

U. S. Department of the Interior
Geological Survey

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by

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Open-File Report 88-404

1988

This report is preliminary and has not been reviewed for conformity with U. S. Geological Survey editorial standards and stratigraphic nomenclature.

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Abstract

Four large earthquakes in Sevier County, Utah, in 1901 and 1921 were investigated and isoseismal maps made. Intensities assigned in this study were somewhat lower than those of some previous researchers, partly because of the transition from Rossi-Forel to Modified Mercalli intensities, and partly because of a seemingly high assignment of intensity to the first and last earthquakes with little supporting evidence.

Previously assigned felt areas for the three 1921 shocks are in general agreement with those found in this study. However, there is a question about the 1901 shock's felt area that cannot be resolved with the intensity information presently available. The accounts of the 1901 earthquake's effects within the epicentral region are quite similar to the accounts of the 1921 shocks. However, the 1901 earthquake was also reported felt in Salt Lake City, 220 km to the north. It is not clear from the available evidence whether Salt Lake City should be included as an integral part of the 1901 felt area or treated as an outlying felt report.

INTRODUCTION

Sevier County, Utah, 220 km south of Salt Lake City has been the location of a concentration of earthquakes, some of them rather large, within recorded history (see figures 1 and 2). However, very little information is available about these shocks. The effects within the immediate epicentral area are recorded, but there is little information about the geographic extent of the felt area. This paper describes the largest of those earthquakes: a single large shock in 1901 and a series of three large shocks in 1921.

The older studies cited in this study use the Rossi-Forel (R.F.) intensity scale. In fact, it may be that the rather high Modified Mercalli (M.M.) intensities in the current literature are partly the result of R.F. intensities being quoted as though they were M.M. intensities. A comparison of the two intensity scales is shown in table 1.

TABLE 1. Comparison of Modified Mercalli Intensities with Rossi-Forel Intensities¹

M.M.	R.F.	M.M.	R.F.	M.M.	R.F.
I	I	V	V to VI	IX	IX ⁺
II	I to II	VI	VI to VII	X	X
III	III	VII	VIII ⁻	XI	X
IV	IV to V	VIII	VIII ⁺ to IX ⁻	XII	X

¹ Wood and Neumann (1931).

1901 NOVEMBER 13 21:30

Date

- 1901 November 13 8:35 p.m. PST (Townley and Allen, 1939)
- 1901 November 13 21:39 MST (Williams and Tapper, 1953)
- 1901 November 14 04:39 UTC (Arabasz and McKee, 1979)
- 1901 November 13 21:30 MST (Coffman and others, 1982)
- 1901 November 14 04:32 UTC (Stover and others, 1986a)

Maximum Intensity

- X R.F. "The shock was definitely many times greater than the Elsinore shocks of 1921." (Townley and Allen, 1939)
- IX M.M. (Williams and Tapper, 1953)
- 9 M.M. (Comments "INT=8.9") (Arabasz and McKee, 1979)
- VIII M.M. (Coffman and others, 1982)
- IX M.M. (Stover and others, 1986a)

Magnitude

- Magnitude 7.0 derived from $M=1+\frac{2}{3}I_0$ of Gutenberg and Richter (1956). (Arabasz and McKee, 1979)

Felt Area

"The area within which the intensity was VI [R.F.] or higher was fully 10,000 square miles [26,000 km²], that of intensity VIII [R.F.] was not less than 3,000 square miles [8,000 km²]." (Townley and Allen, 1939)

50,000 mi² (130,000 km²) (Williams and Tapper, 1953)

Felt area 50,000 mi² (130,000 km²). "Intensity VI [M.M.] was observed over 10,000 square miles [26,000 km²]; intensity VIII [M.M.], 3,000 square miles [8,000 km²]." (Coffman and others, 1982)

"Intensity VIII [M.M.] effects extended over 3000 sq mi [8,000 km²]. Felt over an area of more than 50,000 sq mi [130,000 km²]. Many aftershocks." (Stover and others, 1986a)

Epicenter

"Origin not far from Beaver, Beaver Co." (Townley and Allen, 1939)

Richfield (Williams and Tapper, 1953)

38° 46.15' N., 112° 5.02' W. (38.77° N., 112.08° W.) (Arabasz and McKee, 1979)

Southern Utah (Coffman and others, 1982)

38.7°N., 112.1°W. (Stover and others, 1986a)

Damage—Not Site Specific

"No accurate record has been kept of former disturbances, although it appears from current reports that during the period since the country was first settled, at least two or three earthquakes of considerable violence have been experienced. The one about which most seems to be known occurred some twenty years ago and was sufficiently intense to topple a few chimneys and cause other damage of a similar nature." (Pack, 1921)

Damage—Site Specific

"This shock... was of intensity IV [R.F.] at Salt Lake City, two hundred miles [300 km] from the origin. Damage to brick buildings and chimneys was considerable from Parowan on the south to Richfield, Sevier Co., on the north. In the mountains between Beaver and Marysvale, Piute Co., the intensity seems to have been IX or X [R.F.], with extensive rockslides, and the roads up Bullion and Cottonwood Canyons were rendered almost impassable by masses of fallen rock; creeks increased their flow; cracks formed in the earth; two weeks after the main shock, aftershocks were frequent and rumbling and trembling were almost incessant. The strongest aftershock was at 4:31 a.m., on November 14. In the interval between the occurrence of the main shock and of the strong aftershock at 4:31 a.m., thirty-five distinct shocks were felt in addition to a slight continuous tremor of the earth." (Townley and Allen, 1939)

"Towns suffering damage included Beaver, Monroe, Elsinore, Richfield, Joseph, Marysvale, and to a less extent, Parowan, Milford, Cedar City, St. George, Kanab." (Townley and Allen, 1939)

[Presumably at Richfield] "Lasted 10 seconds; motion southeast to northwest; trees disturbed; rumbling noise; people ran out of doors. Lesser shocks, about 35 in number, duration 3 to 5 seconds each. Cracks in ground in river bottom 3 miles east of town [5 km], to 300 feet [90 m] in length, eject water and white sand. Data from George T. Henry, Weather Bureau Observer. *Deseret News*, December 6, 1901." (Williams and Tapper, 1953)

"Brick buildings and chimneys were damaged from Parowan to Richfield. In the mountains between Beaver and Marysvale there were extensive rockslides. Creeks increased their flow, and some earth cracks with ejection of water and sand were reported." (Coffman and others, 1982)

"Richfield, Utah. Damage to brick buildings and chimneys was considerable from Parowan, Utah on the south to Richfield on the north. In the mountains between Beaver and Marysvale, Utah, there were extensive rock slides almost closing the roads. Creeks increased their flow; and some earth cracks with ejection of water and sand were reported." (Stover and others, 1986a)

Isoseismal Map and Discussion

Modified Mercalli intensities assigned in this study for the 1901 earthquake are listed in table 2 and shown in figures 3(a) and 4. The maximum intensity, VIII M.M., was assigned to seven sites, the six towns listed by Townley and Allen as having the most damage and the "extensive rockslides" between Beaver and Marysville where Townley and Allen (1939) assign "IX or X" R.F. (VIII-XII M.M.). However, rockslides are not necessarily indicative of very high intensities because they frequently occur at much lower intensity levels; in fact, an intensity as low as VII could be appropriate here as well. Townley and Allen also assert that this shock was "definitely many times greater than the Elsinore shocks of 1921," to which they assign a maximum intensity of VIII R.F. (VII-VIII M.M.). This study finds both the 1901 shock and the first 1921 shock to have maximum intensities of VIII M.M., although within the range of intensity VIII there is plenty of room for the 1901 earthquake to be the larger of the two.

