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DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

The Willits, California, Magnitude-4.8 Earthquake of November 22, 1977

By

Ruth B. Simon, Earl H. Pampeyan,

and Carl W. Stover

Open-File Report 78-1075

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Errata

p. 2, line 11. For 1972 read 1970.

line 40. For Willits read Willets.

p. 3, line 1. For July 25 read July 24.

line 3. For nine read ten.

p. 4, para. 4, line 3. For , but did not break. read , but the building appeared sound otherwise.

p. 6 line 14-15. For on which tectonic creep is occurring. read on which creep is occurring (Harsh, Pampeyan, and Coakley, 1978).

p. 7, para. 4, line 4. For tectonic creep read aseismic creep.

para. 6, line 6. Ditto.

p. 9 Insert reference: Harsh, P.W., Pampeyan, E.H., and Coakley, J.M., 1978, Slip on the Willits fault, California (Abst.): Seismological Society of America, Eastern Section, Earthquake Notes, v. 49, no. 1, p. 34.

p. 10, line 6. For source # 3 read Coffman and others (1975)

line 12. For Intensity at Willits read Intensity.

line 14. For source of 1868 earthquake data 2 read 1.

line 28. For VIII-IX (Rossi-Forel) read IX at Willits.

line 33. For May 7 Intensity V read VI.

p. 11, line 2. For Intensity at Willits read Intensity.

line 6. For 39.4° N., 120.6° W. read 39.4° N., 123.0° W.

following line 6, insert: 1962 June 6 Near Lakeport VII 2
39.1° N., 123.1°W.

p. 23, fig. 5. Substitute more nearly correct rendition of Lawson's (1908) atlas Map No. 23.

Introduction

The region of the Willits earthquake has a long history of seismicity, even though few large events have been recorded. The magnitude-4.8 ML Willits earthquake of November 22, 1977 (21 15 52.5 UTC or 1:15 p.m. PST), caused a moderate amount of damage; it was sufficient to warrant investigation by several groups, whose work is reported here. The amount and location of damage and the observed fault creep indicate the presence of active faults in the vicinity of Willits. Tectonic creep may have occurred on the fault passing through the town; however, the epicentral location would place the earthquake on a northwest-trending fault in the unpopulated mountainous terrain about 9 km east of Willits. The hypocenter location provided by the University of California at Berkeley is lat 39.45° N., long 123.26° W. at a depth of 5 km.

Results of an intensity canvass indicate anomalously high intensity values in Willits. These high values are possibly due to geologic effects. Comparison of these intensities with those observed at Willits during the 1906 San Francisco earthquake tend to confirm that geologic effects are significant. The areas near Ukiah and Clear Lake had intensity VIII (Rossi-Forel) in 1906, as reported by Lawson and others (1908), whereas the same areas in the 1977 Willits shock had intensity V (this report). The nearest surface rupture observed in the 1906 earthquake was at Point Arena, which had the same intensity as Willits, although both places are 150 km or more from the 1906 epicenter. No surface rupture was found in the 1977 earthquake.

The damage described is mainly to old, weakened chimneys which probably were standing at the time of, or built shortly after, the 1906 San Francisco earthquake. The structural damage to two or three old buildings is normal for an earthquake of magnitude 4.8.

Acknowledgments

The information contained in this report comes from several sources. We wish to thank the seismograph station of the University of California at Berkeley for the epicenter location and magnitude computation, as well as for the first-motion readings from the Berkeley network stations. We also acknowledge with thanks the cooperation of the following USGS personnel at Menlo Park: R. Lester for first-motion readings from USGS stations in northern California and C. S. Bufe, J. M. Coakley, P. W. Harsh, D. G. Herd, S. Marks, K. McMasters, and D. H. Warren for field reconnaissance of the epicentral area and seismological studies of aftershocks. The City of Willits Building Department kindly supplied damage information and sources of historical data. Additional intensity information and animal-behavior observations from 38 interviews in the field with residents along the east edge of the valley was contributed by K. L. Verosub, who

worked with D. F. Lott, M. Howell, and B. L. Hart, all of the University of California, Davis. USGS personnel in Denver provided first-motion data from seismograms telemetered to NEIS, and S. T. Harding made many unsuccessful tries for a fault-plane solution. B. B. Poppe drafted the figures.

Historic Earthquakes In or Near Willits

The record of seismic activity in this sparsely settled region of northern California dates back to 1868 (table 1) and possibly further. "Earthquake History of the United States" (Coffman and von Hake, 1973) lists shocks of intensity V and above through 1972. Other sources (Townley and Allen, 1939) list many additional epicenters of lower intensity that are not well located in this area. After 1972, earthquake-epicenter intensity information is listed in "United States Earthquakes," published annually (for example, Coffman and others, 1975), and in USGS circulars, "Earthquakes in the United States" (for example, Minsch and others, 1979).

Willits was founded in 1887, and so some of the chimneys damaged in the November 22, 1977, earthquake may date back to 1887 or to the early 1900's. Some earthquakes of higher intensities in the historical record have shaken or weakened these chimneys; for example, the San Francisco earthquake of 1906 was felt severely in Willits. The Report of the State Earthquake Investigation Commission (Lawson and others, 1908) on the 1906 San Francisco earthquake stated (p. 187) that, in Willits, according to R. S. Holway,

> "Brick chimneys were quite generally wrecked. The Buckner Hotel was completely demolished. One wall fell at the time of the shock, killing Mr. Taylor, the proprietor. The building finally fell at 10:20 a.m. The structure was largely frame, with some brick veneer. The stores of the Irvine Muir Company were badly wrecked. Fire-walls fell; plaster, shelving, and goods were thrown to the floor. Brick walls fell in several other stores, and frame buildings were in some cases thrown from their foundations. Small cracks across some of the streets were reported, but they are not now visible. All brick buildings were damaged to some extent. A tank 2 or 3 miles to the east threw the water out on the northwest and southeast. Colonel La Mott, at the spawning station 5 miles north of Willits [sic], stated that the water of a pool 8 to 12 feet in diameter and 2 feet deep splashed out on the south and southeast, wetting the pickets to a height of 18 inches. It did not splash out in any other direction."

The intensities (Rossi-Forel) of the 1906 San Francisco earthquake in northern California are shown on figure 5, according to Lawson and others (1908).

The epicenter of the earthquake of July 25, 1903, with intensity VII at Willows, was less than 100 km from the site of the 1977 Willits earthquake. Since the 1903 earthquake, nine earthquakes of intensity VI or greater have or may have caused minor damage in the vicinity of Willits.

Geological Setting

Willits, a town of 3700 residents located 195 km north of San Francisco, is situated at the west edge of Little Lake Valley, a small alluvial basin near the head of the Eel River drainage. Franciscan assemblage rocks compose the uplands surrounding the valley, and unconsolidated Quaternary deposits form the valley floor and overlie moderately consolidated, steeply dipping Pliocene-Pleistocene gravels which crop out in the southern part of the valley. U.S. Highway 101 (Main Street, the Redwood Highway) follows the west edge of the valley; the main residential area of Willits lies west of the highway, and the industrial and agricultural areas are on the valley floor east of the highway. Broaddus Creek flows eastward through town, dividing the main residential area into approximately equal parts, with the bulk of older homes lying north of the creek. The older residential area appears to be located on two east-west ridges of Franciscan rocks which are covered by a thin veneer of surficial deposits, whereas the newer area to the south is on Pliocene-Pleistocene and Quaternary deposits.

