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Photo courtesy U.S. Geological Survey.

SANTA ROSA EARTHQUAKES

High altitude photograph of the northern portion of the San Francisco Bay area. Santa Rosa is to left center, Lake Berryessa near upper center, San Pablo Bay on right. View approximately east toward fog-filled Sacramento Valley.

STATE OF CALIFORNIA ▪ THE RESOURCES AGENCY ▪ DEPARTMENT OF CONSERVATION ▪ DIVISION OF MINES AND GEOLOGY

THE SANTA ROSA EARTHQUAKES OF OCTOBER, 1969

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On October 1, 1969, the city of Santa Rosa was severely shaken by two earthquakes. These quakes were distinctly felt throughout the San Francisco Bay Area, but it was in Santa Rosa where the most damage was done. The quakes were the most severe to hit that city since 1906, when Santa Rosa experienced catastrophic destruction, along with San Francisco.

Santa Rosa is 50 miles north of San Francisco and has a population of about 49,000, most of whom live in single family dwellings. It is the seat of Sonoma County and a center of light industry, agriculture and merchandising. The city is on the east side of Santa Rosa Valley, an intermontane valley of the Coast Ranges, bounded on the west by the Mendocino Range and on the east by the Sonoma and Mayacmas Mountains.

Many earth scientists in the Bay Area have contributed to this special edition on the Santa Rosa Earthquake, indicative of the cooperative efforts of several Federal, State, and private agencies in studying the effects of this event in order to gain a better understanding of earthquake phenomena.

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D. B. Eisman, Division of Mines and Geology, edited some of this special edition.

Mr. Huffman, who submitted the introductory paragraphs, was able to give us this interesting account of "how it was" the night of the quake, because he was there.

The astonished residents of Santa Rosa gave no thought to epicenters, magnitudes, or faults in those first moments when the onslaught of the quake at 9:56 p.m. plunged their pitching dwellings into darkness. Each individual lived those few moments intensely *there* in the overwhelming grip of the natural events which had so suddenly seized him.

First came the state of dumfounded bewilderment, before recognition that the increasing rumble of his vibrating dwelling and the clatter of falling books, dishes, lamps and even television sets meant an earthquake was occurring. Then, moments of fear as the tempo of shaking reached its peak and the thought of loved ones, falling debris, and injury entered his mind. Parents groped and staggered their way into darkened bedrooms to rescue their now awakened children. Persons stumbled to get outside onto their lawns and as they did so, saw the skyline flashing eerily as, in neighborhood after neighborhood, the lights flashed rapidly on and off before finally going out. Drivers were jerked about by automobiles suddenly bucking unmanageably, some even swerving into adjacent lanes.

Electric power was restored in most areas quickly, but some remained dark until well after the second main tremor at 11:19 p.m. Telephone lines were jammed and service often irregular as relatives tried to contact one another and others sought information.

Traffic became heavy, for such a late hour on a Wednesday, as people travelled about to check up on kin. Little groups of people stood about on their front lawns, undecided about returning inside lest another, more serious, tremor occur. Liquor stores had become reeking pools of broken glass and spirits, and businessmen hurried to their stores to check the damage.

By morning, the assessment began, and would continue for months to come. It was a costly quake, but luckily—almost miraculously—not a life was lost. Now , the scientists and engineers began their evaluation and analysis, which is not complete even as we go to press. Their aim , to understand better the causes and results; hopefully, to be better prepared for the future.—*M.E.H.*

MAGNITUDES, EPICENTERS, AND FAULT PLANE SOLUTIONS

The two earthquakes of magnitudes 5.6 and 5.7 that shook the Santa Rosa area were felt generally as far away as the southern parts of San Francisco Bay. Another shock, 3.5, was registered in the interval between the two major ones, and two aftershocks, with magnitudes of 3.4 and 4.3, followed early the next morning.

The epicenters of these shocks were very closely grouped in an area about two miles north of Santa Rosa. The focal depths of the two main events were 9.6 and 10.4 kms. The smaller shocks were located with less accuracy than the larger ones, because fewer instruments in the University's network recorded the small earthquakes, but these seem to have been of the order of 10 kms. deep.

The accompanying table lists all these shocks. Accuracy of data is greater for those earthquakes for which latitude and longitude are stated in minutes and tenths of minutes.

The area around Santa Rosa has had a fairly active seismic history. The most recent moderate-size earthquake before October 1969 was a magnitude 4.6 shock on April 25, 1968, in nearly the same place. Since then, shocks have occurred nearby on January 15, 1969 (M 3.0), July 18 (M 2.5) and August 17 (M 2.6).

Going back a little further, the University of California Seismographic Station has recorded 23 shocks with magnitudes of more than 2.5 in the general vicinity of Santa Rosa since 1961. This was the year that the University of California telemetered seismographic network began operation. The 23 epicenters are marked on the accompanying map. Uncertainty in location is greatest for the smaller events.

Going back still further, the composite earthquake file on magnetic tape at Berkeley was searched for all earthquakes that have been reported through 1967, centered in the vicinity of Santa Rosa. This list appears on page 46.

The taped file encompasses the Pacific coast earthquake catalogue of Sidney Townley and Maxwell Allen, which goes back two centuries to the arrival of the white man in California, but the first earthquake reported in the Santa Rosa vicinity is 1855.

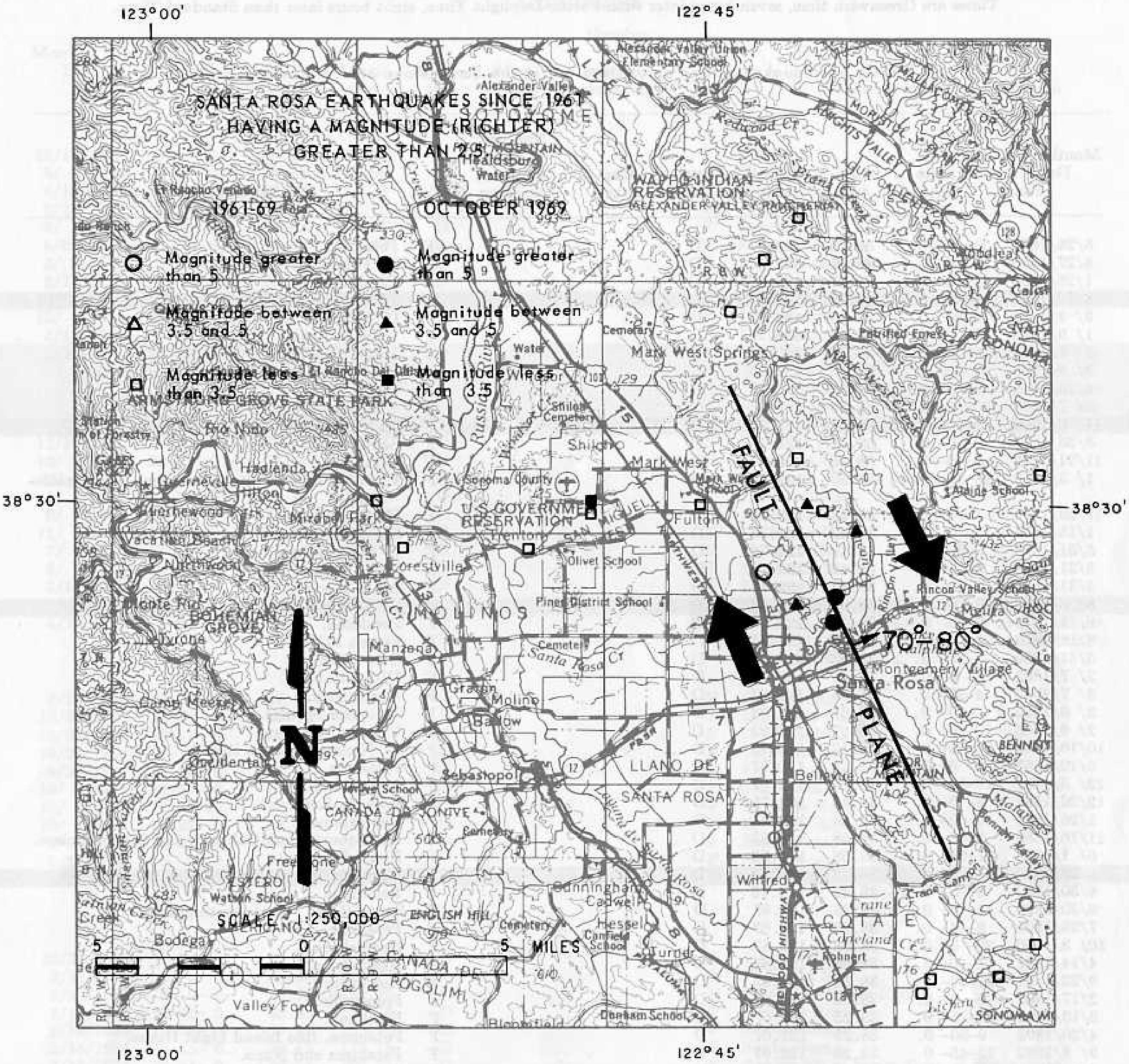
Since seismographs to determine epicenters accurately were not used in California until late in the 19th century, the location for most of the listed quakes are based on the reports of people who felt the events. For the past 30 years, however, seismologists have been able to assign epicenters more confidently, based on instrumental data, and some of the coordinates listed for events since the late 1940s were derived from such data. Increasing accuracy in instrumental epicenters is reflected in the column marked "Quality"; since 1963, the reliability and array of groundshaking sensors has been such that all epicenter determinations have been of "excellent" quality.

Detailed fault plane solutions, based on the radiation pattern of the P-waves, exist for the two large shocks of October, as well as for the April 1968 shock. These all show, very clearly, right lateral motion on a fault plane striking roughly parallel to the Healdsburg fault to the northwest. Smaller earthquakes, while they do not provide widely recorded first motion data for such analyses, generally show the same patterns at the near stations where first motions were clearly recorded. The first-motion data are indicative of a non-vertical fault plane, the three well-determined fault plane solutions giving dips of 70 to 80 degrees northeast. The indicated mechanism is shown on the map on page 45.

The October 1969 Santa Rosa earthquakes were not anomalous. Rather they reflect the historical record of repeated moderately strong earthquakes and earthquake sequences in the region. The zone of activity just north of town seems to be a region of concentrated moderately deep shocks. The larger earthquakes in this region seem to have minor aftershock sequences, a phenomenon probably related to the concentrated source region and to the depth of the shocks. The mechanisms of the earthquakes appear to be right lateral slip on steeply dipping fault planes roughly parallel to the Healdsburg fault to the northwest or the Hayward fault to the southeast. This mechanism seems characteristic of earthquakes in the Coast Ranges east of the San Andreas fault in the Bay Area and northward.—*T.V.M.*

Santa Rosa earthquakes of October, 1969

Date	*Pacific Daylight time*			*Latitude (N)*		*Longitude (W)*		*Magnitude*	*Depth*
	h.	*m.*	*s.*	*deg.*	*min.*	*deg.*	*min.*		*km.*
Oct. 1	21	56	46.5	38	28.0	122	41.5	5.6	9.6
	22	14	21	38.5		122.7		3.5	–
	23	19	57.1	38	27.3	122	41.5	5.7	10.4
Oct. 2	00	10	09	38.5		122.8		3.4	–
	05	27	05.5	38	29.4	122	41.0	4.3	5.7
Oct. 6	07	28	07.6	38	27.7	122	42.8	3.9	14.2



Map of Santa Rosa area showing epicenters of earthquakes of magnitudes greater than 2.5.

SANTA ROSA EARTHQUAKE HISTORY, 1855–1967

Quality: A = excellent quality of epicenter determination, B = good, C = fair, D = poor.
Times are Greenwich time, seven hours later than Pacific Daylight Time, eight hours later than Standard Time.

Only earthquakes whose epicenters are in the Santa Rosa area are included.

