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The 1906 Earthquake on California's North Coast

by Lori Dengler

Abstract Humboldt County on California's north coast was the furthest region from the 1906 epicenter to suffer significant damage in the 1906 earthquake. This study reassesses the impacts described in the state earthquake investigation commission report (Lawson, 1908) and subsequent intensity studies by examining reports from local newspapers, weather service logs, and the large collection of photographs, journals, and letters collected by local historical societies and museums. The highest intensity (modified Mercalli [MMI] IX) occurred in the Petrolia and upper Mattole Valley. The entire coastal region from Shelter Cove to the Eel River Valley experienced intensities of at least VIII. The most detailed damage descriptions come from Ferndale, where newspaper reports detail the damage to over 40 structures in the downtown area. Fewer than 2% of chimneys survived, both brick buildings were severely damaged, and about 25% of the commercial wood buildings were twisted by the ground shaking. Liquefaction was observed in the Mattole Valley throughout the Eel River Valley and as far north as Fields Landing on Humboldt Bay, which exceeded the aerial extent and scale of any other historic event, including the 1992 Cape Mendocino earthquake (M_w 7.2). In contrast to the isoseismal map published in the Lawson Report, damage in Eureka and the Humboldt Bay region was less than in Ferndale. Based on the severity of damage and scale of liquefaction, the 1906 earthquake was Humboldt County's strongest historic event. Peak intensities likely exceeded the Cape Mendocino earthquake, the intensity VII or larger isoseismal was about twice as large, and peak ground velocity values likely exceeded 50 cm/sec in much of southern Humboldt County. The strong shaking in Humboldt County supports models showing significant slip along the northern segment of the 1906 rupture zone.

Introduction

Humboldt County, California, located more than 260 kilometers north of San Francisco, was the furthest region away from the epicenter to suffer significant damage in the 1906 earthquake (Fig. 1).

The state earthquake investigation commission report (Lawson, 1908; referred to in this article as the Lawson Report) documented both fault rupture and shaking effects throughout California, including Humboldt County. This study reassesses the impact described in the Lawson Report and subsequent studies (Toppozada and Parke, 1982; Stover and Coffman 1993; Boatwright and Bundock, 2005, 2008) by examining reports from local newspapers, weather service logs, photographs, journals, and letters that were not available to the state commission.

It is important to understand the ground shaking in Humboldt County for several reasons. To project the impact of future ruptures of this segment of the San Andreas fault and promote emergency planning and mitigation, it is necessary to have as complete a picture as possible of the 1906 ground-shaking levels. There are no direct measurements of shaking strength in the 1906 earthquake, but 1906 shaking can be compared to instrument data from more recent events to provide an estimate of strong ground motions that can be used as input to scenario development for future events. There has been debate about the nature of slip at the northern termination or the rupture zone (see Song *et al.*, 2008) and the intensities in Humboldt County provide a constraint on slip modeling. Intensity reports can also provide a rough estimate of aftershock location and provide evidence for the transfer of stress north of the San Andreas transform system.

Previous Studies of 1906 Ground Shaking in Humboldt County

The Lawson Report includes descriptions of shaking and an isoseismal map for the entire felt area of the 1906 earthquake (map 23, Lawson, 1908). Intensity determinations in the Lawson Report for Humboldt County were based primarily on the field reconnaissance of University of California, Berkeley, mineralogist Arthur Eakle, a member of the

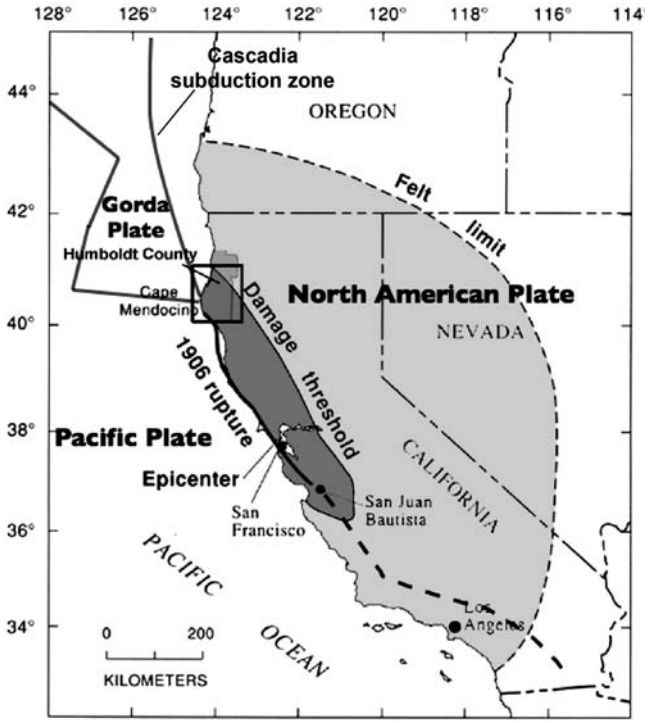

Figure 1. Approximate damage and felt areas of the 1906 earthquake and location of plates and plate boundaries. Box shows areas of Humboldt County where damage occurred.

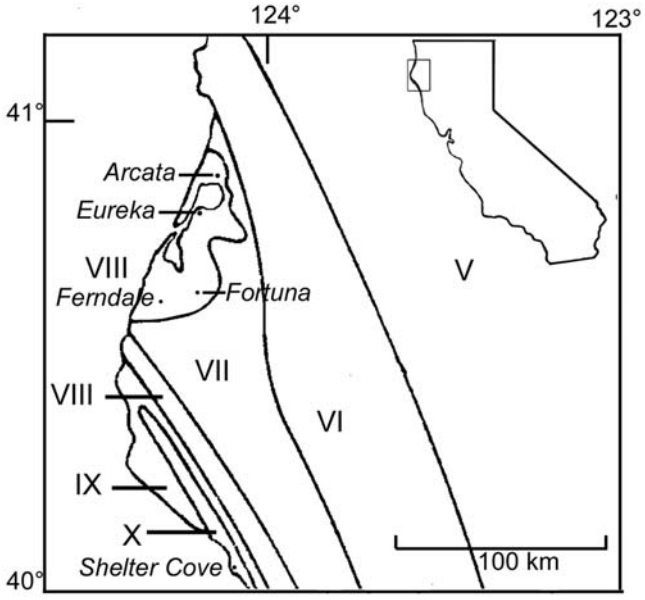

Figure 2. 1906 isoseismals in Humboldt County, from the report of the State Earthquake Investigation Committee (Lawson, 1908). MMI values from the Woodward-Clyde Consultants, 1980.