The urban part of Willits lies athwart a zone of geomorphic features (e.g., scarps, sag ponds, pressure ridges, and offset drainages) of Quaternary (Holocene) age that are indicative of young faulting; this zone can be traced southeastward 65 km through Ukiah to the vicinity of Hopland where it merges with the Maacama fault zone (Herd and Helley, 1977). The northwestward extent of this zone is unknown, but it has been traced for at least 12 km northwest of Willits (Winterhalder, 1977). The sense of movement displayed by the offset drainages and linear nature of these features as they traverse hills and valleys indicate that the features were formed by right-lateral slip in a near-vertical fault zone, an origin which is consistent with that of other faults in the same system farther south.

Linear fault-produced features are also found on the east side of Little Lake Valley (fig. 3) about 4 km east of Willits, but little is known about them. These latter lineaments are close to the epicentral locations and may be more closely related to the earthquake of this report.

Field Reconnaissance of Epicentral Area

A USGS field team composed of Pampeyan, D. G. Herd, and K. McMasters went to Willits the day following the November 22, 1977, earthquake to look for ground breakage and to assess property damage. The following information is abstracted from

notes made by Pampeyan.

No physical evidence that an earthquake had occurred was found in the vicinity of the preliminary epicenter (USGS), which was stated to be 4 km east of Willits and was used in the reconnaissance study. The epicenter, determined by Berkeley and used in this report, 9 km east of Willits, is in an uninhabited, mountainous area. In the city of Willits, damage was concentrated in the business and residential areas west of the Northwestern Pacific Railroad tracks (fig. 1).

Two buildings were reported to have suffered structural damage: the Sprouse-Reitz Store at 150 S. Main St. and a warehouse-type building that houses Little Lake Industries near the northeast corner of Hearst-Willits Road and the Northwestern Pacific Railroad tracks. The team was refused entrance to Little Lake Industries; therefore, the nature of the structural damage could not be determined. The Sprouse-Reitz Store is in two old buildings, one brick and one concrete, joined lengthwise in an east-west direction. Flat roofs are supported by reinforced concrete columns about 30 cm square; there are no north-south walls in this store. The two parts of this store responded differentially to the shaking, as evidenced by cracks and offsets of as much as 12 mm along the join. Patches of new brick (ca. 1972) in the old brick wall also responded independently, as cracks outlined the patches and offsets of as much as 12 mm were formed. Near the building join, the concrete columns were cracked and the ceiling of the concrete building had dropped as much as 50 mm. Evidence of some pounding between the two parts was suggested by damage to cabinets and fixtures fastened to the wall near the join. Aftershocks on the morning of November 23 had damaged the front plate-glass windows, by north-south distortion of the building and window frames.

The corner building, two buildings south of the Sprouse-Reitz Store, had numerous cracks in its south-facing stucco wall. Close inspection showed that most, if not all, of the cracks were pre-earthquake but that some pounding had occurred during the earthquake. These cracks, which formed a rectangular pattern, probably represented former openings in the original wall that had been closed and plastered over within the past few years.

One large pane of glass was broken at the Safeway Store, and many bottled goods were thrown from the shelves during the initial shock but did not break. A few broken windows were seen elsewhere, but the causes or times of breakage were not determined.

Reports were that goods on east-west-oriented shelves were thrown down but that goods on north-south-oriented shelves were not. Visits to two stores confirmed this report. The Sprouse-Reitz Store lost items from its east-west shelves and an

auto parts store lost nothing from its predominantly north-south shelves. The Safeway Store's orientation indicated that most of the shelving was aligned northwest-southeast, with some other shelves along the walls in a northeast-southwest direction.

A drive-through inspection of the cemeteries revealed no toppled monuments; individual monuments were not examined for signs of having been rotated. On the west side of Main Street in the major residential district, damage appeared to have been restricted to brick chimneys on houses estimated to be at least 30 years old and more likely more than 50 years old. Damage to many chimneys was confined to the upper end, within the uppermost two or three courses of brick. Only a few chimneys were seen that had been reduced to the roofline (fig. 2), and it is not known if these chimneys actually collapsed to the roofline or were razed to that point during the subsequent cleanup operation which began soon after the main shock. At least ten of the damaged chimneys were broken midway between the roofline and top, the upper part being offset in a clockwise direction of 5° to 45° from the lower part; only two damaged chimneys were seen to be offset in a counterclockwise sense. The chimneys which suffered the most damage were old unreinforced brick and mortar construction. In contrast, newer chimneys, probably all less than 30 years old, appeared to be undamaged. Presumably, they contained reinforcing steel, but all were brick and mortar surrounding a fire-clay flue which itself may have acted as reinforcement. Forty-nine damaged chimneys were seen during the reconnaissance of the November 22 earthquake. A more accurate tally by the City Building Inspector later listed a total of 65 chimneys damaged by the November 22 shock. All of these defined a north-northwest-trending zone about 2.6 km long and 0.6 km wide, bounded on the east by the railroad and on the north by Willits Creek. Thirty-four of these chimneys were concentrated in the northern third of this zone; the remainder were scattered throughout the southern two-thirds. The highest concentration of damage was on Redwood Street, where 13 damaged chimneys were seen in a three-block area.

Only three slope failures were seen, all in steep roadcuts. These had a total volume estimated at less than 1 cu m. It is not known whether these failures were caused by the heavy rain which preceded the earthquake, by the earthquake, or by some other agent.

In summary, the earthquake effects seen by the field team during their rapid reconnaissance of November 23 were confined to damage of old unreinforced chimneys, an old building lacking shear walls, and one--or possibly more--broken window. The area where most chimney damage occurred was in the residential area north of Broaddus Creek, where the oldest chimneys most susceptible to shaking damage were concentrated. Possibly the intensity of shaking was greater here than elsewhere, perhaps being focused by geologic factors; however, one could only

speculate on whether or not geologic factors localized the damage, for no similar concentration of susceptible chimneys existed elsewhere in the epicentral area for a comparative study.

Evidence of Fault Creep in Willits

J. M. Coakley had made a preliminary observation of cracked pavements in the course of monitoring aftershocks of the November 22 earthquake. On December 14 a second field investigation was carried out by Pampeyan and P. W. Harsh. They noted sets of en echelon cracks in the pavement and related right-lateral offsets in curbs and sidewalks at five localities. When plotted on a map these five localities define a line about 1 km long, which coincides with a photo lineament plotted through Willits in 1975 (fig. 3). The evidence found by Coakley, Pampeyan, and Harsh indicates that a fault passes through Willits on which tectonic creep is occurring. Most of the creep effects observed predate the earthquake of November 22, but at least a small amount of creep occurred between November 23 and December 14, possibly being triggered by the November 22 shock. The average rate of movement is uncertain, however, because the ages of the offset curbs are uncertain, but it appears to be on the order of 2 mm per year. The area of creep is indicated in figure 3 by a heavy line through Willits.