Month Day Year	Hour Minute Second	Latitude	Longitude	Quality	Magnitude	Number of stations recording	Felt	Maximum intensity, comments
8/26/1855	21– 0– 0.	38.25	122.67	D			F	Petaluma.
8/27/1855	23– 0– 0.	38.25	122.67	D			F	VI Petaluma.
1/28/1856	11– 0– 0.	38.25	122.67	D			F	Petaluma.
8/19/1858	6–45– 0.	38.25	122.67	D			F	VI Sonoma County.
9/ 9/1859	17–30– 0.	38.25	122.67	D			F	IV Petaluma. Two shocks.
1/ 9/1865	15– 0– 0.	38.42	122.75	D			F	V Santa Rosa.
3/ 5/1865	0– 0– 0.	38.25	122.67	D			F	Petaluma. Night.
3/ 8/1865	14–30– 0.	38.42	122.75	D			F	VIII Santa Rosa, Petaluma, and Napa.
4/23/1868	0– 0– 0.	38.58	122.83	D			F	Healdsburg.
5/ 7/1868	20– 0– 0.	38.58	122.83	D			F	V Healdsburg.
11/ 8/1868	0– 0– 0.	38.42	122.75	D			F	VI Santa Rosa.
8/25/1871	0– 0– 0.	38.42	122.75	D			F	Santa Rosa.
11/21/1872	0– 0– 0.	38.25	122.67	D			F	Petaluma.
1/ 3/1876	18–55– 0.	38.50	122.83	D			F	VI Santa Rosa, Fulton, Freestone, and Healdsburg.
11/29/1876	1–10– 0.	38.42	122.75	D			F	III Santa Rosa.
1/15/1877	15– 0– 0.	38.42	122.75	D			F	Santa Rosa.
5/31/1878	5–30– 0.	38.42	122.75	D			F	IV Santa Rosa.
5/31/1878	6– 0– 0.	38.42	122.75	D			F	Santa Rosa.
5/31/1878	6–30– 0.	38.42	122.75	D			F	Santa Rosa.
8/ 2/1878	3–30– 0.	38.50	122.92	D			F	VI Forestville.
9/11/1878	0– 0– 0.	38.25	122.67	D			F	Petaluma. Morning.
8/18/1879	0– 0– 0.	38.42	122.75	D			F	Fiske's Mills.
5/31/1880	0–20– 0.	38.42	122.75	D			F	Glen Ellen.
2/ 7/1882	15– 0– 0.	38.42	122.75	D			F	IV Santa Rosa.
3/ 7/1882	4–30– 0.	38.58	122.83	D			F	Healdsburg.
2/ 6/1885	7– 0– 0.	38.67	122.92	D			F	V Geyser Springs.
2/ 6/1885	10– 0– 0.	38.67	122.92	D			F	V Geyser Springs.
10/16/1885	12–45– 0.	38.42	122.75	D			F	IV Napa and Santa Rosa.
5/12/1887	0– 0– 0.	38.25	122.67	D			F	Petaluma.
12/ 5/1887	13–30– 0.	38.25	122.67	D			F	V Petaluma.
12/26/1887	8– 0– 0.	38.42	122.75	D			F	V Santa Rosa.
1/26/1888	0– 0– 0.	38.58	122.83	D			F	Healdsburg.
11/16/1889	3–55– 0.	38.58	122.83	D			F	Healdsburg, East Oakland, and San Francisco.
6/ 1/1890	21–21– 0.	38.58	122.83	D			F	Healdsburg.
6/29/1890	15–25– 0.	38.42	122.75	D			F	VI Santa Rosa. Three distinct shocks.
6/30/1890	0– 0– 0.	38.42	122.75	D			F	Petaluma.
6/30/1890	14– 0– 0.	38.25	122.67	D			F	Santa Rosa. Three earthquakes.
7/28/1890	8– 4– 0.	38.25	122.67	D			F	Petaluma.
10/ 3/1890	20– 5– 0.	38.58	122.83	D			F	Healdsburg.
4/14/1891	7–40– 0.	38.58	122.83	D			F	Healdsburg.
9/23/1891	21–30– 0.	38.58	122.83	D			F	Healdsburg.
2/17/1892	0– 0– 0.	38.50	122.92	D			F	Forestville.
3/13/1892	13–25– 0.	38.25	122.67	D			F	Petaluma.
4/20/1892	9–50– 0.	38.25	122.67	D			F	Petaluma, Roe Island Light House.
9/ 8/1892	12–45– 0.	38.25	122.67	D			F	Petaluma and Napa.
3/28/1893	7–30– 0.	38.42	122.75	D			F	Santa Rosa.
6/18/1893	13– 0– 0.	38.42	122.75	D			F	Santa Rosa.
8/ 9/1893	9–15– 0.	38.42	122.75	D			F	VIII Sonoma County. Santa Rosa—the severest since 1868. Petaluma—six shocks. Sonoma, Napa, Healdsburg, San Rafael, San Francisco, Alameda, Sacramento.
9/10/1896	11–45– 0.	38.42	122.75	D			F	Santa Rosa.
10/19/1896	14– 0– 0.	38.42	122.75	D			F	Santa Rosa.
1/ 1/1898	13–15– 0.	38.42	122.75	D			F	Peachland and Santa Rosa.
10/13/1899	5– 0– 0.	38.42	122.75	D			F	VIII Santa Rosa, Petaluma, and Peachland.
1/31/1900	0– 0– 0.	38.42	122.75	D			F	Peachland.
2/ 9/1900	12–30– 0.	38.25	122.67	D			F	VI Petaluma.
3/20/1900	0– 0– 0.	38.42	122.75	D			F	Peachland.
11/13/1900	17–59– 0.	38.50	122.92	D			F	IV Penn's Grove (Penngrove).
3/ 4/1903	0– 0– 0.	38.42	122.75	D			F	Santa Rosa.
2/15/1904	0– 0– 0.	38.58	122.83	D			F	Healdsburg.
8/21/1904	0– 0– 0.	38.58	122.83	D			F	Healdsburg.
10/14/1905	0– 0– 0.	38.42	122.75	D			F	Santa Rosa.

SANTA ROSA EARTHQUAKE HISTORY, 1855–1967

Continued

Month Day Year	Hour Minute Second	Latitude	Longitude	Quality	Magnitude	Number of stations recording	Felt	Maximum intensity, comments
12/15/1905	0- 0- 0.	38.42	122.67	D			F	Mercury.
5/ 2/1906	5-19- 0.	38.58	122.83	D			F	Healdsburg.
6/16/1906	0- 0- 0.	38.42	122.75	D			F	Peachland.
6/28/1906	0- 0- 0.	38.42	122.75	D			F	Peachland.
8/ 1/1906	14- 0- 0.	38.42	122.75	D			F	Peachland.
6/30/1907	23-10- 0.	38.42	122.67	D			F	Mercury.
2/ 8/1908	0- 0- 0.	38.42	122.75	D			F	Near Santa Rosa.
2/12/1914	0- 0- 0.	38.42	122.67	D			F	Peachland.
10/ 8/1915	3- 2- 0.	38.42	122.83	D			F	III Sebastopol.
10/ 8/1915	21-20- 0.	38.25	122.67	D			F	III Petaluma.
1/16/1916	0-41- 0.	38.42	122.83	D			F	III Sebastopol.
2/25/1919	22-39- 0.	38.33	122.50	D			F	VI North of Bay Counties. Origin probably in Glen Ellen region. VI at Napa, Petaluma, Santa Rosa, and Point Reyes. Felt also at Sebastopol, San Francisco, Oakland, Stanford University, and Mt. Hamilton.
12/20/1919	9-30- 0.	38.42	122.75	D			F	IV Santa Rosa.
10/ 9/1920	22-11- 0.	38.42	122.75	D			F	III Santa Rosa.
1/ 1/1922	1-10- 0.	38.25	122.67	D			F	Petaluma. Three shocks.
4/ 1/1923	4-19- 0.	38.42	122.75	D			F	II Santa Rosa.
9/ 6/1923	12- 0- 0.	38.42	122.75	D			F	III Santa Rosa.
11/ 8/1923	20-39- 0.	38.42	122.75	D			F	III Santa Rosa.
7/ 6/1924	17-48- 0.	38.42	122.75	D			F	II Santa Rosa.
9/ 1/1924	20-16- 0.	38.42	122.75	D			F	III Santa Rosa.
5/10/1925	13- 4- 0.	38.42	122.75	D			F	II Santa Rosa.
8/22/1925	18-15- 0.	38.25	122.67	D			F	III Petaluma.
4/13/1926	2-20- 0.	38.67	122.92	D			F	IV Geyserville. Rattled doors and windows. Lasted 15 seconds in Healdsburg. Felt in Dry Creek Valley.
4/13/1926	3-20- 0.	38.67	122.92	D			F	Healdsburg.
10/22/1926	13-30- 0.	38.42	122.75	D			F	III Santa Rosa.
10/22/1926	13-51- 0.	38.42	122.75	D			F	II Santa Rosa.
10/27/1926	12- 0- 0.	38.42	122.75	D			F	III Santa Rosa.
9/20/1927	15-40- 0.	38.42	122.75	D			F	III Santa Rosa.
10/ 2/1927	18-55-30.	38.42	122.75	D			F	Santa Rosa.
10/ 2/1927	18-55-40.	38.42	122.75	D			F	II Santa Rosa.
10/ 2/1927	19-22- 0.	38.42	122.75	D			F	II Santa Rosa.
2/18/1929	3-25- 0.	38.42	122.75	D			F	Santa Rosa.
9/11/1929	15- 0- 0.	38.42	122.75	D			F	Santa Rosa.
4/21/1932	12-24- 0.	38.25	122.67	D			F	Petaluma.
10/21/1932	10-30- 0.	38.25	122.67	D			F	III at Petaluma.
2/11/1934	0- 0- 0.	38.40	122.75	D			F	IV Santa Rosa.
2/13/1934	0- 0- 0.	38.42	122.75	D			F	Bay (near Santa Rosa).
2/14/1934	18-43- 0.	38.42	122.75	D			F	V Santa Rosa.
2/14/1934	18-51- 0.	38.42	122.75	D			F	Santa Rosa.
2/14/1934	19-15- 0.	38.42	122.75	D			F	Santa Rosa.
2/14/1934	22-24- 0.	38.42	122.75	D			F	2 miles SE of Santa Rosa. V Santa Rosa.
2/14/1934	22-34- 0.	38.42	122.75	D			F	V Santa Rosa. IV Monte Rio and Sebastopol.
2/15/1934	22-30- 0.	38.42	122.75	D			F	IV Sebastopol.
2/16/1934	5-37- 0.	38.42	122.75	D			F	V Santa Rosa. Also felt at Bay, Fulton, Forestville, Jenner, Kenwood, Rincon Valley, Sebastopol, and Windsor.
2/16/1934	5-47- 0.	38.42	122.75	D			F	Same places as above.
2/16/1934	5-50- 0.	38.42	122.75	D			F	Same places as above.
2/16/1934	6-45- 0.	38.42	122.75	D			F	Same places as above.
2/16/1934	7-30- 0.	38.42	122.75	D			F	Santa Rosa.
2/16/1934	9-31- 0.	38.42	122.75	D			F	Same places as 5-37 above.
2/16/1934	14- 1- 0.	38.42	122.75	D			F	Same places as 5-37 above.
2/16/1934	15- 0- 0.	38.42	122.75	D			F	Santa Rosa.
2/16/1934	15-58- 0.	38.42	122.75	D			F	Strongest of series. Felt same places.
2/18/1934	9- 3- 0.	38.42	122.75	D			F	Santa Rosa.
3/12/1934	16-10- 0.	38.42	122.75	D			F	Santa Rosa.

