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CATALOG OF EARTHQUAKES ALONG THE SAN ANDREAS FAULT SYSTEM IN CENTRAL CALIFORNIA, JANUARY - JUNE 1978

By S. L. Kirkman-Reynolds and F. W. Lester

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INTRODUCTION

Numerous small earthquakes occur each day in the Coast Ranges of central California. The detailed study of these earthquakes provides a tool for gaining insight into the tectonic and physical processes responsible for the generation of damaging earthquakes. This catalog contains the fundamental parameters for earthquakes located within and adjacent to the seismograph network operated by the U.S. Geological Survey (USGS), during the first half of 1978.

The motivation for these detailed studies has been described by Pakiser and others (1969) and by Eaton and others (1970). Similar catalogs of earthquakes for the years 1969, 1970, and 1971 have been prepared by Lee and others (1972b, c and d). Catalogs for the first, second, third, and fourth quarters of 1972 and the first, second, third and fourth quarters of 1973 have been prepared by Wesson and others (1972a, b, 1973b, and 1974a and b), by Bufe and others (1975), and by Lester and others (1976a and b). Catalogs for the years 1974, 1975 and 1976 and the first, second, third and fourth quarters of 1977 have been prepared by Lester and Meagher (1978), by McHugh and Lester (1978 and 1979) by Marks and Lester (1980a and 1980b), by Marks and Fluty (1981), and by Fluty and Marks (1981). The basic data contained in these catalogs provide a foundation for further studies.

This catalog contains data on 1370 earthquakes in central California. Arrival times at 244 seismograph stations were used to locate the earthquakes listed in this catalog. Of these 219 were telemetered stations operated by USGS. Readings from the remaining 25 stations were obtained through the courtesy of the joint USGS-California Institute of Technology Seismographic Network, Pasadena (USGS/CIT), the Seismographic Stations, University of California, Berkeley (UCB), and the California Department of Water Resources, Sacramento (CDWR).

The Seismographic Station of the University of California, Berkeley, has for many years published a bulletin describing earthquakes in northern California and the surrounding area and listing readings at UCB stations from more distant events. The purpose of the present catalog is not to replace the UCB Bulletin, but rather to supplement it, by describing the seismicity of a portion of central California in much greater detail.

INSTRUMENTATION

The telemetered seismograph system used may be illustrated by block diagram (Figure 1). The equipment at each station includes a vertical component, 1 Hz seismometer (usually Mark Products, Model L-4C), a package containing a preamplifier and voltage-controlled oscillator (USGS, Model J302; Van Schaack, 1980), and batteries. The frequency-modulated tone produced at each station is carried by wire (occasionally by radio) to a terminal where it is combined with the tones of up to 8 other stations.

The resulting multiplexed signal is then transmitted by voice-grade telephone circuits or radio to the USGS office in Menlo Park, California. The nine channels of data on each line are separated and demodulated by discriminators and most are recorded on 16 mm film using a Develocorder (Teledyne, Geotech, Model FR-400). Each Develocorder records seismic signals of up to 17 stations. In addition, 3 timing signals (WWVB on one trace, and a chronometer on the other two) are recorded simultaneously with the seismic signals. Data from all stations are recorded on magnetic tape and some are recorded on paper seismograms.

Figure 2 illustrates the overall response of the seismic systems for typical stations. Magnification for individual stations is adjusted according to the background noise level in steps of 6 decibels. As a result, the response for an individual station may differ from that of the typical station by a factor of 2, 4, 8, or 16. Precise calibrations indicate that most stations are operated at magnifications of 25,000 to 100,000 at 1 Hz.

All stations used in the present study are listed in Table 1 and the station locations are plotted on Figure 3.

DATA PROCESSING AND ANALYSIS

The telemetered seismic data recorded on 16 mm film were processed manually to yield information on first P-arrivals, directions of first motions, maximum amplitudes, and signal durations. These data were then processed by computer to give origin time, hypocenter location, magnitude, and pattern of first motions of the earthquakes using the HYPO71 computer program (Lee and Lahr, 1972). Each roll of film contains about 24 hours recording time and was processed in the following steps: (1) scanning, (2) timing using a digitizer which prepared punched cards, (3) batch processing by computer program HYPO71, (4) correcting errors, (5) adding data from other sources, (6) rerunning HYPO71, (7) analyzing poor solutions, and (8) eliminating explosions.

In the routine data processing, local events with an average signal duration or coda of 10 seconds or more were always timed. This corresponds to a cutoff at about magnitude 1.2 for events within the USGS network. Some smaller events for which 6 clear first arrivals could be obtained were also timed. The magnitude cutoff for events outside, but near the USGS network, was larger than 1.2. The catalog of earthquakes reported here contains all hypocenter solutions obtained, but because the station coverage was not uniform and because some events outside the network are reported, the cutoff for small magnitudes was not uniform over the entire area reported.