TABLE 2. Modified Mercalli Intensities for the Earthquake of 1901 November 13 21:30

Lat (°N.)	Lon (°W)	I ¹	Location
38.70000	-112.10000	UT	epicenter
38.28333	-112.66667	8 UT	BEAVER
38.37666	-112.44834	8 UT	BETWEEN BEAVER AND MARYSVALE
37.67000	-113.07000	6 UT	CEDAR CITY
38.67000	-112.17000	8 UT	ELSINORE
37.03333	-112.51667	6 UT	KANAB
38.62000	-112.22000	8 UT	JOSEPH
38.47000	-112.23000	8 UT	MARYSVALE
38.36667	-113.00000	6 UT	MILFORD
38.63000	-112.10000	8 UT	MONROE
37.86667	-112.83333	7 UT	PAROWAN
38.76667	-112.10000	8 UT	RICHFIELD
40.75000	-111.85000	4 UT	SALT LAKE CITY
37.11667	-113.56667	6 UT	SAINT GEORGE

¹ Modified Mercalli site intensities.

Townley and Allen report that "damage to brick buildings and chimneys was considerable from Parowan...to Richfield" and "towns suffering damage included Beaver, Monroe, Elsinore, Richfield, Joseph, Marysville, and to a less extent, Parowan, Milford, Cedar City, St. George, Kanab." Since damage is reported for all of these towns, all must be assigned at least intensity VI (lowest level of damage in Modified

Mercalli scale). Also, the more heavily damaged group of towns should probably be assigned an intensity one or two units higher than the less damaged group. Although the maximum intensity could be IX M.M., there is no conclusive indication of intensity as high as IX, since rockslides and damage to poorly constructed or old brick buildings and chimneys occur readily at VIII. Such structures may also be somewhat damaged at intensity VII. The presently available damage descriptions are thus insufficient to resolve the question of the maximum intensity more closely than VII-IX M.M.

TABLE 3. Isoseismal Areas for the 1901 Earthquake

R.F.	M.M.	Area (mi ²)	Area (km ²)
VIII	VII	3,000 ¹	7,800
VI	V ⁺	10,000 ¹	26,000
Felt area	I-III	50,000 ²	130,000

¹ Townley and Allen (1939).

² Williams and Tapper (1953).

Additional information for determining the maximum intensity is given in Townley and Allen's R.F. isoseismal areas, shown in table 3. The area encompassing the more heavily damaged towns (VII area in figure 4) corresponds well with Townley and Allen's area for intensities VII (M.M.) and greater. Thus the heavily damaged towns were assigned intensity VII or VIII M.M. and the less damaged towns, VI M.M. Likewise, the VI isoseismal in figure 4 agrees well with Townley and Allen's area of intensity V⁺ (M.M.). The outer felt area of figure 3(a) has been centered on the interior isoseismals and made to agree in size with Williams and Tapper's felt area. There is an outlying intensity-IV site at Salt Lake City north of the main felt area. There is no data at all for drawing V or IV isoseismals.

Williams and Tapper do not say how they obtained their estimate of the felt area of 130,000 km². Did they include Salt Lake City as an integral part of the felt area? Doing so would make a felt area much larger than 130,000 km². Did they know whether the earthquake was felt in other cities immediately south of Salt Lake City? Information from this region could help establish the northern boundary of the felt area. Comparison of the 1901 felt area with the tiny felt areas of the 1921 Sevier County earthquakes suggests that the 1901 felt area is no larger than that shown in figure 3(a), with Salt Lake City being an outlying point well outside the boundary of the main felt area. It is

common for an area of high population density, such as Salt Lake City, to report a higher intensity than the surrounding territory.

1921 SEPTEMBER 29 07:12

Date

- 1921 September 29 7:12 a.m. (Pack, 1921)
1921 September 29 6:12 a.m. PST (Townley and Allen, 1939)
1921 September 29 07:12 MST (Williams and Tapper, 1953)
1921 September 29 14:12 UTC (Arabasz and McKee, 1979)
1921 September 29 07:12 MST (Coffman and others, 1982)
1921 September 29 14:12 UTC (Stover and others, 1986a)

Maximum Intensity

- "Fully VIII" R.F. (Pack, 1921)
VIII R.F. (Townley and Allen, 1939)
VIII M.M. (Williams and Tapper, 1953)
8 M.M. (Arabasz and McKee, 1979)
VIII M.M. (Coffman and others, 1982)
VIII M.M. (Stover and others, 1986a)

Magnitude

- 5.2 from Jones (1975) (Arabasz and McKee, 1979)
Magnitude 6.3 derived from $M=1+\frac{2}{3}I_0$ of Gutenberg and Richter (1956). (Arabasz and McKee, 1979)
5.2 UKN (source unknown) (Stover and others, 1986a)
5.2 PAS (Seismological Laboratory, California Institute of Technology, Pasadena, California) (Stover and others, 1986a)

Felt Area

- "In no case...were any of the earthquakes felt over a wide range of country. People living as little as twenty-five miles distant did not know of the occurrences except as later informed." (Pack, 1921)
"Affected a wider range of country and did more damage than either of the two that followed." (Pack, 1921)
"Shocks, though strong locally, were not widely felt.—BSSA [Bulletin of the Seismological Society of America], 11, 155." (Townley and Allen, 1939)
1,000 mi² (2,600 km²) (Williams and Tapper, 1953)
"Considerable." "Uncertain." (Coffman and others, 1982)
1,000 mi². "Not felt 25 miles [40 km] away." (Stover and others, 1986a)
"Only felt locally over an area of about 1,000 sq mi. Not felt 25 mi away." (Stover and others, 1986a)

Epicenter

- Elsinore, Monroe, and Joseph, Sevier County (Townley and Allen, 1939)
Elsinore, Sevier Valley (Williams and Tapper, 1953)
38° 40.97' N., 112° 8.98' W. (38.68° N., 112.15° W.) (Arabasz and McKee, 1979)
Elsinore. 38.8°N., 112.2°W. (Coffman and others, 1982)
38.7°N., 112.1°W. (Stover and others, 1986a)

Damage—Not Site Specific

- "Damage to chimneys and brick walls." (Townley and Allen, 1939)
"Damage estimated at \$100,000. Gables of houses thrown out; foundation of a new school sunk one foot, leaving gaps between walls and roof. *Deseret News*, September 29, 1921." (Williams and Tapper, 1953)

"After several weeks of preliminary tremors, the first sharp shock occurred at Elsinore at 07:12 on September 29. It lasted 7 to 10 seconds and was probably of intensity VIII. It threw down scores of chimneys, tore plaster from ceilings, and fractured walls." (Coffman and others, 1982)

Damage—Site Specific

"On September 29 at 7:12 a.m. a very strong shock was experienced at Elsinore and to a less extent in neighboring places. Judged on the basis of the Rossi-Forel scale, it had an intensity of fully VIII [R.F.]... The shock was of sufficient intensity to injure all types of buildings. Scores of chimneys were thrown down, plaster fell from the ceilings, and walls were fractured and displaced." (Pack, 1921).

"It was strongest at Elsinore. It did considerable damage, however, at Monroe and shattered a few chimneys at both Joseph and Richfield. Beyond these points it seems to have been scarcely more than noticeable. It is reported by cattlemen to have been felt in a mountain cabin some five miles southwest of Elsinore." (Pack, 1921)

"Measured in terms of actual cost, the greatest damage done to any single building was at the public school house [presumably at Elsinore]. The structure is a new two-story brick building... with a one-story... gymnasium behind. A firewall some two to five feet high, constructed around three sides of the main building and two sides of the gymnasium, was almost entirely thrown down by the first shock. Several pilasters mounted on the front of the building were also dislodged. In the gymnasium the ceiling was torn loose from the walls in such a manner as to admit daylight. It is very fortunate that the earthquake did not take place at a time when the children were on the grounds... [because] tons of material were plunged to the ground where the children ordinarily play.

Close to the new school house is an older one constructed of rectangular blocks of rock. This building was not seriously impaired except on the second floor, where several yards of plaster fell to the pupils' desks. The walls were also pulled apart from the ceiling....

[At] the Mormon church... of modern design and construction, the only damage... is the cracking of some of the walls and the twisting of two small pilasters mounted near the tower.

The front of one of the store buildings was cracked badly by the first shock and thrown down entirely by the third. The building was also otherwise damaged to such an extent that it will have to be razed.

The greatest aggregate damage... was done to the residences, of which perhaps fully one-half seriously suffered. Probably fifty percent of the chimneys in the town were thrown to the ground, and practically all of the remaining ones were rendered unfit for further use.... Plaster was shaken from the ceilings of nearly every residence... In scores of homes pictures were torn from the walls and bric-a-brac was strewn about the floors. In numerous cases walls were badly cracked and thrown out of alignment. Ten to twelve residences were rendered unfit for further occupancy....