SANTA ROSA EARTHQUAKE HISTORY, 1855–1967

Continued

Month Day Year	Hour Minute Second	Latitude	Longitude	Quality	Magnitude	Number of stations recording	Felt	Maximum intensity, comments
6/12/1936	6–20– 0.	38.40	122.75	D			F	Santa Rosa.
2/28/1939	1–10– 0.	38.40	122.75	D			F	Santa Rosa.
3/ 2/1939	20–13– 0.	38.65	122.90	D			F	Near Geyserville. Felt Cloverdale and Skaggs Springs.
6/ 7/1939	15–14– 0.	38.58	122.83	D			F	Healdsburg-Jenner area. Felt Healdsburg.
10/30/1940	8–35– 0.	38.40	122.75	D			F	Santa Rosa. Possibly an explosion.
7/ 5/1942	0– 0– 0.	38.60	122.85	D			F	Healdsburg. Four shocks. BSSA. Oct. 1942.
10/19/1944	8–37– 0.	38.42	122.75	D			F	Santa Rosa. This and the three following shocks may not have been earthquakes.
10/19/1944	9– 7– 0.	38.42	122.75	D			F	Santa Rosa. See above.
10/19/1944	10– 0– 0.	38.42	122.75	D			F	Santa Rosa. See above.
10/19/1944	13– 0– 0.	38.42	122.75	D			F	Santa Rosa. See above.
11/21/1945	22–56–10.	38.42	122.78	B	3.5		F	III at Santa Rosa.
1/ 2/1948	8–35– 0.	38.50	122.85	D			F	Fulton. Light shock.
2/21/1948	4–19– 0.	38.40	122.75	D			F	IV at Santa Rosa.
9/ 1/1948	21–27–47.	38.33	122.58	B	3.3		F	Felt in Santa Rosa and Cotati.
8/ 9/1949	0–39–27.	38.58	122.67	B	3.6			West of Calistoga.
8/14/1949	8–19–58.	38.58	122.67	D	2.5			Aftershock of quake on August 9 at 0039.
11/ 3/1949	5– 0– 0.	38.40	122.75	D			F	IV at Santa Rosa.
11/ 4/1949	14–45– 0.	38.40	122.75	D			F	Santa Rosa.
11/ 4/1949	14–50– 0.	38.40	122.75	D			F	Santa Rosa.
11/ 8/1949	12–41–16.	38.50	122.70	D	2.5			North of Santa Rosa.
12/28/1950	0–15– 1.	38.58	122.83	C	2.9		F	Felt at Windsor.
2/20/1951	6–52–47.	38.42	122.65	C	2.2			East of Santa Rosa.
4/ 7/1951	19–19–21.	38.30	122.70	D	2.6			North of Petaluma.
11/26/1951	7–21–53.	38.52	122.75	B	3.4		F	North of Santa Rosa. Felt in Santa Rosa.
11/26/1951	8–53–30.	38.53	122.77	B	3.2		F	Aftershock of 0721. Felt in Santa Rosa.
11/26/1951	13–21–26.	38.52	122.75	C	2.1		F	Aftershock of 0721. Felt in Santa Rosa.
7/ 9/1952	22– 4–48.	38.53	122.62	C	2.5			4 miles SE of Calistoga.
9/26/1952	4–35–43.	38.42	122.58	C	3.2		F	7 miles SE of Santa Rosa. IV at Santa Rosa, St. Helena and Kenwood.
11/21/1952	23–27–25.	38.40	122.67	B	2.4			4 miles SE of Santa Rosa.
8/21/1953	10–28– 0.	38.30	122.60	D	2.1			SE of Santa Rosa.
1/29/1954	7–36–56.	38.50	122.65	C	2.8			Northeast of Santa Rosa.
2/25/1955	0–50– 5.	38.40	122.60	C	2.8			East of Santa Rosa.
12/22/1955	8– 4–50.	38.33	122.63	B	3.1			Southeast of Santa Rosa.
5/ 3/1956	3–30–30.	38.43	122.53	C	3.0			East of Santa Rosa.
6/19/1956	18–32–57.	38.28	122.52	B	2.3			Southeast of Santa Rosa.
7/18/1956	23– 3– 7.	38.65	122.73	A	3.5		F	North of Santa Rosa. Felt at Santa Rosa, Windsor.
3/14/1958	6–30–35.	38.60	122.80	D	2.5			Northwest of Santa Rosa. Aftershock, magnitude 2, at 06–32–48.
6/22/1958	6–21– 2.	38.65	122.73	C	3.2		F	North of Santa Rosa. Felt sharply at Healdsburg. Also felt at Rio Nido.
10/29/1959	23–29– 2.	38.40	122.50	D	2.9			Southeast of Santa Rosa.
12/26/1959	0–18–51.	38.40	122.50	D	2.3			East of Santa Rosa.
8/ 5/1960	6–15–53.	38.40	122.60	D	2.0			East of Santa Rosa.
2/28/1962	13–40–32.6	38.57	122.73	B	3.1	14	F	North of Santa Rosa. IV.
3/ 9/1962	8–39– 2.	38.33	122.62	C	3.0	12		Northeast of Point Reyes.
4/14/1962	19–37–37.	38.35	122.60	B	3.0	12		South of Calistoga.
12/ 6/1962	1–41– 6.1	38.52	122.58	B	2.6	11		South of Calistoga.
12/ 7/1963	12– 4–11.6	38.50	122.70		2.7	9		North of Santa Rosa.
9/23/1964	16–30–12.9	38.58	122.72		3.0	7		SW of Calistoga.
7/15/1965	2–57– 8.	38.50	122.80		2.8	8		SW of Rumsey.
10/18/1965	23–19– 0.	38.60	122.70		3.0	9		SW of Rumsey.
10/25/1965	4–50–30.1	38.48	122.88		2.6	9	F	NW of Santa Rosa. Felt at Healdsburg.
6/19/1966	16– 5–31.4	38.32	122.67		2.8	8		South of Santa Rosa.
6/27/1966	6– 4–28.7	38.48	122.83		3.1	9	F	NE of Santa Rosa. V Santa Rosa.
6/11/1967	12–55–48.	38.33	122.67		2.6	9		SE of Santa Rosa.
8/ 2/1967	0–10–35.0	38.50	122.76		2.8	6		NW of Santa Rosa.

Number of quakes = 168.

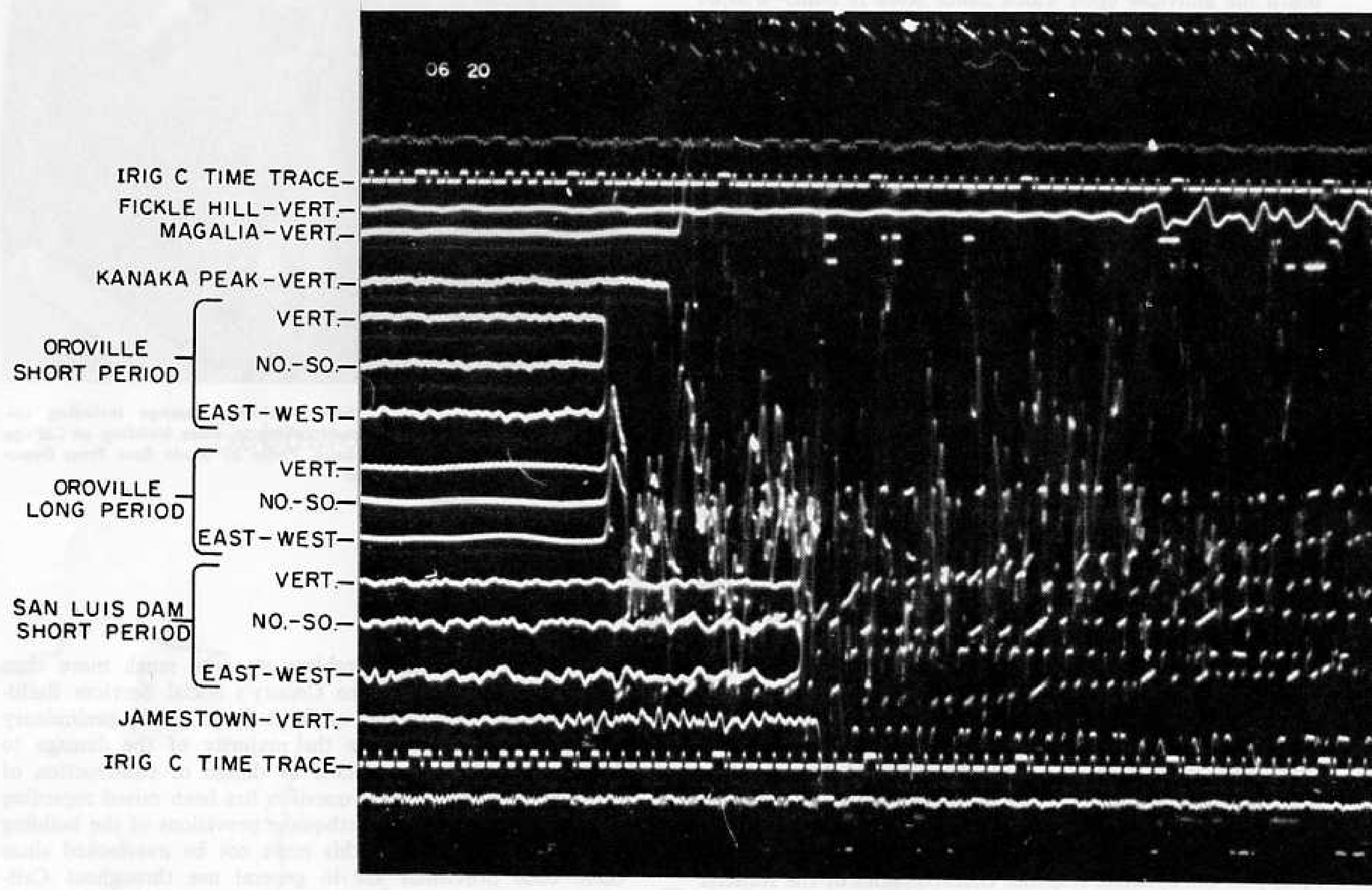
The Department of Water Resources has placed seismometers in the field to monitor earthquakes near State Water Project facilities and to detect seismic activity which may be induced by reservoir loading. The seismic data are telemetered to Sacramento over telephone lines for recording on 16 millimeter film and on magnetic tape for analysis. The figure is an enlargement of a short segment of the film record of the earthquake which shook Santa Rosa at 11:20 p.m., October 1, 1969.

The ground vibrations picked up by the Department's seismometers are amplified 100,000 times or more before recording. This high magnification is necessary so that very small shocks near project facilities may be detected. However, the seismometer output caused by larger quakes exceeds the capacity of the telephone circuits and causes "clipping" of the signal. The clipping effect is shown by the broad peaks on the seismogram traces. This will be remedied when log amplifiers are installed at each sensor. Then the large excursions will be "compressed" within a resolvable range.

The record from the University of California's Fickle Hill station near Arcata was not "clipped" because the station was farther from the earthquake epicenter and is operated at low magnification.

The relative distance from seismograph stations to an earthquake epicenter is indicated by the relative delay in arrival times of the seismic waves.