Intensity Canvass

Questionnaire forms were computer-addressed and mailed to 180 post offices and police headquarters within a radius of 150 km of the epicenter on the day of the earthquake; they subsequently were evaluated by Simon, using the unabridged Modified Mercalli Intensity Scale of 1931. Additional intensity information was obtained from volunteer observers as far north as Rio Dell in Humboldt County and as far south as Santa Rosa in Sonoma County. Thirty-seven communities reported felt effects. Volunteer observers provided valuable intensity data by sending in local press reports. Figure 4 shows the distribution of the Modified Mercalli intensity values from table 2. The felt area for this earthquake was approximately 15,000 sq km. The scattered Modified Mercalli intensity distribution may in part be caused by local geologic conditions. The communities of Upper Lake, Finley, Kelseyville, Lakeport, and Fort Bragg, for example, are situated on unconsolidated, possibly water-saturated sediment, which might have amplified the ground motion from this earthquake (Borcherdt and others, 1975).

Additional intensity information was received from Professor K. L. Verosub of the University of California, Davis, Department of Geology, who went to Willits with D. F. Lott and B. L. Hart. They interviewed residents at 38 locations, most of these along the mountainfront on the eastern edge of the valley, about 3.5 km east of town. Thirty-seven sets of observations were evaluated by Simon and are listed in table 3 and illustrated in figure 6;

one of their reports could not be evaluated. The Berkeley epicenter location is indicated on figure 6. The material added in brackets [ ] at some locations has been excerpted from a newspaper column in the Willits "News" of December 2, 1977; it describes specific observations of animal behavior noted by the residents.

The team from the University of California, Davis, with USGS support, collected information on unusual animal behavior connected to this earthquake. They presented the data orally at the spring 1978 A.G.U. Meeting at Miami Beach. Unfortunately no clear distinction was made in the study of those animal behavior effects that took place prior to, during, or after the earthquake. The same 37 people were interviewed in this regard as in the intensity reports evaluated for figure 6.

Fault-Plane Solution

Eighty-six P-wave arrivals were obtained from the USGS Menlo Park seismograph stations; University of California, Berkeley; California Department of Water Resources; University of Washington; Montana School of Mines; and USGS, National Earthquake Information Service in Golden, Colorado. Numerous attempts were made by S. T. Harding to find a feasible fault-plane solution. The same inconsistencies (errors) appeared in each of four different solutions obtained. Therefore this aspect of the Willits earthquake is not included in this report.

Numbers of aftershocks have been reported, all smaller than the main shock and none causing damage. A total list of these aftershocks is not yet available.

Discussions and conclusions

Photogeologic and field reconnaissance studies indicate a north-northwest-trending near-vertical right-lateral strike-slip fault zone passing through Willits and Ukiah. In Willits good evidence indicates that tectonic creep is occurring in this zone. There is another north-northwest-trending set of lineaments on the east side of Little Lake Valley whose age, geometry, and extent are unknown at this time.

The distribution of chimney damage in Willits trends crudely parallel to the fault zone through town, but the sample is biased by the uneven distribution of chimneys susceptible to damage.

The data collected on the November 22, 1977, Willits earthquake indicate that this event was one pulse of the ongoing seismic activity in a north-northwest-trending zone of faulting through northwestern California. Reconnaissance examination of the epicentral area following the event revealed a fault in Willits on which tectonic creep is occurring, but it is unlikely that this earthquake took place on that fault. It is more likely

that the earthquake occurred on a fault east of Willits nearer the epicenter location. The relatively high intensities reported in the intensity canvass may be the result of specific geologic conditions at specific localities. This same effect was noted by Lawson and others (1908) for the 1906 earthquake. Shaking damage seen was essentially restricted to old, poorly constructed structures in Willits, the largest population center in a radius of 31 km. The ground motion was possibly concentrated in Willits by some focusing effect of the fault through Willits or by a sympathetic response on that fault to the main shock. This same sort of phenomenon may have occurred in the 1906 San Francisco earthquake to cause the unexpectedly high IX intensity at Willits, more than 50 km from the fault trace.

The two epicentral locations for the 1906 earthquake have long been a subject of debate. Bolt (1968) placed the event farther south and east by about 50 km than did Lawson and others (1908). In any case, the effects, as shown in figures 4 and 5, are comparable, suggesting that geological factors strongly influence the intensity of earthquakes felt in this part of California.

A fault-plane solution was attempted with 86 first arrivals. The inconsistent results are not included in this report. The animal-behavior observations reported here contribute to understanding an earthquake in terms of perceptual effects on humans and the animals living close to them. This understanding will improve with further studies of this kind.

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TABLE 1

Previous Felt Earthquakes in Willits Area

Sources are:
1. Townley and Allen (1939) (using Rossi-Forel Intensity Scale)
2. Coffman and von Hake (1973) (using Modified Mercalli Intensity Scale of 1931)
3. Coffman and von Hake (1973) (using Modified Mercalli Intensity Scale of 1931)
4. Minsch and others (1979)
5. Lawson and others (1908) (using Rossi-Forel Intensity Scale)

Year	Date	Location Lat. Long.	Intensity at Willits	Source
1868	Sept. 26	Ukiah	VIII, very severe	2
1869	Oct. 1	Lakeport, Lake Co.	A slight shock (press report).	1
1869	Oct. 8	Ukiah Valley,	Severest shock ever felt, VIII (no evidence for this high an intensity).	1
1870	Aug. 6	Ukiah	V (heavy shock)	1
1882	Nov. 9	Ukiah	Quite severe	1
1889	Jan. 17	Mendocino City	VI	1
1901	Jan. 11 Jan. 23	Ukiah	No intensity information.	1
1903	July 24	Willows 39.5° N., 122.0° W.	VII	2
1906	April 18	San Francisco	VIII-IX (Rossi Forel)	5
1953	May 24	Calpella 39.4° N., 123.3° W.	VI	2
1955	April 29	Near Kelseyville 39.0° N., 122.8° W.	VI	2
	May 7	38.9° N., 122.9° W.	V	2
1956	April 4	Near St. Helena 38.5° N., 122.5° W.	VI	2

Year	Date	Location Lat. Long.	Intensity at Willits	Source
1959	April 5	North of Ukiah 39.3° N., 123.2° W.	VI	2
	Sept. 24	Northeast of Ukiah 39.4° N., 120.6° W.	VI	2
1967	June 26	Near Ukiah 39.3° N., 123.3° W.	VI	2
1968	April 28	South of Willows 39.5° N., 122.0° W.	VI	2
1973	July 24	Calpella-Willits 39.1° N., 123.2° W.	V	3
	Oct. 30	South Clear Lake area not located	IV	3
	Nov. 11	Willits 39.3° N., 123.4° W.	V (damage at supermarket).	3
	Nov. 24	Willits-Pine Mt. area not located	V	3
1976	Nov. 11	Willits not located	V	4
1977	Feb. 21	Willits 39.37° N., 123.30° W.	V	Unpublished

TABLE 2

Results of the Intensity Canvass

Intensity VII

Willits--Of approximately 250 or more chimneys in town, 65 were damaged; many chimneys were shifted or twisted at roof line, 6 being completely destroyed; car windshields were broken by falling bricks; plate glass windows of Star Super and Safeway Stores were broken and groceries were thrown from shelves, forcing the stores to close for 3 hours to clean up. Safeway reported $1,000 worth of food and liquor lost. Three schools closed for the day. The high school had a few bricks dislodged over the front door and some interior plaster damaged. Waves (rippling) appeared on the ground. A few internal walls of older structures collapsed; one of the hardest hit homes was that on Redwood Avenue belonging to Judge Hathaway; an inside wall collapsed and the chimney of the fireplace fell apart, both outside and inside. A 25-year resident of Willits described the quake as a "rolling" one, the largest since he had lived there, and said that eight more shocks had been felt in the 24 hours following the main shock. One observer reported that a bed had moved away from an east wall.