State Earthquake Commission committee on isoseismals. Eakle visited Trinidad, Eureka, Arcata, Petrolia, and Ferndale about three weeks after the earthquake and spent a week in the area. Much of the damage had been cleaned up by the time of his visit. Eakle also collected eyewitness accounts from eight local residents to estimate shaking in other areas of the county. F. E. Mathes mapped the Shelter Cove area for the state report, and his observations were the basis of the shaking estimates in that region. The original report used the Rossi–Forel intensity scale, which fell out of favor when Wood and Neuman's (1931) revision of Mercalli's intensity scale established the modified Mercalli scale (MMI). Stover and Coffman (1993) modernized the MMI scale and defined the criteria that are now accepted for intensity studies in the United States. Lawson's ground-shaking descriptions are translated in terms of the MMI scale in Boatwright and Bundock (2008), and the Woodward-Clyde Consultants (1980) converted the northern California intensities from the Lawson Report into the equivalent MMI values (Fig. 2).

The Lawson isoseismal map shows the strongest ground shaking (MMI VIII) extending from Ferndale to Arcata and including the entire Humboldt Bay region. Reexamination of the 1906 intensities from the Lawson Report and other historic data by Toppozada and Parke (1982) and Stover and Coffman (1993) led to several revisions of the isoseismals in Humboldt County. Toppozada and Parke shifted the zone of strongest shaking south to the Eel River basin and southern Humboldt Bay region and suggested that the strongest shaking reached IX in the Ferndale and Petrolia areas. Stover and Coffman included no intensity IX communities and drew a much smaller area of intensity VIII than the Lawson Report, centering the stronger shaking on the Ferndale and Fortuna areas. Boatwright and Bundock (2005) analyzed intensity data for the entire state, reexamining newspaper and other reports and analyzing damage to cemeteries to update intensity estimates. They used ShakeMap (Wald *et al.*, 2005) to display intensities on a gradational scale and showed peak intensities in the VIII to IX range near Shelter Cove, decreasing to VII–VIII in the Eel River Valley. Boatwright and Bundock (2008) obtained additional newspaper reports for several northern California counties including Humboldt and concluded that some of the Humboldt values were higher than previously estimated, reaching IX at Petrolia and VIII at Ferndale.

Sources of Intensity Data

At the time of the 1906 earthquake, Humboldt County had a population of about 30,000 people (*Humboldt County Directory Year 1903,* [1903]; *Eureka and Humboldt County Directory 1907–1908*, 1907), about 25% of the current population. The county seat and largest city was Eureka, located on Humboldt Bay, with a population of close to 10,000 people. After Eureka, the largest communities were Arcata (2000), Fortuna (1500), and Ferndale (1600). There were more smaller communities than at present; the 1903 and 1907–1908 Humboldt County directories list over 50 towns of population between 20 and 1000 primarily located in the Eel River Valley and in the Humboldt Bay region.

Humboldt County was the largest timber and dairy exporter in the state and had eight newspapers (the *Humboldt*

Times, the *Humboldt Standard*, the *Arcata Union*, the *Humboldt Beacon*, the *Ferndale Enterprise*, the *Evening Herald*, the *Blue Lake Advocate*, and the *Californian*) that documented the 1906 effects. The *Evening Herald* has been lost, but the original editions of the *Ferndale Enterprise* are archived at the Ferndale Museum, and the *Blue Lake Advocate* is available from the Humboldt County Historical Society. Microfiche of the other daily newspapers are available at the Humboldt State University library. Four newspapers in particular, the *Ferndale Enterprise*, the *Humboldt Standard*, the *Humboldt Beacon*, and the *Blue Lake Advocate*, give particularly detailed accounts of 1906 damage in the county. Articles from the *Enterprise* and the *Beacon* relevant to the 1906 earthquake have been made available online by Beltz (2006).

The weather service office was located in Eureka at the time of the earthquake and the weather observer, Aaron Bell, wrote accounts of felt earthquakes in both the daily logs and the monthly weather summaries from 1903 through 1911. The original weather reports are kept at the Eureka office of the National Weather Service. The Humboldt Historical Society, the Clarke Museum in Eureka, and the Ferndale Museum have collected letters, photographs, and other memorabilia from 1906. Additional historic materials have been collected in the Humboldt Room at Humboldt State University's library. There were five professional photography studios in Ferndale at the time of the earthquake. A number of 1906 damage photographs have been preserved by the Ferndale Museum and the late photography historian Peter Palmquist. Edna Garrett, whose photography studio was on Main Street in Ferndale, took most of the surviving photographs, and many are posted online (Beltz, 2006). A local historian, Susie Baker Fountain, kept an archive of newspaper clippings, letters, and other memorabilia from Humboldt and Del Norte counties, California, covering the period 1850–1966. In 1967, Humboldt State University bound her papers into a 119-volume set that is currently housed at the university library (Fountain, 1967). The Susie Baker Fountain papers contain several previously unexamined references to the 1906 earthquake.

North Coast Intensities

The consensus of local newspapers (McCormick, 1984) was that the total loss in the 1906 earthquake was about $200,000 (1906 dollars) in Humboldt County. The damage was almost entirely to homes and businesses. There were no large bridges (the first major bridge over the Eel River was not built until 1911), and roads were primarily gravel.

Estimation of shaking strength is difficult in rural areas with scattered communities, low population density, and few large structures. Most 1906 structures in Humboldt County were small wood-frame buildings, and many were not secured to foundations. There were few brick buildings outside of Eureka, although all homes had brick chimneys. With the exception of Ferndale, where the *Ferndale Enterprise* detailed the damage to every commercial building in the downtown area, descriptions of structural damage in the Lawson Report and newspapers is sketchy. The most reliable reports of structural damage in these documents are downed chimneys, which provide a reasonable indicator of MMI intensity VII or stronger shaking. Boatwright and Bundock (2005) used the percentage of damaged chimneys to estimate half unit intensity values. They characterize MMI VI–VII by a few chimneys damaged, VII by 50% of chimneys damaged, and VII–VIII by nearly all chimneys damaged.

While the MMI includes indicators of shaking strength based on natural phenomena such as bushes shaking and ground cracks, it is difficult to tie these observations to a narrow MMI range. An intensity study of the 1991 Honeydew earthquake (Dengler and McPherson, 1993) attempted to correlate physical phenomena such as rockfall, landslides, and water changes with the intensity scale to provide additional shaking data in sparsely populated areas. Phenomena most applicable to the 1906 reports include frequent fall of limbs and snapped tree tops ($\geq$VII), rockfall and landslides common ($\geq$VII), and cracked and disturbed ground common ($\geq$VIII). In examining the historic documents, it is often only possible to put a lower bound on the strength of shaking.

The 30 communities for which reports on 1906 earthquake shaking were found are shown in Figure 3 and summarized in Table 1. The list includes eight communities not mentioned in previous studies. Areas of particular interest are detailed in the next sections.