The IRIG C time trace provides precise time and date in coded form with narrow marks at half-second intervals and broad marks each 5 seconds. Sequences of medium-width marks indicate the day of the year, hour, and minute in Greenwich Mean Time—the standard time for all seismograph stations. The IRIG C time code generator is calibrated against a time signal from the National Bureau of Standards radio station WWV so that the time code does not deviate more than a few milliseconds from the correct time. Inaccuracy in marking the precise arrival time of earthquake waves at seismograph stations introduces error into the earthquake epicenter computations.—*D.M.H.*



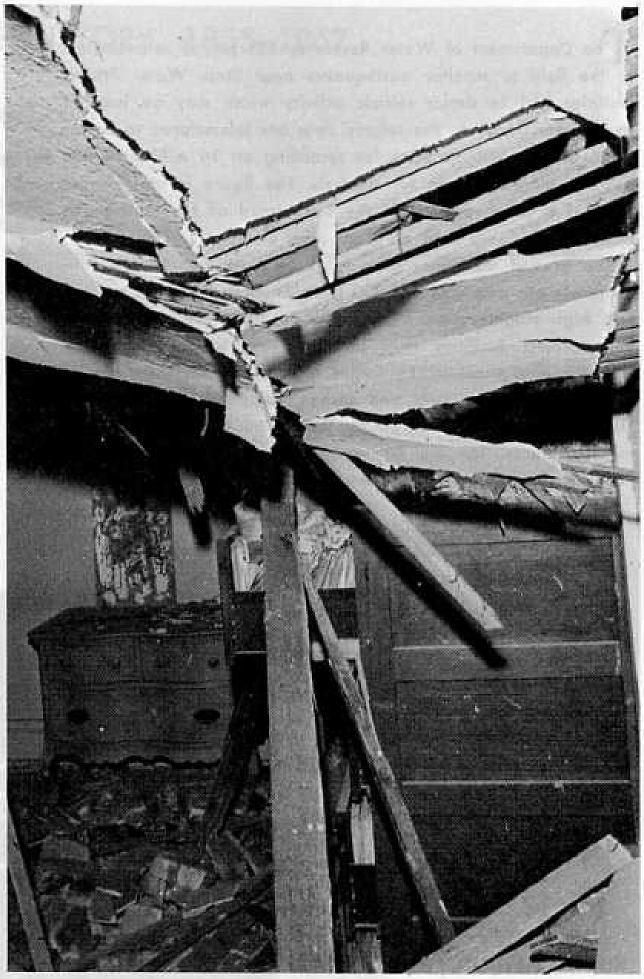
Recorded at California Department of Water Resources Facilities in Sacramento.

SANTA ROSA EARTHQUAKE
OCTOBER 1, 1969
23:20 PDT

AFTERSHOCKS

Within 17 hours of the time the initial shocks had rocked the Santa Rosa area the National Center for Earthquake Research, U. S. Geological Survey, had begun to install a network of portable seismographs to monitor aftershock activity. Twenty systems put into operation by late afternoon of October 4 (page 51) recorded continuously until October 20, when it became evident that aftershock activity had diminished to a very low level.

Preliminary interpretation of the data from the portable network indicate that the hypocenters of the 12 largest aftershocks that occurred within 7 days of the main shocks form a linear pattern trending N25°W through the northern and eastern outskirts of Santa Rosa and in line with the southern extension of the Healdsburg fault. Early work with the data suggests that about 200 aftershocks were sufficiently well recorded to permit accurate location, and of these about 75 percent occurred during the first week of recording. We anticipate that the pattern of hypocenters for the aftershocks will delineate in three dimensions a buried fault plane underneath the alluvium upon which Santa Rosa is built.—*J.D.U.*



Severe interior damage including collapsed ceiling in office building on College Avenue. ***Photo by Santa Rosa Press Democrat.***

GROUND AND BUILDING RESPONSE

In a broad and general sense, the Santa Rosa earthquake damage followed the patterns of other earthquakes. The serious hazards to lives were principally confined to the failures, or near failures, of unreinforced brick buildings. The hazard from such light mass buildings as wood frame dwellings was comparatively insignificant. Even when a wood frame dwelling went off its foundation, the occupants were in no significant danger of losing their lives.

A more detailed examination of the damage patterns, however, shows two problems of considerable importance.

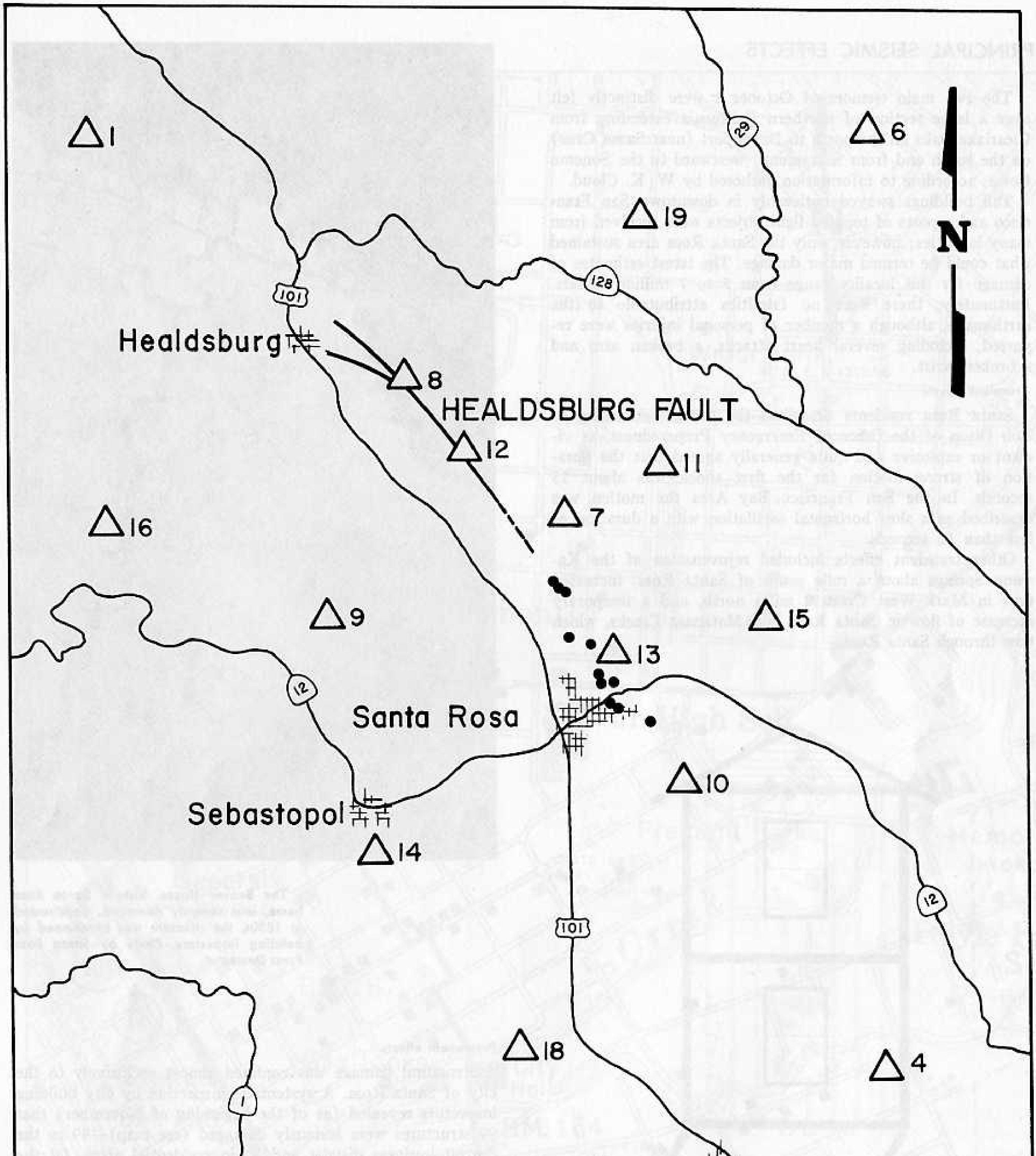
First, the damage to single family wood frame dwellings was concentrated in several areas close to each other. The damage to the older houses was readily explainable by rotten foundations or by inadequate bracing in the space between the ground and the wooden floor. However, in these areas of concentrated damage were many newer dwellings where this explanation would not hold. Spectacular in this regard was the damage to dwellings west of the Montgomery Village Shopping Center, where masonry chimneys, including steel reinforced brick chimneys, broke.

It seems clear from the preliminary work done to date that the concentrations of damage were related to the local geology in a manner that is not well understood. In a simplified sense, it may be that the configuration of the underlying rock, plus the dynamic response characteristics of the surficial soils, resulted in amplification of the seismic waves. The violence of the shaking in these limited areas was clearly evident where, for example, sidewalks were buckled.

Doubly important is the preliminary observation that the 1969 concentrations of damage may have been in about the same areas as those noted in Santa Rosa after the 1906 San Francisco shock. It certainly becomes vital to understand better the relationships between the dynamic characteristics of the geology and building response to them.

A second disquieting problem was the much more than expected damage to Sonoma County's Social Services Building in the northern section of Santa Rosa. A very preliminary analysis tends to attribute the majority of the damage to factors other than the details of design or construction of this new building. A valid question has been raised regarding the adequacy of certain earthquake provisions of the building code; the importance of this must not be overlooked since these code provisions are in general use throughout California. A second valid question has been raised regarding the possibility of quasi-resonance between the building and the vibrating soils beneath. Both of these questions are very fundamental and probably cannot be answered in the near future.

It is interesting that both of the major problems involve the disciplines of geology, soils engineering, and structural engineering. It seems to the author that the solutions can best be obtained from interdisciplinary efforts.—*K.V.S.*



Map showing the locations of the stations used for the aftershocks study (indicated by triangles) and the location of epicenters of the 11 aftershocks of the preliminary analysis (indicated by black dots).

PRINCIPAL SEISMIC EFFECTS

The two main tremors of October 1 were distinctly felt over a large section of northern California extending from Clearlake Oaks on the north to Davenport (near Santa Cruz) on the south and from Sacramento westward to the Sonoma Coast, according to information gathered by W. K. Cloud.

Tall buildings swayed noticeably in downtown San Francisco and reports of toppled light objects were received from many localities; however, only the Santa Rosa area sustained what could be termed major damage. The latest estimates of damage for this locality range from 5 to 7 million dollars. Fortunately, there were no fatalities attributable to the earthquake, although a number of personal injuries were reported, including several heart attacks, a broken arm and a broken wrist.

Transient effects

Santa Rosa residents described the shocks, according to Bob Olson of the Office of Emergency Preparedness, as violent or explosive and quite generally agreed that the duration of strong motion for the first shock was about 15 seconds. In the San Francisco Bay Area the motion was described as a slow horizontal oscillation with a duration of less than 10 seconds.

Other transient effects included rejuvenation of the Kawana Springs about a mile south of Santa Rosa, increased flow in Mark West Creek 2 miles north, and a temporary increase of flow in Santa Rosa and Matanzas Creeks, which flow through Santa Rosa.

The Beaver House, historic Santa Rosa home, was severely damaged. Constructed in 1850s, the structure was condemned by building inspectors. *Photo by Santa Rosa Press Democrat.*