Intensity VI

Booneville--Stone fences cracked, light furniture moved, standing vehicles rocked, trees and bushes shaken.

Clearlake Oaks--Foundation cracks, light furniture and small objects moved, buildings trembled, moving vehicles rocked moderately, water splashed onto sides of lake, many frightened.

Upper Lake--Interior walls split, plaster and dry wall cracked, buildings creaked.

Witter Springs--Sidewalks cracked; hairline cracks in exterior walls; plaster cracked; small objects fallen; hanging objects, doors swung violently north-south.

Intensity V

Albion--Many felt shock, a few frightened, trees and bushes shaken, buildings trembled, north-south motion.

Clearlake Highlands--Frightened some, standing vehicles rocked, trees and bushes shaken, buildings trembled, hanging objects swung.

Cloverdale--Many felt shock, a few frightened, trees and bushes shaken, standing vehicles rocked, buildings trembled, water in small containers disturbed, small objects and light furniture shifted.

Clearlake Park--Standing and moving vehicles rocked moderately, trees and bushes shaken moderately, several people frightened.

Comptche--Many felt shock and frightened by it; buildings trembled; windows, doors, dishes rattled. Pendulum clock did

not stop as it had in previous earthquakes. Pendulum swings in an east-west direction.

Covelo--Many felt shock, a few frightened; buildings trembled, water in small containers disturbed, hanging objects and doors swung moderately east-west.

Dos Rios--Buildings trembled.

Elk--All felt the shock, buildings trembled, pictures displaced, water in small containers disturbed, hanging objects swung slightly.

Finley--Several felt shock, hanging objects and doors swung moderately east-west, small objects moved.

Fort Bragg--Many felt and frightened by shock, trees and bushes shaken moderately, standing vehicles rocked, buildings trembled, small objects and light furniture shifted, water in small containers disturbed, hanging objects and doors swung east-west, moderate earth noise heard.

Hopland--Several felt shock and frightened by it, buildings trembled.

Kelseyville--Many felt shock, several frightened; trees and bushes shaken, standing vehicles rocked, buildings trembled, water in small containers disturbed, hanging objects swung moderately north-south, small objects shifted, coats on hangers swung.

Lakeport--Felt by many; trees and bushes shaken; standing vehicles rocked moderately; sharp ground movement felt indoors as "bobbing in a small boat," lasting about 12 seconds, seemed to come from the south; water in fish tank disturbed.

Leggett--A few frightened; buildings creaked; windows, doors, dishes rattled.

Lucerne--A few felt shock and frightened by it; windows, doors, dishes rattled.

Maxwell--Building trembled, plants swayed east-west.

Navarro--Many felt shock and frightened by it, buildings trembled.

Potter Valley--All felt, some frightened by shock; trees and bushes shaken; standing and moving vehicles rocked moderately; buildings trembled; water in small containers disturbed; hanging objects, doors swung moderately east-west; food knocked from shelves in market.

Point Arena--Several felt shock, buildings trembled, water in small containers disturbed, light fixtures swung east-west.

Redwood Valley--Many felt shock, a few frightened; trees and bushes shaken; moving vehicles rocked moderately; some small objects moved, some broken.

Stewart Point--Trees and bushes shaken moderately, standing vehicles rocked, buildings creaked, water in small containers disturbed, small objects shifted, faint earth noise heard.

Talmage--Many felt, a few frightened; trees and bushes shaken moderately; standing and moving vehicles rocked; buildings trembled; water in small containers disturbed; hanging objects swung moderately north-south.

Ukiah--Many felt shock, many frightened; trees and bushes

shaken moderately, buildings trembled, water in small containers disturbed, hanging objects swung moderately east-west, small objects and light furniture moved.

Intensity IV

Branscomb--Felt by a few; windows, doors, dishes rattled.
Mendocino--Felt by many; windows, doors, dishes rattled.
Rutherford--Felt by a few, buildings creaked.
Scotia--Felt by a few; windows, doors, dishes rattled; buildings creaked.
Stonyford--Several felt shock; windows, doors, dishes rattled; buildings creaked; hanging objects swung.

Intensity III

Yolo--Several felt earthquake.

Intensity II

Alderpoint, Richardson Springs, St. Helena (press report), Willows.

TABLE 3

Intensity Canvass of University of California, Davis, team
Evaluated by Simon

Intensity VII. All three locations at this intensity are on the East Side Road, near East Valley Road.

A--A well pipe was reported broken, water sloshed out of their fish tank, and brackishness was noted in the water from a recently drilled well.

B--The property is located adjacent to A and also adjacent to the Fallen Leaf Nursery. Trees fell and a chandelier fell from the ceiling, breaking the dining room table.

C--At this residence, about 0.7 km north of the two described above, the chimney was cracked above the house line; pictures fell from the walls; heavy furniture, including beds on the second floor, moved away from the wall approximately 15 cm; toilet tank lids flew up and off their bases; plaster was cracked; and glassware was broken.

Intensity VI. Owners or residents of 17 properties reported slight damage.

D--On East Valley Road about halfway between the center of town and East Side Road. Structural damage to the barn and much glass breakage inside the house was reported.

E--On the Hearst-Willits Road northeast of town, also about halfway to the valley's eastern edge. Bookshelves fell, plaster cracked, water sloshed out of open containers, and wavelike motion was visible across the fields.

F--On the East Side Road. Minor structural damage was reported, wooden planks separated, and books and bric-a-brac were knocked from shelves. [Dogs barked and geese honked, but there is no certainty if this was before or during the shaking. The German shepherd whined on the back porch and took shelter under the porch, remaining there the following 2 days.]*

G--On Reynolds Highway, near Hearst-Willits Road. Seams were pulled apart in the building, books were thrown across the room from bookshelves, heavy furniture was displaced several centimeters, and possible fissures appeared in the ground around the home. A recently drilled artesian well, which normally has abundant overflow, slowed dramatically 3 to 4 days before the earthquake. [About 5 days before the quake, the family noted that their horses were acting very "hyper." Through the years they have observed their horses becoming unusually active before specific changes in the weather, so they expected a storm of some kind. Just as the shaking began, the G's looked out into the main pasture and saw all the horses reacting in great panic by sprinting off in different directions instead of running together as they

*The material contained in brackets here and in following sections of this table is from the Willits "News" of December 2, 1977.

usually did. A short time later the roosters began to crow, the first time any of them had ever done so at that time of day.]

H--On northern side of intersection of Berry Canyon and East Side Roads. A doorway spread in one room, tiles cracked in the bathroom shower, and pictures fell from the mantle. Better flow of water from a well was noted after the earthquake.

I--Located 0.8 km north of the G property. Cracks were noted in the plaster, fireplace, and ceilings; there was breakage of figurines; heavily loaded freezers on rollers turned partially away from the walls; and woodpiles in the barn collapsed.

J--Reynolds Highway, 5 km north of Hearst-Willits Road. A crack was reported in a kitchen wall, one corner of the bathroom cracked, and one ceramic figurine was broken.

K--Located in the center of the valley northeast of the town center on Hearst-Willits Road. There were hairline cracks in one house wall and a change in the hang on one door which now sticks; a radio was reported knocked from a shelf.