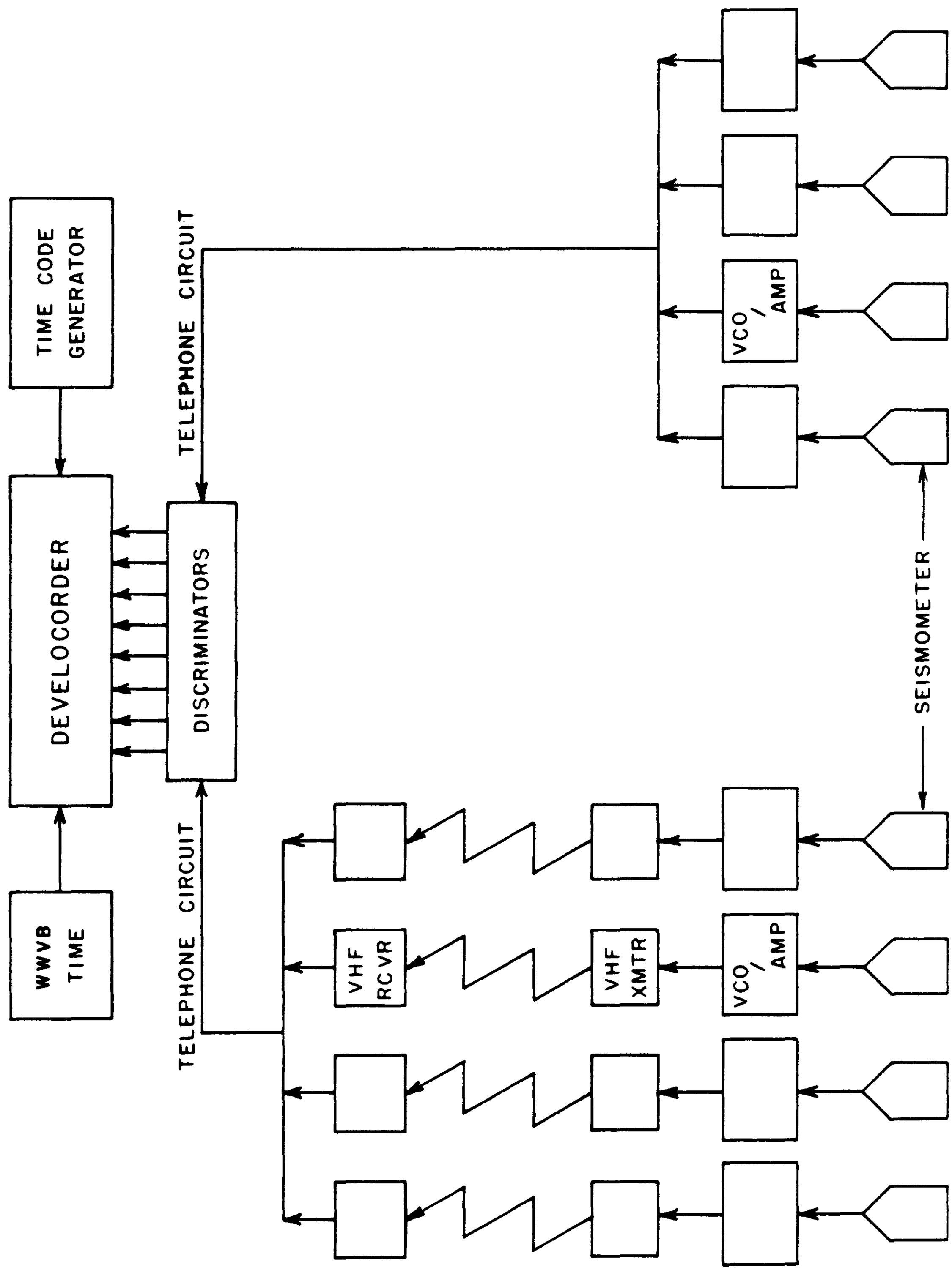

Figure 1. Block diagram of the USGS telemetered seismograph system.

