UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Review of earthquake activity and current status of seismic monitoring in the region of the Bradley Lake Hydroelectric Project, southern Kenai Peninsula, Alaska: December 1981 - May 1983

Christopher D. Stephens, John C. Lahr,
Robert A. Page, and John A. Rogers[1]

Open-File Report 83-744

Submitted to
Alaska Power Authority
334 West Fifth Avenue
Anchorage, Alaska 99511

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature. Any use of trade names is for descriptive purposes only and does not imply endorsement by the U. S. Geological Survey

[1] All at: U. S. Geological Survey
345 Middlefield Road
Menlo Park, California 94025

1983

TABLE OF CONTENTS

ILLUSTRATIONS

TABLES

APPENDIX

HIGHLIGHTS OF RECENT RESULTS

Hypocenters of 91 shallow (depth less than 20 km) earthquakes that occurred between December 1981 and May 1983 indicate that the pattern of recent crustal activity around the southern Kenai Peninsula has remained stable relative to the data prior to December 1981. The earthquakes are generally smaller than about magnitude 2.5. Most of the activity occurred east of the Border Ranges fault, and several concentrations can be observed in an otherwise diffuse distribution of activity. In general there is a poor correlation of the shallow activity with mapped fault traces.

A more reliable estimate of the depth to the Benioff zone beneath Bradley Lake can be made from the greater number of available hypocenters of well-recorded earthquakes now available. Using the current velocity model, the depth to the top of the Benioff zone is 37 ± 5 km.

A strong-motion record was obtained from the SMA-1 instrument co-located at the site of the central high-gain station BRLK, about 2 km from the proposed dam site. A preliminary estimate of 0.14 g (1 g = 980 cm/sec^2) was obtained for the maximum peak-to-peak horizontal acceleration on the record, but at present the event which caused the trigger is uncertain.

Two new stations were installed southeast of Kachemak Bay in June 1983 in order to improve the accuracy of hypocenter determinations for continuing shallow earthquake activity that is observed in this area.

INTRODUCTION

The Alaska Power Authority plans to construct a hydroelectric facility on the southern Kenai Peninsula, Alaska. The project involves damming Bradley Lake, which is located in the Kenai Mountains at an elevation of 1,090 feet, and feeding the water through a tunnel to a power plant at sea level. In this region of tectonic interaction between the Pacific and North American plates (Figure 1), the potential for strong earthquakes needs to be addressed so that the hazards they pose can be minimized. The most serious effect of earthquakes on man-made structures is structural damage from strong shaking. Other potentially damaging aspects of earthquakes include surface faulting as well as shaking-induced effects such as liquefaction, landslides, differential settling, and seiches.

A project to investigate the problem of seismic hazards in the Bradley Lake region was initiated by the U.S. Geological Survey in November 1980 at the request of the Alaska District, U.S. Army Corps of Engineers. This project entails collecting and analyzing earthquake data in the region of the proposed Bradley Lake Hydroelectric Project in order to develop a more detailed model for the tectonic framework. Particular emphasis is being placed on the distribution of shallow crustal earthquakes and their relationship to mapped or inferred faults. On November 15, 1982, the responsibility for funding the project was transferred to the Alaska Power Authority.

The purpose of this report is to summarize the work completed to date, including the operation of the seismic stations and a review of the seismic data collected through May 1983. Part of the data has been presented in two previous reports to the Corps of Engineers (Lahr and Stephens, 1981; Stephens and others, 1982). The data presented in this report generally conform to the distribution of earthquake hypocenters and magnitudes described in the earlier reports, but the greater quantity of high-quality data now available allows us to make more reliable estimates of such parameters as the depth to the Benioff zone beneath Bradley Lake and the location of areas that are currently experiencing high rates of shallow seismicity.

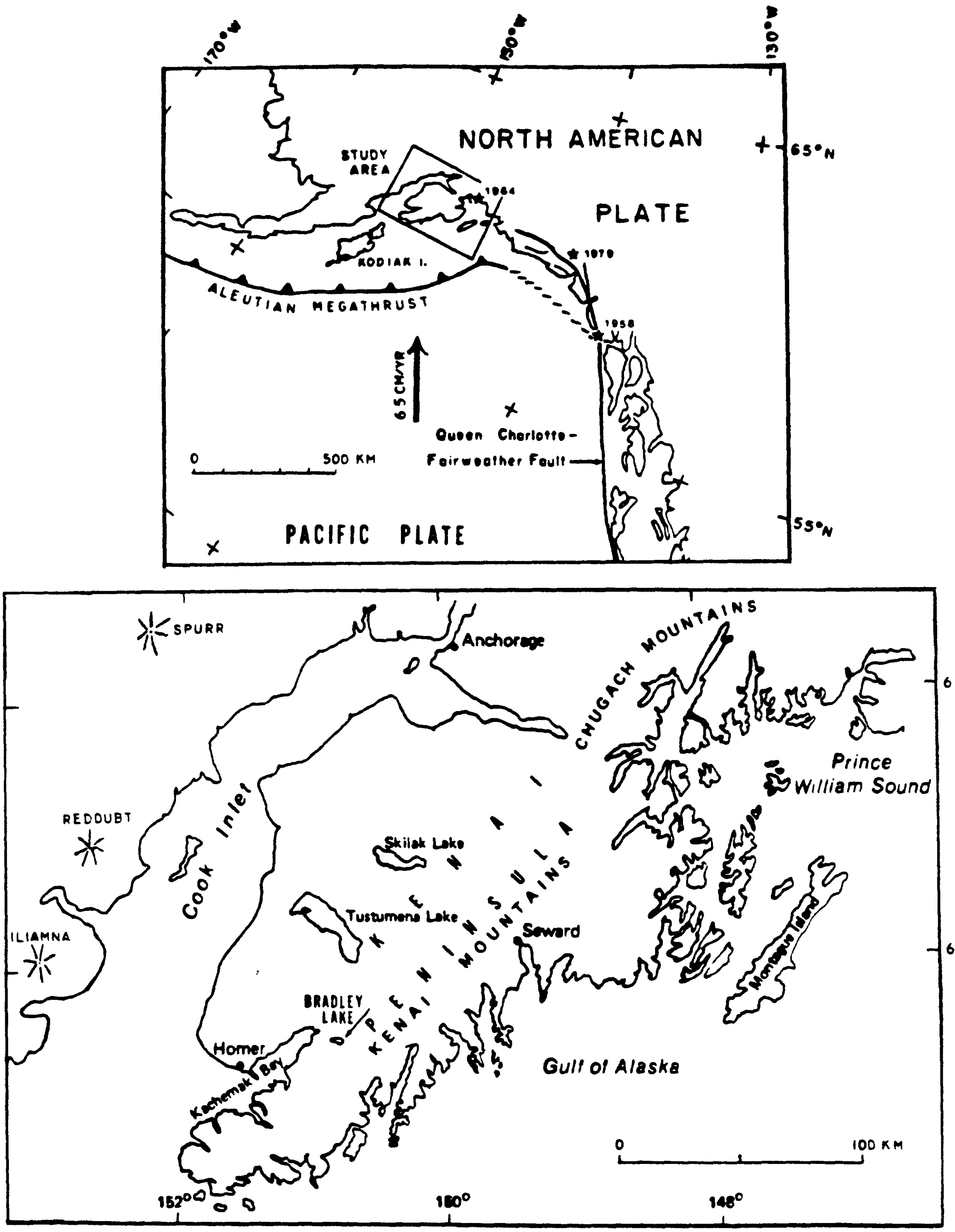

Figure 1. Upper- Current motion of Pacific plate with respect to North American plate. Projection is oblique Mercator using a pole at 54°N and 61°W. Rotation of the Pacific plate with respect to the North American plate about this pole is equivalent to vertical translation in this figure. Epicenters of the 1958, 1964, and 1979 earthquakes are shown.
Lower- Enlargement of the area outlined in upper figure, showing the setting of Bradley Lake. The locations of Spurr, Redoubt, and Iliamna volcanoes are indicated. Modified from Woodward-Clyde Consultants (1979).

SEISMOTECTONIC FRAMEWORK

The Bradley Lake region is located in the zone of tectonic interaction between the North American plate and the relatively northwestward-moving Pacific plate (Figure 1). The average rate of convergence near the southern Kenai Peninsula over the past 3 m.y. is 6.5 cm/yr (Minster and Jordan, 1978). Direct evidence for continued convergent motion comes from the occurrence of recent large earthquakes along portions of the Pacific - North American plate boundary adjacent to the Gulf of Alaska. For example, the 1964 Alaska earthquake resulted from dip-slip motion of about 12 m (Hastie and Savage, 1970) on the portion of the Aleutian megathrust extending from Prince William Sound to southern Kodiak Island and dipping northwestward beneath the continent.

The seismicity associated with the processes of convergent plate motion in Alaska generally may be divided into five spatially distinct groups:

1. Earthquakes which occur on the gently dipping Aleutian megathrust (the the interface zone between the Pacific and North American plates);
2. Earthquakes which occur in the wedge of crust above the active megathrust zone;
3. Earthquakes that occur within the subducted Pacific plate beneath Alaska (Benioff zone events);
4. Earthquakes within the Pacific plate seaward of the Aleutian megathrust;
5. Shallow earthquakes near the active volcanoes.

The Bradley Lake region is most directly affected by the first three types of events.

INSTRUMENTATION

Earthquakes are recorded by high-gain, high-frequency seismograghs of the USGS regional network (Figure 2). Details about the instrumentation can be found in quarterly catalogs of earthquakes (for example, Fogleman and others, 1983). The five stations of the Bradley Lake array (Figure 2 and Table 1) were installed in November 1980. Each station has a vertical-component geophone, and the central station BRLK also has two horizontal-component geophones oriented in north-south and east-west directions. An SMA-1 strong-motion instrument is also operated at the site of the BRLK station.

In June 1983 two new stations were installed between the stations BRSW and SLV in an area where activity was observed during the previous 2 1/2 years of recording. In order to operate these new stations, one of the horizontal components at the BRLK site was discontinued.

DATA PROCESSING

The data recorded by USGS regional seismograph stations in the Bradley Lake region are mailed weekly from Palmer, Alaska, to Menlo Park, California, where they are processed using the following multi-step routine:

1. Scanning: Seismograms with a scale of 15 mm/min for two of the Bradley Lake stations, usually BRLK and BRSW, are scanned to identify and note times of seismic events within the Bradley Lake network and the surrounding area. The events noted are found on the Develocorder film (scale 10 mm/sec) and any event with a P- to S-phase time interval (S-P time) of less than or equal to 6 seconds at one of the Bradley Lake stations is noted for subsequent timing. The upper limit of the S-P timing criterion has varied with time during the project from 10 sec beginning in November 1980, to 12 sec in February 1981, and then to the