Shelter Cove

The strongest shaking in the 1906 earthquake was in southern Humboldt County and in the Eel River Valley. Shelter Cove, an isolated community of about 50 residents, was identified as the northernmost site of surface fault rupture in the Lawson Report. F. E. Mathes mapped the Shelter Cove area for the State Earthquake Commission. He identified the trace of the fault from Wood Gulch to north of Telegraph Hill and mapped a vertical scarp with more than a meter of vertical offset that is still observable today. Brown (1995) reexamined Mathes's original field notes and concluded that the Shelter cove fissures did represent primary fault rupture. McLaughlin *et al.* (2000) questioned whether the Shelter Cove features were an expression of the San Andreas fault because the fissures were located in a major landslide complex, and they interpreted the displacements as rotational slide displacement. Prentice *et al.* (1999) also examined Mathes's notes and trenched the site, confirming the existence of Holocene faulting offsetting the Point Delgada landslide complex but observing little strike-slip displacement on the feature.

The strongest-shaking area on the isoseismal map in the Lawson Report (MMI X, Fig. 2) coincides with the inferred rupture zone of the fault near Shelter Cove. According to the Lawson Report, the McKee Ranch was "entirely ruined by fissures," but Notley's Ranch, less than 1 mile from the in-

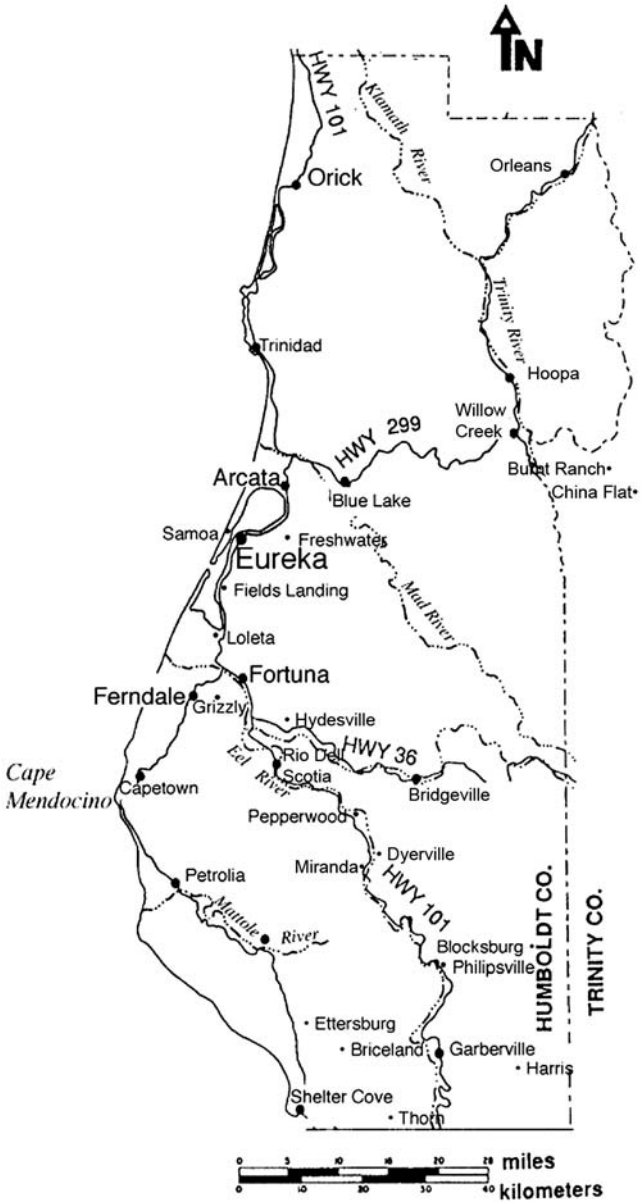

Figure 3. Location map of Humboldt County communities.

ferred fault rupture, suffered no damage. A man was milking a cow, and the shaking threw the cow against him, "knocking him over with the cow on top of him. The other animals were thrown to the ground also." Fallen tree limbs and snapped treetops blocked roads. Wharves and the warehouses suffered great damage, and heavy creamery equipment was displaced. All chimneys in Shelter Cove were reported damaged, but no one was injured. There were numerous landslides. About 20 acres of land washed into the ocean, and the wharf road was completely covered by a slide. These observations are consistent with Boatwright and Bundock's (2008) observations of the intensity at least as high as MMI VIII. The determination is limited by the lack of structures and the sparseness of reports, but there is no evidence that the intensity reached X as shown in the Lawson Report.

It is most likely that the 20 acres of lost land were caused by ground-shaking-induced landslides. However, it is possible that a modest tsunami may have been generated by the right bend or step in the offshore portion of the San Andreas fault north of Point Arena and may have contributed to erosion at the base of the bluff in the Shelter Cover area. A tsunami was observed on the Presidio tide gauge inside San Francisco Bay that has been attributed to the much smaller right step in the fault offshore of the entrance to the bay (Ma *et al.*, 1991; Geist and Zoback, 1999; Lorito *et al.*, 2008). It is not surprising that there are no observations of unusual wave activity. The event occurred in darkness, and there were no nearby tide gauges to record water levels. A 20-acre subaerial landslide also may have produced a tsunami that went unnoticed.

Southern Humboldt County South of the Eel River Valley

There is consensus (Toppozada and Parke, 1982; Stover and Coffman, 1993; Boatwright and Bundock, 2008) that Petrolia and the upper Mattole River area experienced the strongest shaking in Humboldt County. Nearly every house in the region slid off its foundation, and every structure reported severe damage. Several people were injured by falling bricks from chimney collapse. All of the newspaper reports state that Petrolia and the Upper Mattole Valley area were more heavily damaged than any other part of Humboldt County. The *Daily Humboldt Standard*, on 4 May 1906, notes, "It is conceded here that the very heaviest of the shock was between Cape Mendocino and Needle Rock [south of Shelter Cove]. Scarcely a building in this whole country escaped without any damage. All the monuments in the Petrolia cemetery were thrown down and mostly broken." The predominance of reports that the shaking in Petrolia was significantly greater than in Ferndale (VIII, see the next section) supports assigning an IX to the Mattole region.

In 1906, there were a number of small settlements scattered between the Eel River Valley and Shelter Cove, including Briceland and Ettersburg. At Briceland, the damage was noted as severe but not as intense as at Petrolia. The Briceland store was displaced from its foundation, and considerable stock fell from shelves. Local resident J. Bowden reported chimneys downed and the rupture of water and gas pipes (Lawson, 1908). Between Briceland and Shelter Cove, there were only two houses, and both lost their chimneys. Ground cracking and snapped trees are reported as common from the Mattole region to south of Shelter Cove. All of these communities experienced intensities of at least VIII.