Some of the buildings in both Elsinore and Monroe are of very primitive construction, being made either of sun-dried bricks or of angular fragments of stone. The more modern types are perhaps evenly divided between brick and lumber. The public buildings are principally brick and cement. The buildings that suffered most were those made of angular fragments of stone. Next came those of sun-dried bricks, then the brick houses and finally those constructed principally of lumber. The last type suffered very little except from falling plaster and toppling chimneys." (Pack, 1921)

"7:13 Kanosh, V. Duration one to two seconds; sounds heard; felt by many. MWR [Monthly Weather Review], 19:532." (Williams and Tapper, 1953)

"The first shock was strongest at Elsinore... Most severely damaged was the Elsinore schoolhouse, a new two-story brick building. The collapse of a section of the wall could have caused heavy loss of life had it occurred during school hours. Nearby, an old building of rectangular blocks of rock was only slightly damaged. Half the buildings were damaged to some degree, their chimneys thrown down or otherwise rendered unsafe. Plaster fell from ceilings; pictures were thrown from walls. One chimney was twisted through 45°. A hot spring with iron oxide in the water ran blood red for a time after the earthquake." (Coffman and others, 1982)

"Elsinore, Utah. Scores of chimneys were thrown down or broken at roof level, plaster fell from ceilings, and walls were fractured and displaced. The shaking from this event lasted longer than that from the September 30 and October 1 earthquakes, thereby causing the most damage. A new two-story brick school was damaged when a firewall on three sides was thrown down and several pilasters in the front

of the building dislodged. Front of one store building was badly cracked." (Stover and others, 1986a)

Other Relevant Information:

Elsinore in 1921 was a small farming town of 1,000 inhabitants founded by the Mormon pioneers. Its oldest buildings were of sun-dried bricks or of angular fragments of black basaltic lava, built during the nearly fifty years the town had no railroad connection and had to haul supplies overland from Omaha or later Salt Lake City. Houses constructed after the advent of the railroad were not as primitive as the older ones. The church and the schools were the best class of buildings in town, both being made of brick and reinforced concrete. (Pack, 1921)

Isoseismal Map and Discussion

The intensities assigned in this study for the first large 1921 shock are listed in table 4 and shown in figures 3(b) and 5. The maximum intensity, VIII M.M., was assigned only to Elsinore. Pack calls the intensity at Elsinore "fully VIII" R.F. As can be seen from table 1, VIII R.F. ranges from VII to VIII M.M., so VIII M.M. is in agreement with his assignment. The lack of damage to the old stone school, to the modern church, and to wood-frame houses gives additional support to this assignment.

TABLE 4. Modified Mercalli Intensities for the Earthquake of 1921 September 29 07:12

Lat (°N.)	Lon (°W)	I ¹	Location
38.70000	-112.10000	UT	epicenter
38.67000	-112.17000	8 UT	ELSINORE
38.63000	-112.24000	F ² UT	ELSINORE, 5 MI SW OF
38.62000	-112.22000	7 UT	JOSEPH
38.63000	-112.10000	7 UT	MONROE
38.76667	-112.10000	7 UT	RICHFIELD

¹ Modified Mercalli site intensities.

² F="Felt." Insufficient information for a M.M. intensity.

Pack also reports that the shock "did considerable damage" at Monroe, "shattered a few chimneys" at Joseph and Richfield, but beyond those locations was "scarcely more than noticeable." It was not felt at all, he reports, 25 miles (40 km) away. On the basis of this information, Monroe may be assigned an intensity of perhaps VII⁺ and Joseph and Richfield, VII.

Pack does not give a felt area but his 40-km radius suggests a felt area of about 5,100 km². This is about twice as big as the felt area of 1,000 mi² (2,600 km²) suggested by Williams and Tapper (1953). In either case, a felt area of 2,500–5,000 km² is quite small for a shock with a maximum intensity of VIII M.M. For comparison, the maximum intensity-VIII 1934 earthquake in Hansel Valley, had a felt area of 170,000 mi² (440,000 km²) (Coffman and others, 1982).

1921 SEPTEMBER 29 19:30

Date

1921 September 29 7:30 p.m. (Pack, 1921)

1929 September 29 6:30 p.m. PST (Townley and Allen, 1939)

1921 September 29 19:30 MST (Williams and Tapper, 1953)

1921 September 30 02:30 UTC (Arabasz and McKee, 1979)

1921 September 29 19:30 MST (Coffman and others, 1982)

1921 September 30 02:30 UTC (Stover and others, 1986a)

Maximum Intensity

"Of slightly less severity" than the morning shock (Pack, 1921)

VII or probably VIII R.F. at Monroe (Pack, 1921)

VII⁺ R.F. (Townley and Allen, 1939)

VII M.M. (Williams and Tapper, 1953)

7 M.M. (Arabasz and others, 1979)

VII M.M. (Coffman and others, 1982)

VII M.M. (Stover and others, 1986a)

Magnitude

Magnitude 5.7 derived from $M=1+\frac{2}{3}I_0$ of Gutenberg and Richter (1956). (Arabasz and McKee, 1979)

Felt Area

"In no case...were any of the earthquakes felt over a wide range of country. People living as little as twenty-five miles distant did not know of the occurrences except as later informed." (Pack, 1921)

"Shocks, though strong locally, were not widely felt." (Townley and Allen, 1939)

Sevier Valley. 1,000 mi² (2,600 km²) (Williams and Tapper, 1953)

"Not felt 25 mi away." (Stover and others, 1986a)

Epicenter

"At Elsinore it seems to have had an intensity if VII [R.F.] and at Monroe of VII or probably VIII [R.F.]." (Pack, 1921)

Elsinore, Monroe, and Joseph, Sevier County. (Townley and Allen, 1939)

Elsinore, Sevier Valley (Williams and Tapper, 1953)

38° 40.97' N., 112° 8.98' W. (38.68° N., 112.15° W.) (Arabasz and McKee, 1979)

Elsinore. 38.8° N., 112.2° W. (Coffman and others, 1982)

38.7° N., 112.1° W. (Stover and others, 1986a)

Damage—Not Site Specific

"Damage to chimneys and brick walls." (Townley and Allen, 1939)

[Included in description of the 07:12 shock above] (Williams and Tapper, 1953)

Damage—Site Specific

[Presumably at Elsinore] "At 7:30 p.m., on September 29th...another [shock] of slightly less severity was experienced. A good many chimneys were thrown down and the general damage occasioned by the previous disturbance was materially increased... At Elsinore it seems to have had an intensity if VII [R.F.]." (Pack, 1921)

"In the nearby town of Monroe this shock was more destructive than the one occurring twelve hours earlier... This disturbance did not last as long as the one in the morning... At Monroe [it had an intensity] of VII or probably VIII [R.F.]." (Pack, 1921)

"The second major disturbance threw down a few chimneys at Elsinore, but was much more destructive at Monroe than was the first one twelve hours earlier. It was felt only slightly at Richfield and Joseph, each seven miles distant." (Pack, 1921)

Elsinore, Utah. A good many chimneys were thrown down and the general damage was materially increased from the previous shock. The damage was more destructive in Monroe, Utah than the September 29 earthquake." (Stover and others, 1986a)

Isoseismal Map and Discussion

The intensities assigned in this study for the second large 1921 earthquake are listed in table 5 and shown in figures 3(c) and 6. Pack concludes that this shock was "of slightly less severity" than the shock earlier in the same day, and gives an intensity of VII or probably VIII R.F. (VII-VIII M.M.) at Monroe. He also says that at Monroe the shock was more destructive than the morning shock, although not lasting as long. The only damage he mentions were more chimneys thrown down and more damage to buildings already damaged by the morning shock. This suggests a maximum intensity of VII or VII⁺ M.M., located at Monroe. He says the second shock was stronger at Monroe than at Elsinore where it threw down a few more (already weakened) chimneys. At Joseph and Richfield, he reports that it was "felt only slightly."