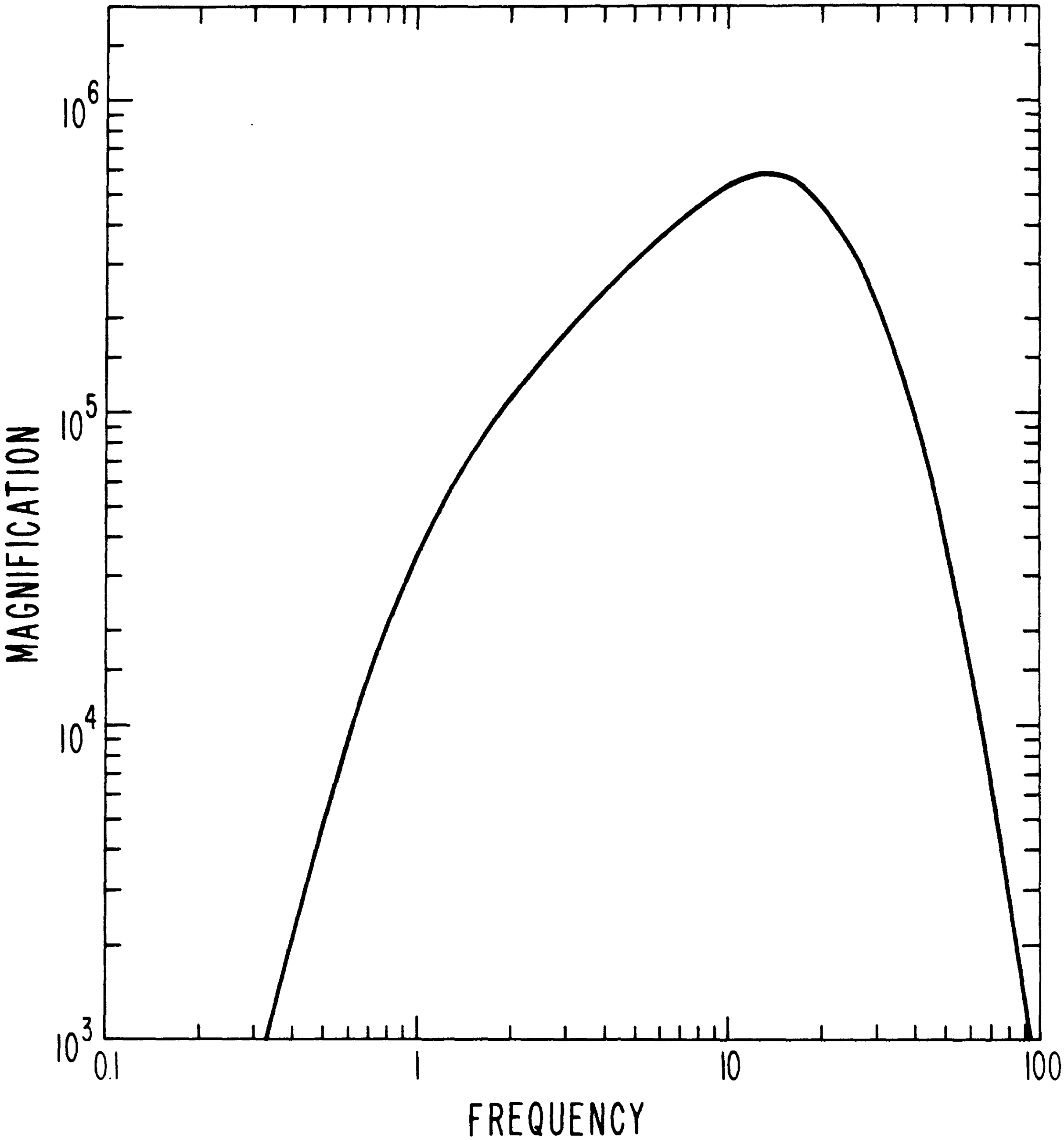

Figure 2. System response of an USGS telemetered seismograph station. This magnification curve is obtained for a system (L-4C seismometer, USGS J302M, VCO/Amplifier with attenuation set at 12 db, Develco Discriminator, and Geotech Develocorder).

TABLE 1. STATION DATA *

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
AAR	39-16.57	121-01.53	930	-0.12	760720	
ABJ	39-09.92	121-11.47	457	-0.22	760727	
ABR	39-08.11	121-29.21	24	-0.09	770214	
ADW	38-26.35	120-50.89	251	-0.01	760721	
AFD	38-56.69	120-58.10	524	-0.13	760129	
AFH	39-02.51	120-47.48	1064	-0.22	760720	
AFR	38-47.54	121-20.91	31	0.32	761202	
AGI	38-50.68	120-58.88	305	-0.16	760130	
AHD	39-02.90	121-04.59	483	0.00	761028	
AHR	38-51.26	121-04.23	354	-0.15	760130	
ALA	38-34.00	120-57.37	293	-0.08	770721	
ALN	38-55.78	121-17.27	54	0.23	761202	
AOD	38-36.89	120-43.71	520	-0.18	761019	
AOH	39-22.52	121-15.36	457	-0.05	770214	
APR	38-52.62	121-13.03	133	0.17	760715	
ARJ	38-41.19	120-57.38	460	-0.22	761123	
ARR	38-45.92	121-10.31	127	0.13	761202	
ARW	38-57.38	121-09.73	320	-0.09	760129	
AVR	39-01.47	121-16.25	114	-0.24	760715	
BAV	36-38.75	121-01.79	604	0.04	750702	
BBG	36-35.48	121-01.52	1216	0.12	720303	
BBN	36-30.60	121-04.53	448	0.26	710128	
BCG	36-42.55	121-20.60	305	0.16	690529	
BEH	36-39.88	121-10.45	342	0.19	710201	
BEM	36-39.68	121-05.76	488	0.03	700814	
BHS	36-21.35	121-32.41	646	-0.09	750904	
BJC	36-32.82	121-23.53	207	-0.25	690618	
BJO	36-36.65	121-18.81	1052	-0.19	740131	
BLR	36-39.96	121-16.36	232	0.26	730215	
BMC	36-39.40	121-21.92	1022	-0.20	760129	
BMH	36-41.18	121-24.80	811	-0.22	760126	
BMS	36-39.78	120-47.51	811	0.08	731206	
BPC	36-33.90	121-38.15	268	-0.11	760214	
BPF	36-13.82	121-46.32	349	-0.09	731218	
BPI	36-29.40	121-10.11	329	-0.16	750703	
BPP	36-10.12	121-22.68	1591	-0.21	731219	
BRM	36-50.70	120-49.40	372	0.21	731203	
BRV	36-25.49	121-01.10	541	0.31	691126	
BSB	36-44.27	121-17.21	398	0.00	750625	
BSC	36-37.98	121-14.05	357	0.12	761006	780225
BSC	36-38.50	121-15.59	323	0.12	780225	
BSG	36-24.83	121-15.22	192	-0.24	690618	

TABLE 1. STATION DATA (CONTINUED)

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
BSL	36-46.53	121-20.96	155	0.24	750716	
BSR	36-39.99	121-31.12	395	-0.20	770309	
BVL	36-34.51	121-11.34	510	0.03	700903	
BVY	36-44.96	121-24.80	585	-0.06	751211	
CAC	37-58.57	121-45.62	74	0.42	731026	
CAD	37-09.74	121-37.45	244	-0.09	670825	
CAI	37-51.68	122-25.77	223	-0.13	690808	
CAL	37-27.07	121-47.95	265	-0.01	671019	
CAO	37-20.96	121-31.96	628	-0.01	671019	
CBR	37-48.97	122-03.72	610	0.04	690823	
CBW	37-55.45	122-06.40	221	0.07	710428	
CCN	37-47.49	121-56.89	219	0.72	760205	
CCO	37-15.46	121-40.35	366	0.31	671013	
CCY	37-33.10	122-05.45	67	-0.24	750501	
CDO	37-43.80	121-50.12	198	0.20	700729	
CDS	37-57.98	122-15.17	109	-0.04	731115	
CDU	38-01.78	122-00.05	168	0.21	710428	
CLC	37-44.28	122-03.83	312	0.02	721121	
CMC	37-46.88	122-10.55	90	-0.05	710720	
CMH	37-21.57	121-45.38	518	0.16	690304	
CMJ	37-31.25	121-52.23	498	-0.01	720701	
CMO	37-48.68	121-48.15	792	0.06	690417	
CMR	37-35.68	121-38.22	500	-0.06	690417	
CPL	37-37.88	121-57.37	463	-0.03	690627	
CRA	37-46.03	121-56.25	171	0.32	760902	
CRP	37-54.75	121-54.33	331	-0.29	700918	
CSC	37-17.11	121-46.35	128	0.27	670610	
CSH	37-38.88	122-02.57	170	-0.09	730101	
CTL	37-39.44	121-38.63	458	0.00	770623	
GAF	38-53.59	123-32.28	710	0.08	750122	
GAX	38-42.65	122-45.30	379	-0.19	730921	
GBD	39-26.52	123-18.55	655	-0.06	780412	
GBG	38-48.84	122-40.76	1125	0.03	750626	
GBO	38-49.46	122-50.57	879	0.17	750620	
GCM	38-48.35	122-45.31	1286	0.02	750423	
GCV	38-46.14	123-00.89	150	0.05	750507	
GCW	39-07.85	123-04.55	1089	-0.07	780330	
GDC	38-46.03	123-14.31	772	0.09	750507	
GDX	38-48.46	122-47.63	931	0.03	771117	
GFT	38-47.58	122-50.04	755	-0.03	780421	
GGL	38-53.80	122-46.58	893	0.44	750418	
GGP	38-45.88	122-50.65	1054	0.07	750418	