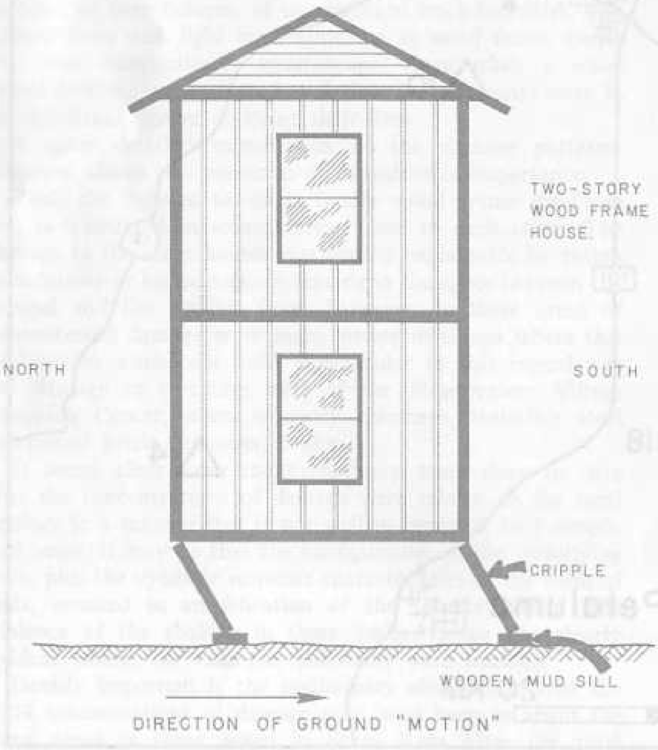
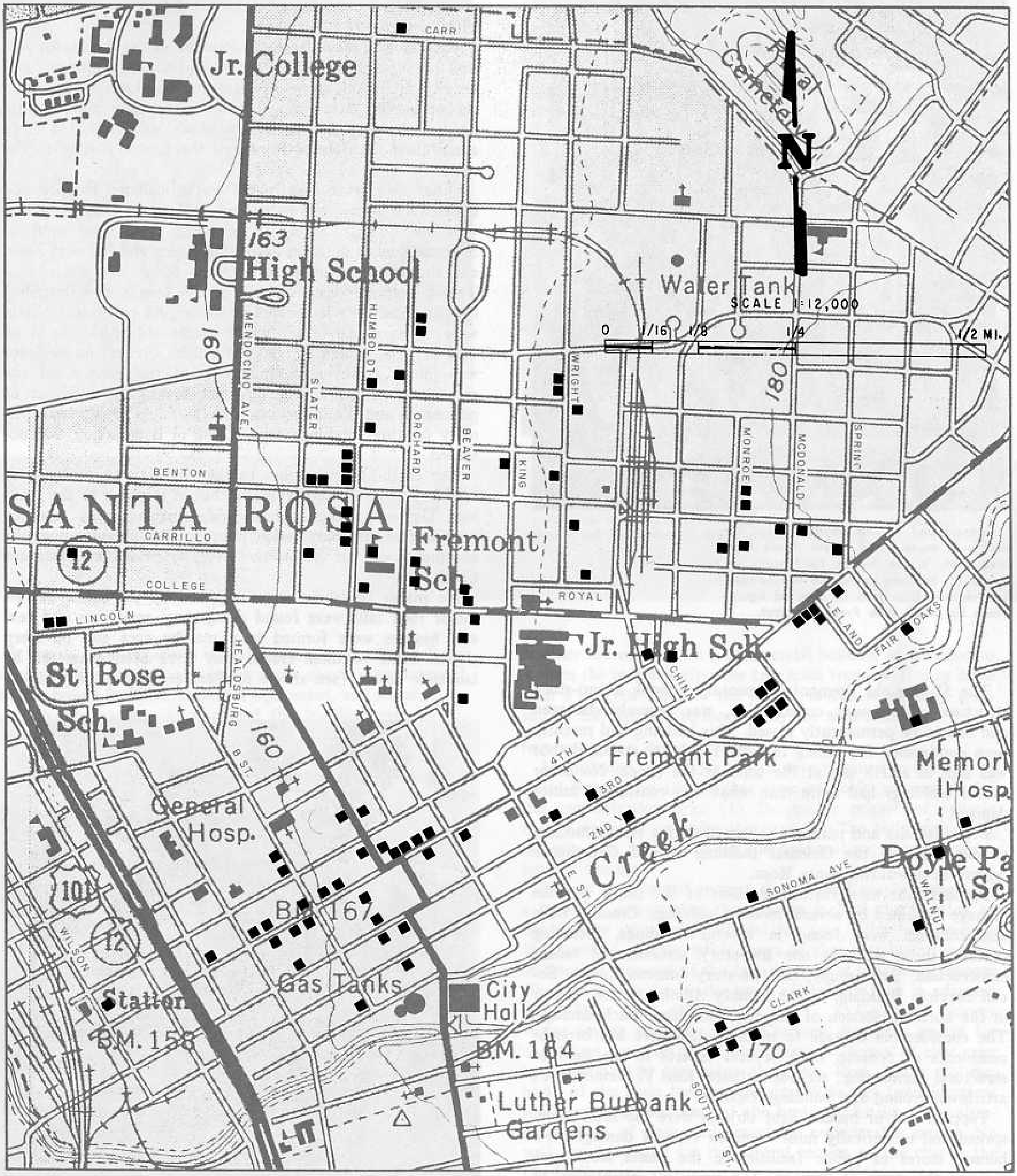


Diagram showing how some of the older dwellings, built before the Uniform Building Code, must have toppled off their foundations as a result of sudden lateral ground motion.

Permanent effects

Structural damage was confined almost exclusively to the city of Santa Rosa. A systematic inspection by city building inspectors revealed (as of the beginning of November) that 99 structures were seriously damaged (see map)—49 in the central business district and 50 in residential areas. Of the central district buildings, 17 were scheduled for abatement; in the residential areas, 28 were so listed.

Older buildings in the downtown section showed the most damage. Several old two-story wood-frame buildings, constructed before the provisions of the Uniform Building Code became effective, displayed a spectacular type of severe damage. These buildings were shaken off their wood foundations, leaving them shattered and leaning (prevalently in the northward direction).



The locations of severely damaged buildings in central Santa Rosa are shown by the square black symbols, from information compiled by the city building inspector's office. Many of these buildings have been demolished or have required extensive repairs.

Canned and bottled goods toppled off shelves in many stores in the Santa Rosa area. This is the health food store on Fourth St. Between shocks the merchandise was reshelved, only to be toppled again. *Photo by Santa Rosa Press Democrat.*

The 57-year-old Fremont Elementary School, a two-story structure of masonry construction, was severely damaged and had to be permanently closed. This building had recently been condemned for failing to meet Field Act standards but was still in active use at the time of the shock. No other school buildings had more than what was considered minor damage.

Brick facades and parapets collapsed during strong motion, as did those of the Galeazzi Building at Old Courthouse Square in downtown Santa Rosa.

Probably the most disturbing effect of the shock was the damage sustained by several modern buildings. Cracked walls and columns were found in several buildings, including cracked shear walls in one five-story structure of recent construction. Surprisingly, the two-story Sonoma County Social Services Building, in the County Administration Center in the northern section of the city, sustained much damage. The considerable damage to modern structures has brought comments of concern from several experts in the field of structural engineering; see, for instance, Karl V. Steinbrugge's article on ground and building response.

Toppled and/or broken light objects were the most widespread and numerically most common type of damage; few homes, stores or public facilities in the Santa Rosa area escaped this type of damage. The prevalent orientation of fall appeared to be north or south. Often, on shelves facing these directions, contents were hurled off; whereas, in the same room, shelves facing east or west showed only minor disturbance.

Collapsed chimneys were another common effect of the shock. Older, unreinforced units proved to be most susceptible to this sort of damage.

Extensive window breakage occurred in the downtown section of Santa Rosa; other sections of the city also suffered heavily from this type of damage. Windows mounted in rubber gaskets fared much better than those more rigidly fixed. Relatively few broken windows were reported from areas other than Santa Rosa and the Rincon Valley to the east.

Other damage to constructed works included chipped and buckled curbs and sidewalks and broken waterlines. Several waterline breaks (all 8-inch or larger mains) occurred on Sonoma Avenue between Sotoyome Street and Farmers Lane, and another break occurred near the corner of Leonard and Talbot Avenues, all in Santa Rosa. The breaks were described by city repairmen as sheared; however, no permanent offsets were detected. All of the above mentioned breaks lie in an area between Matanzas and Santa Rosa Creeks; no evidence was found, however, to indicate that the location of the creeks was related to the pipe line breaks. No evidence of permanent soil displacements, such as might result from primary faulting, lurching, slope failure or liquefaction, was observed.

The earth-fill approaches to the Highway 12 bridge over Highway 101 subsided several inches in response to the shaking. The only other known bridge damage was repeated pounding at the construction joints in the sidewalks over the abutments of the Brookwood Avenue bridge at Matanzas Creek.

No major landslides were triggered by the shock. A few minor rock falls were found along steep road cuts and several fissures were formed in a marshy area and on steep slopes. Some of these cracks may have been generated by landslide action (see article on Surface Breaks, page 60).

Toppled brick chimneys were a common sight in Santa Rosa. *Photo by Santa Rosa Press Democrat.*

Bricks tumbled from many buildings as a result of the quake. These views of rubble derived from the top of the three-story Galeazzi Building, show successive damage caused by the repeated tremors. The photo in the upper left, taken on the night of October 1, shows damage as a result of the first shock.

The photo on the upper right, taken the following morning, shows further damage to automobile by falling debris after second strong tremor. The fire escape also dropped, weighted down by added brick. *Photo to left by Santa Rosa Press Democrat; to right by Robert D. Nason.*

A fire of chemical origin in a laboratory at the Santa Rosa Memorial Hospital was attributed to the shock. Fire damaged the laboratory facilities, technical equipment, and supplies. In addition, the earthquake damaged the building extensively.

House on Wright Street toppled off foundation. *Photo by Robert D. Nason.*

Another fire occurred in a commercial building on Mendocino Avenue the morning after the two main tremors. It may have been a delayed effect of the earlier shocks or possibly a result of the strong aftershock early the next morning.

Factors controlling damage location

As indicated, the major effects were confined to the city of Santa Rosa. Two factors that were probably responsible for this concentration are: (1) the major release of seismic energy was near or under the city. (2) The soils underlying the city may have amplified the base motion, thus intensifying the damage.

Factors that would suggest that ground amplification was a factor in intensifying the damage include the location of Santa Rosa on a gentle alluvial fan (see article on Geologic Framework) and the thick layers of clay that underlie parts of the city. Because of the fan, deposits of older and younger alluvium are thicker under parts of the city than in adjacent areas. Data from well logs in the U. S. Geological Survey Water-Supply Paper by G. T. Cardwell show that except for one 3-foot layer of gravel, uninterrupted layers of clay exist to a depth of 85 feet below the Santa Rosa Junior College, north of the main business district. Well logs from locations southeast and southwest of the business district show alternating beds of clays and gravels to considerable depths. No well logs are listed for the central section of the city in the Cardwell report.

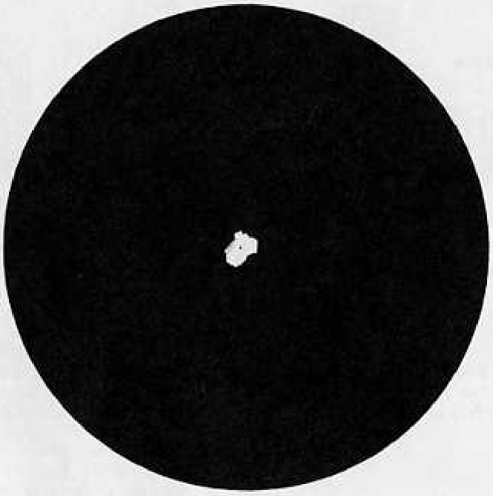
It would appear that a combination of both the location of the main shocks and ground amplification was responsible for the concentration and distribution of damage.—*M.E.H. and T.L.Y.*

STRONG MOTION RECORDS

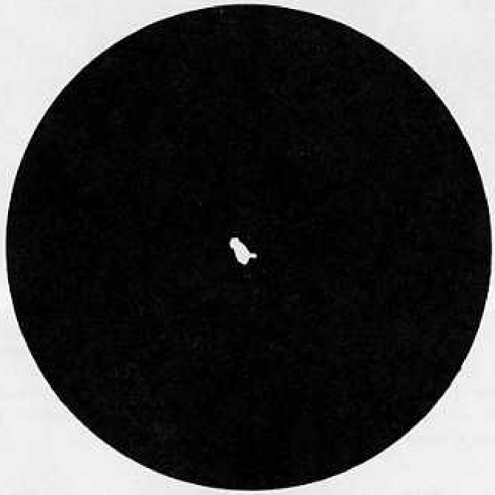
At the time of the 1969 Santa Rosa earthquakes, the U.S. Coast and Geodetic Survey had 91 strong-motion instruments in its cooperative network within 85 miles of the epicenters. These devices are not used to locate earthquakes but to record local ground behavior in response to the energy release. Strong-motion instruments record only as triggered by ground shaking.

Of the 91 instruments, 42 were strong-motion seismographs, mostly accelerographs, and 49 were seismoscopes. From these instruments 38 strong-motion seismograph records and 42 seismoscope records had been obtained.