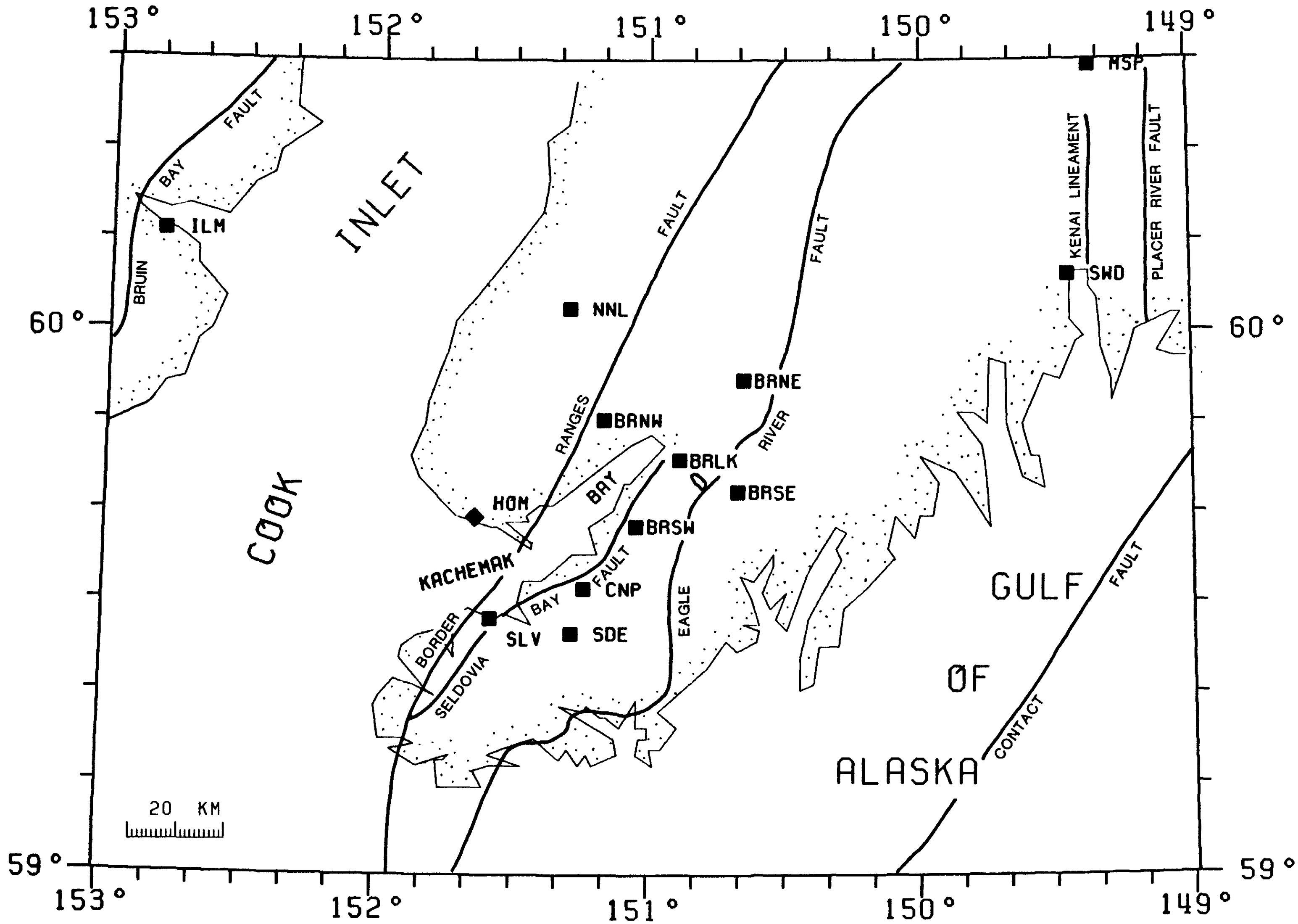

Figure 2 Map of the study area in the Bradley Lake region. All seismic stations are operated by the U.S. Geological Survey with the exception of HOM (diamond) which is operated by the University of Alaska. Faults after Beikman (1980) and Plafker (1969). Bradley Lake is indicated by small oval next to station BRLK near center of map.

TABLE 1. STATION COORDINATES

STATION CODE	LATITUDE, N DEG	MIN	LONGITUDE, W DEG	MIN	ELEV M	DATE OPENED YR	MO	DY
BRLK	59	45.85	150	53.13	631	80	11	17
BRNE	59	54.65	150	39.13	1219	80	11	17
BRNW	59	50.25	151	10.15	582	80	11	17
BRSE	59	42.33	150	40.25	975	80	11	17
BRSW	59	38.46	151	2.69	951	80	11	17
CNP	59	31.55	151	14.16	564	83	6	28
HOM	59	39.50	151	38.60	198	81	3	20
ILM	60	10.92	152	48.97	550	71	8	7
MSP	60	29.35	149	21.64	150	73	8	5
NNL	60	2.53	151	17.78	366	72	8	24
SDE	59	26.60	151	16.92	770	83	6	28
SLV	59	28.28	151	34.83	91	72	9	30
SWD	60	6.22	149	26.96	91	72	8	22

This table lists coordinates for stations shown in Figure 2. All stations are operated by the USGS except HOM, which is operated by the University of Alaska. The five stations BRLK, BRNE, BRNW, BRSE, and BRSW were installed and are operated with support from this program. All sites have vertical-component geophones. Two horizontal component geophones oriented north-south and east-west also have been operating at the BRLK site since November 1980, but in June 1983 one of these components was turned off in order to operate one of the two new stations CNP and SDE. In addition, an SMA-1 strong-motion recorder is co-located at the BRLK site.

current value of 6 sec in March, 1983. A one-second S-P interval approximately corresponds to a distance of 8 km. Thus, shocks within about 50 km of one of the five stations are now being timed.

2. Timing: For each of the identified events that has been recorded on the 16-mm Develocorder films at four or more stations in the Bradley Lake region the following data are read for each station: P- and S-phase arrival times; direction of the first motion of the P-wave; duration of signal in excess of 1 cm threshold amplidue (coda); and period and amplitude of maximum recorded signal.

3. Initial computer processing: The data read from the films are batch processed by computer using the program HYPOELLIPSE (Lahr, 1980) to determine the origin time, hypocenter, magnitude, and first-motion plot for each earthquake.

4. Final processing: Each hypocenter solution is checked for large travel time residuals and for poor station distribution. Arrivals that produce large residuals are re-read. For shocks with a poor azimuthal distribution of stations, readings are sought and added from additional stations. The corrected or improved data are then run again and the solutions checked for large residuals that may indicate remaining errors.

Magnitudes are determined from either the coda duration or the maximum trace amplitude (see Fogleman and others, 1983, for details). The magnitude preferentially assigned to each earthquake is that obtained from the coda duration. For shallow earthquakes, the current relationship for computing magnitudes from coda durations results in estimates that are systematically low compared to body-wave magnitudes (m_b) reported by the National Earthquake Information Service (NEIS) and local magnitudes (m_L) reported by the Alaska Tsumani Warning Center (ATWC). Along the northern Gulf of Alaska, the coda-duration magnitudes for shallow earthquakes are generally smaller than m_b by about 1/3 unit at coda magnitude 3 to as much as about 1 unit at coda magnitude 4 (Lahr and others, 1983). This problem is being studied in order to develop a more reliable method of estimating magnitudes from coda duration.

ANALYSIS OF QUALITY

Two types of errors enter into the determination of hypocenters: systematic errors limiting the accuracy and random errors limiting the precision. Systematic errors arise principally from incorrect modeling of the seismic velocity structure of the earth. Random errors result from effects such as random timing errors, and their effect on each earthquake is estimated by standard statistical techniques.

Systematic errors can be greatly reduced by close spacing of seismographic stations within the area of interest, as the hypocentral solution in this situation is much less sensitive to the velocity model assumed for the earth. For this reason, the earthquakes located in the Bradley Lake region since the installation of the additional five stations in late 1980 are expected to have smaller systematic offsets than those located earlier with the less dense regional network.

For each earthquake the lengths and orientations of the principal axes of the joint confidence ellipsoid are calculated. One is 68 percent confident that the hypocenter lies within the one-standard-deviation confidence ellipsoid, assuming that the only source of error is the estimated random reading error. The size and orientation of the ellipsoid is a function of the station geometry. For earthquakes within the network, the lengths of the ellipsoid axes are generally on the order of 2 to 3 km.

To fully evalutate the quality of a hypocenter, both the size and orientation of the confidence ellipsoid, the root-mean-square (RMS) residual for the solution, and the station geometry must be considered.

RESULTS

The epicenters for 1662 earthquakes that occurred between November 27, 1980, and May 31, 1983, and were located near the southern Kenai Peninsula are shown in Figure 3. Most of these events occurred within the northwestward-dipping Benioff zone that underlies the southern Kenai Peninsula and Cook Inlet (Figure 4). The largest earthquake that occurred during this time period was an event of coda-duration magnitude 4.8 (5.1 m_b) which was located at a depth of 118 km in the northwest part of the study area near Iliamna volcano. Ninety-one earthquakes had coda-duration magnitudes of 3 or larger (Table 2 and Figure 5), but all of these events had computed focal depths of 48 km or greater which would place them in the Benioff zone. Twelve of the largest earthquakes were reported in the Preliminary Determination of Epicenters of the USGS National Earthquake Information Service as being felt with maximum intensities ranging from about II to IV (Table 2 and Appendix) in the Kenai-Anchorage area.

Other features of the seismicity that were noted in earlier reports and which can be observed in the data presented here are that the Benioff zone activity dies out near Bradley Lake (near 140 km along the section in Figure 4), that the shallow crustal activity is concentrated east of Cook Inlet, and that few events were located along the Aleutian megathrust.

Benioff zone earthquakes generally occur within a subducted plate near its upper surface. At shallow depths the upper limit of the Benioff zone activity will be near and possibly coincide with the zone of thrust contact between the plates. Hypocenters of well-recorded earthquakes that occurred beneath Bradley Lake (Figure 4) indicate that the maximum depth to the top of the Benioff zone is 37 ± 5 km based on the abrupt increase in the activity at this depth. This depth might change slightly if a different crustal velocity model were used. The seismic zone appears to dip at about 10° in a west-northwest direction.

A few well-recorded earthquakes of magnitude less than 2 have been located beneath Bradley Lake between the Benioff zone activity at 37 km and the shallow crustal activity of the upper 20 km (Figure 6). No reliable focal mechanisms could be obtained for these events, and too few events have been located to define spatial features. Thus, this activity may indicate that faulting extends down into the lower crust, or alternatively, a zone of megathrust interaction between the two converging plates may extend above the Benioff zone and involve a complex zone of splay faulting. Further work is needed to refine the velocity model in this area and thus improve the accuracy of the hypocenters and their locations relative to the crustal and Benioff zone activity. Additonal data from continued monitoring will contribute to resolving the nature of this activity.

PATTERN OF SHALLOW EARTHQUAKES

Shallow (depth less than 20 km) earthquakes (Figures 7 and 8 and Table 3) confirm the presence of active faults within the crust. In the available data from 2 1/2 years of recording, 207 shallow earthquakes were located in the study area around the southern Kenai Peninsula. Earthquakes as small as coda-magnitude 0.2 that occur near the Bradley Lake array are routinely

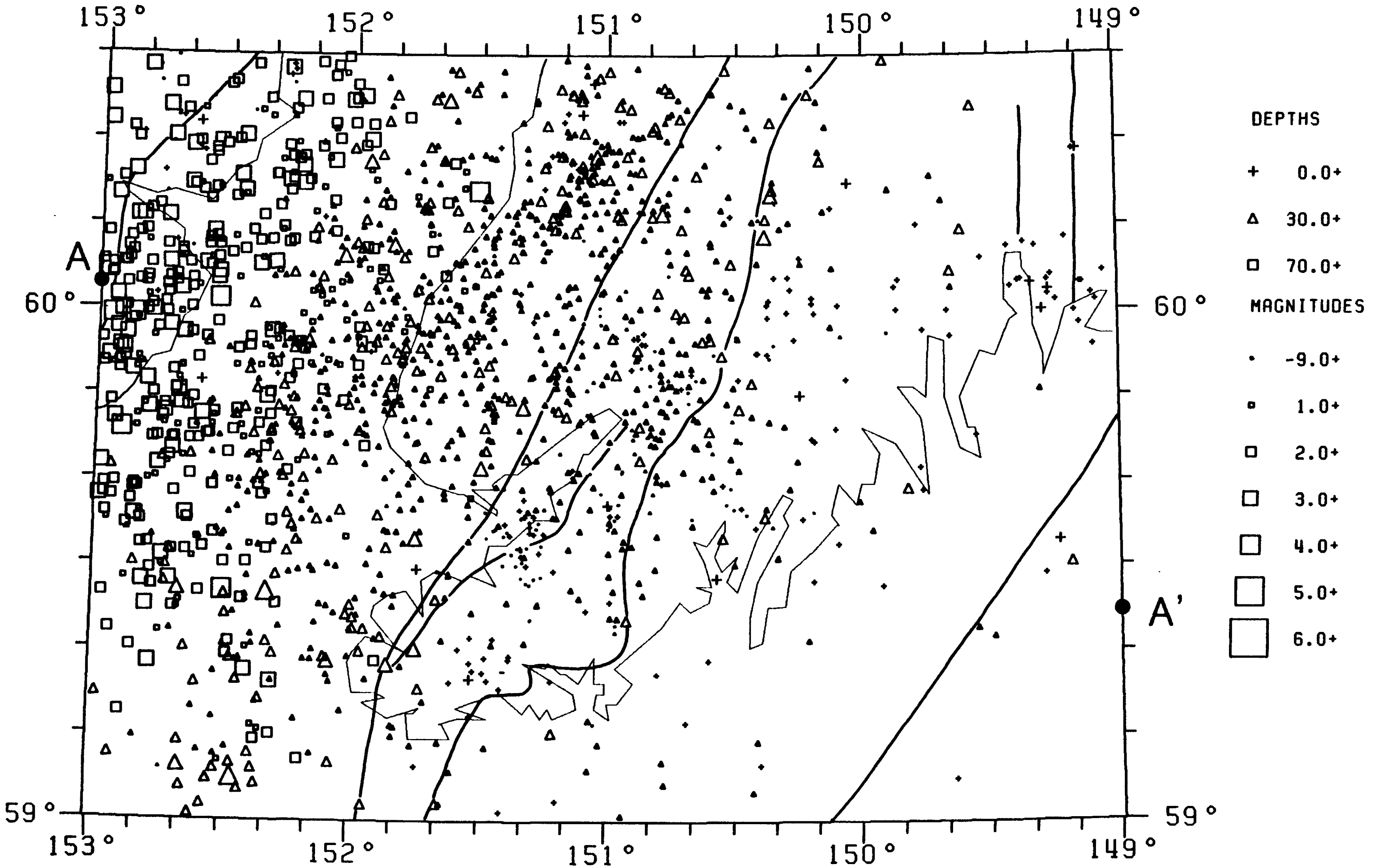

Figure 3 Map of epicenters of 1662 earthquakes that occurred near the southern Kenai Peninsula between November 27, 1980 and May 31, 1983. Heavy lines indicate faults identified in Figure 2.