TABLE 1. STATION DATA (CONTINUED)

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
GHC	38-36.36	123-11.81	518	-0.04	750507	
GHG	39-07.70	122-49.47	903	-0.05	750418	
GHL	39-02.43	123-01.12	956	-0.04	750701	
GHM	39-29.74	122-55.80	1486	0.17	780524	
GMC	38-47.56	123-07.80	426	-0.02	750507	
GMK	38-58.17	122-47.22	906	-0.04	750418	
GMM	38-50.29	122-47.93	963	0.22	780421	
GMO	38-42.61	123-08.59	802	-0.13	750507	
GPM	38-50.85	122-56.78	783	0.02	730921	
GRM	39-01.23	122-35.06	469	-0.05	750626	780523
GRT	38-56.32	122-40.18	619	-0.13	750626	
GSG	38-52.03	122-42.58	1080	0.37	740702	
GSM	38-46.15	122-46.87	1017	-0.04	750718	
GSN	38-56.43	123-11.50	870	0.19	750620	
GSS	38-42.12	123-00.81	282	-0.13	750122	
GWK	39-03.12	122-29.46	841	0.19	780523	
GWR	39-12.43	123-17.99	658	0.05	780330	
HAZ	36-53.08	121-35.45	122	-0.22	670629	
HBT	36-51.01	121-33.04	98	-0.16	750605	
HCA	37-01.52	121-29.02	332	0.03	671013	
HCB	36-55.88	121-39.63	219	-0.17	690101	
HCO	36-53.31	121-42.34	129	-0.15	751119	
HCR	36-57.46	121-35.01	241	-0.18	671005	
HCZ	36-54.54	121-48.02	30	0.05	751113	
HDL	36-50.12	121-38.64	204	-0.28	670809	
HFE	36-59.00	121-24.09	323	-0.05	711014	
HFH	36-53.29	121-28.13	101	0.06	751210	
HFP	36-45.22	121-29.43	705	-0.27	700902	
HGS	37-05.75	121-26.83	778	-0.07	710903	
HGW	37-01.02	121-39.20	133	-0.24	751002	
HJG	36-47.88	121-34.43	171	-0.34	670621	
HJS	36-48.99	121-17.92	215	-0.02	750617	
HKR	36-54.10	121-25.56	66	0.19	750703	
HLT	36-53.07	121-18.49	183	0.06	700817	
HMO	36-36.03	121-55.06	192	-0.18	701127	
HOR	36-55.03	121-30.46	98	-0.10	670626	
HPH	36-51.38	121-24.37	122	0.26	700817	
HPL	37-03.13	121-17.40	152	0.01	680510	
HPR	36-57.19	121-41.70	94	-0.08	670623	
HQR	36-50.02	121-12.76	536	0.07	690529	
HSF	36-48.72	121-29.97	340	0.09	751113	
HSL	37-04.81	121-05.65	122	0.00	740228	

TABLE 1. STATION DATA (CONTINUED)

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
JAL	37-09.50	121-50.82	244	-0.11	681016	
JBC	37-09.62	122-01.57	660	0.01	690521	
JBG	37-20.52	122-20.34	158	0.07	711102	
JBL	37-07.69	122-10.08	792	-0.18	770517	
JBM	37-19.09	122-09.16	820	-0.08	750224	
JBZ	37-01.07	121-49.15	213	0.19	751007	
JCB	37-06.71	121-41.33	192	-0.07	670824	
JEC	37-03.04	121-48.56	438	-0.04	690528	
JEG	37-30.84	122-27.74	202	-0.14	750210	
JHL	37-06.56	121-49.95	908	-0.15	751002	
JLT	37-21.22	122-12.25	270	-0.05	661215	
JLX	37-12.11	121-59.17	244	-0.07	750204	
JMG	37-38.22	122-28.43	201	-0.10	710831	
JPL	36-58.62	121-49.93	158	0.06	720701	
JPP	37-15.81	122-12.78	186	-0.05	750723	
JPR	37-47.70	122-28.43	107	-0.11	760406	
JPS	37-11.94	122-20.90	84	-0.03	701125	
JRG	37-02.22	121-57.87	213	-0.15	760116	
JRR	37-03.27	121-43.61	408	-0.20	760109	
JSA	37-34.95	122-25.03	207	-0.08	690101	
JSC	37-17.07	122-07.42	357	-0.10	661223	
JSF	37-24.31	122-10.55	143	0.09	661213	
JSG	37-16.96	122-03.00	198	0.15	750122	
JSJ	37-20.03	122-05.48	122	0.16	661223	
JSM	37-12.74	122-10.06	262	0.07	710714	
JSS	37-10.17	121-55.84	946	-0.09	750122	
JST	37-12.41	121-47.84	149	-0.10	751002	
JTG	37-01.71	121-52.58	253	0.11	751002	
JUC	37-00.07	122-02.91	177	-0.16	760129	
JWS	37-25.08	122-16.33	280	-0.18	661221	
LCF	40-29.18	121-31.44	2438	0.00	761112	
LHK	40-26.12	121-16.67	2060	0.00	771004	
LMZ	40-32.73	121-33.84	1792	0.00	761112	
LRD	40-27.78	121-27.85	2292	0.00	761112	
LSL	40-25.64	121-32.05	2048	0.00	761112	
MBF	37-40.71	120-21.80	309	0.00	761103	
MCH	38-01.12	120-30.57	475	0.00	720419	
MCU	37-58.36	120-37.02	336	0.17	770609	
MMW	38-03.83	120-10.89	1411	-0.28	760701	
MNH	38-08.75	120-48.82	219	-0.03	761103	
MOY	37-54.00	120-34.04	176	0.11	720419	
MRF	38-14.72	120-31.24	799	-0.10	760702	