Preliminary inspection of the records, all of which are of small amplitude, suggests that acceleration on rock in the San Francisco Bay Area was not high enough to trigger accelerographs into operation. For example, the accelerographs at Berkeley and Golden Gate Park, both on rock, did not operate. Acceleration on softer material and on the upper floors of buildings, however, was high enough to trigger instruments into operation and many small but measurable records were obtained.

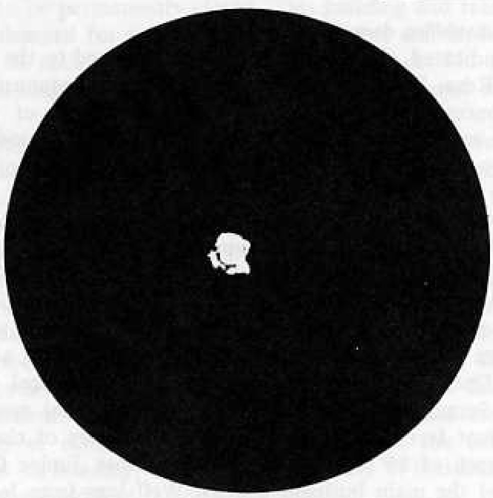


INVERNESS Station
28 miles
granite rock

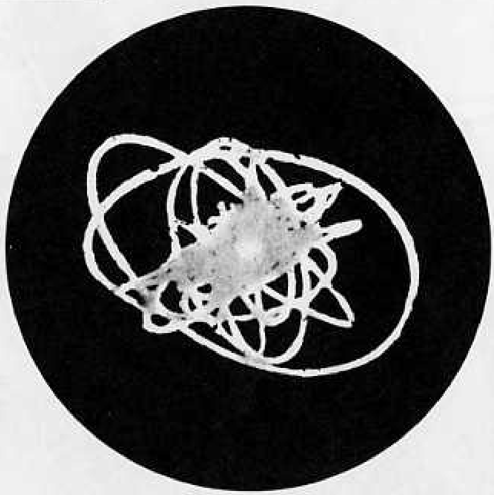


APEEL Array Station 3
71 miles
Franciscan rock

5 millimeters

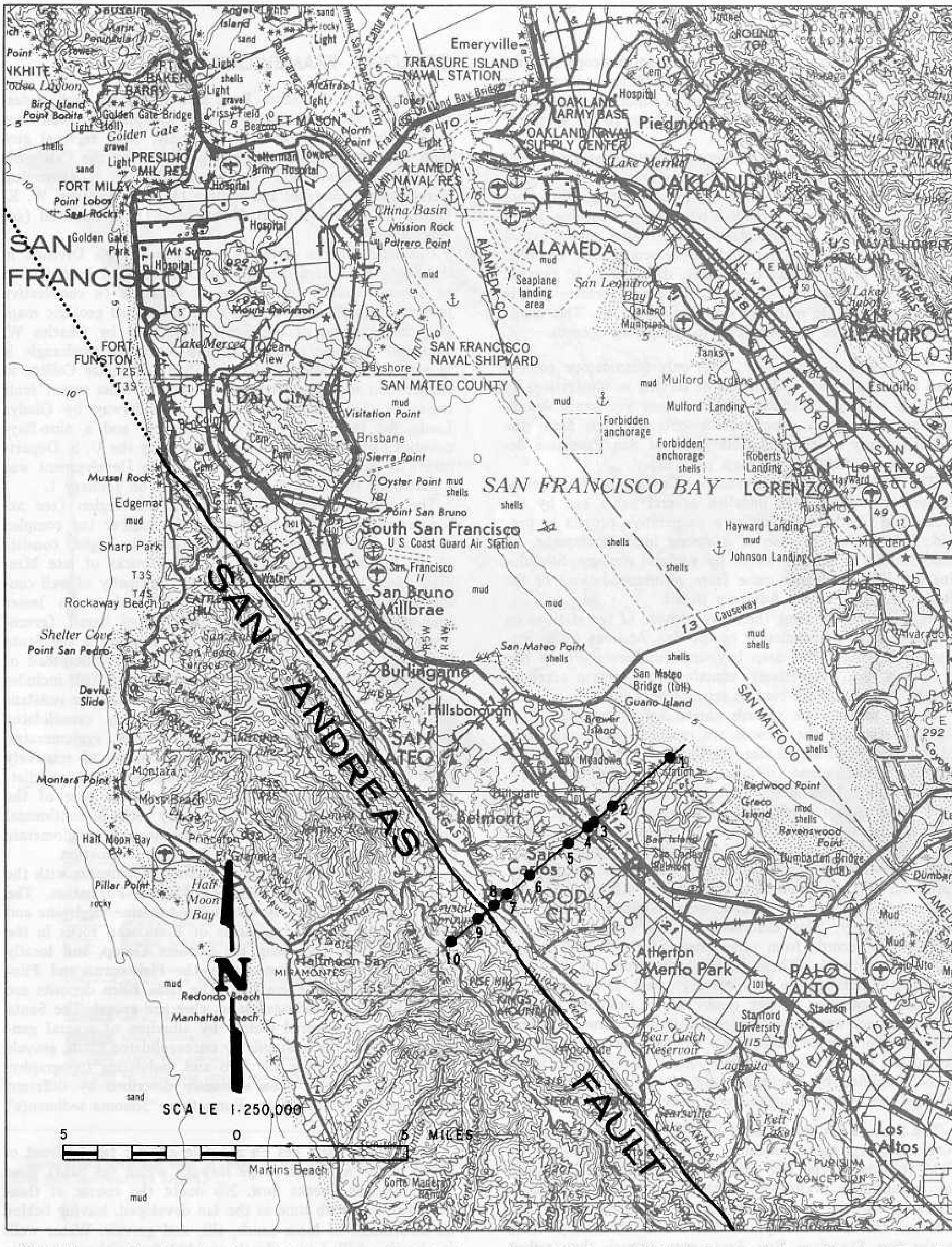


APEEL Array Station 4
71 miles
100 feet alluvium



APEEL Array Station 2
71 miles
25 ft. mud, 275 ft. clay

Sample seismoscope records from the Santa Rosa, California earthquakes of 1 October 1969. U.S. Coast and Geodetic Survey, Seismological Field Survey.



"APEEL" array—line shows locations of the instruments for U. S. Coast and Geodetic Survey (ESSA) Andreas-Peninsula Earthquake Engineering Laboratory.

A similar pattern was observed from seismoscope records. Such instruments, when on rock, recorded little or no motion, while those on softer material recorded small but measurable amplitudes. No network stations were closer to the epicenter than 28 miles.

A seismoscope is basically a very simple standardized structure—a conical pendulum with a natural period of 0.75 seconds that is free to move in any horizontal direction. Magnetic damping is provided but, since recording is by metal stylus on a smoked glass plate, friction causes actual damping to vary with amplitude of recording. For recorded amplitudes of about one centimeter, damping is 10 percent of critical. Below this amplitude, damping increases and is difficult to measure with any degree of accuracy. This qualification should be kept in mind in comparing records.

By the end of November 1969, only seismoscope records had been processed to the point of serving as illustrations of network results; accelerograms were not yet available. Of the network seismoscope records obtained, ten from the APEEL array on the peninsula south of San Francisco deserve special mention (see map, page 57).

The APEEL (Andreas-Peninsula Earthquake Engineering Laboratory) Array was installed several years ago by the Coast and Geodetic Survey as a cooperative project to provide information, in case of a strong local earthquake, on modification of seismic waves by surficial geology. Stimulus for installing the array came from recommendations of the Redwood City Seismic Advisory Board.

As shown on the map, the array consists of ten stations on a line roughly perpendicular to the San Andreas fault. Stations 1, 2, and 6, on deep bay mud, moderately deep bay mud, and rock, respectively, contain strong-motion accelerographs. All 10 stations contain seismoscopes.

In the seismoscope records shown here, three are from APEEL stations; the records are enlarged photographically to ten times their actual size. North is toward the top of the figures. Station name, distance from the earthquake epicenters and a brief description of foundation material appear below each record (see the seismoscope records, p. 56).

From the seismoscope records, it is evident that during the Santa Rosa earthquakes the simple standardized structure represented by seismoscopes was subjected to different forces on different foundation material. In other words, seismic waves reaching the surface were modified by the near surface geology. This difference is also evident from 25 seismoscope records from other parts of the San Francisco Bay Area network. Where seismoscopes were on rock the recorded amplitudes are zero or very small, as compared to recorded amplitudes on bay mud. This is probably because the epicenters were at considerable distance from network stations. Short period waves likely to affect rock were greatly attenuated by the distance, while longer period waves likely to be amplified by bay mud, and in the period range of seismoscopes, were attenuated very little by the distance.

The Santa Rosa earthquakes were of too small magnitude, considering epicentral distance from network stations, to yield records of the size and frequency content necessary for quantitative evaluation of the modification of seismic waves by surficial geology. However, the strong-motion records are the most widespread and useful obtained to date in the San Francisco Bay Area, even though they reflect seismic forces well below the damage level.—*W.K.C.*

GEOLOGIC FRAMEWORK

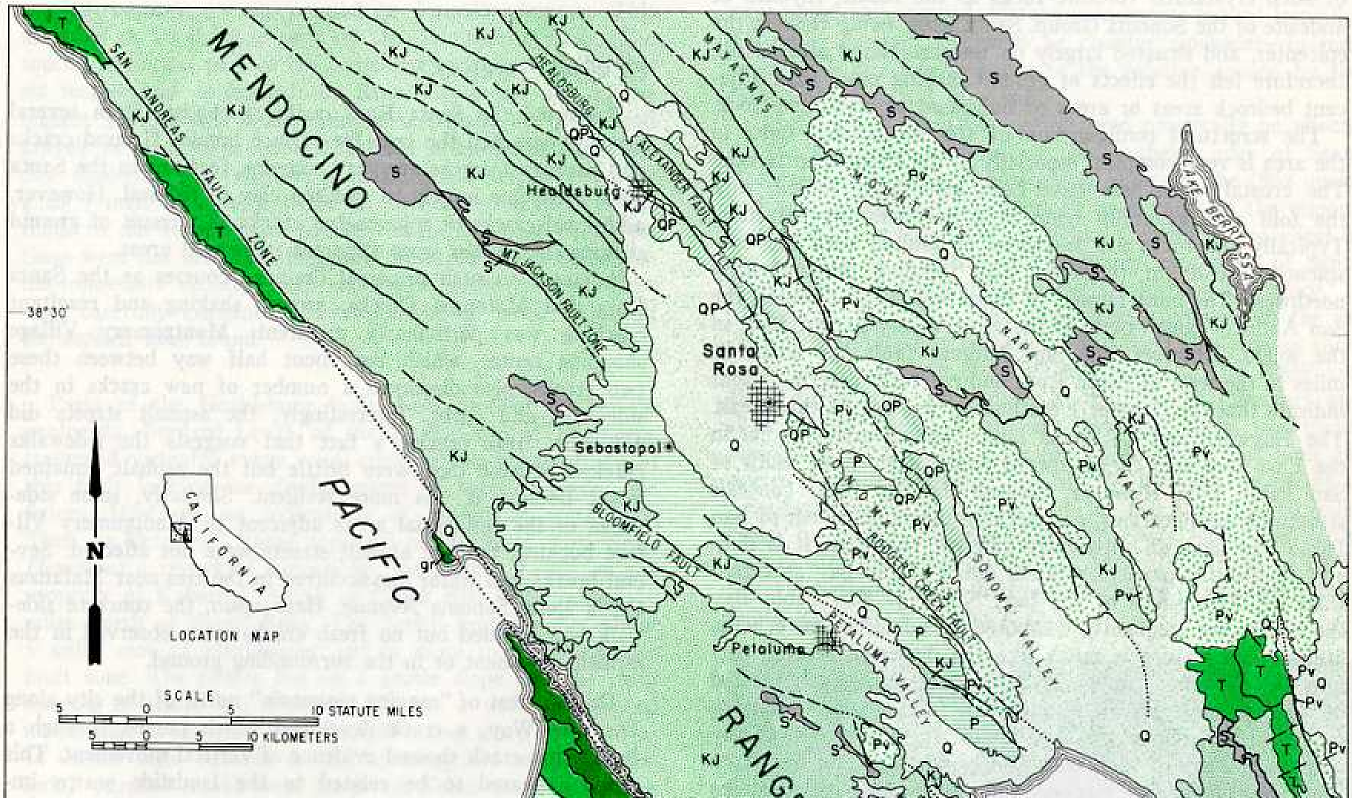
Geologically, the Santa Rosa area is not too well understood, for, with the exception of a few places, it has been mapped in reconnaissance fashion only. Such regional geologic maps and reports as exist, published by the California Division of Mines and Geology and the U. S. Geological Survey, were compiled and written by C. E. Weaver, W. K. Gealey, R. B. Travis, J. B. Koenig, and G. T. Cardwell (see Bibliography).

