heavy damage to masonry buildings, with the most severe damage in Lone Pine and Independence. About 27 people were killed in Lone Pine, nearly 10% of the population (Whitney, 1872a). J. D. Whitney visited the region after the earthquake and described the extent of ground cracking as well as other effects. He identified segments of the scarp but considered it to be a secondary effect of the earthquake and did not describe it in detail. The first—although by no means complete—identification and description of the scarp was made by G. K. Gilbert, who visited the region in 1883 and sketched the fault from a few miles north of Lone Pine to the northern end of Owens Lake, about 10 miles south of Lone Pine. Bateman (1961) presents an overview of early observations, including notes and photographs made by Willard Johnson in 1910. The first detailed, systematic investigation of the surface rupture was made over a century after the earthquake by Beanland and Clark (1994) (hereinafter BC94).

The Owens Valley earthquake predated the instrumental era in seismology. Investigations of rupture parameters must therefore rely on a combination of geological field observations, macroseismic data, and instrumentally recorded seismicity that might or might not reflect the stress change caused by the mainshock. We discuss each of these in following sections.

## Geological Observations

The Owens Valley earthquake (hereinafter OV1872) generated a dramatic surface rupture that was described crudely by Whitney (1872a,b) and later mapped in detail by BC94 (Fig. 1). BC94 estimate a total rupture length on the order of 90–100 km, the uncertainty reflecting their inability to follow the southern end of the mapped rupture once it reached the playa at Owens Lake. Their mapped rupture extends from roughly 36.41° N, −118.00° W to 37.21° N, −118.32° W. They estimate an average right-lateral slip of 6 m and a total oblique slip of 6.1 m, with an estimated uncertainly of ±2 m, yielding a preferred $M_w$ of 7.5, assuming a rupture depth of 12 km. The current National Earthquake Information Center (NEIC) estimate (e.g., http://neic.usgs.gov/neis/eq_depot/usa/1872_03_26.html, last accessed February 2008) for this earthquake is $M_w$ 7.4.

Vittori *et al.* (2003) report surface rupture farther south than the southern terminus inferred by BC94. Using 1:12,000 low-sun angle aerial photographs to augment field investigations, they identify a complex pattern of faulting around and within the Owens Lake playa, which they interpret as a pull-apart basin controlled by a right step of the main right-lateral fault zone. They trace the surface rupture south of Dirty Socks Springs near Red Mountain, roughly 36.325° N, 117.942° W, an extension of approximately 17 km beyond the southernmost rupture mapped by BC94 (Fig. 1). There is also some suggestion of rupture on the Red Ridge fault on the flanks of the Coso range, although no obvious through-going fault connects the Red Ridge and Owens Valley faults (Fig. 1; also see Vittori *et al.*, 2003; Bacon and Pezzopane, 2007). Whitney (1872a) also describes both "frequent cracks in the earth" as far south as Haiwee Meadows (now Haiwee Reservoir), which extends north–south between roughly 36.15° N and 36.23° N (Fig. 1) and notes as much as 4–5 ft of subsidence along the edge of Haiwee Meadows. Weaver and Hill (1978) identify a Haiwee microseismicity lineament trending south–southeast away from the northern end of Haiwee meadows.

One can then ask: Did the mainshock rupture also extend farther north than the surface break mapped by BC94, either on unidentified disjoint fault segments and/or without generating a clear surface rupture? A number of references (e.g., Oakeshott *et al.*, 1972) make reference to fissures between Big Pine and Bishop (37.364° N, −118.393° W). The wellspring for this information appears to be a letter from Dr. David Slemmons quoted by Oakeshott *et al.* (1972): "Whitney's account indicated some fissures between Big Pine and Bishop." Whitney's original publications, however, are ambiguous. In part I (Whitney, 1872a) he describes a large rock fall above Bishop Creek (now Bishop) but makes no mention of fissures north of Big Pine. In part II (Whitney, 1872b), which mostly focuses on general reflections on the nature and origin of earthquakes, he states, "That the wave of the shock emerged under the Sierra, in the region between Owens Lake and Bishop Creek, in a line nearly parallel with the axis of the chain, is sufficiently established by a consideration of the position of the fissures in the soil and rocks." One is left with two possible interpretations: first, that Whitney did observe fissures between Big Pine and Bishop but did not describe them in detail in his 1872 publications, or, second, that the quote from Whitney (1872b) does not mean that the fissures extend all the way to Bishop Creek. (As of 1872, geologists had not established the association between faults and earthquakes, and so spoke only in vague terms about, for example, the "seat of the disturbance.") One finds a measure of support for the former possibility from reports that the ground was pervasively cracked between Independence and Bishop's Creek, a reported distance of 50 miles (Holden, 1887).

Intriguingly, instrumentally recorded microseismicity is low along the Owens Valley corridor, and the suggested gap coincides almost perfectly with the full extent of the source region identified by Whitney (1872b). The suggested microseismicity gap includes the southern extension identified by Vittori *et al.* (2003) as well as the region north of Big Pine, where ground cracking was described. The seismic gap hypothesis remains controversial, but some lines of evidence suggest that once an aftershock sequence is over, the rupture zone of a major earthquake will be characterized by markedly low background seismicity. For example, the 1989 Loma Prieta, California, earthquake arguably filled a previously identified gap characterized by low microseismicity (U.S. Geological Survey, 1990). Whether this is in fact corroboration of a larger rupture zone or merely coincidence remains unclear. We nonetheless consider it to be a plausible

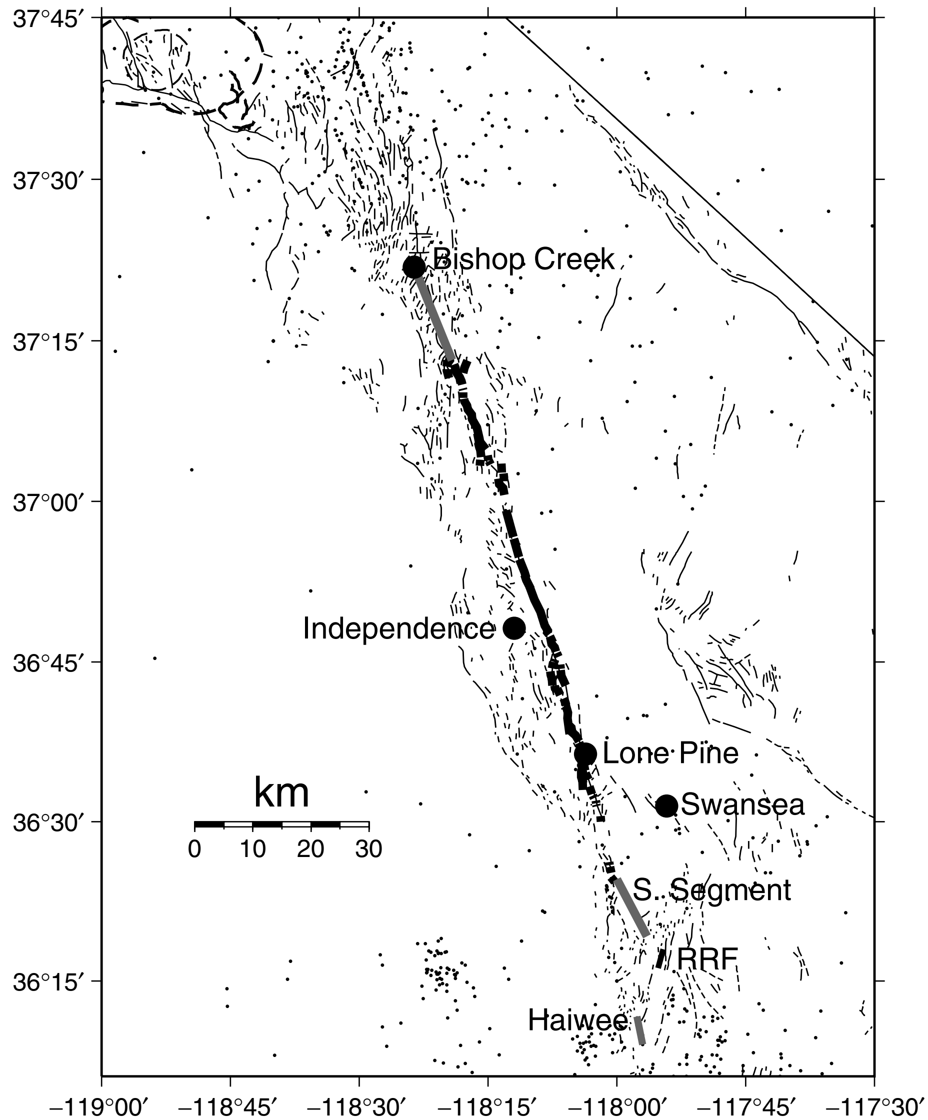



**Figure 1.** Map of the Owens Valley including seismicity recorded by the SCSN between 1932 and 1972 (small dots), perimeter of Long Valley caldera (dashed black line), extent of 1872 rupture as mapped by BC94 (dark black lines), Red Ridge fault (black line, RRF), extent of Haiwee Meadows (gray line, Haiwee), and suggested rupture extensions to the south (heavy gray line, S. Segment) and north (heavy gray line) as discussed in text. Base fault map from Jennings (1994).

interpretation that the rupture did extend to Bishop, an extension of approximately 16 km.

A final possibility that derives some support from early observations is that the 1872 earthquake involved rupture on secondary faults. For example, in addition to the description of subsidence along the edge of Haiwee Meadows, Whitney (1872a) described a large crack trending in an easterly directly in the hills to the east of the meadow. He noted that the crack looked fresh, as if it might have been made during the recent earthquake. Gilbert's sketches (see BC94) also include several east–west trending faults approximately 10-km south of Lone Pine.

If the rupture extended from Dirty Socks Springs to Bishop, the total rupture length would be approximately 123 km. The full apparent microseismicity gap suggests a slightly longer rupture—approximately 140 km.