TABLE 1. STATION DATA (CONTINUED)

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
MST	37-54.27	120-24.29	366	0.00	720419	
NBP	38-40.07	122-11.60	867	0.21	740510	
NBR	38-15.65	122-32.99	137	-0.10	700814	
NCD	38-22.19	122-27.70	620	-0.30	710308	
NCF	38-19.28	122-47.73	98	-0.17	700814	
NFI	37-41.90	123-00.00	107	-0.09	710305	
NFR	38-31.36	123-09.66	528	-0.04	750122	
NGV	38-16.84	122-12.89	257	-0.13	710430	
NHB	38-35.36	122-54.54	165	-0.20	750221	
NHM	38-09.28	121-48.02	65	0.51	710429	
NLH	38-07.19	122-08.87	177	0.00	770915	
NLN	38-09.15	122-42.75	120	-0.11	700814	
NMH	38-40.17	122-37.93	1311	-0.20	770120	
NMT	38-48.34	122-26.76	422	-0.10	750626	
NMW	38-33.03	122-43.37	134	-0.17	700814	
NMX	38-24.68	122-03.44	177	0.15	710612	
NOL	38-02.50	122-47.64	37	-0.10	770223	
NSH	38-31.20	122-36.43	328	-0.23	700814	
NSP	38-10.96	122-27.20	88	-0.10	710203	
NTM	38-23.15	122-40.83	105	-0.10	700814	
NWR	38-27.42	122-53.26	50	-0.18	700814	
OBH	39-39.10	121-27.70	916	0.02	750806	
OCH	39-52.55	121-45.93	530	-0.14	761220	
OGO	39-39.22	121-36.72	158	-0.11	761229	
OHC	39-20.18	121-29.05	76	-0.14	750806	
ORA	39-28.13	121-24.80	585	-0.06	750806	
OST	39-22.12	121-35.80	29	-0.08	750806	
OSU	39-16.23	121-51.10	67	-0.24	760323	
OTB	39-32.75	121-33.65	223	-0.04	750806	
OWY	39-27.19	121-29.20	177	0.09	750806	
PAG	35-43.92	120-14.96	482	-0.03	780629	
PAR	36-14.95	120-20.52	485	0.25	750905	
PBW	36-18.90	120-55.75	381	0.00	720127	
PCA	35-55.90	120-20.22	1189	0.29	701215	
PCR	36-05.65	120-26.08	296	0.03	750904	
PCZ	36-05.45	121-09.43	277	0.00	770923	780605
PGH	35-49.86	120-21.17	433	-0.17	680321	
PHC	35-40.93	121-09.15	514	-0.10	731217	
PHR	36-22.38	120-49.10	732	0.16	691126	
PIV	35-54.39	120-40.94	497	0.04	750924	
PJL	36-05.39	121-09.33	290	-0.01	780605	
PLO	36-14.79	121-02.55	308	-0.23	700814	

TABLE 1. STATION DATA (CONTINUED)

USGS TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY	DATE ON	DATE OFF **
PMG	35-25.79	120-31.22	529	-0.13	780601	
PMP	36-12.91	120-47.69	784	0.11	700814	
PPF	35-52.91	120-24.81	469	-0.01	680111	
PPT	36-06.50	120-43.27	506	-0.01	700416	
PRC	36-15.37	120-37.20	623	0.13	780526	
PSA	36-01.52	120-53.30	184	0.02	780531	
PSM	36-04.18	120-35.68	988	0.25	750924	
PTY	35-56.73	120-28.45	552	0.16	670112	
PWK	35-48.87	120-30.67	503	0.11	680111	

USGS/CIT TELEMETERED STATIONS

CODE	LAT N	LONG W	ELV	DELAY
BCH	35-11.10	120-05.05	1140	0.00
CRG	35-14.53	119-43.40	1204	0.00
ISA	35-39.80	118-28.04	835	0.00
TMB	35-05.24	119-32.08	1021	0.00
YEG	35-26.18	119-57.56	939	0.00

UCB STATIONS

CODE	LAT N	LONG W	ELV	DELAY
ARC	40-52.60	124-04.50	59	0.00
BKS	37-52.60	122-14.10	276	-0.04
BRK	37-52.40	122-15.60	81	0.00
FHC	40-48.10	123-59.10	610	0.00
FRI	36-59.50	119-42.50	119	-0.03
GCC	37-01.80	121-59.80	122	0.00
JAS	37-56.80	120-26.30	457	0.09
LLA	36-37.00	121-56.60	475	0.00
MHC	37-20.50	121-38.50	1282	0.16
MIN	40-20.70	121-36.30	1495	0.00
PCC	37-30.00	120-22.90	91	0.00
PRI	36-08.50	120-39.90	1187	0.00
PRS	36-19.90	121-22.20	363	0.00
SAO	36-45.90	121-26.70	350	0.00
WDC	40-34.80	122-32.40	300	0.00

TABLE 1. STATION DATA (CONTINUED)

CDWR STATIONS

CODE	LAT N	LONG W	ELV	DELAY
KPK	39-35.01	121-18.32	897	0.06
MGL	39-48.71	121-33.42	1010	0.07
ORV	39-33.33	121-30.00	362	-0.15
PAM	39-26.94	121-31.19	131	0.00
SLD	37-04.48	121-13.23	443	0.00

* LAT AND LONG ARE LATITUDE AND LONGITUDE IN DEGREES AND MINUTES. ELV IS ELEVATION IN METERS. DELAY IS IN SECONDS.