Geologic projects currently underway by this Division in the Santa Rosa area include a geologic hazard investigation of Sonoma County by Michael E. Huffman (a cooperative program with Sonoma County) and a detailed geologic mapping investigation of the Santa Rosa area by Charles W. Jennings. Geologic mapping of the Kenwood quadrangle is in progress by Robert L. Rose of San Jose State College in cooperation with this Division. A study of most recent fault traces in the Sonoma Mountains is underway by Gladys Louke for the U. S. Geological Survey, and a nine-Bay-counties planning study financed jointly by the U. S. Departments of Interior and Housing and Urban Development was initiated by the U. S. Geological Survey on January 1.

The principal formational units in this region (see accompanying geologic map) are few in number but complex in detail. The basement rock underlying the region consists of the Franciscan Formation and other rocks of late Mesozoic age. These rocks are comprised principally of well consolidated sandstones (graywacke) and shale, with lesser amounts of serpentinite, chert, and altered basalt (greenstone). The basement rocks are largely covered in the Santa Rosa area by much younger units. The most widespread of these is the Sonoma Group of Pliocene age. This unit includes several contrasting rock types, principal of which are resistant basalts, rhyolites, and andesites, and loosely consolidated pyroclastic rocks including volcanic breccias, agglomerates, and tuffs. Locally, the Sonoma Group consists of relatively weak lake deposits including soft sandstone, siltstone, diatomite and lignite. In the Petaluma area, the base of the Sonoma Group overlies soft sedimentary rocks of continental and brackish-water clay shale, sandstone and conglomerate of the middle or early Pliocene Petaluma Formation.

To the west, the Petaluma Formation interfingers with the late Pliocene and Pleistocene(?) Merced Formation. The Merced consists of weakly consolidated marine sandstone and siltstone, and covers large areas of Franciscan rocks in the Sebastopol area. Overlying the Sonoma Group, and locally interbedded with the Sonoma, is the Pleistocene and Pliocene(?) Glen Ellen Formation. The Glen Ellen deposits are largely loosely consolidated sand, clay and gravel. The Santa Rosa Valley is covered mainly by alluvium of several generations and on the west side by unconsolidated sands, gravels and silty clay forming low hills and undulating topography. These deposits have been variously described by different geologists as the Glen Ellen Formation, "Sonoma sediments" or older alluvium.

Santa Rosa itself lies on a gentle alluvial fan in front of a gap in the mountain range through which the Santa Rosa and Matanzas Creeks flow. No doubt the course of these creeks shifted with time as the fan developed, leaving behind an assortment of loose sands, silt, and gravels. Water wells in the city drilled to a depth of 1200 feet without reaching bedrock.



Generalized geologic map of part of the San Francisco Bay area. (Modified after Geologic Map of California, Olaf P. Jenkins Edition, Santa Rosa and San Francisco Sheets.)

Judging by past experience, buildings on those formations consisting of loosely consolidated deposits are subject to relatively long intervals of shaking and are damaged more than structures on well-indurated rock or on thick sequences of such crystalline volcanic rocks as the basalt, rhyolite or andesite of the Sonoma Group. Santa Rosa, being close to the epicenter, and situated largely on unconsolidated alluvial fill, therefore felt the effects of ground shaking more than adjacent bedrock areas or areas of indurated or crystalline rock.

The structural configuration of the formational units in the area is very complex, especially in the Franciscan terrain. The crustal rocks here have been extensively folded, with the fold axes generally lying in a northwesterly direction. Typically the rocks are fractured or faulted with the conspicuous trends of tectonism also trending predominantly northwest. The most famous of these breaks is, of course, the San Andreas fault—perhaps the most widely known fault in the world. However, the San Andreas fault lies some 20 miles to the west of Santa Rosa and epicenter determinations indicate that the October 1 earthquake was not on this break. The Hayward and Calaveras faults, known active faults in the East Bay area, head toward Santa Rosa from south of San Pablo Bay. However, because the bay itself conceals structural complications, and because the faults north of San Pablo Bay have an apparently different character, it is difficult to identify particular faults north of the bay as extensions of those south of the bay. North of San Pablo Bay the breaks are frequently composed of numerous en echelon faults. This feature is much like the dispersed seismic pattern for this area, in which earthquake epicenters, instead of lying along linear trends, tend to form a scatter pattern suggestive of numerous short faults. It is also noteworthy that the geology of the Coast Ranges north of San Francisco Bay is not adequately mapped, and perhaps this area contains a complex array of faults, of which only relatively few have been recognized.

One of the longer faults that has been recognized and studied in the area is the Healdsburg fault. W. K. Gealey (see bibliography) has mapped this break for some 20 miles across the Healdsburg quadrangle and has speculated as to its continuation to the northwest and southeast for many more miles. The fault is described as a right lateral strike-slip type marked by "alignment of straight drainage segments, by oversteepened slopes, nicked spurs, aligned knobs, landslides, sag ponds, seepage, aligned serpentine smears and the linear occurrence of silica-carbonate rock". Recency of movement along this fault, Gealey says, is exemplified by perched alluviated valleys, where the drainage has been impounded by new fault scarps, forming ponds in which alluvium has been deposited until through drainage has been resumed.

The Alexander fault zone, subparallel to the Healdsburg fault, may also extend southeastward into the Santa Rosa area. To the northwest this fault zone is thought to converge with the Healdsburg fault. The Alexander fault zone may have particular significance because of possible ground rupture in October (see section on Surface Breaks).

The Rodgers Creek fault southeast of Santa Rosa is an important fault on the west flank of the Sonoma Mountains. It is well-defined locally by numerous sag ponds and linear trends in the topography. It is interrupted in places by landslide topography and may consist of a zone of en echelon faults. It appears to lie wholly within the Sonoma Group but may extend under the Napa Slough and San Pablo Bay.

In the area west of Santa Rosa are other prominent faults, such as the Bloomfield fault, the Mt. Jackson fault zone, and unnamed parallel faults. These faults appear to be outside the October 1969 zone of activity.—*C.W.J.*

SURFACE BREAKS

Following the Santa Rosa quake, geologists from several agencies searched the area for surface breaks. Ground cracks and pavement cracks are very common features in the Santa Rosa area, due largely to swelling clay in the soil. However, additional cracks or rejuvenated cracks as a result of ground shaking in October were apparent in several areas.

Adjacent to such principal drainage courses as the Santa Rosa and Matanzas Creeks, ground shaking and resultant cracking was particularly apparent. Montgomery Village shopping center, which lies about half way between these two creeks, also displayed a number of new cracks in the sidewalks and curbs. Interestingly, the asphalt streets did not show fresh cracks, a fact that suggests the sidewalks cracked because they were brittle but the asphalt remained intact because it was more resilient. Similarly, some sidewalks in the residential areas adjacent to Montgomery Village buckled, but the asphalt streets were not affected. Several breaks in a water line occurred in the area near Matanzas Creek along Sonoma Avenue. Here again, the concrete sidewalk was buckled but no fresh cracks were observed in the asphalt pavement or in the surrounding ground.

On the crest of "moving mountain" north of the city along De Vera Way, a crack developed which passed through a house; the crack showed evidence of vertical movement. This crack appeared to be related to the landslide scarps immediately adjacent where several houses were destroyed a few years ago.

A search for fresh ground ruptures along the Rodgers Creek fault was made but none were found. Crane Canyon Road, which crosses the Rodgers Creek fault, was carefully checked, but there were no cracks in the curbing, the street, or the concrete-lined drainage ditch which parallels the road. A few boulders from steep road cuts in this area were dislodged but no sign of fresh landslides were detected other than a small slump beneath a part of the road bounded by a steep embankment.

The most widespread cracking was found in the IOOF Cemetery on the north side of town. Here, along Poppy Drive, the asphalt paving was crossed by several dozen fresh cracks oriented both northwest across the road and also northeast, parallel to the road. The area lies in a low depression close to a swamp. The adjacent ground immediately to the north was also observed to be cracked, but the orientation of the cracks appeared to be random. The cracks in Poppy Drive, which opened from 1/16 to 1/4 inch, were pulled apart perpendicular to the crack faces. There was no apparent lateral motion component or vertical component, nor did the cracks form any en echelon or other regular pattern. The cracks appeared in a zone of filled ground adjacent to the swamp; thus they appeared to be the result of heavy shaking of marshy substrata. It is interesting to note that the report of the 1906 earthquake also mentions severe cracking in this area: "Just north of the cemetery hill is a swampy depression. Part of this settled 2 or 3 feet with the formation of a crack along the side, extending for some 200 feet" (see Bibliography, Lawson 1908, p. 201). The cemetery proper is situated on an elongate northwest-trending knoll and there are several lines of physiographic and geologic evidence suggesting that this knoll is bounded by a northwest-trending fault parallel to Franklin Avenue. This may be an en echelon part of the Healdsburg fault. The southeasternmost part of the cemetery, consisting of the oldest section and designated the Rural Cemetery, lies on the highest part of the knoll, and is underlain by sands and gravels of what is probably the Glen Ellen Formation. The day following the October 1 quake, fresh irregular cracks $\frac{1}{8}$ to $\frac{1}{4}$ inch wide were noted in the hard-packed dry dirt roads in the central part of the Rural Cemetery; however, these were not oriented along any preferred trend. Streets in the immediate vicinity north and south of the cemetery area were carefully examined for cracks but no fresh cracks in the asphalt were found.

Parts of the Healdsburg fault were checked by various geologists. Bernard Lewis, of the U. S. Corp of Engineers, traversed virtually every road crossing the known trace of this fault looking for displacements of terrain, roads, and fences. However, no indications of movement were seen. Then, on October 7, there appeared in the Santa Rosa *Press Democrat* a report of a possible "earthquake fault" on the property of Robert J. Smith of Chalk Hill Road, about 12 miles north of Santa Rosa. The Smith property lies about 5 miles east of Healdsburg and is close to the Alexander fault zone. The fissure lies on a gentle slope and the main opening is about 400 feet long. It has a width of several inches and is bounded by an uphill-facing scarp as much as 14 inches high. Parallel to this opening, and in close proximity, parallel cracks were observed. Fresh cracks on strike with the main fissure could also be followed intermittently for about 500 feet to the southeast and 100 feet to the northwest for a total distance of about 1000 feet. None of the cracks showed conclusive evidence of lateral or vertical movement. On the main fissure, the apparently "upthrown" side was on the southwest or downslope side. This side was also marked by an anomalous, nearly continuous mound about 8 to 10 inches high and 5 feet wide. The trend of the break is northwesterly but also gently curving—concave side to the northeast. The strike is N 15° W. at the north end and N. 55° W. at the south end. Careful examination by U. S. Geological Survey geologists failed to find any further ruptures along the strike. According to Mr. Smith, the main fissure was first noticed about four years ago; however, he felt confident that the fissure had opened further as a result of the October 1 quake. Strain gauges, installed across the fracture by the U. S. Geological Survey on the night of October 7, suggested slight additional enlargement of the fracture during the following few days. The nature and origin of this fissure is uncertain.