The *Blue Lake Advocate* noted that the shaking in Garberville and Phillipsville, located on the Eel River to the east of Shelter Cove, was less than at Ferndale or Briceland. Some trees were snapped, some chimneys fell down, and some houses were knocked of foundations, suggesting that intensities reached at least the VII level. Very similar

Table 1
Intensity Summary

Community	Population	Description	MMI Intensity			References
			Lawson*	B&B†	This Study	
Arcata	2000	Nearly 30 chimneys toppled, and numerous windows were broken on the Plaza. Brizard's Store exhibited spreading of brick walls but no collapse. Nearly all items in stores were thrown from shelves. Many stacks of lumber collapsed, and water sloshed from tanks. Lumber and shingles fell from the Arcata and Bayside docks into the bay. More damage was observed in the south part of town than in the hills.	VIII	VII	VII	3,4,5,6,9
Blue Lake	800	Every store in town lost items off shelves, and 15 chimneys toppled. Plaster was damaged at the school. Damage was less than at Arcata or Eureka.	VII	VI–VII	VII	5,6
Briceland	40	At Briceland, the damage was severe but not as intense as at Petrolia. The Briceland store was displaced from its foundation, and considerable stock fell from shelves. Local resident J. Bowden reported downed chimneys and the rupture of water and gas pipes.	VII	VIII–IX	≥VIII	5,6,11
Bridgeville	20	At least one chimney was downed.	VI	VI–VII	VII	5,6
Cape Mendocino	20	Damage was reported to brick foundations and chimneys.	X	VII–VIII	≥VII	1,6,11
Eel River Valley (unincorporated areas)	1900	Fewer than 2% of chimneys from the mouth of the Eel River to as far east as Grizzly remained intact, and county water tanks and windmills were thrown from foundations. At Cock Robin Island, chimneys were downed, and many fissures in the ground were observed. At Cannibal Island, land was lowered from 1–10 ft, and black sand was ejected. Liquefaction features were prominent at many sites near the Eel River. At Port Kenyon, several acres of land settled several feet. All along the Salt River, land slid into the river and was reported cracked for distances of several hundred feet on either side. At Centerville Beach near the mouth of the Eel River, a half-mile-wide landslide slid into the Pacific near Oil Creek, obstructing the view between the Cape Mendocino and Table Bluff lighthouses	VIII–IX	VIII–IX	≥VIII	1,2,6,9
Eureka	10,000	Numerous downed chimneys and broken glass panes were reported, as were 47 sec of strong shaking. Water poured out of water tanks, sloshing 100 gal at a time; half the plate glass in town was broken, and numerous chimneys were downed. All of the items in Daly's store in downtown Eureka were knocked from the shelves. The Humboldt County Courthouse, a tall, ornate brick building, suffered no structural damage, but the statue of Minerva tipped at an angle of nearly 45°. In addition to broken glass, many buildings had damaged plaster and cracks.	VIII	VII	VII	3,4,7,8,9
Ferndale	1,600	Both brick buildings suffered partial collapse. Almost all brick chimneys were downed. Most homes were knocked from foundations and porches. Many two-story wooden buildings in the downtown area were severely twisted. Almost every window in town was broken, the plaster was damaged, and all stock within buildings was scattered. Most monuments in the cemetery were knocked over.	VIII	VIII	≥VIII	1,2,3,4,9,11
Fields Landing	100	Fissures in roads and 3 ft of subsidence near Pelican Island were reported. The Pacific Lumber Company's wharf collapsed, and damage was estimated at $15,000. A railroad water tank toppled over, and fences were thrown down.	VIII	VII–VIII	≥VII	1,3,11

(*continued*)

Table 1 (Continued)

Community	Population	Description	MMI Intensity			References
			Lawson*	B&B†	This Study	
Fortuna	1500	The brick walls of the McIntyre store were badly damaged. Over half the chimneys in Fortuna were downed, and several houses slid off foundations. Most stores suffered significant loss of merchandise. Clocks stopped, and even the heaviest furniture was displaced. The concrete breakwater at the East ferry landing on the Eel River was cracked and displaced.	VIII	VII–VIII	≥VII	2,3,4,11
Freshwater	150	Every chimney in the Freshwater Valley was downed, and substantial damage to dishes and other household items was reported.	VIII	—	VII	4,5
Garberville	300	Many buildings were knocked out of plumb. Most chimneys and stovepipes were knocked down. All items fell off shelves. Shaking was not as strong as in Ferndale.	VII	VIII	≥VII	1,6,9
Loleta	400	Nearly every chimney collapsed. Water tanks collapsed, and several people were injured by falling objects. The trunks of several large spruce trees were snapped. A cow toppled over while being milked.	VIII	VII–VIII	≥VII	2,11
Orick	100	The shaking was felt by everyone, items fell off shelves, and a few windows were broken.	V	V–VI	VI	5,6
Pepperwood	100	Most chimneys downed and many fissures observed in the ground. Numerous cracks and subsidence. Large limbs and some tops of redwood trees snapped.	VII	VIII	≥VII	2,3,11
Petrolia	250	Nearly every house slid off its foundation, and every chimney was downed. Several people were injured by falling bricks. The bridge near Levant Cook's place sunk at one end about 18 or 20 in. Across the river from Petrolia, a large slide partially dammed the Mattole River.	IX	IX	≥VIII	1,3,4,9
Phillipsville	60	The tops of a few redwood trees snapped, dishes fell, and milk sloshed.	VII	—	≥VI	2,3
Samoa	200	Log decks toppled, and at least one mill was closed for an undetermined amount of time. One chimney was reported downed.	VIII	—	VII	1,3,4,5
Scotia	1000	A slide covered the rail line at the bluffs, and two of the heavy lateral rods on the Van Duzen bridge were broken. No details have been found on damage to structures.	VII	VII	VII	2
Shelter Cove	40	Some ranches were severely damaged; others were relatively undamaged. Animals were knocked to the ground, and roads were blocked by fallen trees. Wharves and warehouses were damaged, and heavy equipment was displaced. All chimneys were damaged, but no one was injured. Numerous landslides occurred, and about 20 acres of land washed into the ocean. The wharf road was completely covered by a slide.	X	VIII	≥VIII	1,2,10
Southern Humboldt	10	Between Briceland and Shelter Cove, there were only two houses, and both lost their chimneys.	IX–X	—	>VII	1
Trinidad	250	The shaking was felt sharply, but no damage was reported.	VI	—	V	5,6,9

References: 1 *Ferndale Enterprise* (1906); 2 *Humboldt Beacon* (1906); 3 *Humboldt Times* (1906); 4 *Humboldt Standard* (1906); 5 *Arcata Union* (1906); 6 *Blue Lake Advocate* (1906); 7 weather service daily logs (U.S. Weather Bureau, 1906); 8 J. P. Tracy (1906); 9 Eakle description in Lawson (1908); 10 Matthes description in Lawson (1908); 11 other source from Lawson (1908).