L--No. 1 and No. 2. Both properties are located at the extreme northernmost end of Little Lake Valley and on Reynolds Highway, adjacent to each other. A cracked chimney occurred at a rental house on the No. 1 place, and cracks in the roof of the No. 2 house were noted.

M--Off Canyon Road. Some brickwork cracks in the chimney were reported, cement walls of the house were seen to move, pictures were knocked askew, some items fell from shelves, and waterbeds sloshed.

N--East Side Road, about 2 km south of East Valley Road. Although no one was at home at the time of the earthquake, a new crack had formed on the roof, the refrigerator and freezer doors were thrown open, and a cookie jar lid was found broken on the floor while the remainder of the cookie jar stayed on the shelf.

O--Just north of the N place. Plaster cracks were noted in the mortar around the fireplace, items fell from cupboards, and small objects tipped over; however, no breakage occurred, because these objects were plastic.

P--On Hearst-Willits Road just west of the Berry Canyon Road. Cracks were noted in the chimney, ceiling, and plastered walls; dresser drawers were thrown out; numerous items fell from shelves, tables, and the television; dishes were thrown out of cupboards, and pictures were knocked askew.

Q--East Side Road at Timberrose Ranch (between I and M properties). The barn cracked and a statue fell and broke.

R--East Side Road at the intersection of East Valley Road. A crack appeared in a brick retaining wall, one dish was broken, items on shelves were knocked over, and a bed on rollers moved approximately 15 cm from the wall. [The owner reported that after the quake, her horses were standing around at the alert, ears up, sniffng the air, as if waiting for something to happen; all of them seemed "hyper" and

stayed that way for several days. She also noted that the large bird population, mostly junkos and Stellar's jays, had disappeared and remained away for the next 24 hours. The chickens were silent and packed into the chicken house, whereas they were usually moving about the yard making all kinds of noises. There was no egg production that day. Her family noted over the next several days while the aftershocks continued that all the animals gave advance notice of each tremor just before it happened by coming to attention in an apprehensive stance. If the cats were asleep, they would jump up and stand stiff-legged until the tremor passed.]

Intensity V.

S--Located along Rock Valley Creek. Shifting of pictures and jangling of pottery were reported, and beds moved.

T--Berry Canyon Road. Everything fell to the floor in a workshop, all the cupboards opened and the contents were thrown out, and figurines and whatnots were thrown off of shelves.

U--Hearst-Willits Road at the intersection with East Valley Road. One small vase toppled.

V--Reynolds Highway just south of the J property. A few pictures were askew.

W--Reynolds Highway, 1 km south of V. Pictures were tilted.

X--Rocktree Valley Creek, 1.5 km east of S. Bells hung throughout the house began to ring, a globe suspended on fishing string began spinning around, water sloshed in beds and buckets, books fell from shelves, and six 1-gal jugs of food fell from pantry shelves and broke. This all occurred in a 70-year-old wooden house built on a mud sill foundation. Mr. X said that although he never associated it with the earthquake, he had noticed a minor spring now present in the yard of the property which had not been there before the earthquake.

Y--Located on Hearst Road in Rocktree Valley Canyon. This location is the farthest point in this study from downtown Willits and the nearest point to the instrumental epicenter located by the Berkeley seismographic station. One vase fell from a high shelf in the kitchen of this home.

Z--Berry Canyon Road. A heavy mirror swung on a wall, cups tilted over on a shelf, and a stereo speaker was knocked over. A spring on this property had increased flow after the earthquake, almost doubling production of water.

AA--Eastside Road south of East Valley Road. A few items were knocked from shelves in this mobile home unit, most from a bathroom medicine cabinet. No one was at home at the time of the earthquake.

BB--East of the N property (VI) on Eastside Road. Pictures fell over on the piano and a chandelier swayed, but there was no breakage. A roar was heard ahead of the quake.

CC--Ridgewood Road, near the Willits water supply settling tank. Drawers slid out of a heavy chest of drawers on metal

casters, and the water heater fittings became loosened.

DD--Lucky 13 Ranch just west of Eastside Road, toward the valley floor, near a creek. A pool filter pipe was broken. No one was at home at the time of the earthquake, and nothing was broken or displaced inside the house.

EE--Locust Knoll Ranch on Eastside Road, north of the CC property. Everything moved, rocking chairs rocked, and ceiling light fixtures swayed.

FF--Hearst-Willits Road, just east of the center of town. A woodburner vent was loosened and the CB radio was knocked from its shelf.

GG--Eastside Road north of EE. In a ceramics shop, only seven pieces were broken, but several pictures on the wall were knocked askew and the earthquake was felt as a strong jolt.

HH--Hearst-Willits Road in the center of the valley. There was some breakage of small items that fell from shelves, and water in the fish tank splashed out.

II--South of the CC property on Eastside Road. A few pictures were knocked crooked.

[On Holly Street in Willits, a full-grown doe was seen running down the middle of the street within the first few minutes after the initial jolt.

A pet owner found one of her cats hiding under a bed and the other inside a cupboard behind the bathroom shower. Both seemed terrified and the one in the cupboard would not come out for 2 days.

One man, who lives on Sherwood Road, reported that for 3 days after the quake, residents were aware of a strange muted roar that went on around the clock and kept all the animals agitated, especially the cattle which milled about and bellowed almost constantly.]