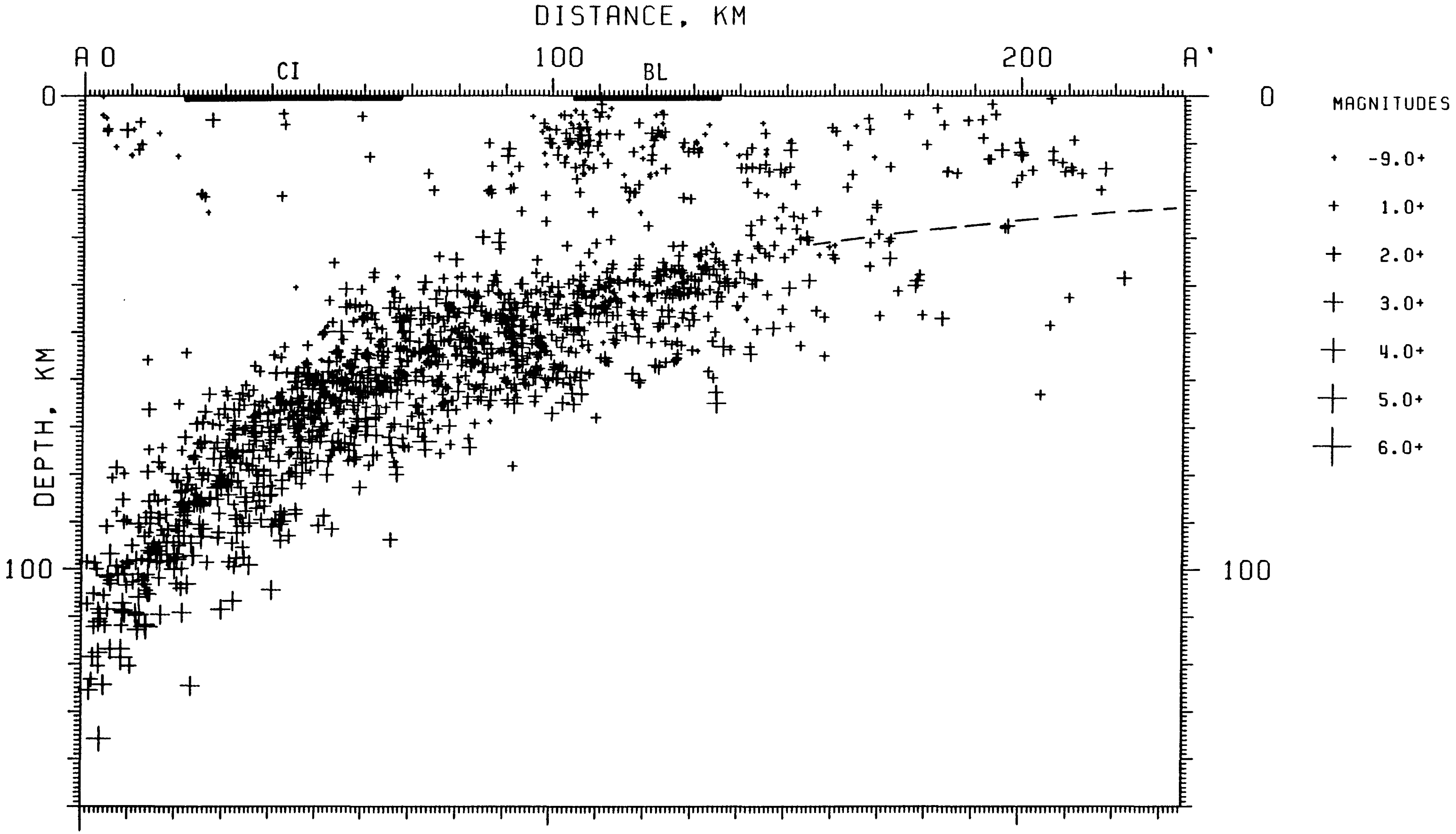

Figure 4 Cross section showing hypocenters of Figure 3 projected onto plane oriented along A-A'. Section width includes area of Figure 3. Heavy lines near 0 km depth indicate approximate locations of Cook Inlet (CI) and Bradley Lake seismic array (BL); light dashed line shows inferred location of Aleutian megathrust.

TABLE 2

EARTHQUAKES OF CODA-DURATION MAGNITUDE 3 AND LARGER NEAR SOUTHERN KENAI PENINSULA
NOVEMBER 27, 1980 - MAY 31, 1983

		ORIGIN TIME			LAT N		LONG W		DEPTH	MAG	MB	NP	NS	GAP	D3	RMS	ERH	ERZ	Q
		HR	MN	SEC	DEG	MIN	DEG	MIN	KM					DEG	KM	SEC	KM	KM	
1980																			
NOV	28	17	44	3.7	60	16.9	152	12.8	90.9	3.6	4.6	35	5	55	57	0.61	1.5	2.9	B
DEC	11	22	10	60.0	60	2.3	152	41.3	98.4	3.8		34	3	55	78	0.52	1.7	3.4	B
		FELT III AT KENAI AND SOLDOTNA																	
1981																			
JAN	23	17	39	41.7	59	57.0	152	53.8	116.9	3.0		35	5	55	75	0.56	1.4	2.6	B
	26	18	24	54.1	60	8.7	150	23.3	53.0	3.2	4.0	38	9	102	51	0.61	1.1	2.4	A
FEB	23	13	3	8.5	60	13.5	150	21.8	64.9	3.8	4.8	36	1	100	52	0.52	1.5	2.3	A
		FELT IV AT KENAI, HOMER, MOOSE PASS, AND SEWARD																	
MAR	6	6	44	33.5	60	5.3	152	22.7	81.6	3.1	4.6	29	7	42	73	0.44	1.2	1.9	A
APR	22	6	31	47.6	60	20.3	152	43.8	124.4	3.6		28	7	81	102	0.57	2.0	3.3	B
	24	7	52	55.0	59	18.3	151	51.0	52.5	3.3	4.0	30	5	111	88	0.49	1.7	3.0	B
		FELT AT HOMER																	
	24	21	29	45.1	60	28.6	152	49.8	132.4	3.4	4.0	27	8	67	89	0.54	1.6	3.1	B
MAY	12	14	36	27.5	59	55.1	152	54.4	107.2	3.1		30	7	137	90	0.55	2.6	2.7	A
	17	8	51	9.5	60	20.4	152	26.8	100.0	3.0		24	5	76	108	0.64	1.5	3.1	B
	21	20	29	33.6	59	45.8	152	54.5	112.2	4.0	4.6	30	1	141	94	0.63	2.3	3.6	B
		FELT ON KENAI PENINSULA AND AT ANCHORAGE																	
	27	5	18	36.6	60	1.5	152	56.5	111.1	3.0		24	6	135	92	0.54	2.2	2.5	B
	28	19	8	23.2	60	10.9	152	44.7	108.7	3.7	4.1	30	8	94	82	0.77	1.5	1.9	A
	30	12	44	54.7	59	55.5	152	55.4	101.1	3.3		33	11	84	78	0.50	1.1	1.4	A
JUL	21	3	17	22.5	59	16.3	152	18.3	76.0	3.3	4.5	38	7	102	97	0.40	1.3	2.5	A
	28	13	43	13.8	59	47.6	152	35.8	82.5	3.0		11	9	222	68	0.49	3.5	2.7	B
	29	5	12	20.5	60	1.3	152	32.3	93.1	4.1		11	6	181	69	0.25	3.5	4.0	B
	30	14	47	32.4	59	26.9	152	19.7	50.0	4.8		13	5	255	86	0.34	3.0	4.8	B
AUG	1	1	42	17.0	59	59.3	152	52.3	118.7	4.8	5.1	36	3	115	77	0.61	1.8	3.6	B
		FELT IV IN ANCHORAGE-HOMER AREA																	
	3	19	43	27.7	60	17.4	151	56.7	59.5	3.7		11	6	114	50	0.37	2.6	4.4	B
	5	10	21	53.1	59	35.9	152	39.1	92.3	3.5		29	6	84	66	0.51	1.4	2.3	A
	7	11	31	17.6	60	25.6	152	59.3	137.5	3.3		31	4	75	98	0.47	1.9	3.9	B
	11	21	27	51.3	59	49.7	152	20.5	90.6	3.2		30	8	71	59	0.50	1.3	1.9	A
SEP	7	9	57	13.1	60	17.5	152	5.3	104.3	3.2		34	10	60	52	0.68	1.6	2.5	A
	9	18	0	3.8	60	24.6	152	13.2	108.5	3.4		32	8	55	66	0.56	1.2	2.3	A
OCT	14	11	3	22.4	60	25.1	151	58.4	89.9	3.4		30	7	52	56	0.56	1.1	2.1	A
	15	21	14	28.5	59	48.9	152	40.7	85.7	3.0		36	8	75	85	0.58	1.3	1.7	A
	18	12	36	49.3	60	24.6	151	38.3	69.9	3.0		34	9	55	46	0.72	1.1	2.2	A
	19	1	46	18.2	60	15.2	152	16.1	106.8	3.6		34	3	57	75	0.58	1.3	2.9	B
NOV	1	9	57	26.0	60	14.8	152	39.5	109.3	3.0		35	8	62	79	0.57	1.1	2.2	A
	3	4	3	15.5	60	4.3	152	32.4	97.2	3.5		39	7	64	68	0.67	1.1	1.6	A
	13	18	10	31.0	60	11.4	150	47.2	50.1	3.0		30	4	77	45	0.67	1.3	2.9	B
	16	23	49	49.4	60	4.6	152	59.0	126.7	4.3	4.5	43	2	65	64	0.61	1.5	2.2	A
		FELT II AT HOMER																	
	17	11	28	42.0	60	14.0	151	31.0	73.0	4.1	4.7	41	3	54	59	0.63	1.3	2.5	A
		FELT IV AT KENAI, HOMER, NINILCHIK, SOLDOTNA, CLAM GULCH, COOPER LANDING, TYONEK STERLING, KASILOF, AND GIRDWOOD; ALSO FELT III AT ANCHORAGE,AND II AT PALMER																	
DEC	20	14	13	50.2	59	59.7	152	55.3	101.3	3.4		38	8	68	70	0.47	1.1	1.7	A
	22	4	31	37.4	59	59.7	152	47.8	105.9	3.2		40	8	68	68	0.49	1.2	1.7	A
	25	22	26	40.4	59	35.7	152	51.1	103.2	3.5	4.3	36	3	87	79	0.44	1.5	3.5	B
1982																			
JAN	1	11	21	32.9	60	13.4	152	56.6	130.3	3.5		40	7	69	49	0.56	1.3	2.1	A
	19	0	48	16.2	60	5.3	152	35.5	97.9	3.3		38	6	64	55	0.58	1.1	2.2	A
	19	17	47	34.0	60	9.1	152	33.9	96.8	3.7	4.3	40	6	61	48	0.68	1.0	1.7	A
FEB	6	11	50	51.7	59	57.2	152	40.4	97.5	3.0		36	9	69	77	0.61	1.1	2.1	A
	19	18	57	53.7	59	51.6	152	48.8	96.1	3.5	3.9	35	5	142	69	0.53	1.4	2.3	A
	22	11	54	58.3	60	10.9	152	52.1	118.5	3.3		38	8	99	51	0.84	1.1	2.1	A
	26	7	16	58.2	59	59.2	152	57.4	135.8	4.6	4.9	39	1	69	72	0.57	1.7	3.5	B
		FELT IV AT HOMER, CLAM GULCH, KENAI, NINILCHICK, AND TYONEK. FELT III AT ANCHOR POINT COOPER LANDING, ENGLISH BAY, SELDOVIA, SOLDOTNA, ANCHORAGE, AND PALMER																	
	28	6	57	32.5	59	47.1	152	56.2	98.2	3.8	4.4	39	5	78	71	0.58	1.1	2.0	A