** IF THIS COLUMN IS BLANK THEN THE STATION WAS OPERATING THROUGH THE END OF THE TIME PERIOD COVERED BY THIS CATALOG.

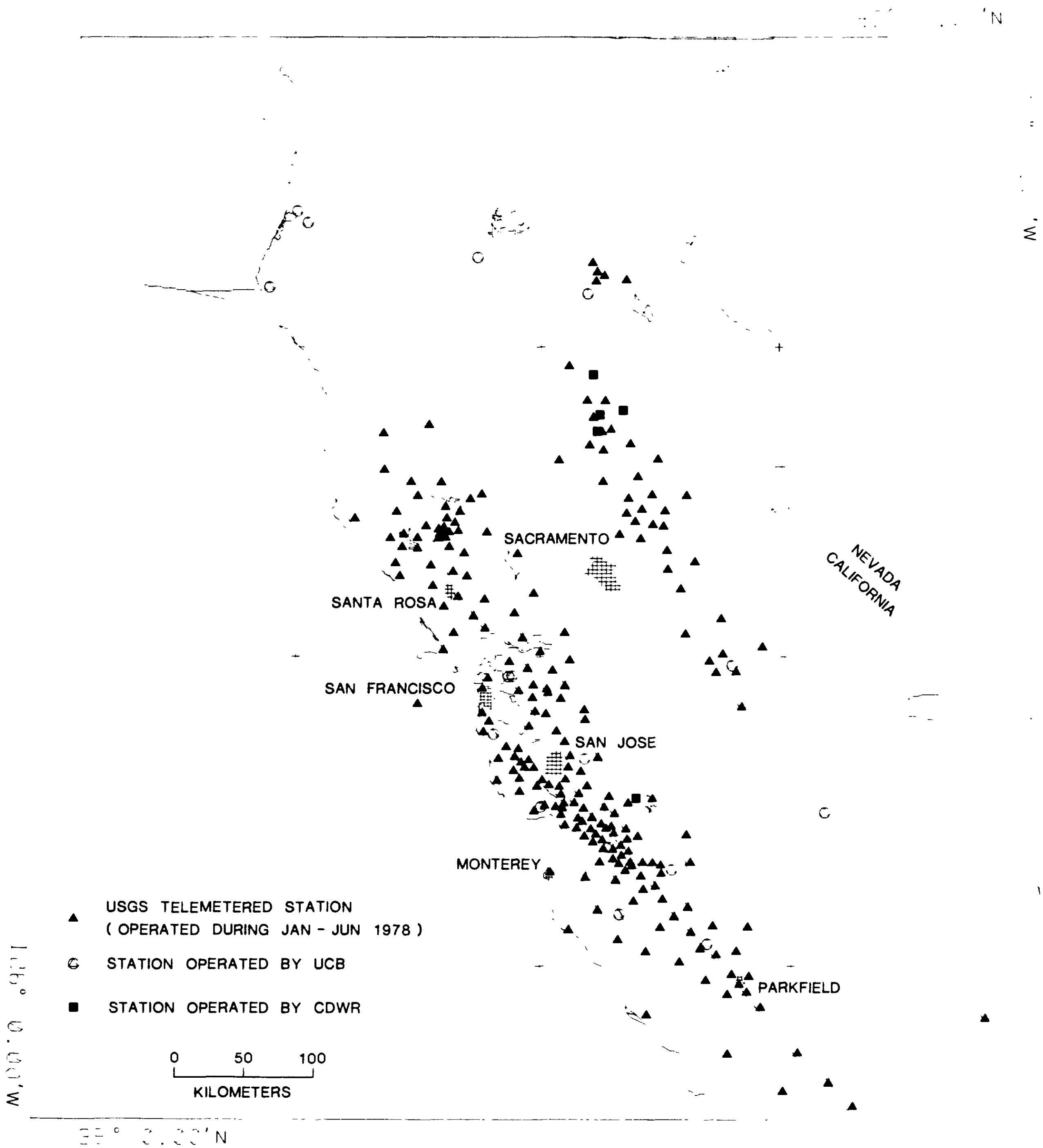

Figure 3. Map showing principal seismograph stations used in locating earthquakes for the first half of 1978.

The location of each earthquake was based mainly on first P-arrivals. When an adequate location could not be obtained using P-arrivals alone, S-arrivals were used to supplement the P-arrivals whenever possible. The HYPO71 computer program uses Geiger's method (Geiger, 1912) to determine hypocenters by minimizing the differences between observed and calculated traveltimes through an iterative least-squares scheme. Traveltimes from a trial hypocenter to the stations and their partial derivatives are computed on the assumptions of a horizontal multilayer velocity model by a technique introduced by Eaton (1969).