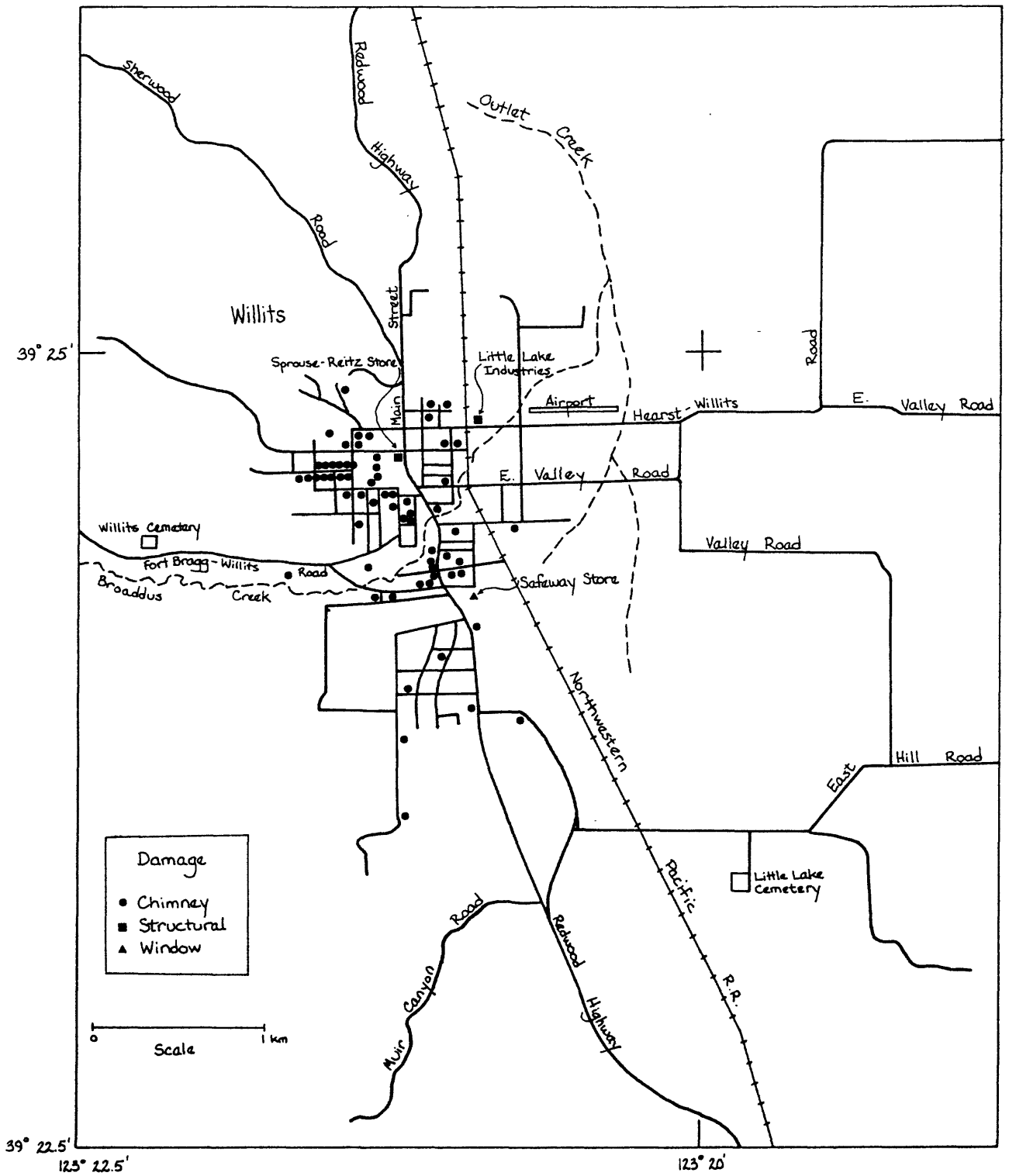

Figure 1.--Map showing the area of damage in Willits, California, from the November 22, 1977, earthquake.

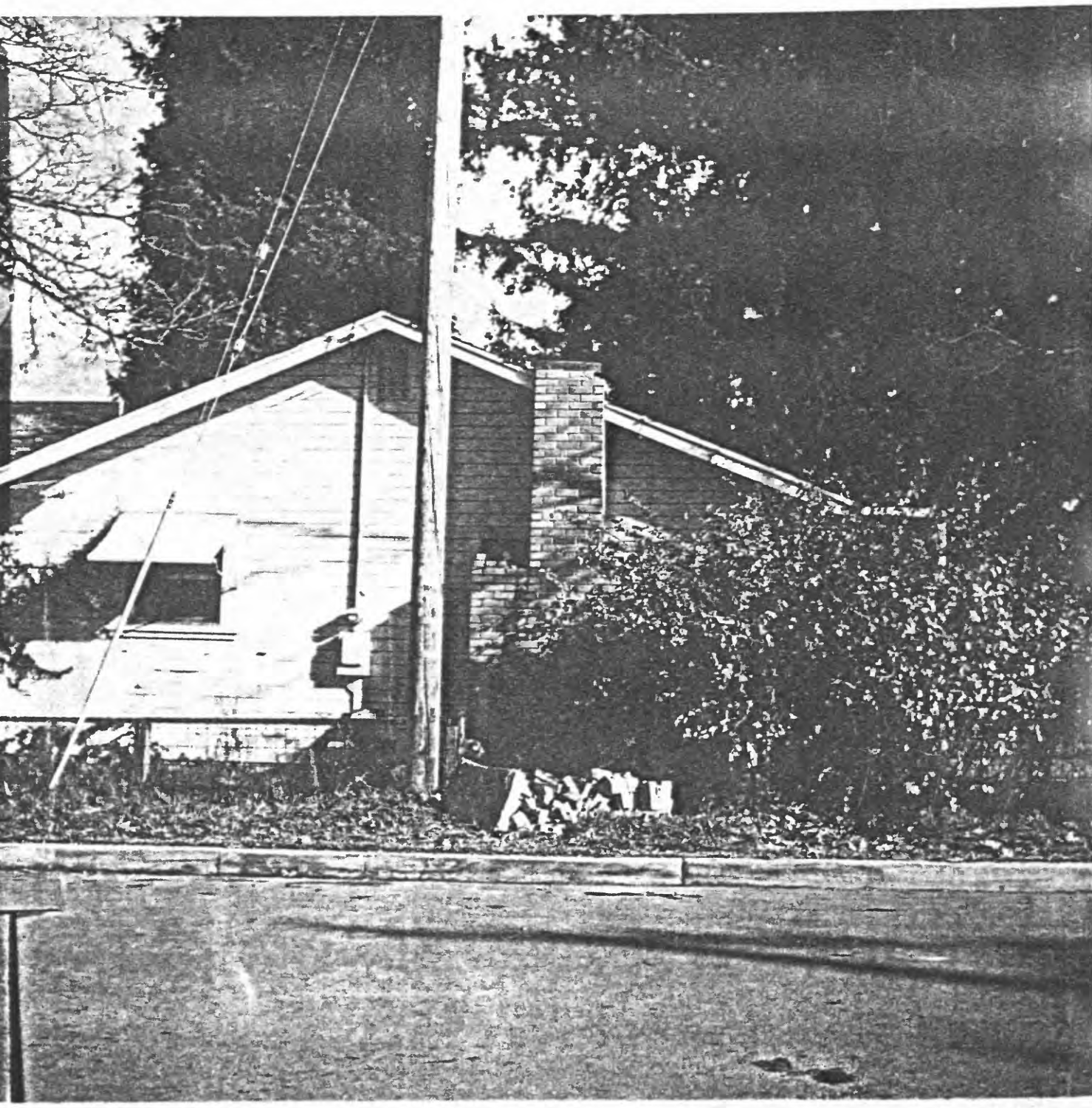

Figure 2.--Earthquake chimney damage, Willits, California, November 22, 1977. (Photo courtesy of R. E. Wallace, U.S. Geological Survey.)