## Macroseismic Observations

As summarized by Richter (1958), the Owens Valley earthquake "has generally been considered the largest known in the entire California–Nevada region, thus placing in magnitude above those of 1857 and 1906 on the San Andreas fault." Richter further notes, "Such judgment rests on the violence of effects over the large meizoseismal area, as well as perceptibility extending to great distances." Although, as Richter goes on to discuss, the macroseismic observations are notably incomplete, the effects of the earthquake were generally regarded in the early- to mid-twentieth century as being more severe than those of the 1906 earthquake. Toppozada and Parke (1982) estimated magnitudes of 7.7 and 7.8 for OV1872 and the 1906 San Francisco earthquake (hereinafter SF1906), respectively. Recent archival investigations suggest that the macroseismic effects of the 1857 earthquake might have been more severe than recognized earlier (Martindale and Evans, 2002). Given the early date of this event, the distribution of intensities cannot be as well constrained as those of the OV1872 and SF1906.

Macroseismic effects of the earthquake are described in archival sources, principally newspapers. An exhaustive archival search by Toppozada *et al.* (1981) yielded newspaper accounts of the Owens Valley earthquake at 160 locations throughout California and Nevada. A number of these documented dramatic effects in early mining communities along Owens Valley. The most severe damage occurred in Lone Pine, where 27 people were killed. An oft-cited conclusion by Toppozada *et al.* (1981) is that the earthquake stopped clocks and awakened people as far south as San Diego, as far north as Red Bluff, and as far east as Elko, Nevada. According to traditional intensity scales (e.g., Stover and Coffman, 1993), these two effects indicate intensity V. Accounts from these three anchor points, and similar accounts from many other locations at closer distances, suggest that modified Mercalli intensity (MMI) V shaking extended over much of California (Fig. 2).

It is also now recognized that a number of macroseismic effects are not reliable indicators of overall intensity level. As Boatwright and Bundock (2005) discuss, the long-duration, long-period waves from large ($M > 7$) and even moderate earthquakes can stop pendulum clocks at overall intensity levels much lower than V. It is not uncommon for pendulum clocks to stop in locations where intensity is as low as II, which reflects shaking that is barely felt. It has moreover become clear in recent years that, in large earthquakes, intensity levels lower that than V will awaken many or most people. During the 1999 *M* 7.1 Hector Mine, California, earthquake, results from the Community Internet Intensity Map website (Wald *et al.*, 1999) reveal intensity levels of III–IV throughout large parts of the greater Los Angeles region, where, in our experience, shaking was sufficiently strong to awaken many if not most people. Similar results have been found for large historical earthquakes in other regions (N. Ambraseys, personal comm., 2006).

Liquefaction, and spring/water-level changes in wells are also now recognized to not be reliable indicators of intensity (e.g., Ambraseys and Bilham, 2003). According to classic intensity scales, for example, liquefaction is sufficient to assign MMI values of at least VIII, whereas recent studies have documented liquefaction from earthquakes as small as *M* 3.5, for which MMI cannot have been above perhaps V (Musson, 1998). The distribution of rock falls will moreover largely correspond to the distribution of steep slopes. Rockfalls can clearly also occur at very low intensities, as rockfalls sometimes occur in the absence of shaking. During the 1892 *M* 7.2 Laguna Salada earthquake, rockfalls and landslides were observed at locations for which Hough and Elliott (2004) assign MMI values ranging from VI to VII+.

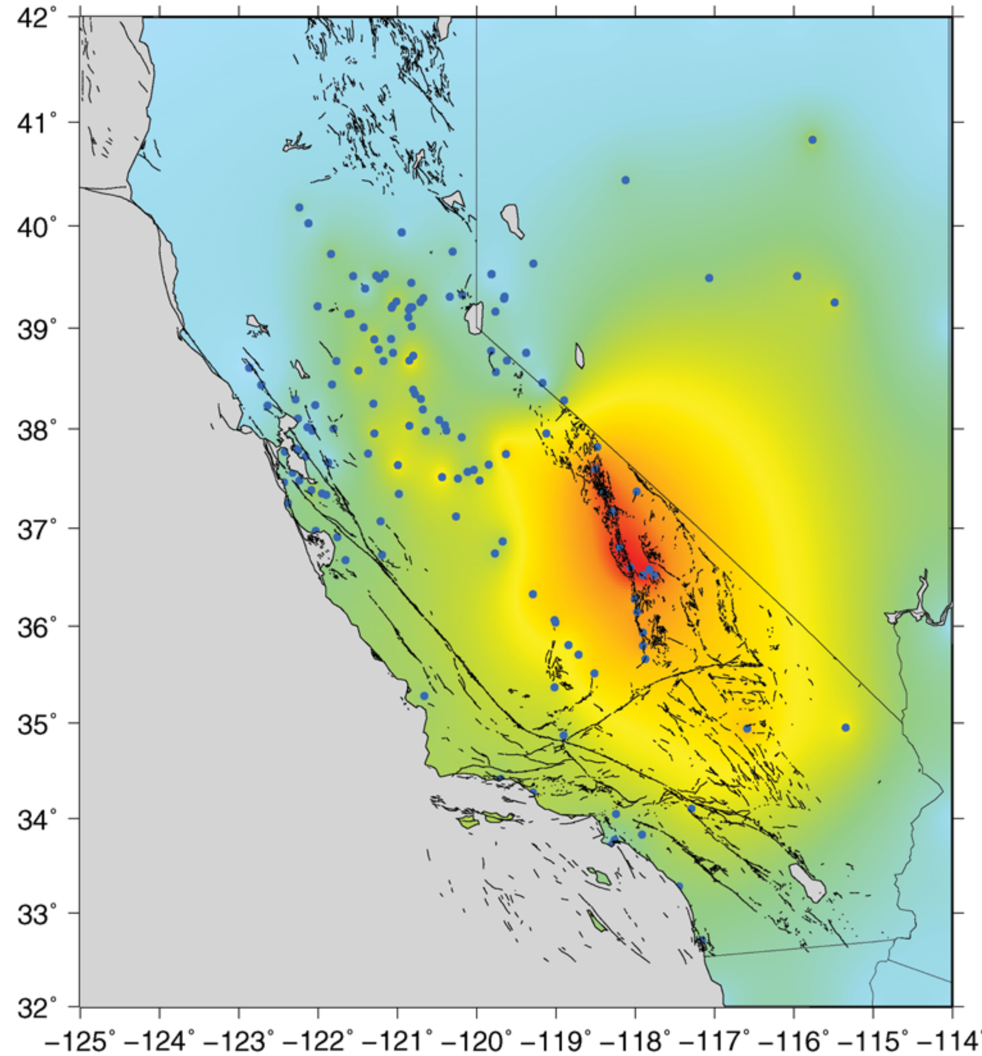
A final consideration in the interpretation of accounts of older historical earthquakes is the so-called media bias, the tendency of brief media accounts to report especially dramatic rather than representative effects (Hough and Pande, 2007). In cases where information is especially brief, we interpret accounts conservatively, assigning the lowest MMI value that might reasonably be consistent with observed effects. At many locations where shaking is described as heavy or severe and reportedly awakened many or most people, we assign intensity values of III–IV. We assign intensity V only when accounts document the fall of light objects from shelves (crockery, bottles, etc.) or light damage to plaster and intensity V–VI for accounts of light damage to masonry.

At locations in the near field, it can be difficult to assign intensities given accounts such as that from King's River (36°49.8′ N, −118°53.5′ W), where two adobe houses were reportedly thrown down, or even Lone Pine, where almost all stone/adobe buildings reportedly collapsed, because early California masonry structures were presumably highly vulnerable to damage. Whitney's (1872a) summary of damage does provide some details that are useful in this regard, for example noting that a barn made of hewn blocks was thrown down in Haiwee, while a nearby wood-frame house was "almost entirely uninjured." Similarly, a private letter sent from Mrs. Nancy Kelsey reveals that, while other accounts tell us that almost all adobe houses in Lone Pine were leveled, the presumably more substantial house owned by a more prosperous family lost its chimney but did not collapse (Appendix A). At a house six miles south of Independence, "a front adobe room" collapsed while the "frame-portion of the building was intact" (Johnston, 1941). A small number of photographs of damage (e.g., Fig. 3) tend to corroborate these accounts. Other accounts from Lone Pine and elsewhere do describe apparently significant damage to, although not total collapse of, some wood-frame homes (see sources in Topozada *et al.*, 1981). Chalfant (1933) notes that only one frame house in the valley was leveled, but adds that many were "racked, and all plastering was shattered."

At Bishop Creek shaking was less severe and damaging than towns farther south, but still strong enough to damage chimneys, move heavy objects on the floor, and make it difficult to stand or walk (Clark, 1970; Toppozada *et al.*, 1981)

One detailed account from Independence, published in the 6 April 1872 *Inyo Independent* newpaper, suggests near-field acceleration in excess of 1*g*. A man who was awake at the time of the earthquake, writing by the light of a tall kerosene lamp, described the chimney of the lamp being thrown straight up in the air and landing upright on the desk, while the lamp fell over, spilling hot oil.

Accounts from some locations describe only damage to masonry structures, with no mention of damage—or lack thereof—to wood-frame buildings. In these cases, intensity assignments might saturate at MMI VIII.




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | ***<.17*** | ***.17-1.4*** | ***1.4-3.9*** | ***3.9-9.2*** | ***9.2-18*** | 18–34 | 34–65 | 65–124 | >124 |
| PEAK VEL.(cm/s) | <0.1 | 0.1–1.1 | 1.1–3.4 | 3.4–8.1 | 8.1–16 | ***16-31*** | ***31-60*** | ***60-116*** | ***>116*** |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

**Figure 2.** Intensity distribution for the 1872 Owens Valley mainshock. MMI intensity values from Toppozada *et al.* (1981).

The intensity map shown in Figure 4 is relatively well constrained by observations (Ⓔ MSP 9, lower part, in the electronic edition of *BSSA*): most of the accounts cluster to the west/northwest of the mainshock, but reports are available from cities such as Los Angeles and San Diego to the south, as well as in Nevada. For display purposes, the intensity values are interpolated. Interpolation is done with the gridding algorithm used in the surface utility of the Generic Mapping Tools (Wessel and Smith, 1991). This algorithm uses a tension factor, $T$, to control the degree of curvature. The minimum curvature solution, $T = 0$, can generate unrealistic oscillations, while $T = 1$ will generate a solution with no maxima or minima away from control points. Here we use $T = 0.5$.