EARTHQUAKES OF CODA-DURATION MAGNITUDE 3 AND LARGER NEAR SOUTHERN KENAI PENINSULA
NOVEMBER 27, 1980 - MAY 31, 1983 (CONT)

1982																			
MAR	5	0	31	1.4	59	47.9	152	44.5	92.9	3.0		37	9	76	69	0.55	1.2	1.6	A
	9	16	25	21.0	60	10.9	152	50.7	117.6	3.7	4.4	39	9	64	50	0.68	1.3	1.9	A
	FELT II AT HOMER																		
	18	14	19	26.3	60	5.4	152	44.2	109.6	3.2		37	13	64	57	0.65	1.1	1.3	A
APR	27	12	39	27.3	60	3.6	152	32.7	97.2	3.7	4.2	37	6	53	67	0.74	1.0	1.8	A
MAY	4	9	35	37.2	60	15.8	152	27.7	109.1	3.9	4.4	40	6	57	81	0.61	1.0	2.1	A
	7	7	42	4.4	59	6.4	152	39.4	66.7	3.2	4.4	31	10	117	84	0.49	1.2	2.7	B
	23	12	53	25.3	60	28.3	152	16.1	90.5	3.1		36	11	57	64	0.61	1.0	2.1	A
JUN	1	9	29	5.4	59	57.9	152	43.6	109.6	3.8		36	9	52	80	0.60	1.4	2.0	A
	3	16	58	13.4	60	14.8	152	12.5	90.3	3.3		34	13	56	73	0.61	0.9	1.3	A
	5	16	41	44.4	59	18.4	152	46.7	99.1	3.0		28	6	100	97	0.66	1.6	2.8	B
	16	17	24	45.2	60	24.6	152	1.1	91.1	3.7		34	13	51	57	0.56	0.9	1.5	A
	18	14	8	15.2	59	26.9	152	30.0	74.3	4.3		37	3	93	84	0.56	1.4	2.9	B
	FELT IV AT HOMER																		
JUL	2	3	49	8.2	59	57.4	152	19.6	82.7	3.6	3.8	36	6	46	66	0.61	1.0	1.4	A
	3	16	46	48.0	59	17.6	152	24.4	73.4	3.0		33	7	115	59	0.60	1.6	2.9	B
	6	17	33	9.9	59	5.1	152	26.9	68.4	4.5	4.8	39	0	102	79	0.53	1.8	3.2	B
	FELT IV AT HOMER																		
	11	17	4	34.6	60	19.3	152	39.4	109.3	3.2		33	7	63	82	0.59	1.0	1.7	A
	12	20	55	19.5	60	16.2	152	52.8	119.0	3.0		33	10	78	91	0.50	1.2	1.7	A
	14	9	12	42.6	59	43.5	152	42.5	91.5	3.3		38	12	63	60	0.64	1.0	1.5	A
	29	0	42	56.4	60	13.9	152	26.7	124.6	3.5		15	4	149	166	0.62	3.4	7.8	C
	29	5	56	22.5	59	28.2	152	42.5	75.3	3.6		38	6	86	64	0.63	1.2	2.7	B
AUG	9	13	53	33.1	59	41.7	152	45.8	86.0	3.0		33	10	101	91	0.40	1.3	1.8	A
	11	15	13	1.7	59	41.4	151	29.6	65.0	3.0		22	4	172	35	0.56	1.5	2.2	A
	13	5	17	32.4	59	57.6	152	56.1	96.8	3.6		35	9	70	92	0.52	1.1	1.9	A
	22	13	33	28.1	59	50.2	152	41.3	94.4	3.3		30	5	89	84	0.39	2.2	1.9	A
	30	15	1	11.4	59	41.8	152	59.0	112.8	3.2		32	7	65	76	0.48	2.2	3.3	B
SEP	7	11	5	30.6	60	7.7	151	50.8	64.8	3.0		25	6	118	54	0.82	2.1	3.1	B
	7	16	41	0.3	59	18.8	152	5.0	59.3	3.1		19	5	126	69	0.34	3.2	2.3	B
	14	18	14	52.7	59	20.2	151	44.7	48.2	3.4		36	9	113	52	0.47	1.3	1.7	A
	15	3	37	28.3	59	48.6	151	19.8	51.2	3.0		34	11	57	25	0.65	0.9	1.6	A
OCT	1	18	6	46.7	59	54.4	152	58.0	116.8	3.1		27	5	192	94	0.46	2.9	3.8	B
NOV	16	22	10	15.4	60	23.8	152	45.2	125.6	3.2		18	7	151	102	0.34	3.4	7.0	C
	19	16	43	59.3	59	25.2	152	47.7	84.3	3.3		17	3	147	103	0.36	4.5	7.4	C
DEC	1	12	47	7.4	59	52.7	152	52.2	90.4	3.2		17	9	192	90	0.38	3.2	3.6	B
	5	12	9	52.7	60	6.3	152	2.5	62.0	3.9	4.9	21	0	142	56	0.38	2.9	5.1	B
	FELT AT HOMER																		
	9	14	56	28.3	59	31.0	152	44.5	75.3	3.2		16	5	225	97	0.50	3.6	6.1	B
	31	2	58	46.4	60	19.9	151	56.7	76.8	3.3		22	7	127	60	0.38	1.6	1.8	A
1983																			
JAN	12	17	9	35.2	59	27.1	152	40.5	69.7	3.0		13	6	232	95	0.42	3.8	5.0	C
	23	4	55	35.0	60	29.3	152	57.4	136.0	3.0		17	3	151	97	0.37	3.5	2.5	B
	29	18	16	50.1	59	48.3	152	48.2	94.4	3.0		18	11	139	88	0.46	2.6	2.8	B
	30	2	50	8.0	60	22.1	152	59.0	119.4	3.3		18	8	145	104	0.33	3.1	2.5	B
FEB	25	5	30	35.3	60	18.1	151	2.7	59.1	3.4	4.3	21	2	57	50	0.29	1.1	3.7	B
MAR	10	16	41	59.5	59	33.1	151	44.9	56.3	3.0		16	4	186	46	0.25	4.5	7.3	C
	14	6	47	30.5	60	5.5	152	19.1	84.9	3.0		20	14	141	57	0.48	1.6	1.7	A
APR	16	17	20	59.6	59	38.0	152	59.5	111.8	3.0		16	7	218	105	0.36	3.6	3.0	B
MAY	28	19	35	55.5	59	28.0	152	48.9	82.9	3.5		15	8	147	102	0.33	3.3	3.1	B

ORIGIN TIME: UNIVERSAL TIME (UT). TO CONVERT TO ALASKA STANDARD TIME SUBTRACT 10 HRS.
MAG: CODA-DURATION MAGNITUDE
MB: BODY WAVE MAGNITUDE
NP: NUMBER OF P-WAVE ARRIVALS USED IN DETERMINING THE HYPOCENTER
NS: NUMBER OF S-WAVE ARRIVALS USED IN DETERMINING THE HYPOCENTER
GAP: LARGEST AZIMUTHAL SEPARATION IN DEGREES BETWEEN STATIONS
D3: DISTANCE IN KILOMETERS TO THE THIRD CLOSEST STATION
RMS: ROOT-MEAN-SQUARE IN SECONDS OF THE TRAVELTIME RESIDUALS
ERH: LARGEST HORIZONTAL DEVIATION FROM THE HYPOCENTER WITHIN THE ONE-STANDARD-DEVIATION CONFIDENCE ELLIPSOID. THIS QUANTITY IS A MEASURE OF THE EPICENTRAL PRECISION.
ERZ: LARGEST HORIZONTAL DEVIATION FROM THE HYPOCENTER WITHIN THE ONE-STANDARD-DEVIATION CONFIDENCE ELLIPSOID. THIS QUANTITY IS A MEASURE OF THE DEPTH PRECISION.
Q: QUALITY OF THE HYPOCENTER. THIS INDEX IS A MEASURE OF THE PRECISION OF THE HYPOCENTER AND IS DETERMINED FROM ERH AND ERZ AS FOLLOWS:

Q	ERH	ERZ
A	_ 2.5	_ 2.5
B	_ 5.0	_ 5.0
C	_ 10.0	_ 10.0
D	‾ 10.0	‾ 10.0

POOR DETEMINATIONS OF THE PARAMETERS MAY RESULT FROM RANDOM ERRORS PRESENT IN THE PHASE DATA, OR FROM SYSTEMATIC ERRORS INTRODUCED EITHER BY THE VELOCITY MODELS USED OR BY THE RELATIVE POSITIONS OF THE TRUE HYPOCENTER AND THE STATIONS USED IN THE SOLUTION. ONE SHOULD BE PARTICULARLY CAUTIOUS USING SOLUTIONS THAT HAVE GAP > 180 DEG, NP < 5, NS = 0, D3 > 75 KM, RMS > 0.75 SEC, ERH > 5 KM, OR ERZ > 5 KM. SOLUTIONS WITH A AND B QUALITY ARE GENERALLY MORE RELIABLE, BUT THIS DOES NOT GUARANTEE THAT THE ACCURACY OF THESE SOLUTIONS IS WITHIN THE LIMITS IMPLIED BY ERH AND ERZ.

FELT REPORTS ARE TAKEN FROM THE PRELIMINARY DETERMINATION OF EPICENTERS OF THE USGS NATIONAL EARTHQUAKE INFORMATION SERVICE (NEIS). A COPY OF THE INTENSITY SCALE CURRENTLY IN USE BY NEIS IS INCLUDED IN THE APPENDIX.

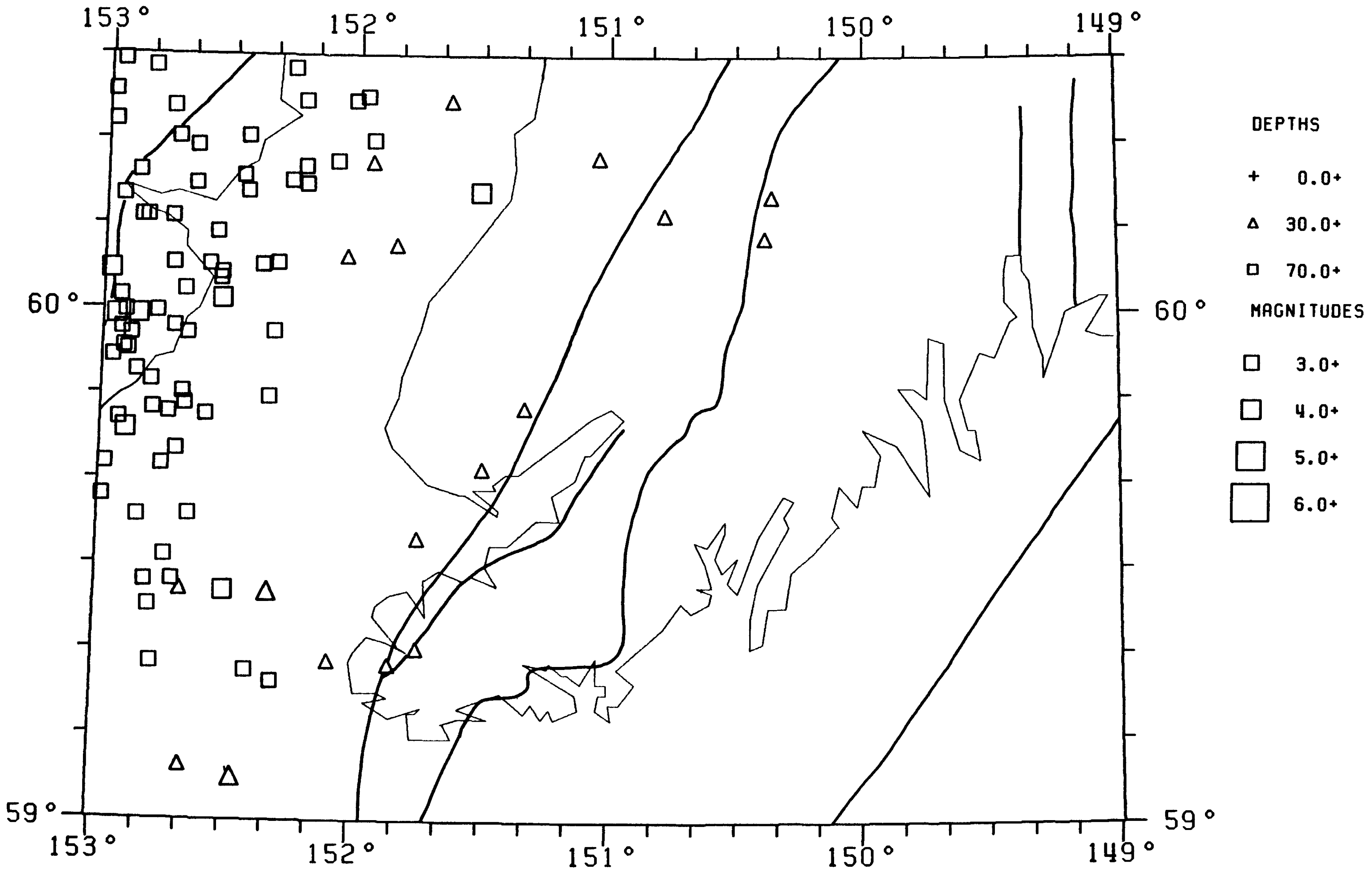

Figure 5 Map of epicenters of coda-magnitude 3 and larger earthquakes that occurred near the southern Kenai Peninsula between November 27, 1980 and May 31, 1983. Heavy lines indicate faults identified in Figure 2.