*From the isoseismal map in the state earthquake investigation report (Lawson, 1908).

†From Boatwright and Bundock (2005) and where modified in this volume of *BSSA*.

descriptions continue to the north in the upper Eel communities of Miranda, Dyerville, and Pepperwood. Boatwright and Bundock assign an VII to Garberville and Pepperwood and put Miranda in the VII–VIII range. This study supports the somewhat lower level, as several reports (Lawson, 1908; *Blue Lake Advocate*, 1906) clearly note that the damage here was less than in Ferndale and Briceland. There are few communities to the east of the Eel River to constrain ground motions. Blocksburg, about 10 km east of Garberville, also had chimney damage and snapped trees and should be assigned a VII. A single letter from the tiny community of Harris's school teacher (E. Tracy, 1906) who describes

muddied water but no damage, provides the only eastward limit to the VII isoseismal.

Ferndale and the Eel River Valley

Eakle (Lawson, 1908) notes Ferndale as the most heavily damaged community in Humboldt County. The *Ferndale Enterprise* describes the damage to over 40 structures on Main Street in the commercial center of town (Beltz, 2006). There were two brick buildings in the town at the time of the earthquake. The General Mercantile (339 Main Street), owned by the Russ, Early, and Williams Company, had been completed only four months before the earthquake, and suffered loss of the brick parapet and all-glass windows (Fig. 4a). The parapet collapse did not kill two cows, as erroneously published by the *Ferndale Enterprise* in 1992 (Beltz, 2006). There is no mention in 1906 newspapers of any injuries or animal losses associated with the collapse. The building was repaired and continued as a commercial establishment until 1992, when it suffered similar damage in the Cape Mendocino earthquake. The second brick structure, the J. Gollober building (Fig. 4b), suffered irreparable damage in the earthquake and was subsequently demolished.

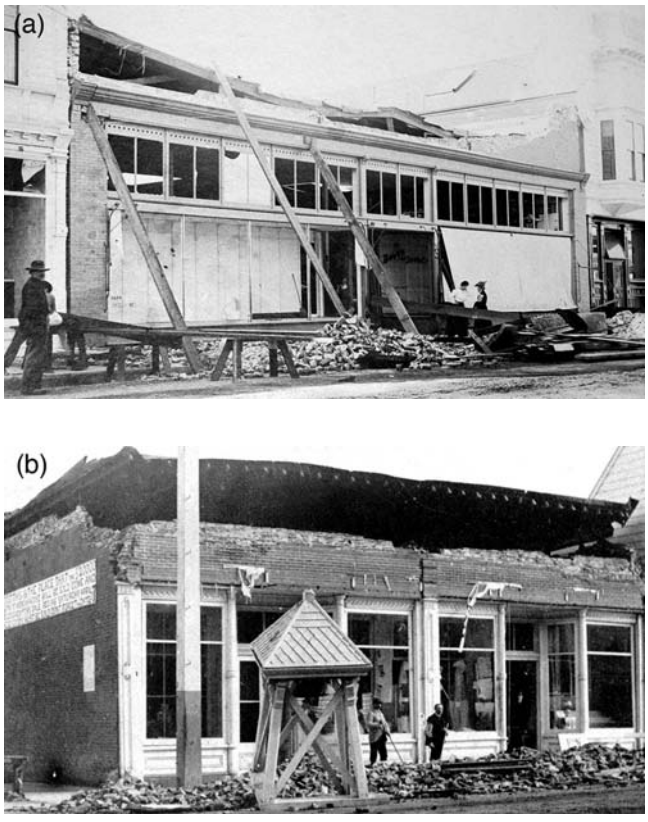

Figure 4. Damage to brick buildings in Ferndale. (a) The General Mercantile on 339 Main Street suffered collapse of the parapet wall, and every window was broken. The building was repaired and then damaged again in the 1992 Cape Mendocino earthquake (see Fig. 9). (b) J. Gollober store. The cupola housed the fire bell and was thrown to the ground. The building was demolished. Photos by E. Garrett, courtesy Peter Palmquist.

The other structures in Ferndale were of wood-frame construction. Of the 40 wooden commercial structures in the town, 12 suffered twisting and wrenching. The largest wood structure in town, the Knights of Pythias Hall (Fig. 5a), was severely twisted and required shoring to prevent collapse. According to the *Ferndale Enterprise*, almost every window in town was broken, many homes were knocked off foundations, and porches and chimneys collapsed (Fig. 5b). Plaster damage was common, and all merchandise within buildings scattered. There were no serious injuries, although the *Enterprise* noted a number of close escapes. Damage was at least as extensive as in the 1992 Cape Mendocino earthquake, where Ferndale was assigned an MMI VIII (Reagor and Brewer, 1992; Oppenheimer *et al.*, 1993).

Fortuna, located about 10 km east–northeast of Ferndale, also suffered major damage. The brick walls of the McIntyre store were badly damaged. The *Humboldt Beacon* reported that many chimneys in Fortuna were downed, and several houses slid off foundations; however, the damage was not as great as in Ferndale. Most stores suffered significant loss of merchandise. Clocks stopped, and even the heaviest furniture was displaced. The concrete breakwater at the east

Figure 5. Damage to wood-frame buildings in Ferndale. (a) The Knights of Pythias Hall, repaired after the earthquake, was eventually replaced by a gas station. (b) Unidentified home. Photos by E. Garrett, courtesy Peter Palmquist.

ferry landing on the Eel River was cracked and displaced. The damage to brick structures supports an intensity in the VII–VIII range.

The *Ferndale Enterprise* notes that fewer than 2% of chimneys elsewhere in the Eel River Valley remained intact and that county water tanks and windmills were thrown to the ground (Fig. 6). Cracks, fissures, lateral spreads, and other liquefaction effects were widespread in the lower Eel River Valley, west of Fortuna. The islands near the mouth of the Eel River were particularly hard hit. The *Enterprise* notes, "Cock Robin Island came in for its share of the shake, chimneys being torn down and many holes and cracks in the ground made. The same destruction visited Cannibal Island, it being said that the land there that was quite high before the shake-up is now lowered from one to 10 ft, while low places have been filled up. In many instances where the ground opened a kind of black sand or sediment oozed forth, showing that it must have been thrown from the very bowels of the earth. On the Hamner ranch on the island, under lease to Rasmus Nielsen, we are told that this sand or sediment was very warm and that smoke arose from it for several hours after the convulsion." At Port Kenyon, 4-km northeast of Ferndale, the *Ferndale Enterprise* reported that several acres of land settled several feet. All along the Salt River (part of the Eel River estuary), land slid into the river and was reported cracked for distances of several hundred feet on either side (Fig. 7). At Centerville Beach near the mouth of the Eel River, the *Ferndale Enterprise* reported a half-mile-wide landslide into the Pacific near Oil Creek, obstructing the view between the Cape Mendocino and Table Bluff lighthouses. All reports suggest that ground motions throughout the Eel River Valley as far east as Grizzly (about 3-km south of Fortuna) were at least as strong as at Ferndale and should be assigned an intensity of VIII.