## A Note on Earlier Events

The historical catalog includes few events in the Owens Valley region prior to the 1872 mainshock. Based on extensive archival investigations, Toppozada *et al.* (1981) identifies a moderate event, apparently located near Lone Pine, at 21:06 GMT (Greenwich mean time) on 5 July 1871. The event is estimated to have been around magnitude 5.5. The principle source of information for this event is an 8 July


**Figure 3.** Photograph showing collapsed adobe structure flanked by two wood-frame structures that escaped serious damage. The location of the photograph is not identified, but it was probably taken in Independence. (Photograph reprinted courtesy of Laws Railroad Museum.)

1871 article in the *Inyo Independent*. The shaking is described as severe at Swansea, Lone Pine, and Independence, but with no reported damage; and was felt only weakly at Bishop Creek. The event was also felt at Bear Valley (37.57° N, 120.12° W) and Visalia (36.33° N, 119.29° W). Given the vulnerability of local structures in the Owens Valley, an absence of documented damage suggests intensities no higher than IV–V. The distribution of macroseismic effects, while sparse, is broadly similar to that of a 17 July 2001 *M* 4.9 event located at 36.02° N, 117.88° W, about 50-km south of Lone Pine (http://pasadena.wr.usgs.gov/shake/ca/2001.html, last accessed February 2008).

A later article in the *Inyo Independent* describes additional earthquake activity on 11 and 12 July 1871. At Swansea, "violent" shaking, noted to have been stronger than that on 5 July, was felt around 7:30 p.m. on 11 July. A less severe shock was felt around midnight that night, and another strong shock was felt on the night of 12 July. Strong shocks were also felt at Bishop Creek at midnight on 12 July and around 9:00 p.m. on 11 July. These accounts appear to suggest that two additional moderate earthquakes occurred on the nights of 11 July and 12 July. However, the article further states that around 7:00 p.m. on 11 July a slight shock was felt "at this place." It is unclear if "this" refers to Bishop Creek, or to Independence, where the *Independent* was published. In any case, there is no account of strong shaking at Independence. The accounts are not sufficient to identify times or locations of individual events, especially because one can never rule out transcription and/or reporting errors in individual archival accounts. Taken at face value, the accounts at least suggest that events strong enough to generate local intensities around IV occurred near both Bishop Creek and Swansea on the nights of 11 and 12 July 1871.

The July 1871 *Inyo Independent* articles do suggest that felt earthquakes generally were reported. Apart from the events in July 1871, the only other mention of an earthquake prior to the 1872 mainshock was an article in the 27 January 1872 newspaper, stating that "a lively, rattling little earthquake occurred" the previous Wednesday (24 January 1872) around midnight.

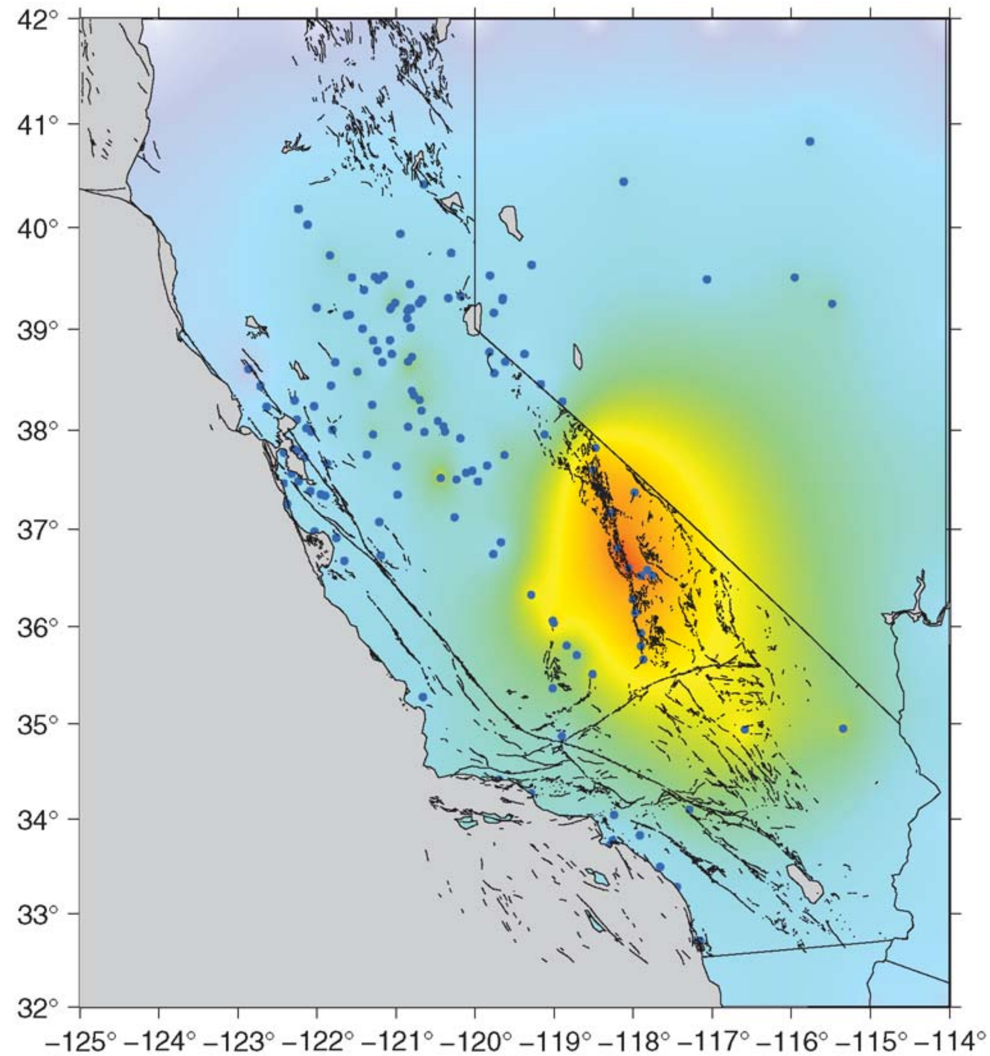
## Interpretation of Macroseismic Observations

Bakun and Wentworth (1997) present a method (hereinafter BW97) to determine magnitude from the distance decay of MMI values for earthquakes in western North America. This method estimates an optimal magnitude and location using observed MMI values as a function of distance and calibrations established from instrumentally recorded earthquakes in western North America. More recently, Bakun (2006) developed an attenuation relation for earthquakes in the Basin and Range province, and used this relation to estimate a preferred magnitude of 7.5 for the Owens Valley earthquake using the MMI values estimated by Toppozada *et al.* (1981). In an earlier study, Evernden (1975) also explained the larger isoseismals of OV1872 relative to SF1906 as a consequence of differences in attenuation in the Basin and Range versus California.

However, while the Owens Valley is a major structural depression the boundary between the Sierra Nevada to the west and the Basin and Range province to the east, Figure 4 reveals that most of the historical accounts of the 1872 mainshock are from locations in California, west of the Sierra range. To our knowledge, no studies document significant differences in attenuation of intensities within California. We therefore suggest that it is more appropriate to analyze the event using the California relation published earlier. Using the BW97 relation, even with the lower MMI values inferred in this study, the preferred magnitude estimate is 7.9.

We note, however, that, apart from the question of whether the BW97 attenuation relation is appropriate for OV1872, the BW97 method assumes a point source and is therefore not appropriate for extended ruptures. In particular, if an earthquake generates documented high intensities at near-fault sites along an extended rupture, the assumption of a point source will generate apparently high values at considerable distance.

Because, however, the range of inferred magnitudes for the OV1872 are in the range 7.4–7.8, a key question is how its intensity distribution compares to that of the SF1906, for which we have both an instrumentally determined magnitude of 7.7–7.9 (Sieh, 1978; Wald *et al.*, 1993; Thatcher *et al.*, 1997; Song *et al.*, 2008) and a set of recently reinterpreted intensities (Boatwright and Bundock, 2005). To compare intensity values for OV1872 and SF1906, we first determine MMI as a function of distance to the fault (Fig. 5a). For this calculation, we assume that the OV1872 rupture extends from 36.32° N, −117.94° W to 37.364° N, −118.393° W, and that the SF1906 rupture extends from San Juan Bautista to Point Arena. (The rupture length used for this calculation




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
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| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

**Figure 4.** Intensity distribution for the 1872 Owens Valley mainshock. MMI intensity values estimated in this study.

assumes the rupture did not continue offshore; we discuss the implications of this assumption next.)

In any comparison of intensity values for different earthquakes, one must first ask whether consistent criteria were used to assign intensities. We have spot-checked the assignments of Boatwright and Bundock (2005) and confirmed them to be assigned consistently with those estimated for this study, with only occasional, minor discrepancies. The number of locations for which accounts are available is substantially higher for SF1906 than for OV1872, raising the possibility that the two distributions will look different on average only because the low-intensity field of the former event is better sampled.

It is also possible for intensity distributions of early earthquakes to be systematically biased by site response if early settlements are especially concentrated in valleys and/or along rivers and coasts (e.g., Hough *et al.*, 2000). To address this possible bias, we also compare the intensity distributions using only the set of 70 locations for which accounts of both earthquakes are available (Fig. 5b). Figure 5b reveals that, at this subset of locations, intensities are systematically higher for 1872 than 1906.

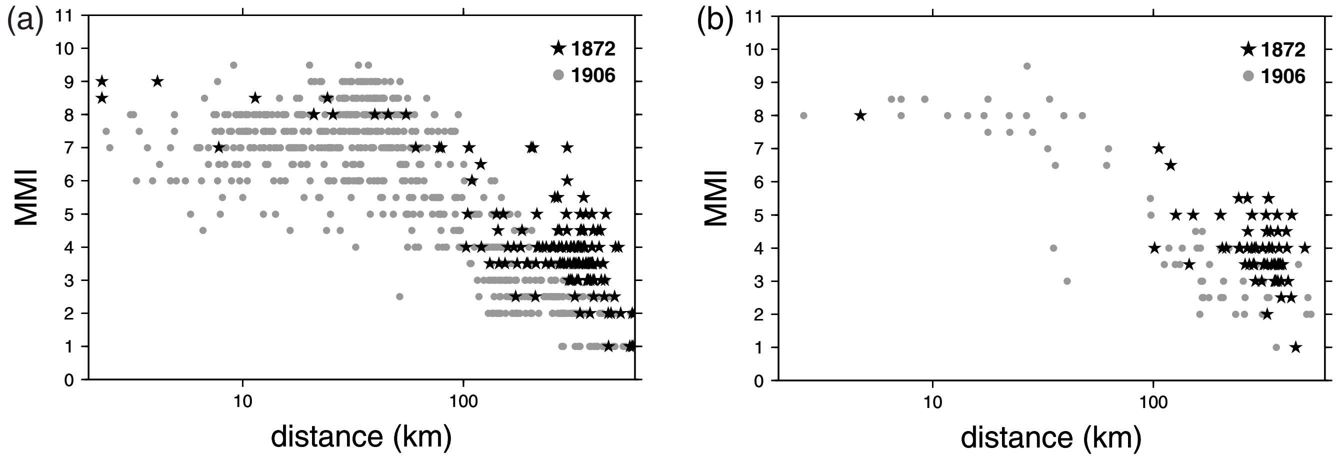



**Figure 5.** (a) MMI values for the Owens Valley mainshock (black stars) and the 1906 San Francisco mainshock (gray circles). (b) Intensity distributions for the Owens Valley mainshock (black stars) and the 1906 San Francisco earthquake (gray circles) using only intensity values from the 70 towns for which accounts of both earthquakes are available.