The fissure was extensively studied by geologists of the U. S. Geological Survey, who concluded that, although a tectonic origin could not yet be ruled out, it was unlikely; nor could the fracture be attributed to landsliding. Other explanations, including a relation to a bed of swelling clay or possibly some artificial origin, are being considered.—*C.W.J. and R.D.N., edited in part by R.E.W. and M.G.B.*

EFFECTS ON CEMETERIES AND MONUMENTS

In addition to cracking the earth in cemeteries, the earthquake toppled, rotated or moved many tombstones in both the IOOF and Rural Cemeteries. A total of 45 "topples" were noted and mapped. Sixteen monuments moved laterally. Thirty-six rotated, clockwise or counter clockwise—in nine cases, in a direction opposite to the rotation caused by the earthquake of April 25, 1968.

Other cemeteries in the area showed practically no effects. At the Calvary Cemetery, on the southeast edge of Santa Rosa, two monuments were possibly affected. The 1968 quake had a similar impact on cemetery tombstones in the region: major effects in the IOOF and Rural Cemeteries, no effect in the Calvary or in the Shiloh Cemetery northwest of Santa Rosa, and only slight effect in the Healdsburg Cemetery.

The records of the 1906 earthquake contained in the report of the State Earthquake Investigation Commission show a comparable pattern. Damage was major at the IOOF and Rural Cemeteries, very minor at the Calvary Cemetery and slight at the Shiloh Cemetery. However, there was major damage in 1906 at the Sebastopol Cemetery; and none reported there in either the 1968 or 1969 quakes. The effects at Sebastopol might be explained by the fact that it is 10 miles closer to the San Andreas fault than Santa Rosa, and earthquakes with epicenters on the San Andreas fault (as in 1906) affect Sebastopol more than earthquakes with epicenters near Santa Rosa.—*C.W.J. and R.D.N.*

One of forty-five monuments known to have toppled in Santa Rosa's Rural and IOOF Cemeteries. Fifty-two other monuments shifted or rotated on their bases. *Photo by Robert D. Nason.*

HISTORY OF THE STRONGER EARTHQUAKES AT SANTA ROSA, 1865–1969

Because seismographs were not introduced in California until 1887, the earliest records of earthquakes are non-instrumental. In that year the first two seismograph stations in the Western Hemisphere were established—one at the University of California, Berkeley campus, and one at the university's observatory at Mount Hamilton. While the original installations included the best seismographs then available, sensitivity was very low by present-day standards. Earthquakes were not recorded on these early instruments unless they were very strong or very close to one of the stations. Relatively accurate instrumental locations did not become available until comparatively recent years.

The following list has been abstracted mainly from the earthquake catalogue of Townley and Allen for the years through 1927, and for later years from the reports published annually by the U. S. Coast and Geodetic Survey entitled *United States Earthquakes*.—*D.T.*

CONTINUING RESEARCH

Much of the information provided in the previous paragraphs by those who studied the Santa Rosa earthquake is preliminary, and will be revised as new information is added, or material already gathered is more carefully analyzed.

One piece of research still to be completed is an intensity map that is being prepared by students of the Santa Rosa Junior College, under the direction of L. J. Gex. Using the U. S. Coast and Geodetic Survey earthquake report form, which asks the respondent for his location, whether he felt the earthquakes, was awakened, and/or frightened, what noises he heard, and what he saw happen to objects during the earthquake or observed had happened to them afterward, the students interviewed more than 4,000 people in Sonoma County.

From this information, they will compile an isoseismal map. On the basis of work now finished, it is likely that the map will show isoseismal lines describing arcs of concentric circles.—*M.R.H.*

1865 March 8, 6:00 a.m. Intensity VIII at Santa Rosa and upper Bennett Valley. Plaster cracked, clocks stopped, and chimneys thrown down.

1868 October 21, 7:53 a.m. The Hayward Earthquake. Maximum intensity X at Hayward. Surface breakage was observed on the Hayward fault from Warm Springs to San Leandro. The shock was perceptible over an area of roughly 100,000 square miles. At Santa Rosa, the earthquake was reported as the "severest shock yet felt." Nearly all brick buildings in town were more or less injured. Many chimneys down.

1888 February 29, 2:50 p.m. Intensity VII at Petaluma, where walls were cracked; VI at Santa Rosa, where the shock was violent and people ran out of houses.

1891 October 11, 10:28 p.m. Maximum intensity VIII to IX at Napa and at Sonoma, where people were shaken out of their beds, chimneys demolished, windows broken, and considerable damage to plaster occurred. At Santa Rosa, one observer reported the shock as the "severest in four years" (presumably a recollection of February 29, 1888); the oscillations lasted 45 seconds; slight trembling perceptible for 3 or 4 minutes.

1892 April 19, 2:50 a.m. Intensity IX to X at Vacaville, Dixon, and Winters. The Holden catalogue (1898) estimates the intensity was VII at Santa Rosa, where many windows were broken, some plaster was damaged, and "panic prevailed at hotels."

1892 April 21, 9:43 a.m. Large aftershock of the foregoing. Maximum intensity IX at Winters. At Santa Rosa (VII) many brick buildings were cracked, more plaster damage occurred, two brick walls slightly bulged out, iron columns moved, and in some parts of town chimneys were wrecked.

1893 August 9, 1:15 a.m. Sonoma County, VII to VIII at Santa Rosa, where this was said to have been the most severe shock since 1868. Chimneys fell and windows were broken. The plaster in the courthouse was extensively damaged.

1898 March 30, 11:43 p.m. The Mare Island Earthquake (intensity VIII). At Santa Rosa, the vibrations lasted fully one and three-quarters minutes. Heavy plate glass windows in many business houses were broken; throughout the city plaster was shaken from walls and ceilings.

1899 October 12, 9:00 p.m. Maximum intensity VII to VIII at Santa Rosa, where plaster was knocked from walls and some chimneys fell.

1906 April 18, 5:12 a.m. Magnitude 8.3. One of the greatest shocks on record in California; caused by movement on the San Andreas fault from San Benito County to Humboldt County. Maximum fault offset was a 21-foot horizontal shift near the head of Tomales Bay. Extensive damage at San Francisco, Santa Rosa, San Jose, Sebastopol, and many other places. In the opinion of Townley and Allen, Santa Rosa, 20 miles from the San Andreas fault, sustained more damage, in proportion to its size, than any other city in the state.

1906 to 1968 Many smaller earthquakes felt in Santa Rosa, the strongest being in 1919, 1929, and 1956. With the possible exception of the earthquake at 2:39 p.m. February 25, 1919 (intensity VI), none was as severe as the earlier shocks in this tabulation. Seismic activity of interest to the residents of Santa Rosa was clearly at a much lower level throughout the 62 years following the major shock of April 18, 1906, than it had been in the 41 years preceding that event.

1968 April 25, 11:49 a.m. Epicenter 38° 28′N, 122° 40′W. Magnitude 4.6. This earthquake, centered just north or northwest of Santa Rosa, damaged some chimneys, broke windows, and rotated or overturned a number of tombstones. Maximum intensity VIII, at Santa Rosa.

1969 October 1, 9:56 p.m. and 11:20 p.m. Two earthquakes, magnitudes 5.6 and 5.7, respectively. Epicenters 38° 28′N, 122° 41.5′W, and 38° 27.3′N, 122° 41.5′W. Extensive light damage in the Santa Rosa area, where some chimneys fell, many windows were broken, and a half-dozen frame houses were rocked off or overturned their foundations. Partial collapse of several brick building walls occurred, and minor structural damage was noted in one reinforced concrete building. Some minor ground cracking occurred on the northeast edge of Santa Rosa.

—*D.T.*

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NEW MAP ALONG PORTION OF SAN ANDREAS FAULT

A new map, entitled *Geology of a portion of western Marin County, California*, has recently been released as Map Sheet 11 by the California Division of Mines and Geology.

The map, lithographed in full color with an accompanying text, includes parts of Bolinas, San Geronimo, and Inverness 7½ minute quadrangles, all on the Marin Peninsula. The San Andreas fault runs through the southern half of the area, separating the older rocks of the Bolinas Ridge, Mt. Tamalpais, Samuel Taylor Park, and Black Mountain areas from the younger sedimentary rock of Bolinas Mesa, a part of the Point Reyes Peninsula. In this area, the fault zone is from 2,000 to 2,800 feet in width.

Copies of Map Sheet 11 may be obtained from the San Francisco office of the Division of Mines and Geology, Ferry Building, San Francisco, 94111. It is sold folded in a manila envelope, priced at $1.50, plus 8¢ tax for California residents. . . . *M.R.H.*

INTERNATIONAL MINING EXHIBITION 1972

An International Exhibition of Mining Equipment will be held at Olympia, London, England, on August 18–25, 1972 under the auspices of the Council of Underground Machinerey Manufacturers. The foremost British and Overseas Manufacturers will be present exhibiting representative displays of machinery, equipment, supplies and services used in every type of mining.

The Fifth International Strata Control Conference, organised by the National Coal Board, is to be held concurrently in London on August 21–25, 1972. Some 30 papers, contributed by experts from 14 countries are to be read. Preprints of papers and the proceedings of the conference will be in English, French and German, and simultaneous interpretation will be provided at the congress sessions.

Several organised tours with fixed programs are to be arranged during the week following the exhibition and conference. A full program of visits in and around the London area will also be devised for ladies during the conference period.

Inquiries concerning the Exhibition should be sent to: Council of Underground Machinery Manufacturers, c/o Messrs. Peat, Marwick, Mitchell & Co., P.O. Box 121, 301 Glossop Road, SHEFFIELD. S10 2HN, U.K.

Correspondence regarding the Strata Control Conference should be adderssed to: Mr. W. J. Adcock, National Coal Board, Hobart House, Grosvenor Place, LONDON, S.W.1. U.K.

SECRETARY HICKEL RELEASES SANTA BARBARA CHANNEL TECHNICAL DATA

A summary of the technical data upon which a scientific panel appointed by the President's Office of Science and Technology based its recommendations for offshore oil drilling operations in the Santa Barbara Channel of California, was recently released by Secretary of the Interior Walter J. Hickel.

The compilation was made by the U.S. Geological Survey in response to public requests for the information received by Secretary Hickel and Lee A. DuBridge, science adviser to the President, who released the panel's recommendations last June 2.

"This Geological Survey report incorporates geological and engineering information upon which the recommendations of the panel were based and includes additional material pertinent to the subject that has become available since the original studies," Secretary Walter J. Hickel said. "It also includes proprietary information which the oil companies operating in the channel recently agreed to release."

The Santa Barbara Channel was the scene last January of the "blowout" of an oil well being drilled by the Union Oil Company.

The 11-man panel, composed of leading independent experts in geology, petroleum engineering and reservoir management, recommended pumping out the oil on the Union Oil lease and on a contiguous Sun Oil Company lease as rapidly as possible in order to reduce pressure and to prevent future seepage.

John C. Calhoun, vice president of Texas A&M University, as chairman of the panel, stated that it believed it was "less hazardous to proceed with development of the lease (upon which the blowout well is located) than to attempt to seal the structure with its oil content intact.... The panel concludes that it would be hazardous to withdraw from this lease at the present time."

Most of the recommendations of the panel have been put into practice by the Department under new, stringent operating regulations in effect in the Channel since last March and subsequently applied to the entire U.S. Outer Continental Shelf last August.

The amount of oil seeping up from the "blowout" well has been reduced to a current average level of less than 10 barrels a day, compared with more than 500 barrels at the height of the seepage in January and February.

U.S. Geological Survey Professional Paper 679, the background summary recently published, contains 77 pages of text, tables and line drawings plus maps in color compiled by 11 USGS scientists.

The report (GPO Catalog Number I:19.16:679) may be purchased from the Superintendent of Documents, Government Printing Office, Washington, D.C. 20402 at $2.25 a copy. The Division of Mines and Geology has copies for reference, but none for sale.