The crustal velocity model used was derived mostly from analysis of explosion data by Wesson and others (1973a). It is specified by:

Layer	Depth (km)	P-velocity (km/sec)	S-velocity (km/sec)
1	0 to 3.5	4.0	2.2
2	3.5 to 15	5.9	3.3
3	15 to 25	6.8	3.8
4	below 25	8.05	4.5

The method used for estimating the local Richter magnitude of the earth-
quakes has been described by Lee and others (1972a). In brief, the magnitude of an earthquake is based on the average of magnitudes estimated at various stations. Station magnitude M is derived from its recorded signal duration T according to:

$$M = -0.87 + 2.00 \log T + 0.0035 D \qquad (1)$$

where D is the epicentral distance in kilometers. The signal duration or coda is defined as the duration time in seconds from the onset of the first P-arrival to the point where the trace amplitude (peak-to-peak) falls below 1 cm as it appears on the Geotech film viewer.

For earthquakes with Richter magnitudes of 3.5 and below, equation (1) gives a good estimate of the magnitude. Richter magnitudes have been calculated (Richter, 1942) for earthquakes with coda magnitudes of 3.5 or greater using records obtained from the UCB Wood-Anderson seismographs at Berkeley, Mount Hamilton, Arcata, and Mineral. The earthquakes for which the Richter magnitude has been determined from Wood-Anderson records are indicated in the catalog by an R next to the magnitude.

A substantial effort has been made to identify explosions so as to eliminate them from the catalog. Explosions can be identified on the basis of several criteria: location of a known quarry or blasting site, shallow focal depth, time of day, focal mechanism, and through correspondence with quarry operators. During the first half of 1978, 59 blasts were identified and eliminated from the catalog.

DISCUSSION OF CATALOG

The parameters for the earthquakes listed in the Appendix include the origin time, location of hypocenter (epicenter and focal depth), and magnitude. In addition, six other parameters are listed so that an evaluation of the quality of the hypocenter solution may be made. These parameters are (1) the largest azimuthal separation between stations (GAP), (2) the epicentral distance to the nearest station (DMIN), (3) the root-mean-square error of the traveltime residuals in seconds (RMS), (4) the standard error of the epicenter (ERH), (5) the standard error of the focal depth (ERZ) and (6) the number of P- and S-arrivals used in the location (NO). Based on these parameters, the general reliability of each earthquake solution is graded as either excellent (A), good (B), fair (C), or poor (D). Exact rules of quality classification are given in the Appendix.

A brief discussion on the accuracy of hypocenter determinations has been given by Lee and others (1971). To obtain a reliable epicenter, GAP should be less than 180 degrees; to obtain a reliable focal depth, DMIN should be less than the focal depth. In addition, systematic errors arise from uncertainties in the crustal velocity model. These errors cannot be determined except through controlled experiments, e.g., known explosions in the focal region. Because we present all hypocenter solutions of earthquakes in the region we studied, their quality varies. Although standard errors of epicenter and focal depth (ERH and ERZ) are given, they must be interpreted with caution, especially for quality C and D solutions. Hypocenter solutions for known blasts distributed throughout the San Francisco Bay region indicate that the true positions are often within the standard error limits of the solutions, provided that the conditions, GAP less than 180 degrees and DMIN within a few kilometers, are met. For example, comparison of locations determined for well-recorded quarry blasts (solution quality A) with the known coordinates indicate a typical error of about 1 km. As suggested by our computer locations of known blasts, a general statement on the accuracy of our hypocenter solutions is as follows:

Solution Quality	Approximate accuracy in Epicenter	Focal Depth
A (excellent)	≤ 1 km	≤ 2 km
B (good)	≤ 2.5 km	≤ 5 km
C (fair)	≤ 5 km	> 5 km
D (poor)	> 5 km	> 5 km

Epicenters listed in the Appendix are plotted according to magnitude in Figure 4. The dashed lines in Figure 4 indicate the boundaries of the USGS seismograph network as it existed during the first half of 1978. We feel that the hypocenters listed in the the Appendix represent a nearly complete set of earthquakes above magnitude 1.5 within these boundaries and that these earthquakes are generally well located. Earthquakes outside the dashed boundaries in Figure 4 tend to be less well located, depending on their distance from the network and their relationship to its geometry. Further, the minimum magnitude event that we can detect and locate increases with increasing distance from the network. For earthquakes outside the network, which yielded unsatisfactory locations on the basis of first P-arrivals alone, S-arrivals were included whenever possible.

We believe that the precision of the earthquake locations (or the relative locations) is better than the absolute accuracy of the earthquake locations. Despite our attempts to model the laterally inhomogeneous nature of the velocity structure within the earth's crust, we suspect that the locations within certain parts of the area included in the boundaries of the network may be systematically biased by as much as 2-3 km (Mayer-Rosa, 1973).

Some of the earthquakes listed in this catalog are multiple events, that is, earthquakes from a given source region which occur in such rapid succession that the seismographs are still recording arrivals from one earthquake when the first arrivals from a following earthquake begin to appear. Depending on the size of the individual events and their separation in time, it may be possible to accurately time and locate the later event(s). Sometimes, however, this is not possible.

The contents of the Appendix, along with similar location information for central California earthquakes since 1969, may be obtained in forms amenable to computer input (magnetic tape) by contacting:

National Oceanic and Atmospheric Administration
Environmental Data and Information Service
NGSDC, Mail Code D62
325 Broadway
Boulder, CO 80303