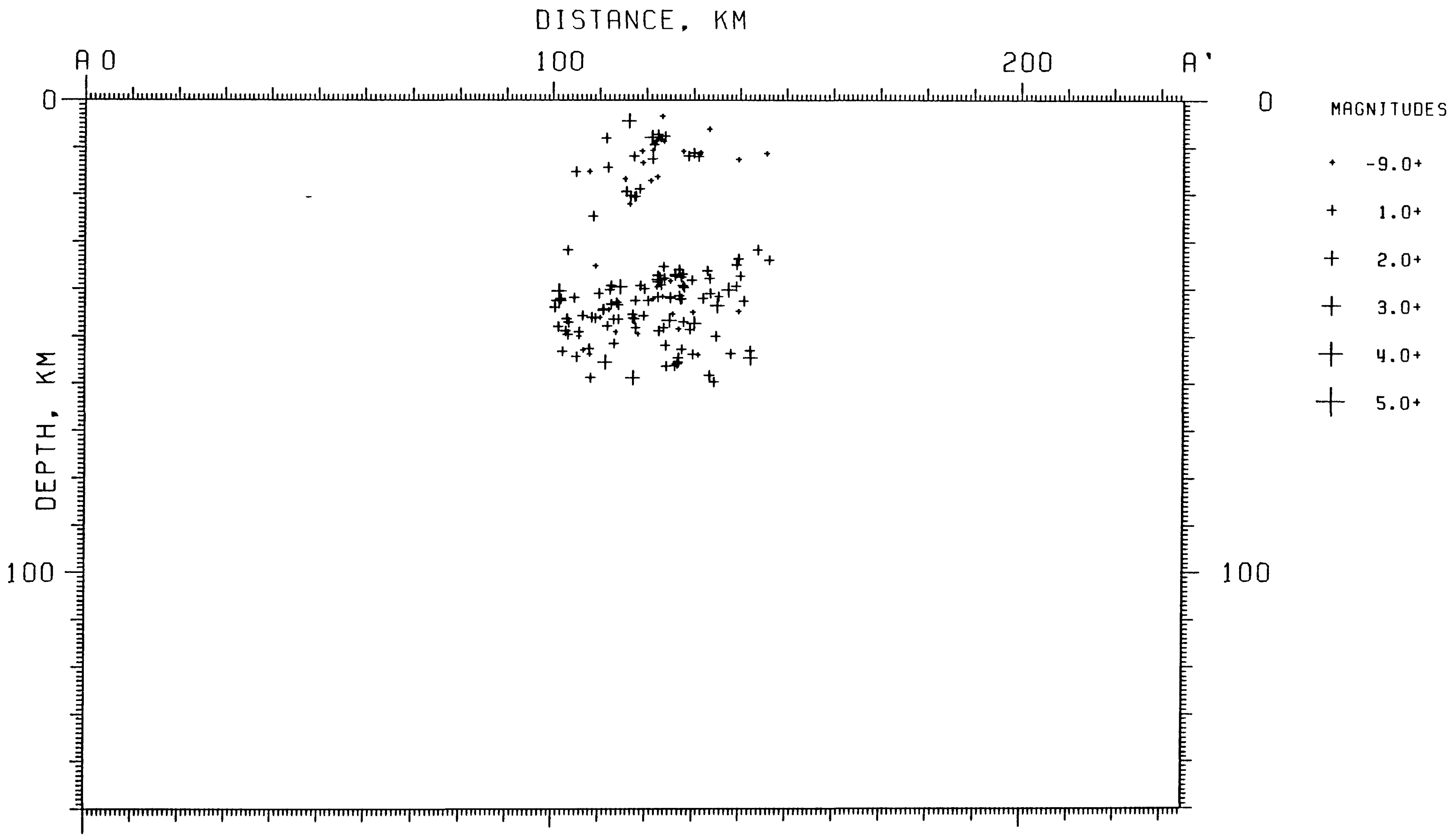

Figure 6 Cross section showing hypocenters of earthquakes located within 25 km epicentral distance from the station BRLK projected onto plane A-A' of Figure 3. Events were also selected to have standard location errors of 5 km or less.

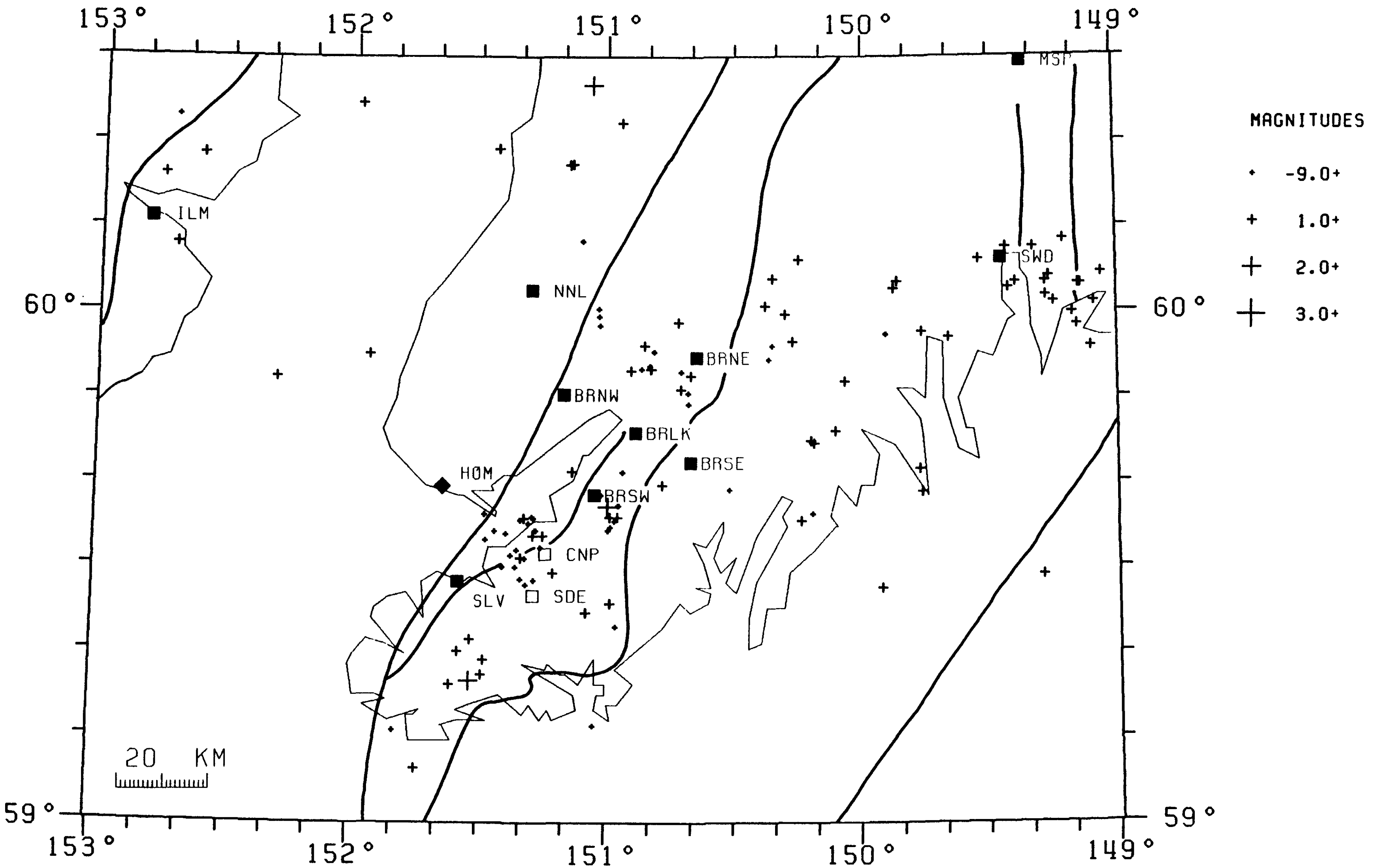

Figure 7 Map of epicenters of shallow (depth less than or equal to 20 km) earthquakes that occurred near the southern Kenai Peninsula between December 1, 1981 and May 31, 1983. Heavy lines indicate faults identified in Figure 2. The open symbols for CNP and SDE indicate that these stations were not operating during this period.

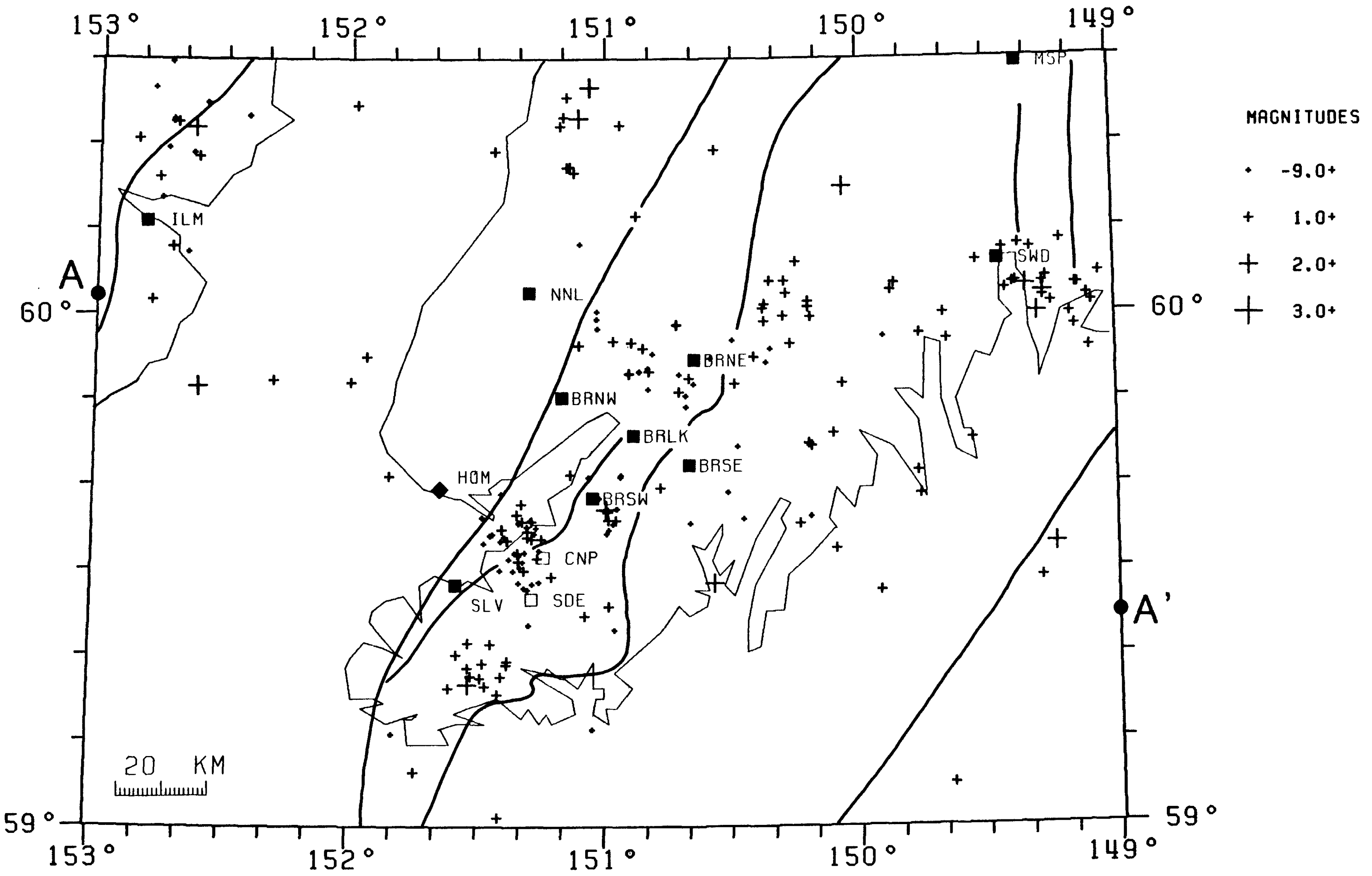

Figure 8 Map of epicenters of shallow (depth less than or equal to 20 km) earthquakes that occurred near the southern Kenai Peninsula between November 27, 1980 and May 31, 1983. Heavy lines indicate faults identified in Figure 2. The open symbols for CNP and SDE indicate that these stations were not operating during this period.