To the east of the Eel River Valley, up the Van Duzen drainage, shaking levels diminish. Hydesville likely had an intensity of VII, similar to the communities along the upper Eel River. Further east, Bridgeville may be close to the boundary between VI and VII shaking. One chimney was downed but little other damage was reported.

Humboldt Bay Region

Loleta, at the south end of Humboldt Bay, had impacts similar to those in the Eel River Valley communities, including ground cracking and many downed chimneys. The next community to the north, Fields Landing, apparently marked the northern extent of significant liquefaction. The Lawson Report includes an account from H. Buhne, a prominent Eureka citizen, who describes downed chimneys but relatively little other damage south of Eureka until reaching Fields Landing. At Fields Landing, Buhne notes fissures in roads and 3 ft of subsidence near Pelican Island. The *Humboldt Beacon* reported that the Pacific Lumber Company's wharf collapsed (Fig. 8), and damage was estimated at $15,000. A railroad water tank toppled over, and fences were thrown down. Both Loleta and Fields Landing should be assigned intensities in the VII–VIII range.

Further north, the *Ferndale Enterprise* noted that "Eureka escaped very lightly." By the time Eakle visited Eureka, most of the damage had been repaired. There were at least 45 brick buildings in Eureka at the time of the earthquake, and Eakle noted that none of them were damaged and that no

Figure 6. Twin windmills in the Eel River Valley; mill on the right has collapsed. Photo by E. Garrett, courtesy Peter Palmquist.

Figure 7. Liquefaction on the Salt River, Eel River Valley. Photo by E. Garrett, courtesy Peter Palmquist.

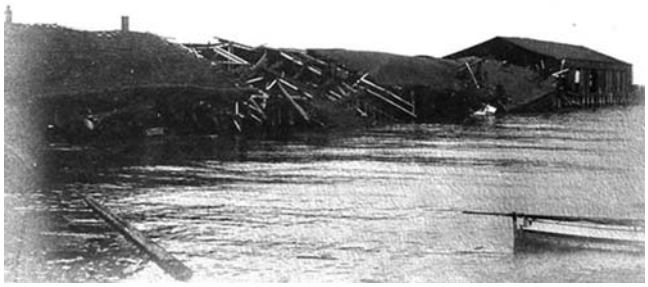

Figure 8. Pacific Lumber Company's dock at Fields Landing. Photographer unknown, courtesy Ferndale Museum.

books had been thrown from library shelves. Other reports suggest somewhat greater impact. Weather observer Aaron H. Bell wrote notes about the earthquake in the Eureka weather service daily log (U.S. Weather Bureau, 1906). The weather service office was in downtown Eureka, and Bell describes numerous downed chimneys and broken glass panes and 47 sec of strong shaking that were "more severe than any previous earthquake" in the area. A letter by 18-year-old J. P. Tracy (1906) provides the most detailed account of ground shaking in Eureka. Tracy describes great volumes of water pouring out of water tanks sloshing 100 gal at a time, half the plate glass in town broken, and numerous downed chimneys. All of the items in Daly's store in downtown Eureka were knocked from the shelves. The Humboldt County Courthouse, a tall, ornate brick building, suffered no structural damage, but the earthquake caused the statue of Minerva to tip at an angle of nearly 45°. The prevalence of downed chimneys and lack of major damage to other brick structures bracket the intensity in Eureka at MMI VII.

The Samoa Peninsula, bounding Humboldt Bay on the northwest, was and still is an industrial area of mills and mill towns. The Lawson Report does not mention any of these communities, although the peninsula is included in the MMI VIII zone (see Fig. 2). The largest town was Samoa, where the *Ferndale Enterprise* reported that log decks toppled and at least one mill was closed for an undetermined amount of time, causing considerable financial losses. Only one chimney was reported downed, but the accounts do not make it clear whether others were undamaged. The intensity in Samoa was likely in the VII range, comparable to Eureka.

Arcata, on the northern arm of Humboldt Bay, suffered comparable damage to Eureka. The *Blue Lake Advocate* noted nearly 30 chimneys toppled and numerous windows broken in shops on the Arcata Plaza. Brizard's Store, the only brick building in town, exhibited spreading of brick walls but no collapse. Nearly all items in stores were thrown from shelves. Many stacks of lumber collapsed, and water sloshed from tanks. Lumber and shingles fell from the Arcata and Bayside docks into the bay. More damage was observed in the south part of town (the Arcata Bottom) than in the hills.

North of Humboldt Bay

Blue Lake, located on the Mad River about 10-km east–northeast of Arcata, was the northernmost community where downed chimneys were reported. The *Blue Lake Advocate* describes the damage as less than in Arcata but reports at least 15 chimneys toppled, suggesting a higher ratio than in the much larger town of Arcata. Blue Lake likely marks the northern extent of the intensity VII isoseismal.

There were several small communities between the Mad River and Trindad in 1906, none of which are mentioned by Eakle or in any of the newspaper accounts. The lack of damage descriptions, particularly from the *Blue Lake Advocate*, which was published in nearby Blue Lake, is a good indicator that the shaking strength rapidly diminishes north of Humboldt Bay. Eakle, the *Blue Lake Advocate*, and the *Humboldt Beacon* all specifically mention that Trinidad, located on the coast 20-km north of Humboldt Bay, experienced no damage. Eakle mentions that a few windows were broken in Orick, about 25-km farther north, but he reports no other significant damage. There are no reports to constrain the shaking levels to the east of Blue Lake until Trinity County, about 70 km to the east, where shaking was likely no more than intensity V.