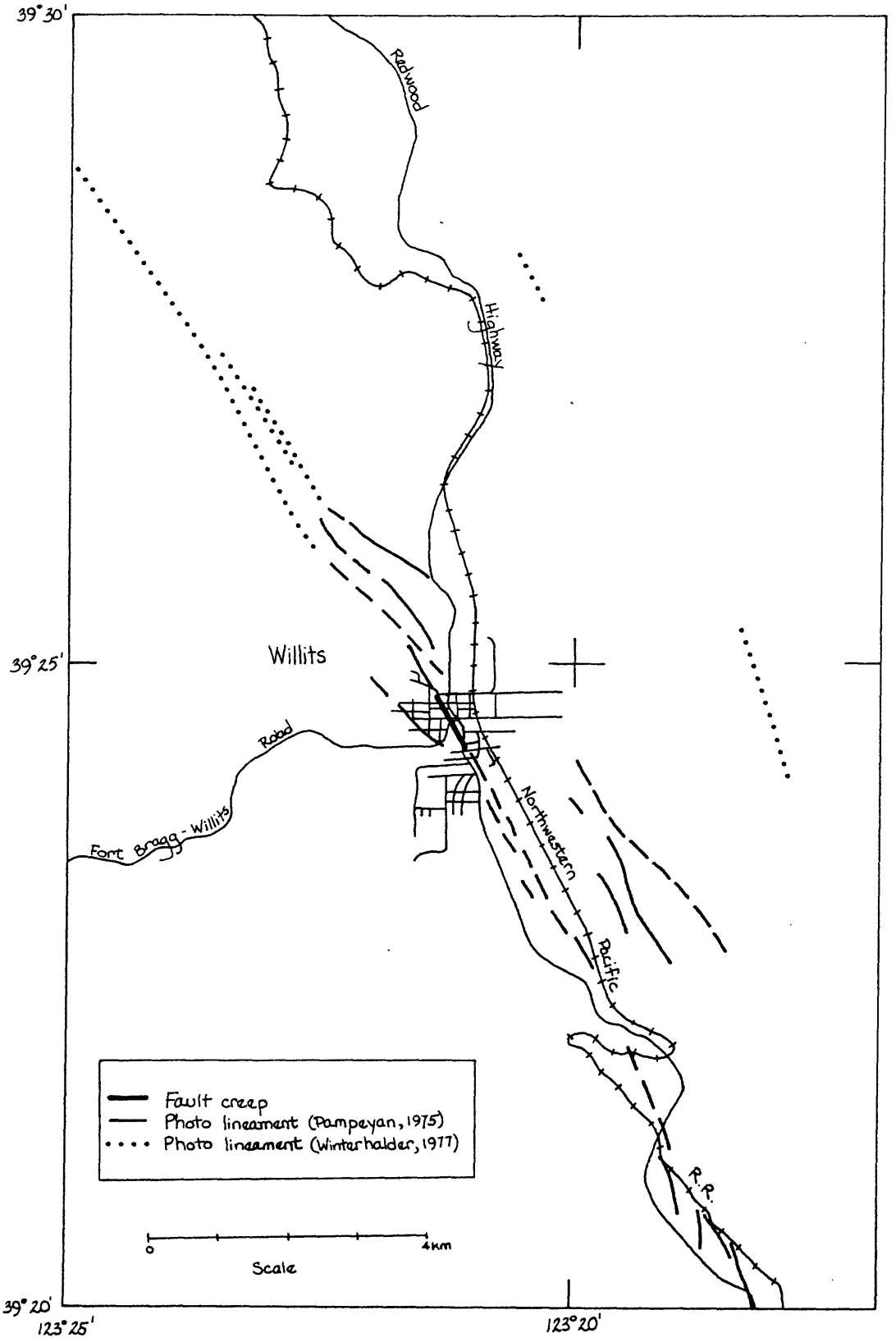

Figure 3.--Map of the photo lineaments in the Willits, California, area (from E. H. Pampeyan (unpublished data), 1975; Winterhalder, 1977).

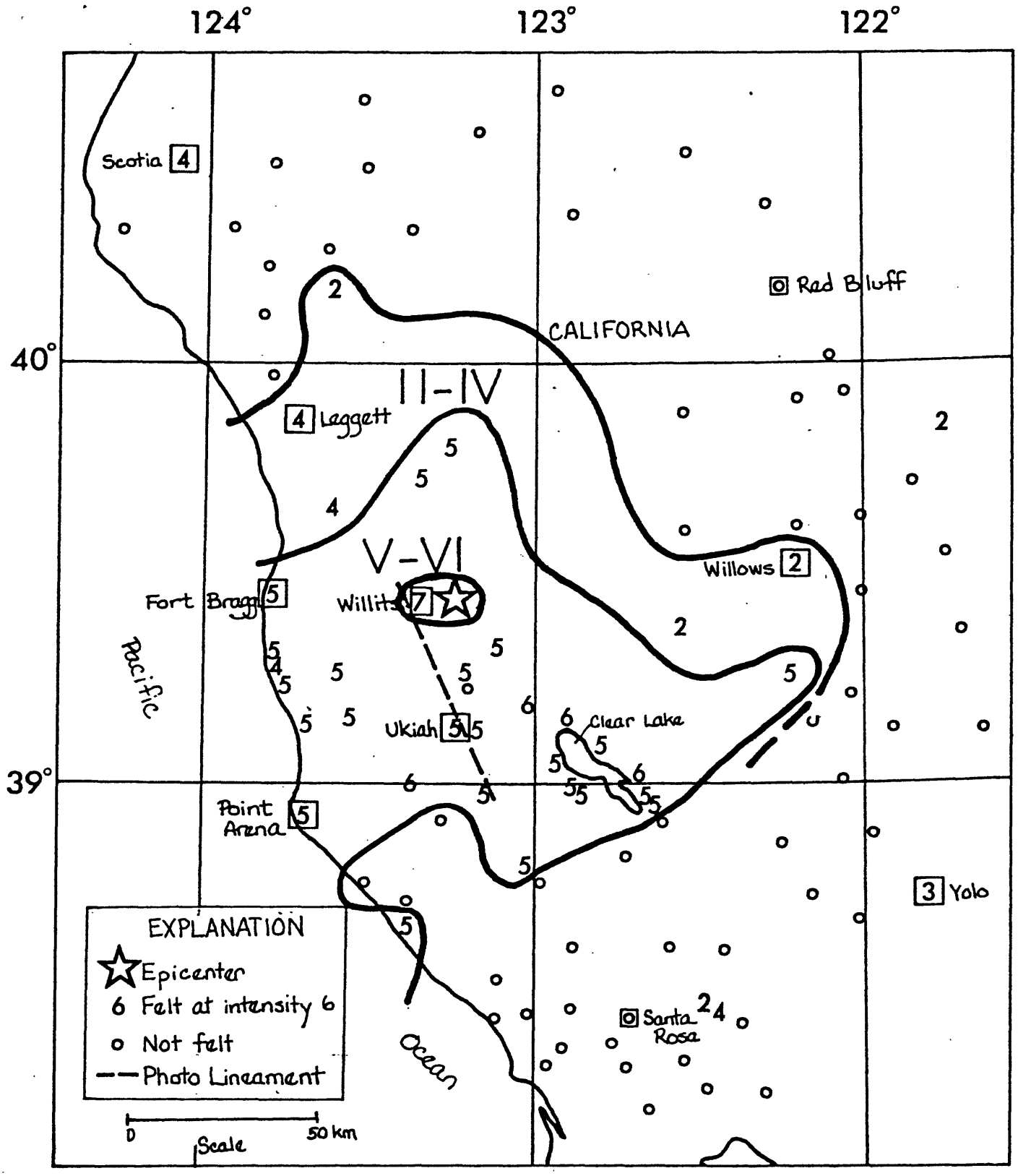

Figure 4.--Isoseismal map for the northern California earthquake of November 22, 1977, 21 15 52.5 UTC. Roman numerals represent Modified Mercalli intensities between isoseismals; Arabic numerals are used to represent these intensities at specific sites.