TABLE 5. Modified Mercalli Intensities for the Earthquake of 1921 September 29 19:30

Lat (°N.)	Lon (°W)	I ¹	Location
38.70000	-112.10000	UT	epicenter
38.67000	-112.17000	6 UT	ELSINORE
38.62000	-112.22000	F ² UT	JOSEPH
38.63000	-112.10000	7 UT	MONROE
38.76667	-112.10000	F ² UT	RICHFIELD

¹ Modified Mercalli site intensities.

² F=“Felt.” Insufficient information for a M.M. intensity.

As with the morning earthquake, the second shock is estimated to have a felt area of 2,500–5,000 km².

1921 OCTOBER 1 08:32

Date

1921 October 1 8:32 a.m. (Pack, 1921)

1921 October 1 7:32 a.m. PST (Townley and Allen, 1939)

1921 October 1 08:32 MST (Williams and Tapper, 1953)

1921 October 1 15:32 UTC (Arabasz and McKee, 1979)

1921 October 1 08:32 MST (Coffman and others, 1982)

1921 October 1 15:32 UTC (Stover and others, 1986a)

Maximum Intensity

VIII R.F. “just about the same as the one of two days earlier. The former disturbance, however, wrought considerably more damage, but this is probably explained by the fact that it lasted longer, rather than that it was actually more violent.” (Pack, 1921)

VIII R.F. (Townley and Allen, 1939)

VIII M.M. (Williams and Tapper, 1953)

8 M.M. (Arabasz and McKee, 1979)

VIII M.M. (Coffman and others, 1982)

VIII M.M. (Stover and others, 1986a)

Magnitude

Magnitude 6.3 derived from $M=1+\frac{2}{3}I_0$ of Gutenberg and Richter (1956). (Arabasz and McKee, 1979)

Felt Area

“In no case...were any of the earthquakes felt over a wide range of country. People living as little as twenty-five miles distant did not know of the occurrences except as later informed.” (Pack, 1921)

1,000 mi² (2,600 km²) (Williams and Tapper, 1953)

“Not felt 25 mi away.” (Stover and others, 1986a)

Epicenter

Elsinore (Townley and Allen, 1939)

Elsinore, Sevier Valley (Williams and Tapper, 1953)

38° 40.97' N., 112° 8.98' W. (38.68° N., 112.15° W.) (Arabasz and McKee, 1979)

Elsinore. 38.8° N., 112.2° W. (Coffman and others, 1982)

38.7° N., 112.1° W. (Stover and others, 1986a)

Damage—Not Site Specific

“Brick and stone buildings rendered uninhabitable; ‘ten more residences were so wrecked by this morning’s shock as to be uninhabitable.’ *Deseret News*, October 1, 1921.” (Williams and Tapper, 1953)

“Car swung around on road and nearly overturned. Man thrown from high bank of river, where he was seated, to water’s edge. Small disturbances noted all night and all day yesterday after the big shock. *Salt Lake Tribune*, October 2, 1921.” (Williams and Tapper, 1953)

“Large rock falls were caused on both sides of the valley. Warm springs on both sides were discolored for hours with iron oxides.” (Williams and Tapper, 1953)

TABLE 6. Modified Mercalli Intensities for the Earthquake of 1921 October 1 08:32

Lat (°N.)	Lon (°W.)	I ¹	Location
38.70000	-112.10000	UT	epicenter
38.67000	-112.17000	7 UT	ELSINORE
38.62000	-112.22000	F ² UT	JOSEPH
38.63000	-112.10000	6 UT	MONROE
38.76667	-112.10000	F ² UT	RICHFIELD
38.95000	-111.85000	F ² UT	SALINA

¹ Modified Mercalli site intensities.

² F="Felt." Insufficient information for a M.M. intensity.

"At 08:32 on October 1, there was yet another shock, like the blow of a great hammer, unaccompanied by noise except the creaking of buildings and falling of chimneys; it was probably of intensity VIII. Great clouds of dust arose because of the very dry country." (Coffman and others, 1982)

Damage—Site Specific

Pack (Pack, 1921) was in (presumably) Elsinore at the time of the third large shock. He "was standing on a lawn in front of a two-story brick residence and across the street from a line of store buildings... The blow was as quick and as short as the detonation of a cannon at a gunner's side. In fact the effect when standing in the open was not altogether unlike that experienced when a nearby field piece is discharged... The trees were shaken as violently as a school boy shakes a limb when stealing his neighbor's fruit... The various walls [presumably of the brick residence mentioned above] were not [synchronous] in the same direction, but rather in opposite directions, in and out, as if the building were inflated and deflated in quick succession... Furthermore, every brick appeared to be loosened from contiguous ones... The entire structure looked as if it would tumble into a heap at any instant, and yet it suffered nothing more than the loss of some plaster and a chimney or two... The noise arising from creaking houses and falling chimneys came in from every part of the town and sounded not unlike the clattering of many horses feet on a wooden floor... The dust arising from the shock was fully as dense as that occasioned by a sudden wind storm. About a hundred yards from where the writer stood a store front was projected violently into the street." (Pack, 1921)

"Of the three major disturbances the one occurring at 8:32 on the morning of October 1st appears to have been the most highly localized. It was very severe at Elsinore but constituted scarcely more than a well-defined tremor in each of the other towns, and in them was attended by no property damage, except a little at Monroe. At Elsinore, however, this shock caused much loss to property and undoubtedly would have equaled that of two days earlier had the disturbance lasted as long." (Pack, 1921)

"Slight damage at Monroe; barely noticed at Richfield and Joseph. BSSA [Bulletin of the Seismological Society of America], 11, 155." (Townley and Allen, 1939)

"Monroe city hall, built of rock, shattered. Reported felt from Salina to Marysville. *Deseret News*, October 1, 1921." (Williams and Tapper, 1953)

"The greatest damage to any single structure was done to the new brick school house in Elsinore. The greatest aggregate damage was to residences. Practically all chimneys in the town were thrown down or shaken loose. Buildings that suffered much general damage were those made of rubblework and adobe. Brick buildings suffered less, except the schoolhouse; and lumber buildings little or none." (Williams and Tapper, 1953)

"Elsinore, Utah. Very localized earthquake, barely felt in other towns. Additional chimneys fell, additional damage to buildings. The store building cracked by the September 29 shock was thrown down entirely by this earthquake. The worst damage was to buildings of stone or sun-dried brick construction." (Stover and others, 1986a)

Isoseismal Map and Discussion

The intensities assigned in this study for the third large 1921 earthquake are listed in table 6 and shown in figures 3(d) and 7. The highest intensity assigned in this study was VII M.M. at Elsinore. This is lower than the intensity, VIII R.F. (VII-VIII M.M.), assigned by Pack and cited by all other later researchers. Note, however, that Pack actually experienced the third shock himself and was quite impressed by it. This, plus greater damage due to weakening of structures by the previous shocks, may account for his assignment of as high a maximum intensity to the third large shock as to the first one. He admits that the first shock "caused considerably more damage" and "lasted longer" than the third.

Like the two previous shocks, this one is estimated to have a small felt area of 2,500–5,000 km². However, based on Pack's assertion that it was "the most highly localized" of the three shocks, and that it was "scarcely more than a well-defined tremor" at Richfield and Joseph, the felt area seems likely to be smaller than that of the first shock.

CONCLUSIONS

The four earthquakes studied are assigned maximum intensities of VIII, VIII, VII, and VII M.M., respectively (see table 7). Site intensities are assigned to each account and the isoseismal maps are shown in figures 3–7.

TABLE 7. Summary of Findings

Year	1901	1921	1921	1921
Date	Nov. 13	Sept. 29	Sept. 29	Oct. 1
Time ¹	21:30	07:12	19:30	08:32
Intensity ²	VIII ⁺	VIII	VII	VII
Latitude	38.7° N.	38.7° N.	38.7° N.	38.7° N.
Longitude	121.1° W.	121.1° W.	121.1° W.	121.1° W.
Felt Area ³	≤130,000	2,500–5,000	2,500–5,000	2,500–5,000

¹ Mountain Standard Time.

² Maximum Modified Mercalli intensity.

³ In km².