TABLE 3

SHALLOW (DEPTH < 20 KM) EARTHQUAKES, SOUTHERN KENAI PENINSULA

			ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
1980	NOV	27	0	53	10.3	59	57.3	149	54.3	13.0	0.7A	5	3	180	51	0.23	2.1	2.5	A
		27	15	51	36.8	59	11.3	151	2.7	8.1	0.7A	5	1	334	65	0.17	6.8	7.2	C
	DEC	5	14	24	40.0	60	3.5	149	16.4	18.2	1.3	11	5	234	79	0.33	4.0	1.8	B
		8	22	55	6.6	59	35.7	151	16.9	6.8	0.5A	7	3	160	28	0.33	1.4	1.2	A
		11	5	20	14.8	59	52.5	150	40.3	11.2	1.4A	8	4	160	19	0.42	1.3	0.9	A
		18	8	42	2.9	59	34.3	151	16.5	9.5	0.7A	7	3	171	30	0.29	3.4	1.2	B
		18	10	10	5.2	59	34.3	151	16.4	7.1	0.6A	6	3	171	30	0.30	2.6	2.9	B
		19	8	5	4.9	59	24.6	151	4.6	4.0	1.4	12	7	218	40	0.41	1.5	1.9	A
		19	13	9	23.5	60	3.9	150	21.0	15.3	1.0A	9	6	119	45	0.50	1.0	7.1	C
		19	16	12	36.5	60	8.3	151	6.0	14.6	0.8A	8	5	184	36	0.46	2.0	2.4	A
		20	5	10	22.0	60	5.2	149	32.2	6.1	1.2A	8	4	146	66	0.66	8.4	9.0	C
		21	13	24	10.9	59	37.3	150	57.1	5.9	0.3A	5	2	233	18	0.12	2.7	7.6	C
		22	15	56	46.5	59	39.7	150	47.0	11.9	1.4	12	5	188	15	0.33	1.2	0.9	A
		23	11	33	5.2	59	35.9	150	59.1	7.2	1.3	10	4	191	21	0.41	1.4	1.1	A
		23	12	28	1.6	59	34.7	150	58.9	8.3	0.5A	6	4	199	23	0.38	1.6	3.1	B
		26	4	54	53.3	59	19.1	151	28.4	17.5	1.6A	5	3	294	60	0.10	4.0	3.0	B
		26	15	22	53.4	60	2.7	149	52.4	4.9	1.5	11	2	155	56	0.49	2.1	2.9	B
		27	19	18	35.5	59	30.0	151	24.3	12.9	0.8A	7	4	191	40	0.20	3.3	2.6	B
1981	JAN	1	11	52	45.9	59	55.0	151	56.0	13.0	1.3	10	4	181	54	0.44	1.7	2.1	A
		6	3	47	22.3	59	36.3	150	11.4	6.4	0.7A	7	4	223	43	0.18	2.4	5.0	C
		6	11	34	27.4	59	27.9	151	18.8	3.0	0.6A	7	3	219	41	0.31	2.2	3.1	B
		11	0	11	51.2	59	37.3	150	57.2	3.4	0.4A	4	3	234	18	0.18	1.5	2.1	A
		14	2	54	17.2	59	41.6	149	46.3	15.9	1.5A	6	4	235	55	0.24	3.3	27.8	D
		16	7	24	16.6	59	35.9	151	17.4	7.0	0.7A	8	4	158	28	0.31	1.4	1.4	A
		16	7	31	23.6	59	41.2	151	8.0	8.0	1.2	9	4	120	17	0.84	1.2	1.4	A
		27	7	33	36.2	59	32.3	151	15.2	8.0	0.8A	7	3	187	33	0.31	3.7	1.9	B
		28	0	58	38.1	59	59.5	151	2.0	16.4	0.7A	6	4	182	23	0.41	1.1	3.4	B
		28	22	56	7.9	59	41.1	150	56.3	8.6	0.5	7	3	149	15	0.61	1.3	1.0	A
	FEB	2	8	0	57.4	59	39.1	150	31.0	11.3	0.7A	6	3	202	42	0.34	2.4	2.5	A
		3	0	19	40.7	59	57.7	149	45.8	4.0	1.3	9	5	193	58	0.42	1.9	2.1	A
		7	19	44	44.5	60	1.1	149	14.2	15.8	1.3	11	7	238	77	0.47	2.4	1.8	A
		13	13	55	40.2	60	3.5	149	51.7	7.2	1.5	11	4	151	54	0.36	2.6	5.8	C
		13	18	36	52.2	60	1.9	149	16.1	16.8	1.1	10	5	250	75	0.34	4.5	1.8	B
		15	6	50	7.8	59	59.9	149	10.0	13.6	1.7	14	4	173	82	0.48	1.5	1.4	A
		15	9	5	1.7	59	16.6	151	31.7	9.6	2.0	10	5	222	65	0.38	3.4	2.6	B
		16	8	34	32.1	59	33.7	151	17.0	11.9	1.0A	7	4	174	31	0.34	3.2	2.3	B
		16	11	49	17.2	59	35.5	151	20.0	5.8	0.4A	6	3	155	29	0.25	2.9	7.5	C
		17	0	26	32.6	59	37.1	150	59.6	7.9	2.1	12	5	182	21	0.42	1.5	1.0	A
		17	10	49	7.1	59	35.4	150	57.9	8.8	0.7	6	3	197	21	0.22	2.6	2.2	A
		25	1	51	27.2	59	35.9	150	57.3	7.7	1.0	6	3	222	29	0.27	5.5	3.9	B
		27	4	32	35.2	60	0.3	151	2.0	16.4	0.9A	7	4	113	24	0.41	1.6	3.5	B
	MAR	3	6	51	34.6	59	59.8	150	18.0	16.0	1.2A	6	5	183	52	0.46	3.9	6.3	C
		3	11	54	33.0	59	55.9	150	21.0	12.2	0.8A	6	4	189	47	0.33	5.0	2.6	B
		4	9	49	40.5	59	28.4	151	16.8	12.4	0.2A	5	4	233	39	0.29	4.2	3.6	B
		7	5	23	45.7	59	21.5	151	31.7	12.5	1.2	7	4	226	57	0.39	6.1	2.4	C
		8	1	45	3.2	59	56.0	150	51.1	18.8	1.0	8	4	150	21	0.26	3.1	2.2	B
		8	15	32	32.6	59	31.3	151	22.3	10.0	0.5A	5	4	190	39	0.35	8.3	10.9	D
		9	3	36	7.5	59	56.5	150	16.2	16.1	1.1A	6	4	172	49	0.48	3.7	4.6	B
		28	1	45	52.6	60	1.1	149	4.8	15.7	1.5	10	3	173	84	0.63	2.4	3.5	B
	APR	12	17	37	19.0	59	58.8	150	43.3	15.4	1.3A	5	4	148	42	0.52	2.0	5.0	B
		13	13	43	35.5	60	5.1	150	14.8	7.9	1.1	8	3	131	52	0.33	2.0	2.9	B
		19	8	38	28.2	59	23.0	150	57.6	10.0	0.8A	5	2	249	43	0.15	8.1	12.7	D
		22	10	30	16.8	59	34.0	151	23.4	4.1	0.5A	5	3	159	36	0.20	6.0	28.8	D
		23	4	35	55.3	59	40.8	151	13.6	10.8	-0.2A	4	4	134	31	0.16	4.5	6.4	C
		28	19	17	7.7	59	6.3	151	44.2	5.8	1.2	10	5	230	101	0.55	4.9	2.6	B
		29	14	3	47.4	59	52.3	152	18.0	6.1	1.5	10	3	91	60	0.56	1.2	2.5	A
	MAY	1	14	46	8.1	59	10.8	151	49.3	16.6	0.9A	4	2	334	100	0.43	21.5	13.2	D
		1	19	56	50.0	59	53.1	150	54.2	11.8	1.2	5	4	144	60	0.45	1.5	2.7	B
		7	14	6	16.5	59	34.3	151	26.1	6.9	0.3A	3	2	152	100	0.10	20.0	18.3	D
		8	1	59	15.3	59	31.0	151	19.0	5.5	0.8	4	4	203	127	0.16	6.3	3.1	C
1981	MAY	11	20	55	18.3	59	53.6	150	50.0	16.5	0.9A	5	2	130	63	0.24	4.8	12.6	D
		17	20	17	12.8	59	58.4	149	8.8	14.1	1.1A	13	7	176	85	0.58	1.7	1.5	A
		17	23	28	43.5	59	32.0	151	20.9	3.0	0.9A	3	3	187	126	0.24	22.1	6.9	D
		18	6	12	43.3	59	50.5	150	41.0	9.6	0.8A	5	4	155	65	0.32	2.2	7.2	C
		18	6	15	48.2	59	50.9	150	42.7	11.8	1.1A	6	5	151	65	0.45	2.0	3.4	B
		21	0	34	43.8	60	24.5	151	58.8	3.8	1.5	4	4	279	145	0.14	16.6	14.6	D
		23	8	22	12.3	59	27.6	149	55.0	16.0	1.2	4	5	251	94	0.16	5.0	5.7	C
		23	16	20	11.8	60	19.2	151	26.0	20.0	1.7	6	5	114	79	0.23	1.5	7.0	C
		25	22	3	57.6	59	20.1	151	34.5	9.0	1.3	7	4	269	80	0.64	4.8	1.7	B
		25	23	36	41.2	59	29.9	151	21.2	7.7	0.7A	4	3	209	61	0.16	8.1	2.5	C
		26	5	25	28.8	59	58.4	151	1.7	15.1	0.8	6	6	123	64	0.57	2.2	4.6	B
	JUN	6	1	4	3.6	60	3.2	149	8.5	0.7	1.1	5	3	259	116	1.82	2.3	1.3	A
		7	18	22	7.4	59	36.2	151	28.6	4.3	0.7A	4	4	170	100	0.15	2.9	6.5	C
		8	3	2	20.0	60	8.5	149	12.0	12.6	1.3	8	4	254	70	0.22	2.8	1.3	B
		9	8	23	3.8	59	28.6	151	20.0	10.6	0.2A	3	1	226	63	0.01	8.6	5.8	C
		9	16	12	31.3	59	33.2	151	28.2	7.7	0.6A	3	2	156	55	0.10	19.9	17.6	D
		11	13	36	15.7	59	55.8	149	5.4	16.4	1.5	13	6	180	104	0.63	2.0	3.3	B
		15	1	44	53.8	59	52.9	150	42.7	10.8	0.6A	4	3	193	67	0.41	2.9	4.1	B
		15	14	49	23.4	59	16.2	151	36.3	10.0	1.1	6	4	311	105	0.61	3.3	4.8	B
		15	23	56	10.2	59	35.1	151	18.1	6.7	0.6A	4	3	164	100	0.13	23.1	13.4	D
		21	3	30	45.7	59	46.1	150	6.2	16.7	1.2	6	5	204	83	0.26	3.5	6.4	C
		23	0	46	9.4	59	29.1	149	17.2	19.8	1.8	7	5	271	126	0.15	8.5	17.3	D
	JUL	21	4	54	47.9	60	7.5	149	19.2	4.0	1.5	11	5	241	66	0.45	2.7	1.0	B
		23	6	59	16.7	59	35.5	150	14.0	19.3	1.4	14	6	222	43	0.23	2.0	2.1	A
		27	15	57	47.9	59	53.3	150	51.9	13.3	0.2A	6	5	132	18	0.28	1.2	1.3	A
	AUG	4	23	20	14.3	59	31.1	151	20.0	10.0	1.1	10	3	189	37	0.27	7.2	6.2	C
		5	2	18	35.4	59	55.4	150	48.9	17.0	0.8A	6	4	90	26	0.32	1.9	2.4	A
		5	2	42	28.9	60	3.2	149	8.0	11.8	1.3	12	8	169	79	0.65	1.7	2.0	A
		5	5	51	22.6	60	7.5	149	25.7	5.3	1.6	8	6	200	61	0.54	3.7	1.4	B
		13	1	13	13.4	60	17.3	151	8.3	19.4	1.6	14	9	70	50	0.33	0.9	2.5	B
		15	9	17	2.1	59	53.3	150	49.7	12.4	1.4	11	8	83	20	0.43	1.2	1.2	A
		28	22	29	47.8	60	16.1	152	46.2	7.5	1.6A	11	8	145	85	0.32	1.2	0.9	A
	SEP	5	4	15	49.1	60	4.5	149	3.0	15.1	1.9	36	15	162	81	0.68	1.3	1.9	A
		5	23	19	54.3	60	17.3	151	8.9	19.7	1.1A	7	5	227	50	0.43	3.8	4.8	B
		7	7	26	17.7	60	2.8	149	25.2	5.2	1.4	9	6	238	70	0.53	6.6	7.4	C
		15	5	41	4.2	59	35.8	151	19.3	6.9	1.3	10	4	155	31	0.45	2.2	1.6	A
		17	10	56	0.7	59	38.9	149	45.6	16.3	1.8	13	7	240	58	0.37	3.0	2.9	B
		27	0	59	31.8	59	54.4	150	22.0	12.3	0.8	6	3	177	33	0.33	3.5	3.2	B
	OCT	2	13	58	26.4	59	44.6	150	11.2	7.5	1.2A	7	7	220	39	0.40	4.3	2.8	B
		4	6	59	34.2	59	33.7	151	14.7	10.5	1.0A	7	4	179	25	0.23	2.1	4.3	B
		5	5	22	9.1	60	26.6	151	3.7	11.2	2.3	31	8	47	68	0.56	0.6	1.4	A
		6	10	56	7.3	59	57.0	149	39.4	2.7	1.3	11	5	210	62	0.57	3.4	2.3	B
		9	5	24	55.1	60	22.9	152	43.1	0.1	0.2A	3	4	205	123	0.34	11.1	8.2	D
		17	13	26	32.8	60	7.9	152	42.8	10.3	1.4	17	6	108	79	0.58	1.1	1.4	A
		26	1	23	50.8	59	34.3	150	59.4	8.3	0.8	6	4	201	23	0.29	2.3	2.1	A
		26	5	35	13.6	60	0.7	150	22.8	12.3	1.0A	8	4	159	40	0.43	2.3	2.1	A
		26	9	9	9.7	60	4.1	149	15.5	9.9	1.5	11	3	250	80	0.66	4.7	1.5	B
		27	23	13	8.3	59	29.3	151	12.3	8.1	1.3	11	5	210	31	0.39	2.4	1.5	A
	NOV	2	17	9	58.7	59	44.9	150	11.8	6.8	1.0A	8	6	219	39	0.33	2.4	2.8	B
		2	19	25	17.0	59	51.9	150	3.9	10.4	1.0A	6	4	213	47	0.11	8.2	14.6	D
		3	7	2	24.3	59	38.5	151	1.2	10.8	0.4A	5	4	169	21	0.27	3.4	2.0	B
		5	6	30	41.1	60	18.5	152	36.9	5.5	1.2A	15	10	79	96	0.88	1.2	1.2	A
		6	10	49	17.1	59	49.1	150	40.9	11.5	0.8	8	4	112	13	0.25	1.8	1.4	A
		18	14	48	10.0	60	22.2	150	56.6	9.9	1.8	18	5	89	45	0.45	0.9	3.4	B
		20	7	29	18.7	59	17.4	151	28.9	11.2	1.1A	9	5	245	46	0.23	2.4	2.8	B
		21	10	56	57.4	59	25.8	150	58.9	10.0	1.0A	5	4	317	38	0.09	13.1	22.5	D
		29	10	21	7.8	60	3.5	149	23.3	13.4	1.1	8	4	239	68	0.48	4.6	1.5	B
	DEC	3	4	19	18.5	59	35.0	151	16.0	8.3	0.6A	6	3	167	29	0.20	2.4	2.1	A
		9	11	59	36.3	60	1.2	150	22.2	18.1	1.0	9	5	159	40	0.59	2.2	2.0	A
		21	18	13	34.5	60	3.8	150	17.7	15.3	1.1	9	4	123	47	0.50	1.5	23.0	D