Comparing Ground Shaking to the 1992 Cape Mendocino Earthquake

Humboldt County and the adjacent offshore area is one of the most seismically active areas in the contiguous 48 states. Seven earthquakes in the past century have equaled or exceeded magnitude 7 and 14 earthquakes have produced peak MMI intensities of VIII or greater since 1853 (Dengler, Carver, and McPherson, 1992). Most of these earthquakes have been centered offshore within the Gorda plate, along the Mendocino fault that separates the Gorda and Pacific plates, or near Cape Mendocino (see Fig. 1), sparing the more-populated Humboldt Bay region the strongest shaking levels. The best-studied and the most-damaging historic earthquake since 1906 was the 25 April 1992 Cape Mendocino (M_w 7.2) earthquake centered onshore near Petrolia (Oppenheimer *et al.*, 1993). An isoseismal map of the 1992 earthquake was compiled from postal surveys distributed by the U. S. Geological Survey (USGS) post-event damage assessments, and over 1500 surveys of individuals (Dengler, Moley, *et al.*, 1992; Oppenheimer *et al.*, 1993). Instrumental peak ground acceleration (PGA) and peak ground velocity (PGV) data are available at five locations within the MMI VII and larger isoseismal zone (Fig. 9; USGS, 2007a).

Figure 9 superimposes the 1906 intensity estimates from this study on the 1992 isoseismal map. There are similarities in the shaking pattern. The strongest ground motion for both events was centered in the Petrolia area and the Eel River Valley, where 1992 intensities were at least MMI VIII. The city of Ferndale provides a unique opportunity to com-

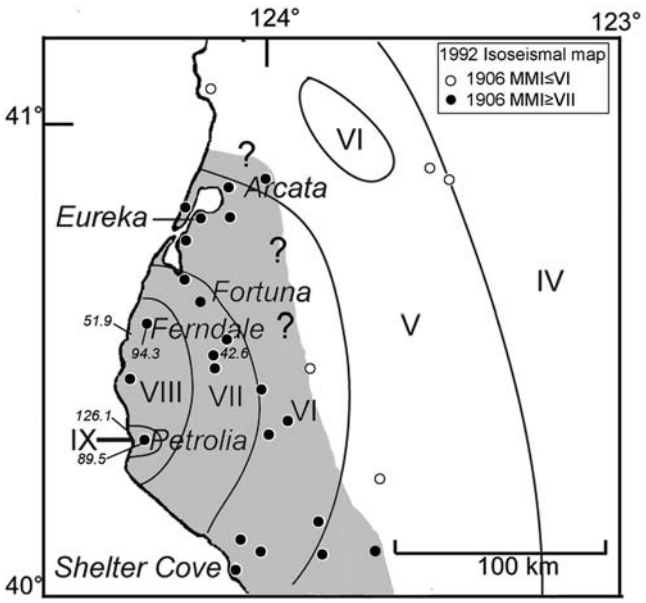

Figure 9. 1906 intensity data superimposed on the 1992 Cape Mendocino isoseismal map from Oppenheimer *et al.*, 1993. Italicized numbers are instrumental PGV values in cm/sec for the 1992 earthquake (USGS, 2007a). Solid circles are communities from this study with 1906 intensities of VII or larger; open circles are communities with VI or less. The shaded area defines the approximate 1906 VII and greater isoseismal. It covers an area twice as large as the 1992 VII and larger zone.

pare the two earthquakes. Seventy percent of the downtown buildings on Main Street that experienced the 1906 earthquake still existed in 1992. In 1906, almost all of the buildings on Main Street suffered some damage. The two brick buildings were badly damaged (see Fig. 4) and approximately 25% of the wooden buildings on Main Street were severely twisted (Fig. 5a). In 1992, few of the wooden buildings on Main Street suffered structural damage. Only one brick building remained in the town. In 1906, the building was the brand new General Mercantile. The entire brick parapet collapsed in the earthquake, and all the windows were broken (see Fig. 4a). The building was repaired, and by 1992, had become the Valley Grocery. The Cape Mendocino earthquake produced a similar, although not as extensive, collapse to the parapet wall (Fig. 10).

The 1992 earthquake took place at the same time of year as the 1906 earthquake, under very similar conditions—a high groundwater table after a winter of heavy rainfall. Liquefaction was observed at a number of sites in both the Mattole Valley near Petrolia and in the Eel River Valley after the 1992 earthquake. Linear lateral spreading cracks were observed along the Salt River near Port Kenyon, where three 6- to 9-m-long cracks with up to 15 cm and 0.5–1 m of total vertical displacement were observed (Taylor, 1992). Similar-sized spreading cracks were observed near the mouth of the Mattole River (Fig. 11b). No liquefaction was seen in Loleta or in Fields Landing in 1992. In 1906, lateral spread features were longer and vertical offsets larger (Fig. 11a), and

Figure 10. History repeats itself in Ferndale. 339 Main Street (now the Valley Grocery) 86 yr later. Photograph taken 25 April 1992 after the Cape Mendocino earthquake, by K. Bayless.

many liquefaction features were observed as far north as Fields Landing.

In 1992, the intensity VII and larger area extended from the southern edge of Humboldt Bay to south of Petrolia and east to Scotia and Rio Dell on the Eel River (see Fig. 9). The

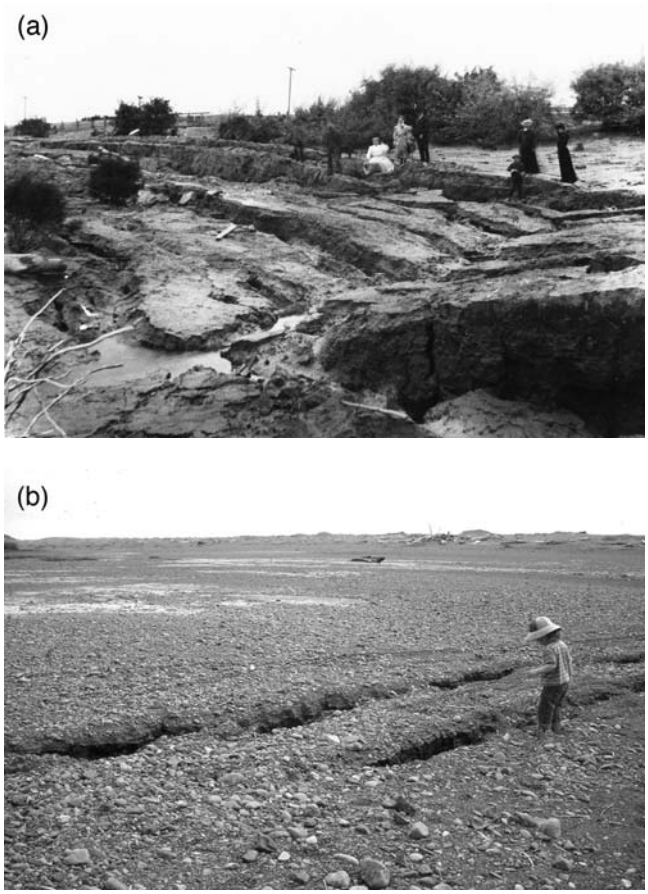

Figure 11. Comparing liquefaction in 1906 and 1992. (a) Spread failures on the banks of the Eel River near Port Kenyon in 1906. Photo E. Garrett, courtesy of Peter Palmquist. (b) Largest spread failures observed in 1992, located at the mouth of the Mattole River. Photo by L. Dengler.