The comparison of the full intensity data sets (Fig. 6a) reveals that the values for OV1872 generally cluster toward the top of the range estimated at any given distance for SF1906, although at distances greater than ~200 km, intensities for the former event are systematically higher. Furthermore, if we one assumed a longer rupture length for SF1906, as inferred by some studies (e.g., Thatcher *et al.*, 1997; Boatwright and Bundock, 2005; Song *et al.*, 2008), one would reduce the near-fault distance for a number of the high intensity values. That is, the SF1906 intensity values shown in Figure 6a would decay even more quickly with distance. One might argue that the two intensity distributions were in fact comparable, but that our values for OV1872 preferentially sample the more dramatic effects at regional distances. The higher intensity values at 200 + km still beg explanation, however.

One possible explanation is that the apparently high regional intensity values are exaggerated. Considering the details in available accounts, we consider this implausible.

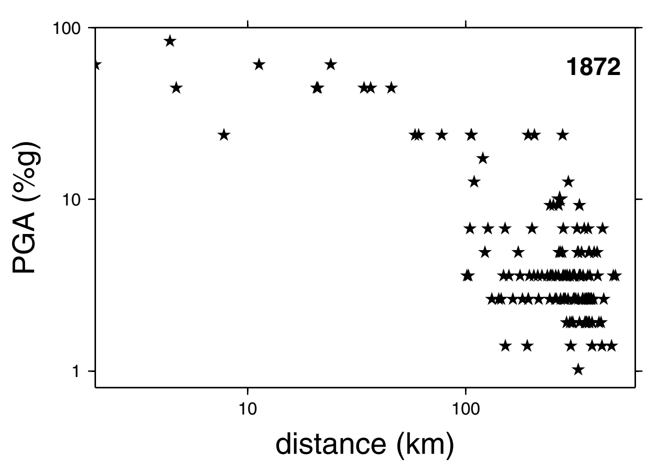



**Figure 6.** Estimated PGA values for the Owens Valley mainshock.

The relatively detailed compilation of accounts published in the *New York Times* (Appendix B) provides several illustrative examples. In Visalia, for example, "goods were hurled off of shelves in the stores," and at least some brick buildings were damaged. Even if one assumes the damaged buildings were weak, this account implies MMI VI. In Sacramento, plaster and a few walls were cracked. In Chico, at a distance of 400 km from the northern end of the rupture, the brick walls of the new Presbyterian Church were cracked (Oakeshott *et al.*, 1972); here we assign MMI V. Even in Los Angeles, the shaking "aroused nearly everybody from sleep," and notably the shaking was described as having been as long or longer than that from the 1857 Fort Tejon earthquake. Here we assign MMI III–IV. We note that, while one could perhaps assign lower intensities by appealing to the possibility that damaged buildings were extremely weak, such assignments would not be consistent with those by Boatwright and Bundock (2005) for SF1906.

Accounts of the SF1906 earthquake, in contrast, generally describe a remarkably rapid diminution of effects away from the fault trace. As G. K. Gilbert summarized in 1907, "At a distance of 20 miles, only an occasional chimney was overturned, the walls of some brick buildings were cracked…and not all sleepers were wakened. At 75 miles, the shock was observed by nearly all persons awake at the time, but there were no destructive effects; and at 200 miles, it was perceived by only a few persons" (Gilbert, 1907). Gilbert's summary is consistent with the assessments by Boatwright and Bundock (2005): at a distances of approximately 300 km, intensity values generally range from I–III, with only a few values of 3.5.

One could appeal to a number of explanations to explain why the Owens Valley earthquake might have generated relatively more severe shaking than 1906 (e.g., especially efficient [high-$Q$] transmission of energy along the Sierra Nevada). Large-scale anisotropy of apparent attenuation has been suggested and/or observed in previous studies. Kennett (1984) demonstrates that the development of higher-mode crustal surface waves is affected by large-scale crustal structure. This work was developed in subsequent theoretical studies (e.g., Kennett, 1986) and confirmed in observational investigations of *Lg* propagation (e.g., Hough *et al.*, 1989; Baumgardt, 1990; Wald and Heaton, 1991; McNamara *et al.*, 1996, among others) as well as macroseismic effects (e.g., Hough and Elliott, 2004). One might also conjecture that a focusing effect, akin to that inferred to explain damage in Santa Monica during the 1994 Northridge, California, earthquake (Gao *et al.*, 1996), was responsible for the dramatic effects in towns close to the western Sierra front, in particular Visalia. It is further not unexpected that shaking effects to the east of Owens Valley would be more severe than to the west, because the Basin and Range is characterized by lower attenuation of intensities than California (e.g., Bakun, 2006).

While the effects discussed previously would contribute to elevated intensity values in some azimuths, the intensity values for OV1872 are generally relatively higher than SF1906 at regional distances. We consider this observation to be robust. While detailed intensity assignments might be open to interpretation, the rapid attenuation of shaking away from the San Andreas fault in 1906 is documented by Gilbert (1907) and corroborated by modern intensity assignments (Boatwright and Bundock, 2005). The observation that “at 200 miles, it was perceived by only a few persons” stands in contrast to documented effects from OV1872, which awakened many or most people in many locations at 300–500 km distance. In the near field, OV1872 values cluster towards the top of the distribution for SF1906 even though it is possible if not probable that the OV1872 MMI values saturate due to the lack of solidly built structures.

Although one thus cannot easily appeal to propagation effects to explain the overall intensity distribution of OV1872, another possibility is that the source was a high-stress-drop rupture that produced relatively high ground motions for its magnitude (e.g., Hanks and Johnston, 1992).

One can also compare OV1872 intensities to predicted shaking intensities based on modern attenuation relations. For this comparison, it is necessary to convert MMI values into PGA, or spectral acceleration. We use the MMI–PGA relation determined from instrumentally recorded earthquakes in California (Wald *et al.*, 1999):

$$\mathrm{MMI} = 3.66 \log(\mathrm{PGA}) - 1.66.$$

The estimated PGA values are shown in Figure 6b. As discussed previously, peak accelerations at near-field distances are difficult to estimate with precision, although at least one account suggests PGA in excess of $1g$.

## Triggered Earthquake

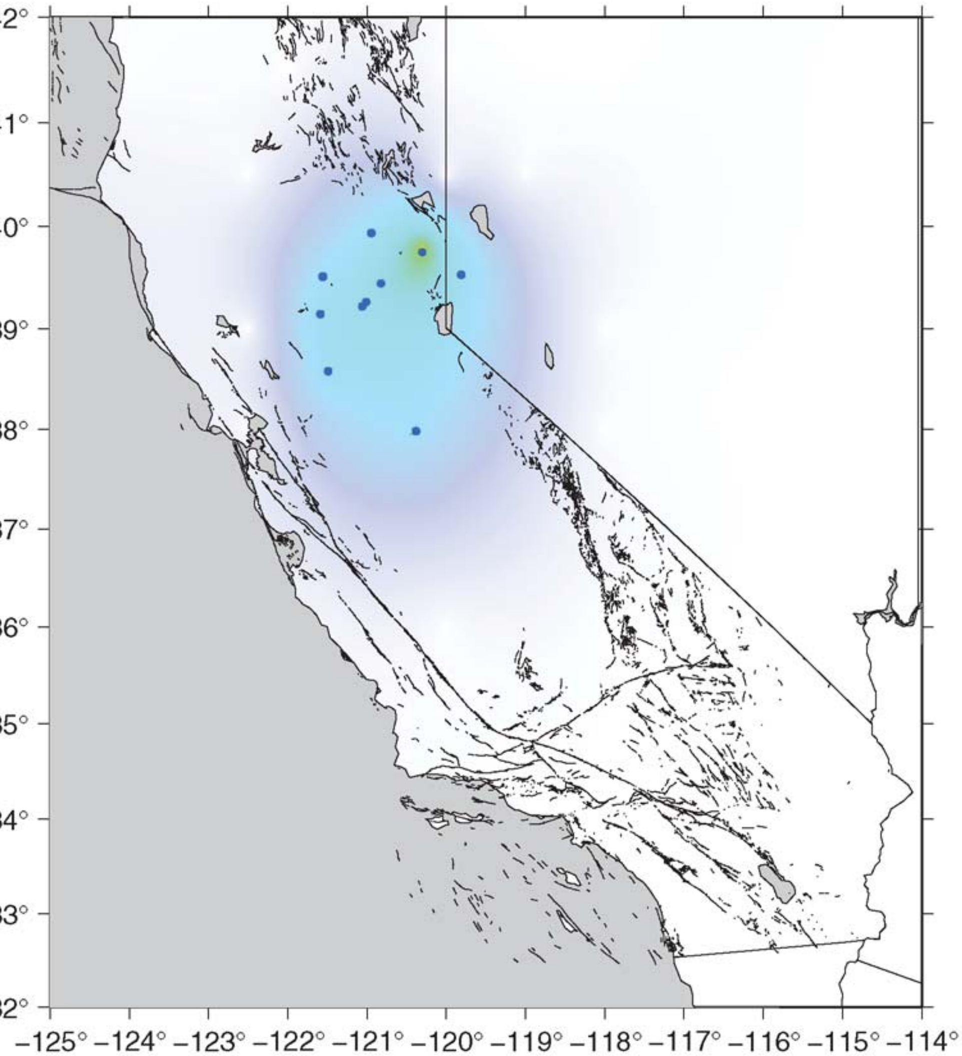
Among the events identified by Toppozada *et al.* (1981) is a moderate earthquake at approximately 13:00 GMT on 28 March 1872. This event was felt in northern California, with one account describing considerable damage to bottles and crockery near the town of Sierra Valley. We reinterpret ten available accounts of this event (Fig. 7). Although few in number, the overall distribution corroborates a location in the vicinity of Sierra Valley. Using the method of BW97, we obtain an optimal location of 39.59° N, −120.360° W, and an optimal magnitude of 5.4—in good general agreement with the results of Toppozada *et al.* (1981).