SHALLOW (DEPTH < 20 KM) EARTHQUAKES, SOUTHERN KENAI PENINSULA

		ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
1981 DEC	22	5	49	16.0	59	56.9	150	58.0	14.2	1.7	12	8	71	63	0.62	1.0	1.5	A
	31	4	45	39.4	60	16.7	151	7.4	15.0	1.4	17	8	69	49	0.51	0.7	2.2	A
	31	9	21	38.5	59	31.8	151	20.0	10.3	0.9A	6	3	183	36	0.26	4.5	13.7	D
1982 JAN	1	16	9	38.2	60	23.1	151	9.8	14.9	1.5	16	8	89	60	0.54	1.1	3.6	B
	3	18	49	54.4	59	41.0	151	50.4	16.4	1.3	12	B	127	41	0.47	1.0	2.0	A
	5	10	58	39.8	60	7.2	152	39.1	7.9	0.7A	4	3	195	100	0.23	17.7	17.7	D
	6	22	56	37.2	59	39.0	151	24.2	12.2	0.3A	6	4	186	25	0.10	3.0	4.8	B
	8	12	27	15.2	59	51.5	152	36.1	5.1	2.2	37	9	72	63	0.99	0.9	1.5	A
	11	13	46	33.2	59	32.0	151	20.3	9.0	1.3	14	8	180	22	0.67	1.3	1.0	A
	20	17	19	44.8	60	18.9	152	38.2	7.1	0.9A	8	6	92	31	0.67	1.5	1.7	A
	21	11	55	6.6	59	56.7	150	53.9	19.3	1.3A	11	8	68	25	0.34	1.0	1.2	A
	31	5	19	10.4	59	35.7	151	17.0	4.0	1.0	7	5	289	29	0.48	3.5	1.5	B
FEB	1	19	51	9.2	60	13.7	152	45.4	10.8	0.6A	5	4	148	94	0.24	3.9	2.0	B
	7	12	59	11.0	60	26.6	152	47.6	12.7	0.5A	8	5	157	29	0.51	2.5	1.1	B
	11	17	37	22.5	59	33.5	151	22.7	4.1	1.2	13	6	162	33	0.45	1.6	2.0	A
	15	2	45	13.9	60	1.4	150	11.9	15.0	1.1	15	8	139	43	0.35	1.1	25.0	D
	15	7	4	21.3	60	3.2	149	20.3	11.5	2.5	31	8	168	71	0.81	1.1	1.2	A
	16	21	37	18.0	60	3.6	149	22.7	13.3	1.3	9	3	206	91	0.41	9.4	12.8	D
	16	21	37	19.2	60	8.0	149	21.9	9.0	1.4	17	6	179	84	1.13	1.9	1.5	A
	27	11	29	22.6	60	1.7	152	47.3	11.4	1.8	15	6	119	64	0.46	1.2	1.9	A
MAR	20	7	24	31.8	60	20.6	152	51.4	10.1	1.4	12	7	87	97	0.93	1.3	1.0	A
	22	12	35	3.4	59	32.5	150	5.5	15.0	1.4	8	5	235	52	0.32	3.8	6.3	C
	29	14	16	1.5	59	40.9	151	3.8	16.6	0.6A	4	4	174	18	0.06	2.6	2.8	B
	30	11	57	27.9	60	0.8	150	12.0	10.0	1.2	11	4	152	47	0.55	1.1	3.9	B
APR	2	5	48	32.6	59	34.2	151	26.6	6.9	0.6A	6	3	153	34	0.41	4.0	2.9	B
.	5	2	45	58.0	59	51.8	150	39.3	11.1	0.7	6	5	203	29	0.47	2.4	1.7	A
	6	21	20	45.2	59	51.2	150	49.8	16.2	0.8A	5	4	153	19	0.21	1.9	3.7	B
	7	23	15	35.4	59	35.1	151	18.2	6.0	0.7A	5	3	162	29	0.23	3.8	6.0	C
	8	20	42	57.0	59	59.2	150	22.4	15.0	1.2A	8	6	132	48	0.57	1.9	10.2	D
	23	2	10	44.4	60	29.7	152	43.8	2.4	0.7A	5	4	198	100	0.80	4.8	4.7	B
	23	20	51	38.6	60	1.9	149	5.9	16.0	1.0	8	5	295	95	0.40	3.4	2.2	B
MAY	12	4	7	49.8	59	33.4	151	24.3	10.9	0.6A	6	6	158	37	0.25	5.4	4.1	B
	31	4	34	10.5	60	23.0	151	6.2	12.7	2.6	34	10	46	51	0.61	0.5	1.2	A
JUN	5	3	3	57.5	59	35.6	151	19.9	4.3	0.7A	4	2	154	29	0.04	2.3	26.8	D
	9	10	8	20.1	59	59.7	150	11.4	18.7	1.0A	6	4	159	43	0.33	2.6	2.3	B
	12	9	9	19.5	59	30.0	151	18.8	9.4	1.6	14	6	200	26	0.48	1.9	1.1	A
	17	14	5	5.5	59	30.4	151	19.8	10.3	0.7A	6	3	196	38	0.25	3.3	5.2	B
	24	9	13	48.0	59	17.6	151	31.2	9.0	1.7A	11	3	277	64	0.55	4.7	1.7	B
JUL	9	7	17	8.3	60	25.5	151.	9.0	10.0	1.7	13	7	104	64	0.90	1.0	2.7	B
	9	10	41	36.7	59	27.7	151	18.0	9.7	0.6A	7	6	238	29	0.39	2.5	1.4	A
	13	12	43	5.2	59	16.5	151	27.7	6.6	1.1A	9	4	300	47	0.40	2.2	1.9	A
	13	17	55	3.9	59	56.3	151	6.2	15.2	1.1	10	3	81	23	0.39	1.6	3.2	B
	20	11	2	23.2	59	55.0	150	24.9	11.0	1.2A	7	4	160	43	0.44	2.3	4.0	B
	22	14	13	15.1	59	33.0	149	13.9	15.4	2.4	18	6	244	103	0.72	2.2	2.2	A
AUG	7	18	12	8.1	60	22.0	152	37.9	7.3	2.2	24	11	78	82	0.90	0.9	1.1	A
	8	21	43	18.0	59	31.5	151	15.7	4.4	1.0	7	4	299	35	0.49	3.0	2.1	B
	9	1	43	3.0	60	22.6	152	43.3	4.0	0.6A	7	4	167	105	0.33	2.1	2.0	A
	9	4	24	54.6	60	22.6	152	42.0	7.1	1.2A	9	5	150	106	0.37	2.2	1.4	A
	9	12	21	58.2	59	4.9	149	38.4	9.4	1.3A	5	3	308	109	0.16	20.2	17.1	D
	16	22	59	12.3	59	32.1	151	18.7	13.6	0.6A	6	3	299	35	0.21	4.5	2.4	B
	22	6	35	34.5	59	36.0	150	27.2	9.4	0.8A	6	3	246	36	0.08	10.2	23.0	D
	27	5	13	53.2	59	37.8	151	19.4	10.1	1.0	8	5	134	23	0.39	1.1	2.7	B
SEP	9	6	20	3.3	59	56.9	150	30.0	10.1	0.8A	6	4	150	39	0.39	1.6	3.3	B
	13	21	11	7.5	60	2.4	149	16.1	12.4	2.1	21	4	186	87	0.72	1.5	1.5	A
	15	6	53	49.3	60	22.1	151	10.7	19.8	1.4	10	5	96	59	0.50	1.1	5.3	C
	22	4	42	58.5	60	19.3	150	34.1	13.6	1.4A	5	4	138	60	0.43	1.6	3.0	B
	23	12	48	22.5	60	2.4	150	17.2	14.5	1.3A	6	4	165	46	0.47	3.0	2.1	B
	23	22	27	31.4	60	0.0	149	40.1	10.3	1.4A	6	3	232	65	0.38	4.7	3.4	B
OCT	3	2	42	12.9	59	34.8	151	24.0	7.1	1.6	11	7	149	31	0.61	1.8	1.6	A
	14	12	28	26.3	59	35.5	150	40.0	12.6	0.8	10	5	206	23	0.36	2.1	2.0	A