Felt areas for the 1921 shocks are found to be quite small, on the order of 2,500–5,000 km². The felt area of the 1901 shock is even less certain but it is unlikely to be any larger than the 130,000 km² given by Williams and Tapper. Moreover, the similarity of the 1901 damage reports to the 1921 damage reports suggests that its felt area should be only a little larger than theirs. It is not possible, with the accounts available at this time, to determine if damage-level intensities from the 1901 shock extended much farther than those of 1921. In particular, it is not possible to say with any certainty whether there could have been intensities high enough to cause damage (VI M.M.) within the now heavily populated Wasatch Front region south of Salt Lake City.

The rapid attenuation of intensities from high epicentral intensities indicates a very shallow source for these earthquakes. Although depths are unknown, they are presumably similar to depths of other regional earthquakes with similar felt areas. For example, the felt area of the 1901 shock is comparable to the felt area of the 1975 Pocatello Valley (Malad

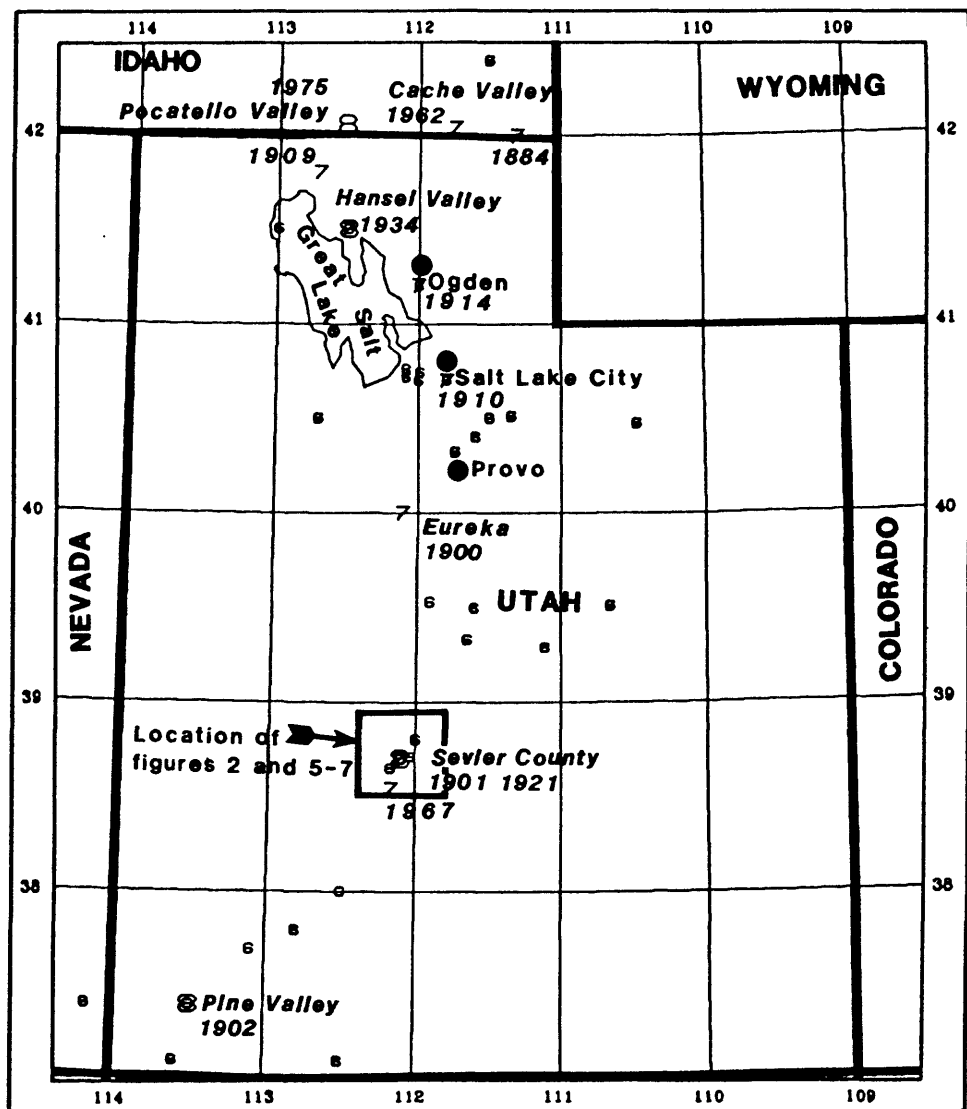
City), Idaho, shock (I_0 =VIII, felt area=160,000 km², depth=5 km) (Coffman and Stover, 1977) and to the felt area of the 1962 Cache Valley, Idaho, shock (I_0 =VII, felt area=168,000 km², depth=7 km) (Arabaz and McKee, 1979; Lander and Cloud, 1964).

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Historical Epicenters with Maximum Intensity of VI M.M. or Greater
(Stover and others, 1986a, 1986b)

0 50 100 150 200 250 KILOMETERS

Figure 1. Regional historical seismicity for the state of Utah. Arabic numbers indicate locations of historical epicenters and their maximum Modified Mercalli intensities. The rectangle shows the location of figures 2 and 5-7.