The temporal proximity of the 28 March 1872 event and the 26 March mainshock suggest that the former was triggered by the latter. Recent studies have shown that remotely triggered earthquakes occur ubiquitously following even small and moderate mainshocks, suggesting that triggering occurs pervasively and in diverse tectonic settings (e.g., Hough, 2005; Felzer and Brodsky, 2006). It remains open to debate whether there is a physical basis for distinguishing these events from conventional aftershocks. In any case, both OV1872 and SF1906 were followed by moderate (potentially) damaging events at regional distances (see Meltzner and Wald, 2003 for a discussion of the 1906 sequence). This small sample suggests that, if not common, moderate triggered events are at least not unusual following large mainshocks in California.

## The 1872 Rupture: Seismological Observations

Instrumentally recorded microseismicity can perhaps help illuminate the Owens Valley fault and the OV1872 rupture (Fig. 1). Locations in this region tend to be poorly constrained given sparse network coverage, especially prior to 1984. An immediate conclusion, however, is that seismicity is very low along the OV1872 rupture zone. Even in recent years, available network locations reveal notably sparse seismicity extending along the Owens Valley between 36.25° N and Bishop (37.364° N) (Fig. 8). The low-seismicity zone continues from the northern terminus of the BC94 rupture up to Bishop, along the full extent of the rupture mapped by BC94, and continues along the southern segment of rupture identified by Vittori *et al.* (2003). As discussed earlier, there is some suggestion that the surface rupture continued as far north as Bishop. Short of field investigations that identify previously unrecognized surface rupture, it will probably be impossible to ever answer this question, or to rule out the possibility that the rupture extended farther north in the subsurface. Nevertheless, the distribution of instrumentally recorded seismicity appears to suggest that the seismic gap—and therefore the OV1872 rupture—does extend as far north as roughly Bishop.

One can also turn to instrumentally recorded microseismicity to estimate the depth of the Owens Valley fault. In their moment calculation, BC94 assumed a fault depth of 12 km based on inferred depths of network solutions. As noted, however, seismicity is sparse along the mainshock rupture zone, and locations are generally not well constrained. Given the paucity of events and stations, Hauksson




| PERCEIVED SHAKING | Not felt | Weak | Light | Moderate | Strong | Very strong | Severe | Violent | Extreme |
|---|---|---|---|---|---|---|---|---|---|
| POTENTIAL DAMAGE | none | none | none | Very light | Light | Moderate | Moderate/Heavy | Heavy | Very Heavy |
| PEAK ACC.(%g) | *<.17* | *.17-1.4* | *1.4-3.9* | *3.9-9.2* | *9.2-18* | 18–34 | 34–65 | 65–124 | >124 |
| PEAK VEL.(cm/s) | <0.1 | 0.1–1.1 | 1.1–3.4 | 3.4–8.1 | 8.1–16 | *16-31* | *31-60* | *60-116* | *>116* |
| INSTRUMENTAL INTENSITY | I | II-III | IV | V | VI | VII | VIII | IX | X+ |

**Figure 7.** Intensity distribution for the event at 13:00 GMT on 28 March 1872.

and Shearer (2005) do not analyze events north of 36.75° N in their double-difference relocation of southern California seismicity. However, their results, which include events between 1984 and 2007, do include events that extend up to the southern end of the Owens Valley fault. While the locations and depths of these events are relatively poor, they still provide some illumination of recent microseismicity along the Owens Valley fault. Focusing on events at the southern end of the OV1872 rupture zone, where hypocenters are relatively well constrained, most events are above a 15-km depth, but sparse seismicity does extend to a depth of at least 20 km, and possibly down to 25 km (Fig. 9a). However, given the poor ray path coverage in this region, depths are not well resolved (Hauksson and Shearer, 2005).

The Southern California Seismic Network (SCSN) catalog solutions suggest a more shallow seismogenic depth (Fig. 9b). We revisited the phase picks for events whose initial network locations were deeper than 15 km. All of the relocated hypocenters are more shallow. The difference between Figure 9a,b results in large part from the velocity models used for locations. SCSN events are located using a standard 1D model that is heavily constrained by paths through the Mojave. The Hauksson and Shearer (2005) hypocenters are located with an iterative process, whereby

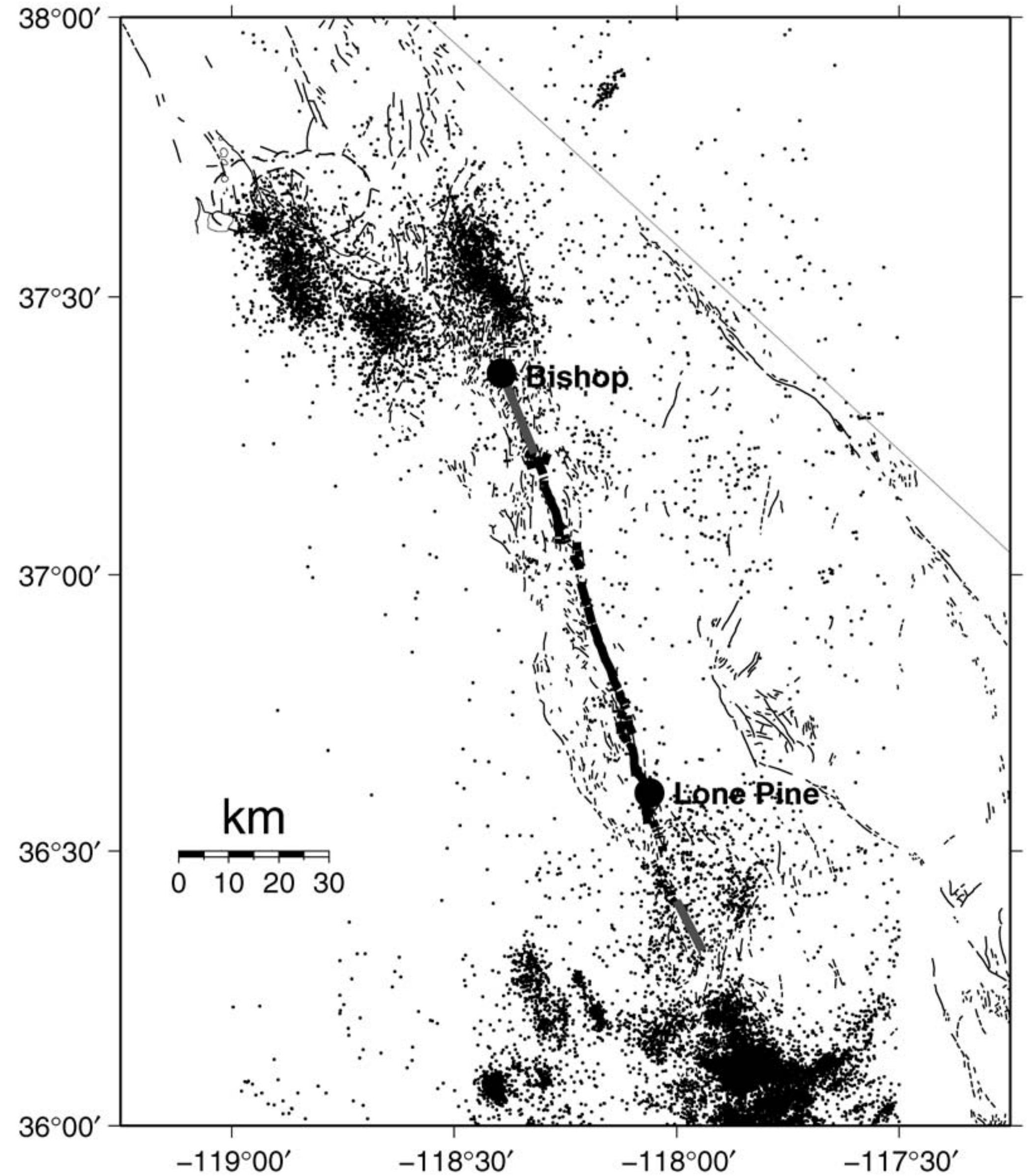



**Figure 8.** Network locations for events through 1990. Extent of fault rupture mapped by BC94 (dark lines) and suggested extensions (gray lines) discussed in text are also shown.

initial locations are determined with the 3D models of Hauksson (2000) and then a 1D model is used in a double-difference algorithm to obtain precise relative locations. The 3D model of Hauksson (2000) has generally higher velocities in the Owens Valley region than the standard 1D SCSN model, Again, however, ray path coverage is limited because this region is at the edge of the inversion area. With so few close stations, one is thus left with an unresolvable trade-off between hypocentral depths and local velocity structure.

In effect, Figure 9a,b can perhaps be taken as an indication of the uncertainty of hypocentral locations in this region. They suggest a minimum seismogenic depth of 15 km and a maximum depth of approximately 25 km.

One can thus revisit the moment calculation of BC94 using updated estimates of mainshock rupture parameters. Based on the investigations of BC94 and Vittori *et al.* (2003), we infer a plausible range of rupture lengths to be 120–140 km. Considering the relocated hypocenters of Hauksson and Shearer (2005) we infer a range of rupture widths to be 15–25 km, assuming the rupture broke the full extent of the seismogenic zone. Using the average slip ($6 \pm 2$ m) inferred by BC94, the rupture dimensions imply $M_w$ 7.5–7.9. Our preferred parameters for the mainshock rupture include (1) the average slip value reported by BC94, (2) a fault depth of 20 km, and (3) a length of 130 km, as suggested by the gap in instrumentally recorded microseismicity. This yields a preferred $M_w$ estimate of 7.75.