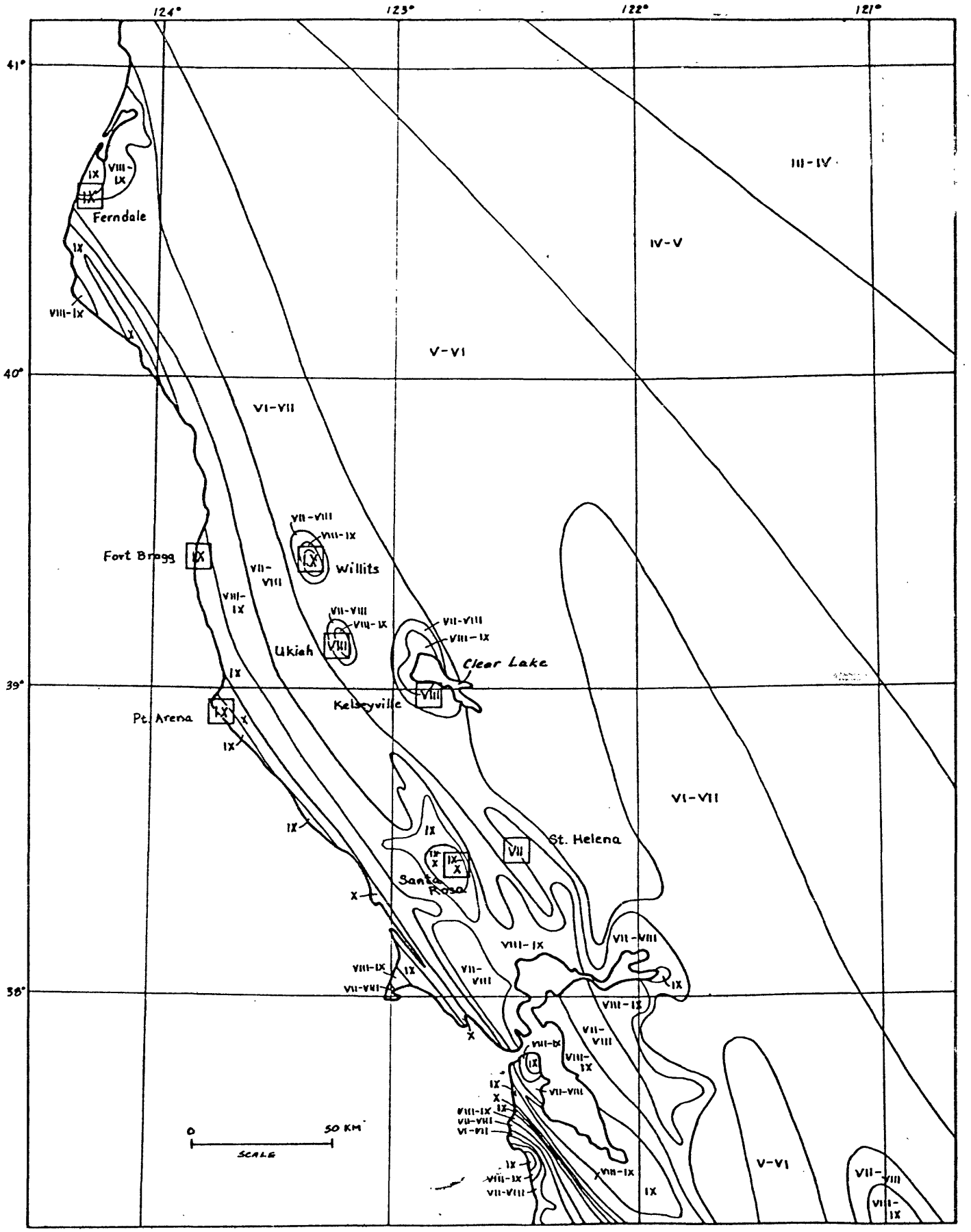

Figure 5.--Isoseismal map for the 1906 San Francisco earthquake. Modified from Lawson (1908), Rossi-Forel intensities.

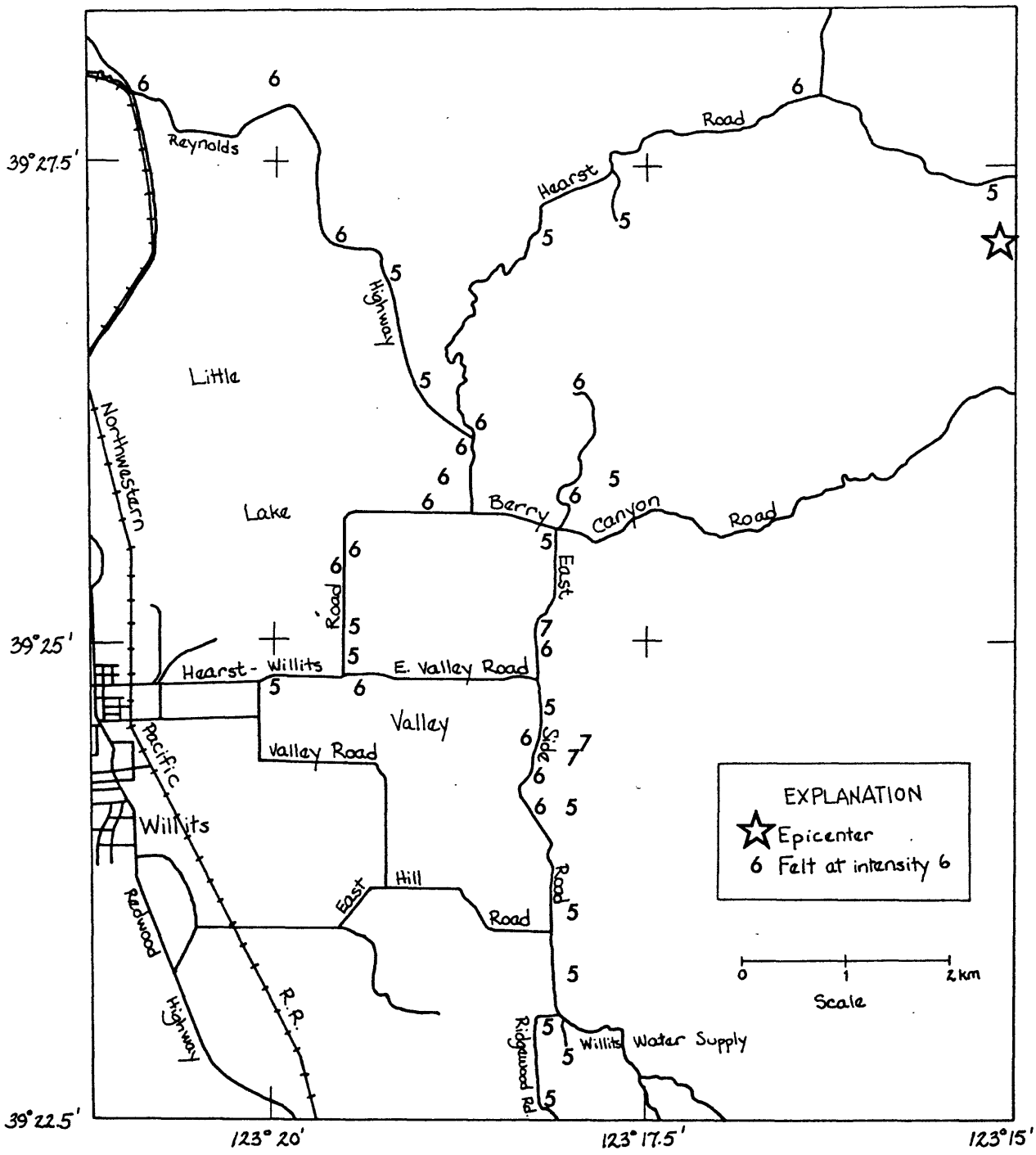

Figure 6.--Intensity map from University of California, Davis, team; data evaluated by Simon for area east of Willits.