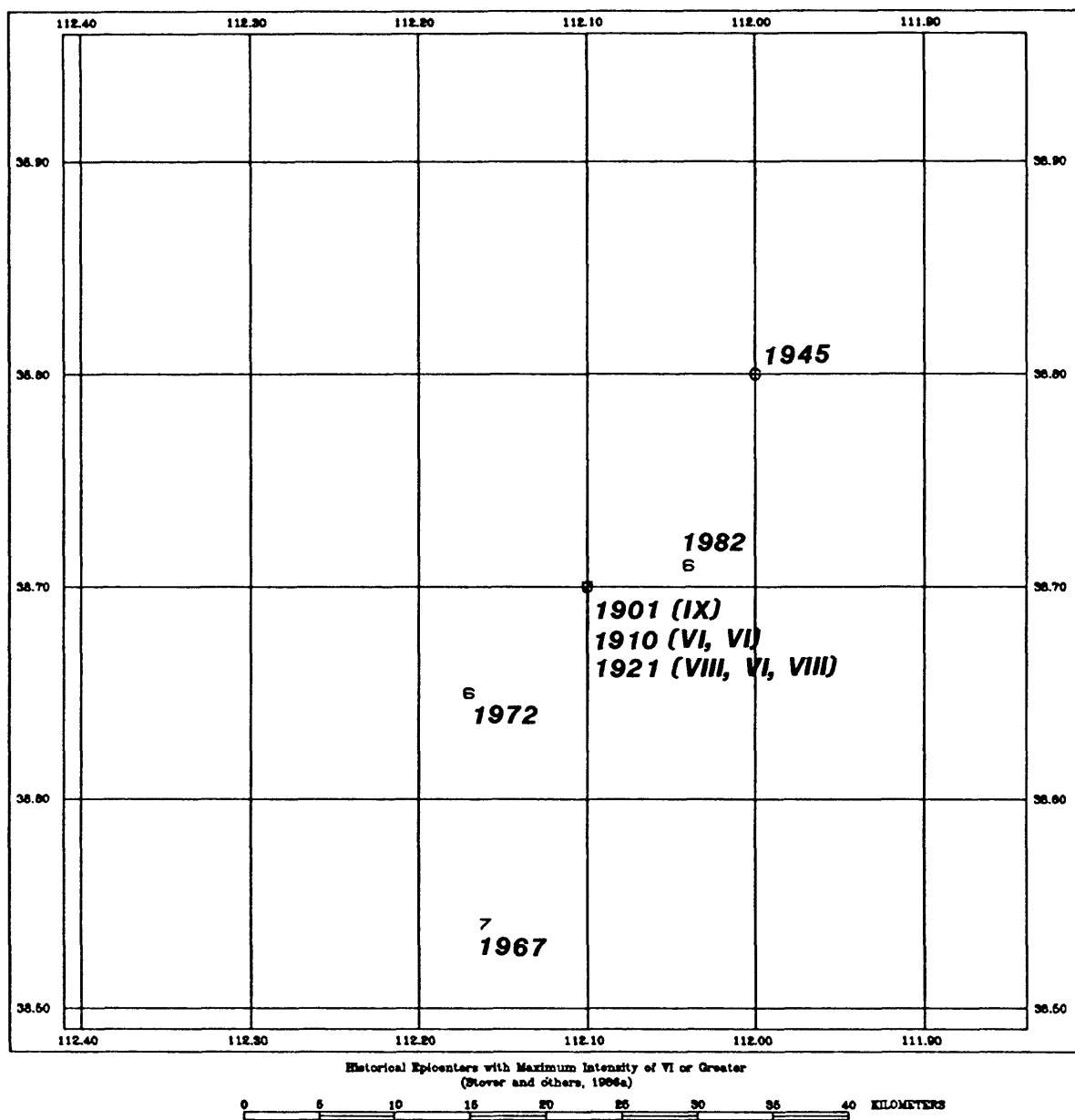
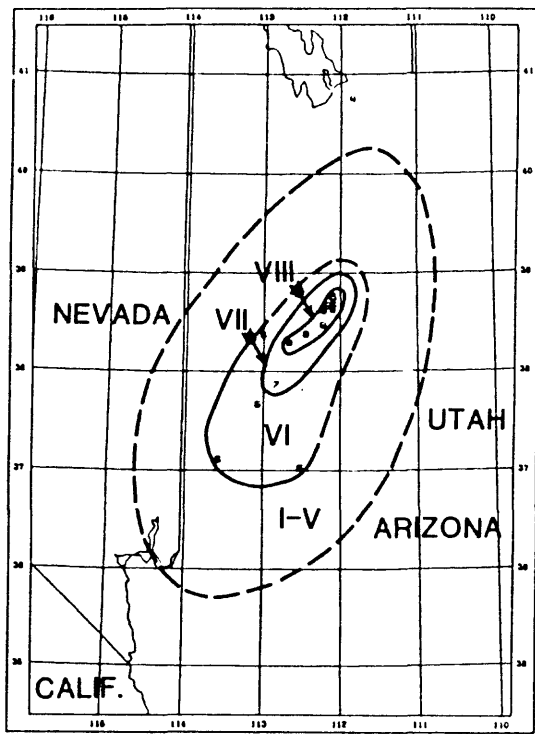
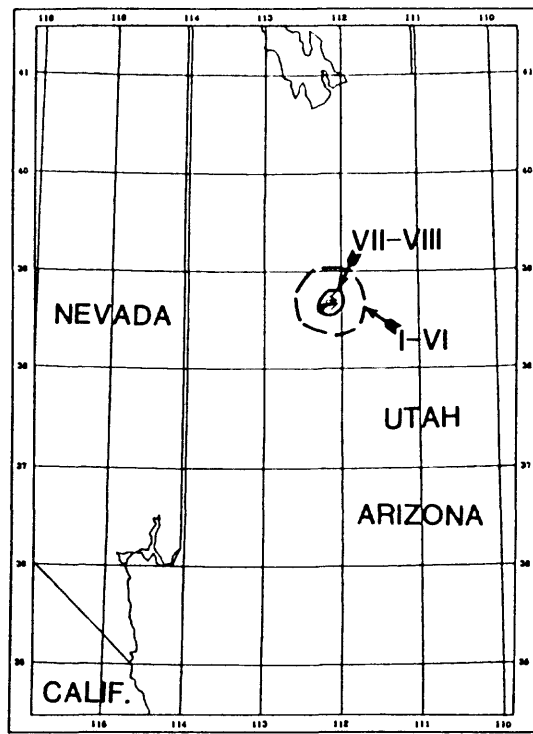


Figure 2. Historical seismicity in Sevier County, Utah. Arabic numbers indicate locations of historical epicenters and their maximum Modified Mercalli intensities.



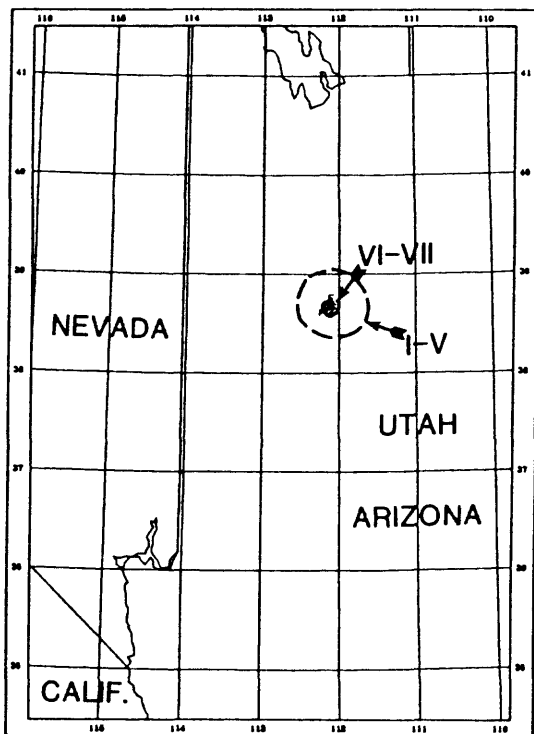
(a)

1901 11 13



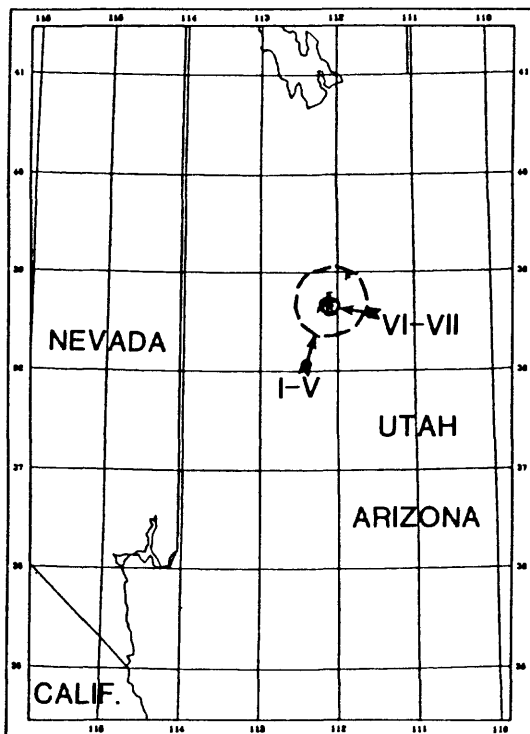
(b)

1921 09 29 7 12



(c)

1921 09 29 19 30



(d)

1921 10 01

Figure 3. Isoseismal maps for the Sevier County, Utah, earthquakes of (a) 1901 November 13 (b) 1921 September 29 (07:12), (c) 1921 September 29 (19:30), and (d) 1921 October 1. The numbers indicate site intensities and the roman numerals indicate isoseismal intensities (Modified Mercalli). 'F' is used for reports that were not assigned Modified Mercalli intensities. Isoseismals (dashed where uncertain) are by the author. The outer dotted 'isoseismals' for the three 1921 shocks are circles of 40-km radius based on Pack's assertion that these shocks were not felt 40-km from their epicenters.