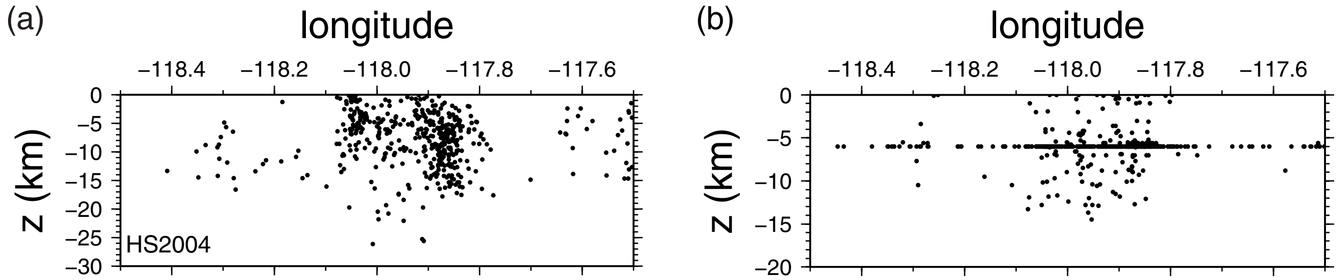



**Figure 9.** (a) Cross section of seismicity across the southern end of the 1872 rupture zone (36.35°–36.45° N) using double-difference locations of Hauksson and Shearer, 2005); (b) cross section using SCSN hypocentral locations.

The least certain preferred parameter is the rupture length, which assumes that the rupture extended farther north than the mapped surface trace. However, we note that even with a rupture length of 120 km, $M_w$ 7.8 is within the range predicted given the uncertainties of the other values.

The previously mentioned results can also be compared with established empirical scaling relations (e.g., Wells and Coppersmith, 1994; Stirling *et al.*, 2002). Stirling *et al.* (2002) show that a rupture length of ~130 km corresponds to an average $M_w$ 7.6–7.7, but $M_w$ 7.8–7.9 is not inconsistent given the scatter observed for instrumentally recorded earthquakes worldwide.

## Stress Shadow?

In recent years, a number of studies have shown or suggested that Coulomb stress changes caused by large earthquakes will create a so-called stress shadow in which subsequent activity is low (e.g., Harris and Simpson, 1992; King *et al.*, 1994; Jaume and Sykes, 1996). More recent investigations have tested the hypothesis and failed to find compelling evidence for pronounced stress shadows following large earthquakes (e.g., Felzer and Brodsky, 2005; Mallman and Zoback, 2007). Given the uncertainties regarding the rupture parameters of OV1872 and the limitations of the early catalog, a detailed consideration of stress change caused by OV1872 is probably not warranted. However, because much of our current thinking about stress shadows is based on SF1906, it is illustrative to consider briefly what is known about regional seismicity before and after OV1872.

The historical record is clearly very incomplete prior to 1872; the catalog includes just three moderate events along the Owens Valley corridor prior to OV1872, one in 1868 and two probable foreshocks in 1871 and 1872 (Fig. 10a). Bishop Creek was first settled around 1861, and there is no evidence that early settlers felt frequent earthquakes. Also, as discussed earlier, the *Inyo Independent*, established in July of 1870 (Chalfant, 1933), appears to have reliably reported felt earthquakes in the Owens Valley, and mentions only a half-dozen or so events in the year prior to the mainshock.

Accounts of the 1872 sequence itself include mention of many felt aftershocks (e.g., Kelsey, 1872), of which magnitudes and locations have been estimated for only a few events (e.g., Toppozada and Parke, 1982). Between 1882 and 1892, two moderate events occurred along the Owens Valley/eastern Sierra corridor (Fig. 10b).

One can also consider activity in the Sierra Block region directly south of Long Valley caldera remained notably quiet in the years following OV1872, but moderate events (*M* 5.5–6) occurred in this region in 1910, 1912, 1927, and 1938; a sequence of three moderate (*M* 5.5–5.8) events occurred in 1941 (Fig. 10c). A notable upsurge in activity, however, began with the Wheeler Ridge earthquake in 1978 and then the dramatic episode of unrest in 1980 (Fig. 10d; Hill, 1984).

It remains unclear if episodes of unrest within and south of Long Valley Caldera are due to deep magmatic processes or to crustal seismotectonics; the former interpretation is plausible (see Hill, 2005). We note, however, that moderate earthquakes in the Sierra block region tend to occur on strike-slip faults with orientations roughly parallel to the Owens Valley fault, and the OV1872 rupture would have likely lowered Coulomb stress on these faults (Fig. 11). The evolution of activity illustrated in Figure 10 is suggestive of an eroding stress shadow. Again, however, it is important to note that the recent upsurge in activity in and south of Long Valley might have been due to magmatic processes.

## Discussion

Reinterpretations of historical observations often yield lower magnitudes than the original estimates, in large part because many (not all) early intensity evaluations yielded higher values than what one would assign according to current practices. Indeed, our inferred MMI values are significantly lower than those assigned following the initial archival search (Toppozada *et al.*, 1981). However, our reinterpretation confirms what was widely recognized, or at least believed, prior to 1982: the shaking effects of the Owens Valley earthquake were more dramatic at regional distances than those of the 1906 San Francisco earthquake. We conclude that, even assessed as conservatively as reasonably possible, the macroseismic observations suggest a magnitude no smaller than that of SF1906.

One can then address the question: How big was SF1906? Wald *et al.* (1993) infer a surface-wave magnitude

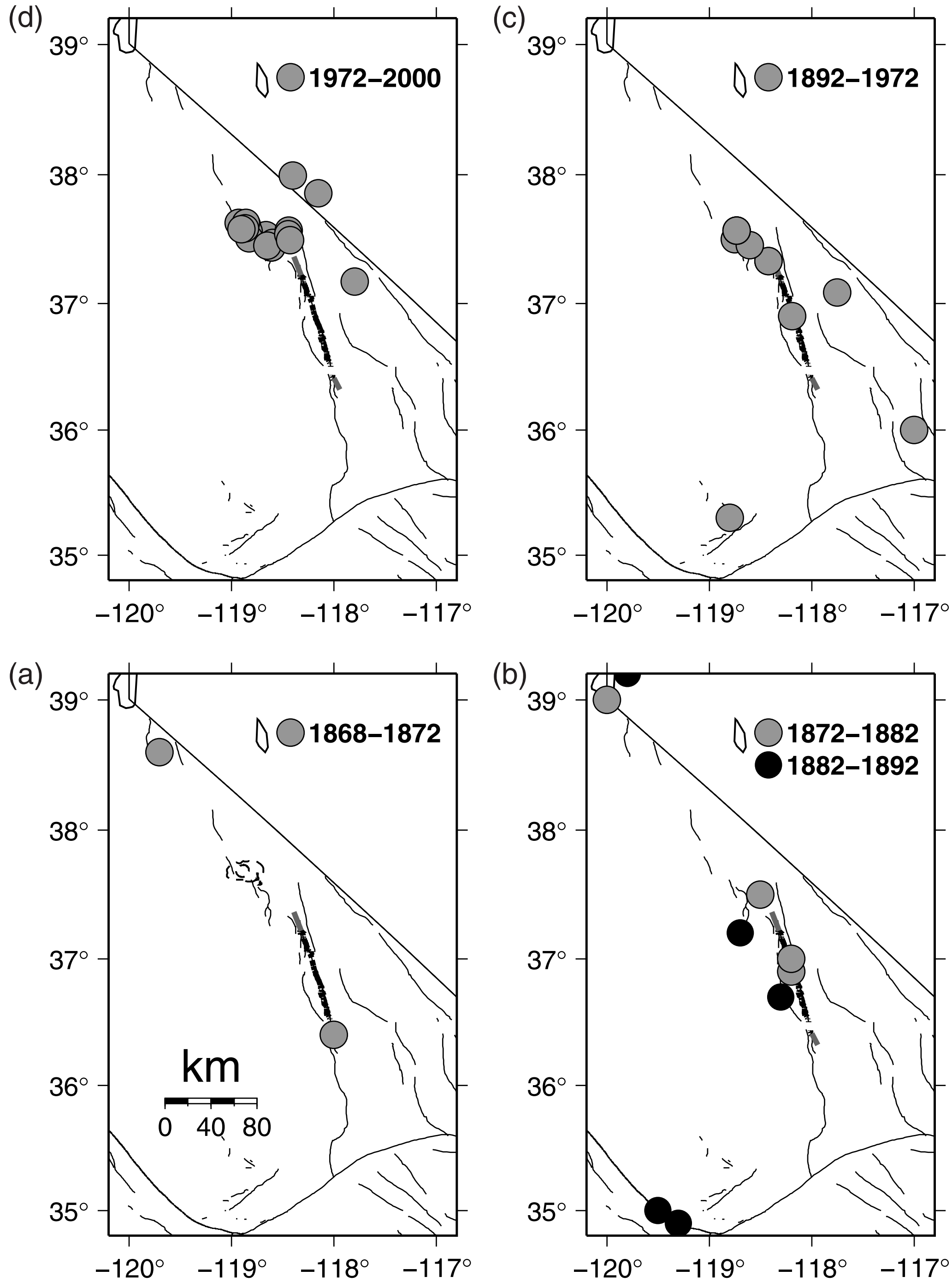



**Figure 10.** (a) Moderate (*M* 5.5–6.5) earthquakes prior to OV1872 as located by Toppozada *et al.* (1981). (b) Located aftershocks of OV1872 (gray circles) and moderate events between 1882 and 1899 (black circles), as located by Toppozada *et al.* (1981). (c) Moderate events between 1900 and 1972. (d) Moderate events between 1978 and 2006.

of 7.7; Thatcher *et al.* (1997) estimate *M* 7.9 from geodetic observations. Rupture lengths from 300–480 km are reported in the literature; the range of values reflects uncertainties in the extent of the rupture offshore north of Point Arena. Geodetic data suggests the rupture did continue offshore; the intensity distribution (Boatwright and Bundock, 2005) supports this conclusion as well. Aagard *et al.* (2008) concludes that the intensity distribution is best fit by $M_w$ 7.8. Wald *et al.* (1993) conclude that if the rupture did continue offshore, this part of the rupture did not release significant seismic radiation. Song *et al.* (2008) show that the geodetic and seismic data can be reconciled if supershear rupture is allowed, estimating $M_w$ 7.9. (Song *et al.* (2008) do not consider uncertainties, but report only a preferred value. The event is listed