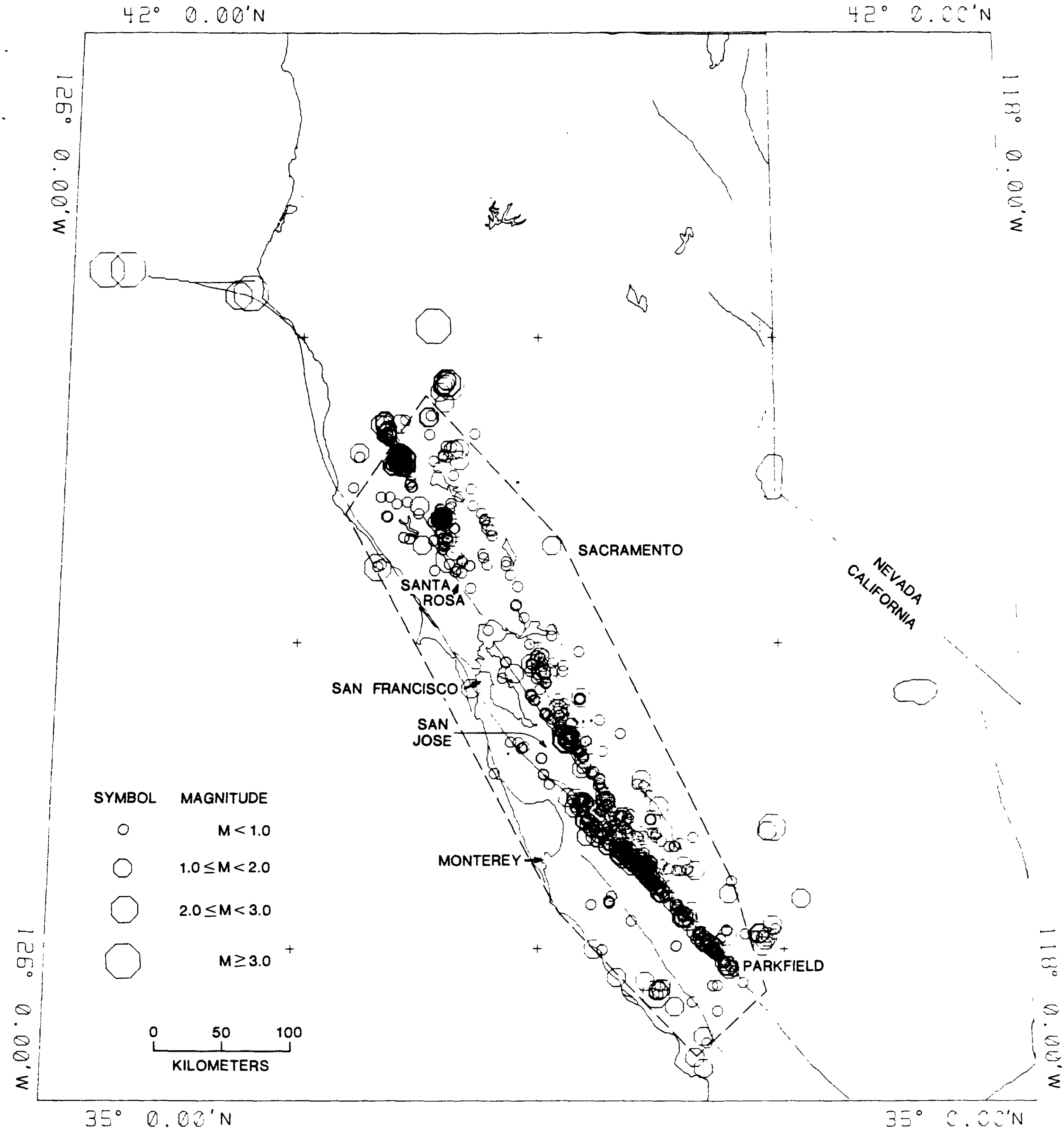

Figure 4. Map showing earthquake epicenters for January - June 1978 reported in the Appendix. Earthquakes in the region enclosed by the dashed line are generally well recorded and located.

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APPENDIX: CATALOG OF EARTHQUAKES JANUARY - JUNE (1978)

Earthquakes along the San Andreas fault system in central California for January - June 1978 are listed chronologically in this APPENDIX.

The following data are given for each event:

1. Origin time in Coordinated Universal Time (UTC): date, hour (HR), minute (MN), and second (SEC). To convert to Pacific Standard Time (PST), subtract eight hours, to Pacific Daylight Time (PDT), subtract seven hours.

2. Epicenter in degrees and minutes of north latitude (LAT N) and west longitude (LONG W).

3. DEPTH, depth of focus in kilometers. If "*" follows the DEPTH, it means that the focal depth is constrained by the location program.

4. MAG, local magnitude of the earthquake. If "R" follows the magnitude, it indicates the local Richter magnitude calculated from Wood-Anderson seismograph records.

5. NO, number of P- and S-arrivals used in locating earthquake.

6. GAP, largest azimuthal separation in degrees between stations.

7. DMIN, epicentral distance in kilometers to the nearest station.

8. RMS, root-mean-square error of the time residuals:

$$RMS = \sqrt{\sum_i R_i^2 / NO}$$

where R_i is the observed seismic-wave arrival time minus the computed time at the i^{th} station.

9. ERH, standard error of the epicenter in kilometers:

$$ERH = \sqrt{SDX^2 + SDY^2}$$

where SDX and SDY are the standard errors in latitude and longitude, respectively, of the epicenter.

10. ERZ, standard error of the depth in kilometers.

11. Q, solution quality of the hypocenter. This measure is intended to indicate the general reliability of each solution.

Q	Epicenter	Focal Depth
A	excellent	good
B	good	fair
C	fair	poor
D	poor	poor

Q is based on both the nature of the station distribution with respect to the earthquake and the statistical measure of the solution. These two factors are each rated independently according to the following schemes.

Station Distribution

	NO	GAP	DMIN
A	$\geq$ 6	$\leq$ 90	$\leq$ DEPTH or 5 km
B	$\geq$ 6	$\leq$ 135	$\leq$ 2 x DEPTH or 10 km
C	$\geq$ 6	$\leq$ 180	$\leq$ 50 km
D	Others		

Statistical Measures

	RMS (sec)	ERH (km)	ERZ (km)
A	< 0.15	< 1.0	< 2.0
B	< 0.30	< 2.5	< 5.0
C	< 0.50	< 5.0	
D	Others		

Q is taken as the average of the ratings from the two schemes, i.e., an A an a C yield a B, and two B's yield a B. When the two ratings are only one unit apart the lower one is used, i.e., an A and a B yield a B.