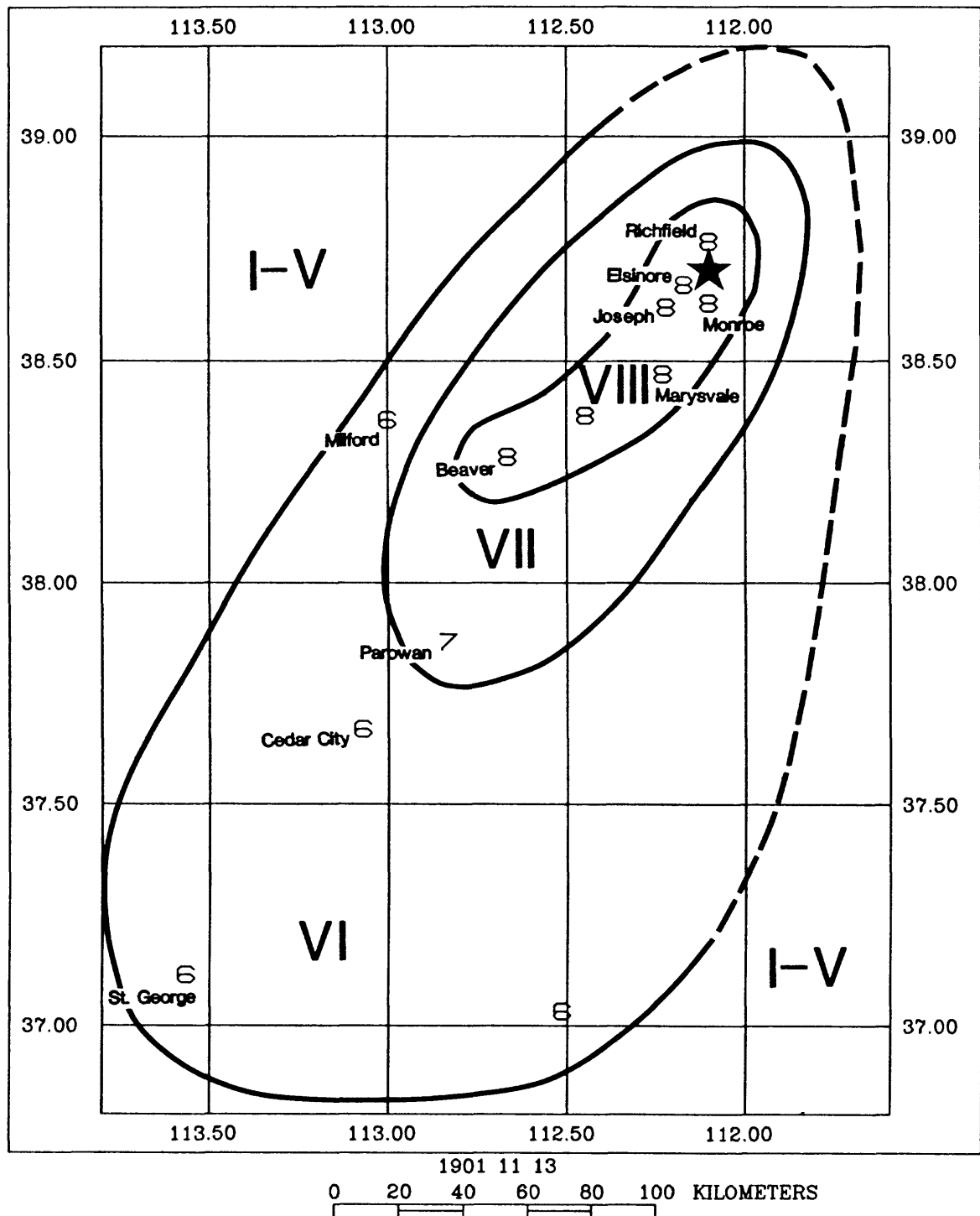


Figure 4. Iseismal map for the earthquake of 1901 November 13, in Sevier County, Utah. Arabic numbers represent Modified Mercalli site intensities; roman numerals represent isoseismal intensities; a star is at the epicenter. The maximum intensity assigned is VIII M.M. The areas of the VII and VI isoseismals agree well with Townley and Allen's (1939) estimates. The outer isoseismal (shown only on figure 3(a)) has been drawn to fit Williams and Tapper's (1953) estimated 130,000 km² felt area. There is an isolated intensity-IV site at Salt Lake City, beyond the presumed outer boundary of the main felt area.

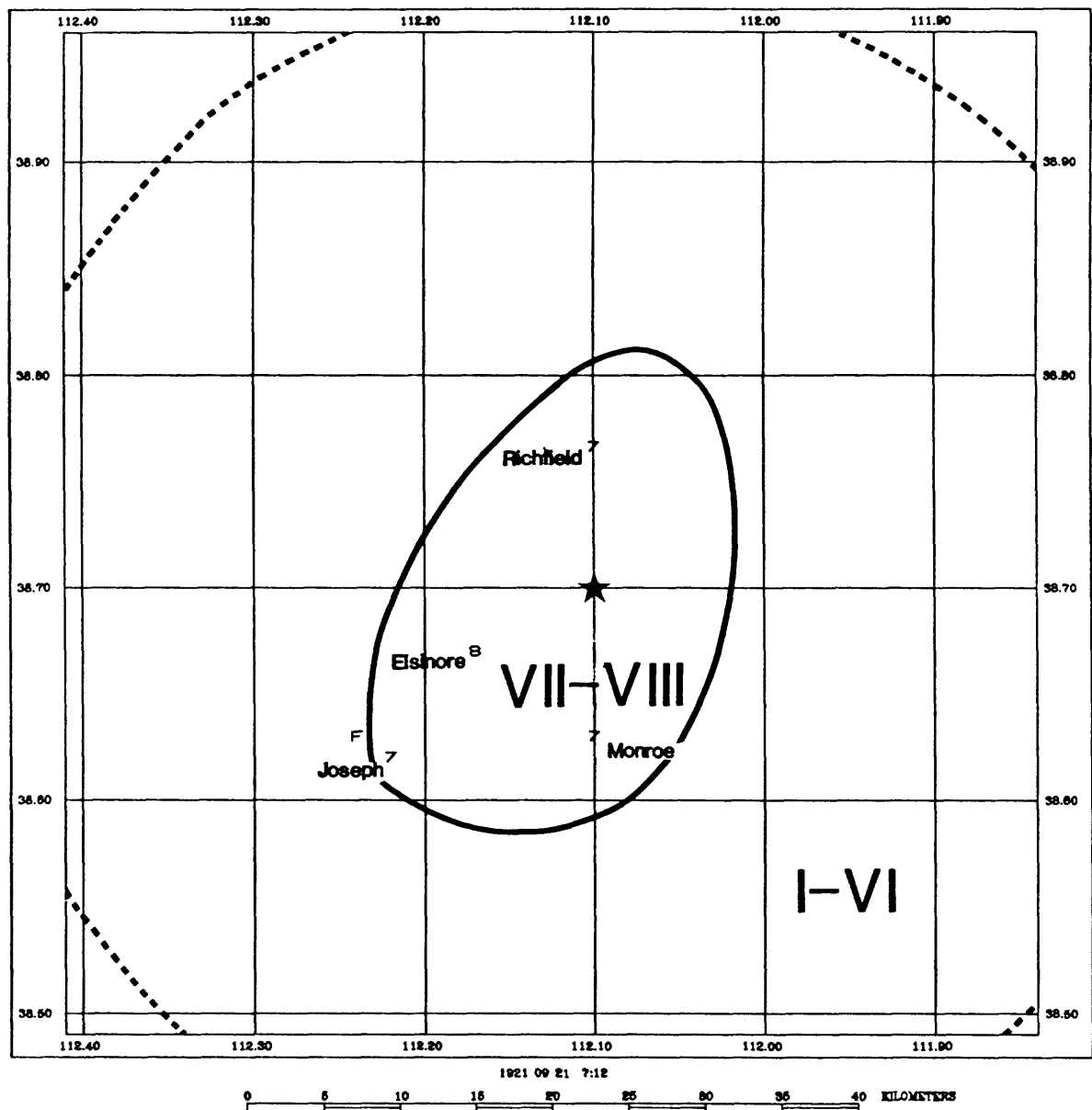


Figure 5. Isoseismal map for the earthquake of 1921 September 29 (07:12) in Sevier County, Utah. Arabic numbers represent Modified Mercalli site intensities; roman numerals represent isoseismal intensities; a star is at the epicenter. The maximum intensity assigned is VIII M.M. The outer dotted isoseismal is a circle of 40-km radius, based on Pack's assertion that the shock was not felt 40 km from the epicenter. This is a larger felt area than Townley and Allen's suggested 2,500 km².