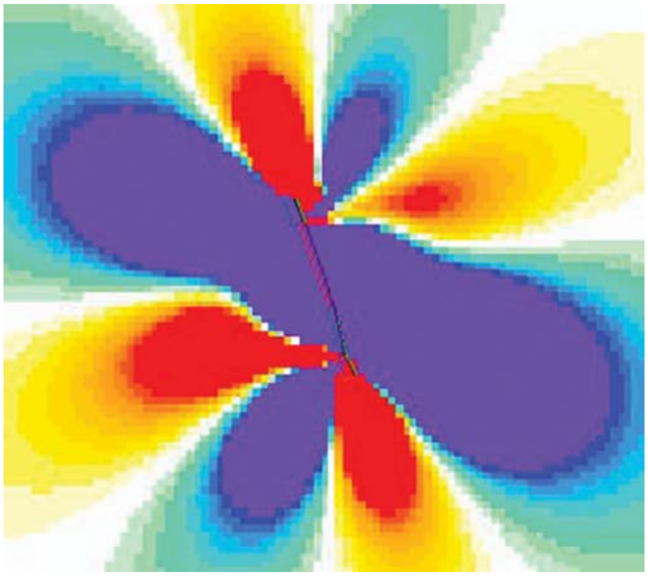


**Figure 11.** Predicted Coulomb stress change (Toda *et al.*, 2005; http://quake.usgs.gov/research/deformation/modeling/coulomb, last accessed September 2007) caused by OV1872 rupture (dark line) resolved on right-lateral strike-slip faults with orientation parallel to the mainshock.

by NEIC as 7.8 (http://neic.usgs.gov/neis/eq_depot/usa/1906_04_18.html, last accessed February 2008). Rupture depth is generally inferred to be 10 km; average slip is estimated to have been 3–5 m. The range of inferred rupture parameters implies $M_w$ values of 7.6–7.9.

A comparison between OV1872 and SF1906 is illuminating because consistently determined intensity values are available for both events, and the magnitude of the larger event (but not the former) is constrained by instrumental data. The range of estimated magnitudes for SF1906 is almost identical to the range estimated here for OV1872. Returning, however, to the macroseismic effects of the two events, one is led to the suggestion that, within the range $M_w$ 7.6–7.9, OV1872 was relatively larger than SF1906. Our preferred estimate based on rupture parameters is $M_w$ 7.8.

If SF1906 was as large as $M_w$ 7.9, as inferred by Song *et al.* (2008), one is left with the conclusion that either OV1872 was at least this large, or that it produced relatively higher regional ground motions despite a smaller magnitude. Considering the macroseismic data as well as the geological observations, we estimate a preferred magnitude of 7.8–7.9 for OV1872.

As discussed, we consider it plausible but unlikely that propagation effects can account for the relatively high intensities generated by OV1872. It is possible that, by virtue of being a high-stress-drop rupture, ground motions were relatively high at frequencies associated with macroseismic effects (e.g., Hanks and Johnston, 1992). In the absence of instrumental data, one cannot distinguish between a high magnitude, low-/average-stress-drop event and a lower magnitude, high-stress-drop event.

We note, however, that in any case, our results imply that some large earthquakes in California, whether they are $M_w$ 7.5 or $M_w$ 7.9, will produce systematically higher shaking at frequencies of engineering concern than did the 1906 San Francisco earthquake. One can further speculate that SF1906 and OV1872 might be representative of different classes of large California earthquakes; respectively, they represent events on large, well-developed faults versus large events on relatively low-slip-rate faults. Sagy *et al.* (2007) show that the surfaces of faults with low overall displacement are rougher than well-developed, high-slip faults. Analyzing source spectra of small earthquakes, Harrington and Brodsky (2007) find evidence that this topographic difference leads to systematic differences in radiated energy. These recent studies provide a measure of support for a large body of earlier research suggesting that intraplate faults, which generally have low slip rates as well as low overall slip, are characterized by higher stress drops than interplate faults (e.g., Scholz, 2002). The results of this study as well as Harrington and Brodsky (2007) suggest that there might be important differences among faults in interplate regions.

The conclusions of this study have other important general implications for hazard assessment. For example, it has remained an open question in modern seismic hazard analysis whether an earthquake that ruptures at any given point in California (say) will follow Gutenberg–Richter statistics (Gutenberg and Richter, 1944), or if big earthquakes can only happen on big faults (see Field, 2007, for a discussion of the point). In such discussions, big earthquakes are often taken to be those that are comparable in size to SF1906 and the 1857 Fort Tejon earthquake (i.e., extended ruptures that are expected to have extended impact). Recent studies have shown that big earthquakes can be generated by ruptures that involve multiple distinct faults (e.g., Black *et al.*, 2004; Bird and Liu, 2007) argue that, given the fractal nature of fault systems, a rupture that begins at any point will always have potential to grow.

It can be difficult to consider a regional distribution of faults and say what earthquake ruptures can or cannot happen. However, if OV1872 was *M* 7.7–7.9 as the results of this study suggest, then clearly big earthquakes are not restricted to the San Andreas fault, but can occur on faults as short as 100–140 km, if not shorter. Considering the highly segmented nature of the Owens Valley fault zone, arguably it would not have been identified as a single fault zone if the 1872 rupture had not demonstrated otherwise.

In any case, one can consider the database of mapped active faults in California to identify other faults that are at least this large. This long list includes the San Jacinto, Elsinore, Hayward/Rodgers Creek, Garlock, Hosgri, Calavaras, Coronado Bank, Palos Verdes, Rinconada, Great Valley, Death Valley, Panamint Valley, White Mountains, Maacama, Mendocino, and Hat Creek–McArthur–Mayfield faults (Fig. 12). Notably, while a few of these are considered

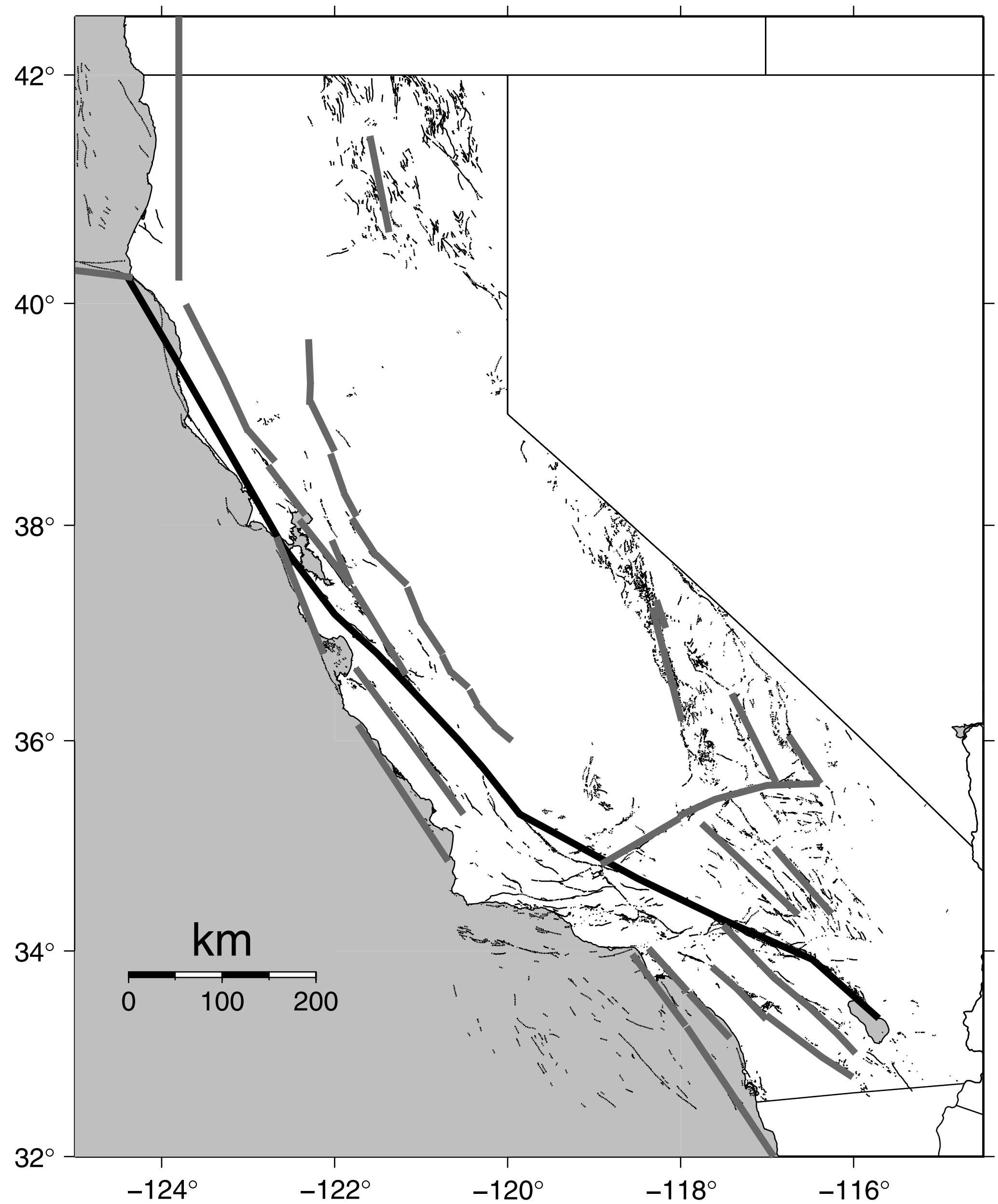



**Figure 12.** Map showing fault zones in California whose mapped length is at least 100 km.

to be low-slip-rate faults, most have slip rates higher than the ~1 mm/yr estimate for the Owens Valley fault (Bacon and Pezzopane, 2007). Not all of these faults extend as deeply as the inferred depth of the Owens Valley fault: a more shallow seismogenic zone would of course reduce the maximum magnitude that a given fault could generate. On the other hand, several lines of observational and theoretical evidence suggest that earthquake ruptures often extend beyond the confines of individually mapped faults (e.g., the 1992 Landers, California, earthquake). In any case, much of the state of California, including most of the major urban centers, are within 50 km of a fault that, we conclude, could generate an *M* 7.8 earthquake (Fig. 12).