1906 VII and larger zone includes all of the 1992 zone and extends as far north as Arcata and Blue Lake, including the entire Humboldt Bay region, as far east as the upper Eel River, and south to Shelter Cove, an area at least twice as large as in 1992. There is some debate over the peak intensities of the 1992 earthquake. Oppenheimer *et al.* (1993) show a small zone of intensity IX shaking, based on the instrumental recording of accelerations exceeding 1*g* near Cape Mendocino, damage to one well-engineered structure, and large building equipment thrown into the air. The USGS intensity (Reagor and Brewer, 1992; USGS, 2007b) gives VIII as the peak intensity. Boatwright and Bundock (2008) and this study agree that the Petrolia area experienced intensity IX in 1906.

Five strong-motion instruments were located within the MMI VII and larger intensity zone of the 1992 earthquake (see Fig. 9). Wald *et al.* (2005) developed several relationships between strong-motion data and MMI intensities and found that PGV is a good predictor of intensities of VII or larger. All of the macroseismic indicators of strong motion in the 1906 earthquake suggest stronger shaking than in 1992. Wald *et al.*'s (2005) relationship predicts a 1906 zone of PGV values in excess of 50 cm/sec over an area extending from south of Shelter Cove to Loleta at the south end of Humboldt Bay and extending eastward at least as far as Fortuna.

Discussion

Of the 30 communities examined in this study, 10 differ by one or more intensity levels from the isoseismal map in the Lawson Report (Table 1). The variation is systematic. Communities in the Humboldt Bay region shown on the Lawson map within the VIII isoseismal should be assigned VIIs. The Lawson map intensities are too low in much of the Eel River and along the upper Eel River in southern Humboldt County. This may largely be due to errors in compiling the final map. The description of ground shaking in the text of the Lawson Report does not match what was actually published (map 23, Lawson, 1908). Eakle notes particularly high intensities in the Ferndale and Petrolia areas, with shaking strength described as weaker in Eureka and Arcata to the north, in general agreement with the findings here and in Boatwright and Bundock (2008). The intensities in the Lawson report assigned to the Shelter Cove area are too high. VIII is the largest credible intensity that can be assigned to Shelter Cove from the existing data.

All of Boatwright and Bundock's (2008) intensities for Humboldt communities are within half an intensity unit of the estimates in this study with the minor exception of the upper Eel River communities of Garberville and Phillipsville. Boatwright and Bundock assign VIIIs to these communities, while the data examined here can only confidently assign a VII or larger. The 10 additional communities included in this study but not listed by Boatwright and Bundock reinforce the general pattern. There is no question that shaking reached or exceeded VIII in the coastal areas of southern Humboldt County, including Shelter Cove, Petrolia, and Ferndale. Intensity VII or stronger shaking extends at least to the east as far as the Eel River, throughout Humboldt County, and as far north as Arcata and Blue Lake. The northern limit of intensity MMI VII and stronger shaking is relatively well constrained in coastal Humboldt County by the abundance of newspaper and other reports of downed chimneys reaching as far north as Arcata and Blue Lake.

The 1906 earthquake produced ground shaking that likely exceeded 50 cm/sec PGV over a large area of the Eel River basin and southern Humboldt County. The 1906 intensity VII or larger zone was at least twice as extensive as in the 1992 Cape Mendocino earthquake. The 1992 earthquake caused over $60 million in losses (Oppenheimer *et al.*, 1993). The 1906 earthquake only caused an estimated $200,000 in losses (McCormick, 1984) because there were few substantial buildings in the region of strongest ground shaking, and there was little infrastructure. A repeat of the 1906 earthquake is likely to cause substantially larger losses than in 1992. The study of Kircher *et al.* (2006) used Federal Emergency Management Agency's Hazards U.S. (HAZUS) loss estimation software to examine the likely losses if the 1906 earthquake were to occur today. The Kircher study was limited to the San Francisco Bay Area counties. An unintended consequence of this limitation was that the American Red Cross, in developing response and relief plans for a repeat of the 1906 rupture, considered only the counties included in the Kircher study likely to suffer significant damage in a future earthquake on the northern San Andreas (B. Caldwell, personal comm., 2007). As a result, the American Red Cross has designated Humboldt County as a region that will assist in the relief efforts, rather than one that will need help itself. The Humboldt County Red Cross director explained, "When I told them that of course we would do everything we could, etc., etc., but we would also be dealing with damage here, the response was that Humboldt is not listed in studies as potentially getting damage. It has been difficult to convince at least the people I am dealing with (who head up the study) that our resources will be stretched to deal with damages in Humboldt in such a scenario" (B. Caldwell, personal comm., 2007). To fully understand the likely impact of another rupture of the northern San Andreas and to promote robust planning efforts, damage and impact studies need to be expanded to include the entire MMI VII and larger region of the 1906 earthquake.

One of the unanswered questions about the 1906 earthquake is where rupture terminated and how much slip occurred along the northernmost segment of the rupture. Thatcher *et al.* (1997) analyzed repeated geodetic surveys and suggested that the Shelter Cove and offshore Humboldt County area may have had some of the greatest fault displacements anywhere during the 1906 earthquake. Song *et al.* (2008) use geodetics and seismic waveform analysis to strengthen the case for significant slip along the offshore portion of the fault from Point Arena to Cape Mendocino. The

present study confirms the high intensities extending from Shelter Cove to north of Petrolia and the zone of intensity VII shaking that reaches more than 60 km north of the triple junction. This pattern of shaking is difficult to explain if significant slip does not extend into Humboldt County as far north as the Mendocino triple junction in the Cape Mendocino area.

Large slip at the northern end of the rupture is also supported by the rich aftershock sequence in Humboldt County (Meltzner and Wald, 2003; Dengler, 2006). In the six weeks following the 1906 earthquake, at least 22 earthquakes were reportedly felt in Humboldt County, including the largest aftershock (M 6.7) in the entire aftershock sequence. The spurt of earthquake activity was clearly triggered by the 1906 main shock; no felt earthquakes had been reported in Humboldt County during the preceding year (Townley and Allen, 1939). These aftershocks were likely centered north of the triple junction, as none, with the exception of the M 6.7 event on 23 April 1906, were felt outside of the Ferndale and Eureka areas (U.S. Weather Bureau, 1906; Townley and Allen, 1939). Meltzner and Wald (2003) locate the M 6.7 event within the Gorda plate. Slip at the northern end of the 1906 rupture zone was clearly large enough to transfer significant energy across the boundary between the San Andreas transform system and into the tectonic regime of the Cascadia subduction zone.

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