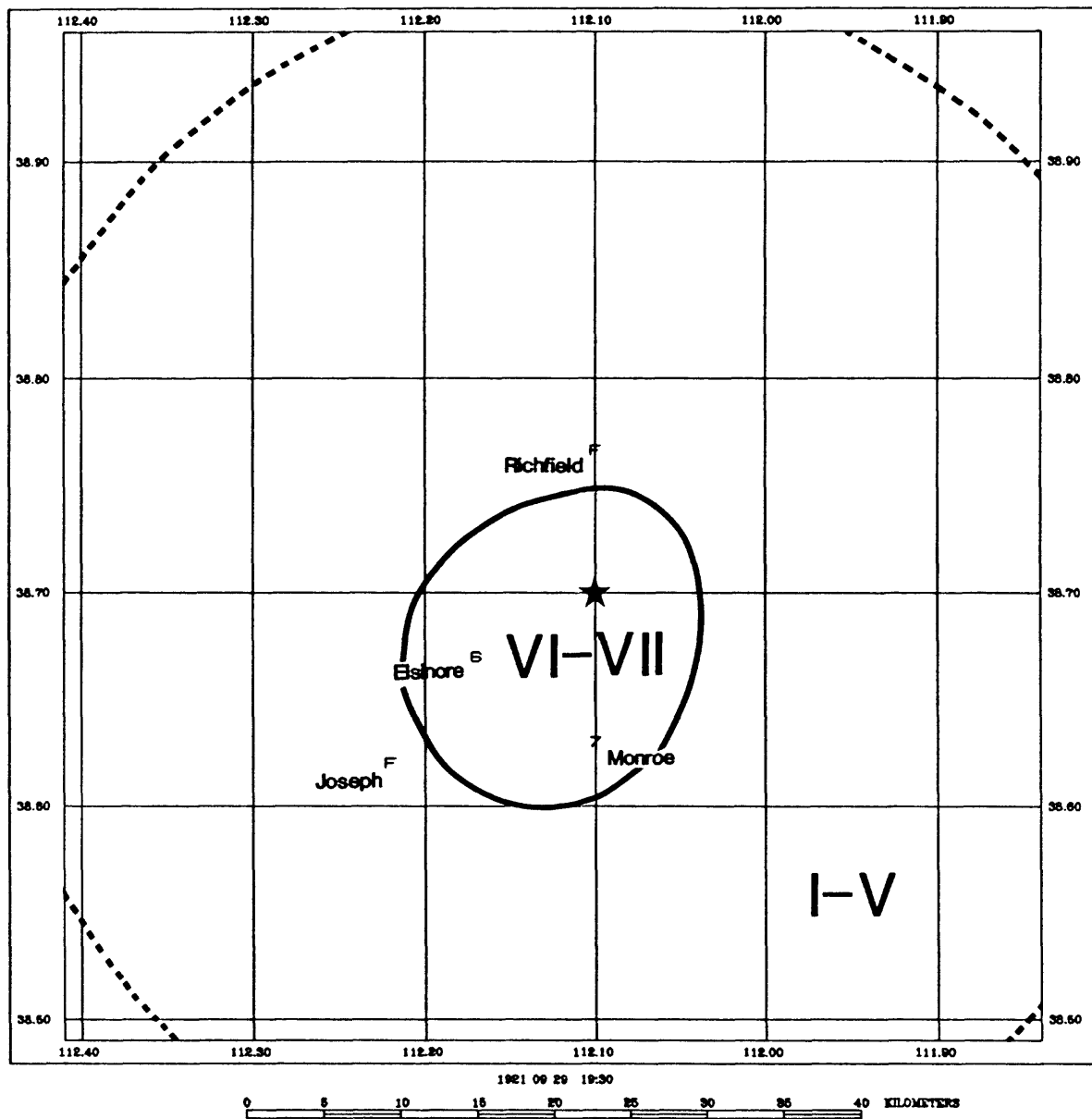


Figure 6. Isoseismal map for the earthquake of 1921 September 29 (19:30) in Sevier County, Utah. Arabic numbers represent Modified Mercalli site intensities; roman numerals represent isoseismal intensities; a star is at the epicenter. The maximum intensity assigned is VII M.M. The outer dotted isoseismal is a circle of 40-km radius, based on Pack's assertion that the shock was not felt 40 km from the epicenter. This is a larger felt area than Townley and Allen's suggested 2,500 km².

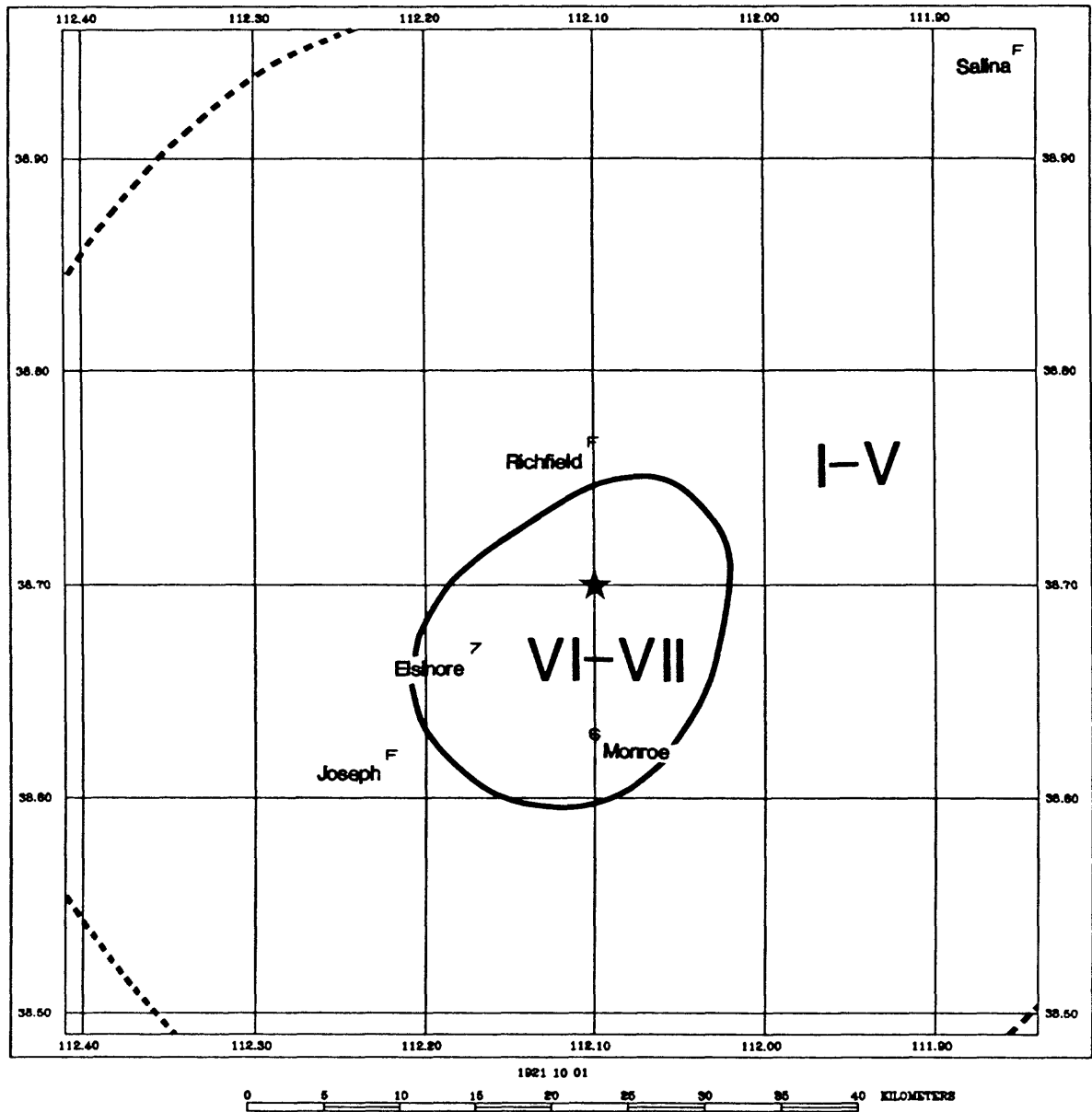


Figure 7. Isoseismal map for the earthquake of 1921 October 10 in Sevier County, Utah. Arabic numbers represent Modified Mercalli site intensities; roman numerals represent isoseismal intensities; a star is at the epicenter. The maximum intensity assigned is VII M.M. The outer dotted dotted isoseismal is a circle of 40-km radius, based on Pack's assertion that the shock was not felt 40 km from the epicenter. The outer isoseismal has been slightly extended in the northeast corner in order to include the felt report at Salina. This is a larger felt area than Townley and Allen's suggested 2,500 km².