It does present conceptual difficulties, to hypothesize that an *M* 7.8+ earthquake could occur and not involve rupture of a well-established fault zone. Nonetheless, the results of this study suggest that events with magnitudes of 7.5–8.0 are not restricted to the San Andreas fault, but can occur over much, if not quite all, of California.

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## Appendix A

### Account of Nancy Kelsey

Three letters written by Mrs. Nancy Kelsey are included in the Weber Family Papers collection at the Bancroft Library. Two of these letters, dated 9 October 1872 and 28 February 1873, indicate that they were written from Gilroy. An archivist at the Bancroft assumed that the earliest letter, which was dated 11 April 1872 and talks about earthquake damage, had also been written in Gilroy. However, the contents of the letters suggest strongly that the Kelsey family moved between April and October of 1872, and available genealogical records reveal that one of the Kelsey children was born in Lone Pine in 1869. The Kelseys were relatively prosperous landowners, unlike most of the population "of 250–300 persons, mostly Mexicans who had brought with them the practice of building adobe and stone houses" (Oakeshott *et al.*, 1972). Their house was thus presumably more substantially built than the highly vulnerable adobe-brick dwellings in town, almost all of which were leveled. Kelsey wrote that, "As I promised to wright to you I will proceed. I would of written to you sooner but the country has bin in such an up roar that I couldn't. There was none of my folks was hurt but they were all most scared to death. The earthquake shook down our chimney but the house did not fall. We have earthquakes every day and night yet." It is not clear if their house was wood frame or relatively well-built masonry, but in either case, we conclude that the effects in Lone Pine suggest MMI VIII.

## Appendix B

### *New York Times* Article, 4 April 1872

A number of articles in the *Inyo Independence* describe the effect of the 1872 mainshock in the Owens Valley region. The following article, published in the *New York Times*, provides an especially thorough description of macroseismic effects at regional distances.

"Our dispatches show that it extended at least from Red Bluff in the northern, to Visalia, in the southern part of the State, and it is probable that it really extended from Sisk(?) to Los Angeles including nearly the entire length of the state. It seems to have increased energy as it moved southward, and to have reached up to the Sierra to an elevation of 3000 to 4000 feet. Thus the whole Sacramento, San Joaquin, and Tulare Valleys were disturbed, and the eastern slope of the Sierra to the height named, making an area of disturbance equal to at least 500 miles long by 60 to 100 miles wide. The shock was severest in the valleys, where the deep alluvium would propagate the waves of disturbance more vigorously than they would be propagated on the isolated and rocky peninsula upon which San Francisco is built. To this circumstance the city owes its comparative exemption from the shock, and the general solicitude(?) felt for the metropolis will be relieved on learning this fact. The line of the shock followed the trend of the Sierra, apparently proceeding southeasterly by northwesterly. So far as our reports are received, they tend to fix the centre of greatest energy near Visalia, in the Tulare Valley, which is the bed of a former lake. The alluvium was profoundly and frequently agitated, and in the adjacent hills trees and rocks were dislodged. Altogether the phenomena recorded are very remarkable."

At Sacramento

The account from Sacramento reads as follows: "A severe and prolonged shock of earthquake was experienced in this city at about 2 o'clock in the morning. Almost the entire population was aroused from sleep, and a great deal of alarm was felt which, with many, did not subside until morning. Although the movement was less violent than that of the great shock of 1868 in San Francisco its length of duration was, undoubtedly, much greater. Some of those who were awake at the commencement of the tremor say that the first vibrations (?) from east to west, but changed from north to south. Others say the first two of three vibrations were vertical, as though proceeding from the depths of the earth. the variety of movement was certainly unusual. At one time a gentle (…)ing motion was perceptible, not unlike that of a vessel moored at anchor moved by a light wind, at another the concussion seemed to be general violent vibrations from north to south, and rotary. The vibration was plainly felt, while clocks were stopped, doorbells run, plastering cracked, crockery, furniture and windows shaken and rattled. But little serious damage was done. The walls of a few buildings were found to have been slightly cracked this morning. The time of duration is variously stated at from one and a half to three minutes. All residents of San Francisco here agree that the vibration was much longer than that of 1868. The printers in the third story of the Union office state the (?) to have been three minutes. S. L–T stood on the sidewalk in front of the Golden Eagle Hotel, conversing with a friend, when he exclaimed, "where is that carriage?" On realizing that the noise and motion were produced by an earthquake instead of a carriage, L–T took out his watch and noted the time. He says the vibration continued a full minute and a half. Turn(?) Hall was crowded with dancers, and when the shock approached in climax a rush was commenced for the door which was restrained by those who exercised their presence of mind. Many others at the ball and elsewhere experienced (?) sickness from the rocking motion to which they were subjected. At the Golden Eagle, the Orleans, the Capital and other hotels and boarding houses, the lodgers generally rushed pell-mell from their bedrooms to the (?)way and some of them without especial regard to (?) In a few minutes after the shock there were hundreds of people on the streets, many of them walking in the middle of the street to avoid danger. Both telegraph offices were besieged by crowds of people anxious especially to hear from San Francisco. The offices were lighted up, and the operators were on hand, but nothing could be heard."

In Other Quarters

Visalia. March 26. "At 2:25 this morning the citizens of this town were awakened from their slumbers by a loud rumbling noise, followed by a violent pitching of the earth from south-east to north, which continued from two to three minutes. Houses were vacated in an instant; people ran out into the streets; goods were hurled off the shelves in the stores, and bottles and crockery broken. Several brick buildings were more or less strained and walls cracked. The front wall of a large brick saloon was moved out an inch. The walls of the Overland stable, burned last week, were partially thrown down. The gable ends of the Tulare Valley Flouring Mills were thrown down. Fissures opened in clay land an inch or more wide. Parties who were in the foothills, twenty-five miles east of town, report the crash east of them as though the chain of mountains was rent in two, and rocks and trees rolling down an immense chasm. Upward of thirty shocks have been counted up to 11 o'clock. Much anxiety is expressed for the safety of San Francisco. The general opinion is that the city has fared badly."

Sonora, March 28. "The most severe earthquake ever felt here occurred at 2:30 AM, and continued at intervals until 6 o'clock. The first shock lasted one and one-half minutes, nearly everyone in town being startled from their slumber and rushing into the streets in their night-clothes. The vibrations appeared to be from north-east to southwest. Much anxiety is felt to know the effects of the shock in San Francisco."

Sutter Creek. March 26. "A very severe shock of earthquake was felt here this morning between 3 and 4 o'clock, waking nearly all the inhabitants, and causing the occupants of Sutter Hotel to abandon the house in their night-robes. The shock ranged from west to east."

Iowa Hill. March 26. "We had a very heavy earthquake here at 2:20 AM., and one at (?) light, one at 2:35, light, one at 2:40, light, one at 2:50, very heavy, and one at 6, very heavy."

Los Angeles. March 26. "At 2:34 this morning two severe shocks of earthquake were felt. The shocks were over a minute in duration. The second shock was the heaviest and longest. It seemed like a wave rolling from north to south. The earthquake aroused nearly everybody from sleep, and caused a general feeling of alarm, although no damage was done of the slightest nature. The shocks were more severe than any since 1868 and as long or longer than those of 1857. Two lighter and scarcely perceptible shocks occurred, one at 4 and the other at 7 o'clock. Not a breath of air was stirring at the time. The appearance of the moon was dark, murky, and blood red. At Wilmington and San Pedro a correspondent writes that the earthquake was felt about 3 o'clock this morning, lasting one or two minutes. No unusual disturbances at sea were observed."

In Nevada

The *Virginia City Enterprise* (Nevada), of March 27 gives an account as follows: "This city was yesterday visited by two or three pretty lively shocks. The first came about 2 o'clock, and was of two or three seconds duration. It caused windows and crockery to rattle at a lively rate, and died away in a faint quivering motion. The next shock came about 4 o'clock and was much the same as the first, except the vibrations seemed to be rather more sharp and rapid. We believe that in a few places bottles were thrown down and clocks stopped, but no damage was anywhere done to any building. Between the principal shocks there appear to have been several slight tremors of the earth, which were observed by susceptible persons. About 11 o'clock there was a third shock, which was quite distinctly felt by many persons in the city, while others who were moving about in the streets did not observe it. the shocks before daylight caused some persons to arise and make preparations for flight, while others passed a very uneasy night, being afraid that a shock would presently come which would bring their houses tumbling about their ears. The quakes seem to have been felt pretty generally throughout this part of the State."

In Carson City

"In Carson City, it is said, four heavy and distinct shocks were felt, each being separated from the other by a space of time filled in with constant trembling which (…)ed more terror among the sleepy inhabitants than the shocks which stopped clocks, and upset bottles and crockery. The vibrations in this city appeared to be from southwest to northeast , and were accompanied with a roaring or rushing sound. At Parke & Howie's mill in Six Mile Canyon, the first shock is said to have been preceded by a sudden and heavy blast of wind. Some of the men working in the mines say the sensations they experienced down in the bowels of the earth—down where the quakes were rushing along—were very disagreeable. They say they would in(?)finitely prefer being on the surface during earthquaky times. A gentleman who was sleeping on an (?) spring bed in the second story of a light frame building sends us an account of his sensations, the substance of which we give below—we think he is a little shaky on earthquakes, and must have experienced some of his shocks while sound asleep. He was lying on his left side when the first heavy shake turned him into a pivotal position on …and back and awoke. In this position he could distinctly feel the slightest tremulous motion of the earth. For many minutes, but a succession of pulsations, the earth seemed to rise from west to east, dropping back to its position with a 'thud' about once a second—reminding him of the nervous tremulousness of the human chest and the heavy heart (throb?) consequent on violent physical exertion. Turning upon his right side, the gentleman was just falling into a deep sleep when the last heavy shock came and whirled him over upon his back with great violence. Then all was still, and finally our friend dropped off to sleep, dreaming of shipwrecks and volcanoes. T. C. Plunkett, County Clerk of Nevada County, California, telegraphs us that in Nevada City two slight shocks were felt yesterday morning, one at about 2 and the other about 6 o'clock. the vibrations were from north to south. The shocks seem to have been felt very generally in the State and California, and in most places seem to have been stronger than here."

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