SHALLOW (DEPTH < 20 KM) EARTHQUAKES, SOUTHERN KENAI PENINSULA

		ORIGIN TIME HR	MN	SEC	LAT N DEG	MIN	LONG W DEG	MIN	DEPTH KM	MAG	NP	NS	GAP DEG	D3 KM	RMS SEC	ERH KM	ERZ KM	Q
1982 NOV	3	4	4	1.3	59	37.2	150	59.6	10.7	0.8	8	3	182	21	0.27	2.3	1.9	A
	12	12	58	38.0	59	21.4	151	26.5	8.3	1.1	7	3	276	55	0.48	4.9	3.4	B
	21	7	24	53.2	59	45.3	149	33.4	1.8	1.7	10	3	240	64	0.32	4.9	2.5	B
DEC	9	13	0	36.8	60	24.8	152	35.0	12.6	0.8A	7	2	227	102	0.15	6.3	4.2	C
	16	19	46	58.4	60	23.3	152	24.8	12.7	0.8A	4	3	233	100	0.18	8.8	5.6	C
	30	3	47	23.1	59	28.5	150	34.2	15.6	2.4	16	4	228	37	0.39	1.7	2.8	B
	31	8	47	44.9	59	33.9	151	18.0	14.6	1.0A	5	3	171	32	0.68	6.6	1.6	C
1983 JAN	3	21	35	7.2	59	19.3	151	22.6	0.2	1.1	8	4	282	57	0.26	1.8	2.0	A
	9	20	48	8.1	59	52.0	151	59.7	4.4	1.3	10	4	156	50	0.83	1.3	1.8	A
	24	21	47	52.6	59	17.5	151	24.0	8.1	1.5	10	8	291	60	0.54	1.8	1.7	A
	24	23	51	34.2	59	15.5	151	24.8	3.5	1.7	9	6	298	64	0.45	2.0	2.4	A
	30	8	2	8.6	59	36.9	150	59.2	9.4	1.2	9	8	185	21	0.39	1.1	0.7	A
FEB	1	12	4	32.3	59	28.6	151	15.2	4.3	0.8A	6	5	216	38	0.46	1.8	27.2	D
	2	1	35	14.7	59	54.8	150	35.3	6.2	0.8	8	5	145	24	0.48	2.1	1.1	A
	2	5	50	50.2	59	41.0	150	56.4	4.1	0.8A	3	3	213	15	0.06	1.4	5.8	C
	9	6	36	22.7	60	11.6	150	52.7	15.2	1.4	18	8	62	43	0.59	0.9	3.2	B
	23	10	49	55.7	60	14.9	150	3.5	11.4	2.4	23	6	94	47	0.45	0.8	1.7	A
	23	12	13	26.4	60	19.6	152	44.3	4.7	0.3A	4	4	186	100	0.47	6.1	4.2	C
	28	6	4	23.6	59	18.9	151	22.7	1.8	1.0A	6	5	284	57	0.49	1.8	2.4	A
MAR	3	12	47	38.9	59	1.0	151	24.6	5.8	1.5A	4	2	321	87	0.09	7.9	5.0	C
APR	6	4	38	21.4	59	36.5	151	20.5	7.9	1.6	13	5	144	27	0.55	1.6	1.5	A
	22	19	57	31.3	59	60.0	149	17.5	11.9	2.0	23	8	173	77	0.91	1.3	1.2	A
MAY	3	6	41	52.2	59	51.8	150	29.4	15.2	1.3A	10	5	169	38	0.57	1.1	1.9	A
	6	5	33	43.8	59	18.5	151	31.8	14.1	1.0A	4	3	304	66	0.16	8.0	6.3	C
	6	10	33	9.2	59	23.6	151	17.6	2.7	0.6A	4	2	253	49	0.19	9.1	23.3	D
	15	11	44	34.1	59	34.5	151	18.0	8.3	1.2A	7	4	166	30	0.32	2.2	1.9	A
	21	18	3	29.0	59	44.5	150	28.5	5.8	0.5A	3	3	277	100	0.11	5.5	9.4	C

located, but the magnitude threshold increases away from the array due to the criteria used in selecting events for processing and to the increased station separation. The largest shallow event that occurred within the area of Figure 8 during this time had a magnitude of 2.6. The largest shallow event within 25 km of the central station BRLK near Bradley Lake had a magnitude of 2.1, as compared to a magnitude of 2.7 for the largest event in the Benioff zone within the same epicentral distance. Within 25 km of the station BRLK, the rate of shallow activity has been between 15 and 25 times lower than the rate of Benioff zone activity. Along the Kenai Peninsula the rate of shallow activity larger than magnitude 1 remained relatively uniform (Figure 9).

Most of the shallow activity occurred beneath the Kenai Peninsula southeast of the Border Ranges fault. There is no strong correlation of earthquakes with the traces of mapped faults, but the earthquakes do tend to cluster spatially. In the recent period from December 1981 to May 1983, concentrations of activity occurred in areas that had been relatively active during the previous year. These concentrations include one on the southern Kenai Peninsula about 20 km south of the station SLV, one straddling the Seldovia Bay fault southeast of Kachemak Bay between the stations SLV and BRSW, one about 25 km northeast of the station BRNE, and one close to the Kenai lineament near the station SWD (Figure 7). Areas that apparently were less active during the recent time period as compared to the earlier one include one about 7 km southeast of the station BRSW and two others near BRNE, one about 10 to the west and one about 7 km to the south.

FOCAL MECHANISMS

Focal mechanisms have been determined for eight shallow (depth less than 20 km) events that occured beneath the southern Kenai peninsula since the Bradley Lake network was installed (Stephens and others, 1982). For many of the events the coverage of the focal sphere is poor, but five events near the Bradley Lake network have mechanisms that are reasonably consistent and compatable with normal faulting. The orientations of the tension axes for these events range from east-west to southeast-northwest. This orientation of stress is contrary to what might be expected in a region of northwest-directed plate convergence and is contrary to geologic evidence. However, theoretical studies (for example, Melosh and Fleitout, 1982; Bischke, 1974) suggest that portions of the overriding plate adjacent to a subduction zone may be in tension during the early part of the seismic cycle following a large earthquake (in this case, the 1964 earthquake), and that these zones change to compression prior to the next large earthquake.

STRONG MOTION RECORD

The SMA-1 strong-motion instrument co-located at the site of the high-gain station BRLK was triggered by an earthquake that occurred between June 24, 1982 and June 26, 1983. A preliminary estimate of 0.14 g was obtained for the maximum peak-to-peak horizontal acceleration on the record. At present, the event which caused the trigger is uncertain. In normal operation, an event which causes the strong-motion recorder to trigger can be identified by observing a distinct signal from the strong-motion instrument that is superimposed on the trace of the high-gain instrument. To date, the seismograms of fourteen candidate events of coda magnitude 2.5 and larger have been checked and no signal that would indicate a trigger of the strong-motion recorder was found. Four other events in this magnitude range occurred at times when the BRLK station was not operating or when the seismic signal was not recorded, so there is no direct way to determine whether or not any of these events triggered the instrument. Another possibility is that the triggering mechanism which sends the signal to the high-gain instrument was not working properly.

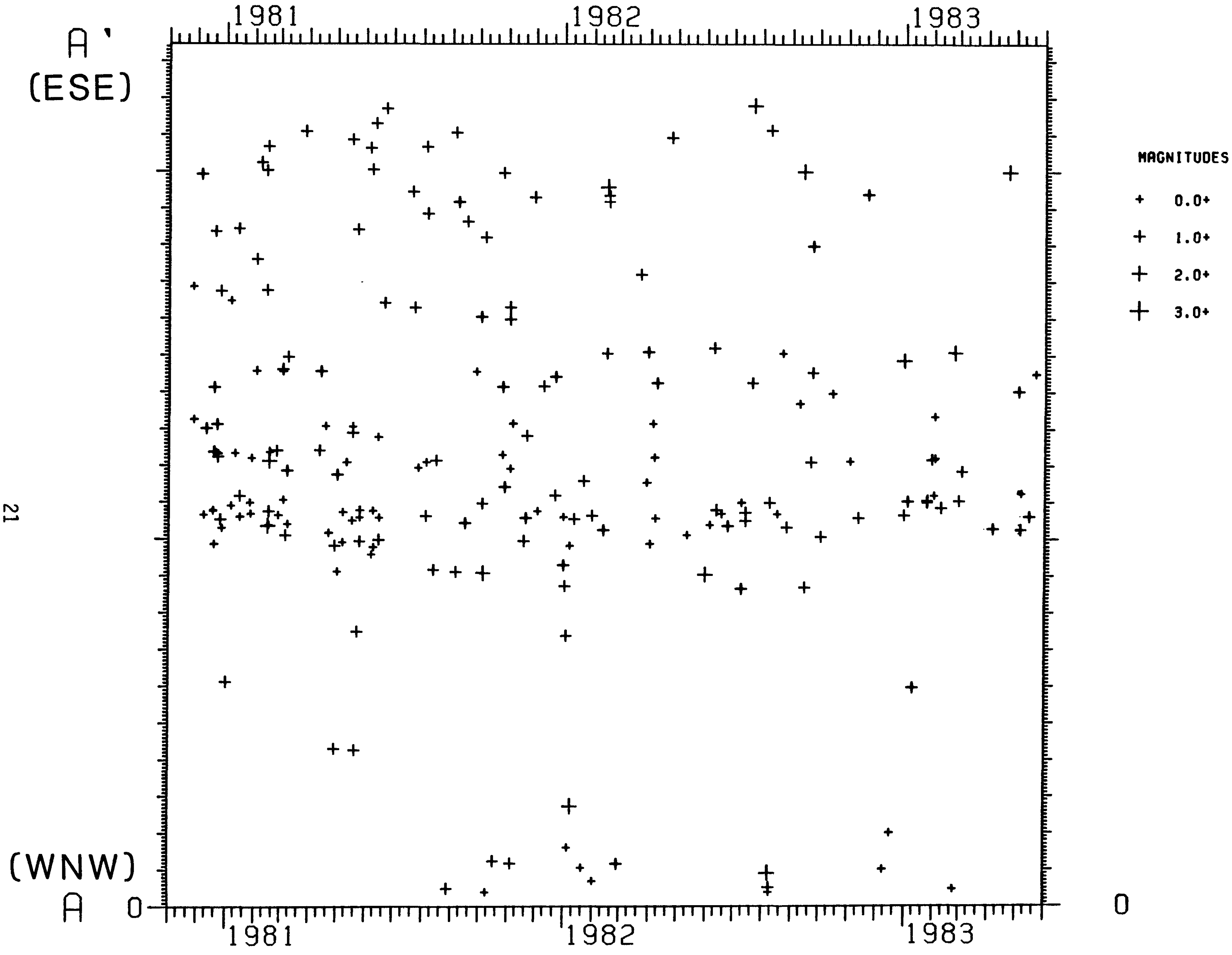

Figure 9 Space-time plot of shallow earthquakes (depth less than or equal to 20 km) from Figure 8 projected onto line A-A' indicated in Figure 8.

In this case, any of the eighteen events described above could have triggered the instrument. A visit to the site is planned for later this summer to check the operation of the trigger. The option of installing an internal clock in the strong-motion recorder should be considered to provide an independent method of identifying earthquakes which cause this instrument to trigger.

CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The Bradley Lake seismic network has proved highly successful to date. High-quality hypocenter data are helping to improve our understanding of the tectonic processes active in the Bradley Lake region. The occurence of shallow earthquakes confirms the presence of active faults within the crust, but faults other than the presently mapped faults must be active to account for the distribution of shallow activity. Well-recorded earthquakes that occur beneath the Bradley Lake array indicate that the depth to the top of the Benioff zone is about 37 ± 5 km. The few earthquakes that occur above the Benioff zone activity between depths of 20 and 35 km suggest that some faults within the upper crust may extend into the lower crust. Alternatively, the zone of megathrust interaction may be shallower than 35 km and involve a complex zone of splay faulting. During the past 2 1/2 years the rate of activity within the crust near Bradley Lake has been about 15 to 25 times lower than in the underlying Benioff zone.

Continued monitoring of the shallow activity near Bradley Lake is essential to help clarify the nature of the crustal activity that occurs throughout the southern Kenai Peninsula. The most critical information will come from the operation of new stations such as CNP and SDE. New stations should be close to seismically active areas because of the improved hypocenter accuracy for resolving the relationship of earthquakes to mapped fault traces. In addition, the P-wave first motions recorded at nearby stations (at distances on the order of a focal depth) constrain focal mechanisms of dip-slip events such as those along the southern Kenai Peninsula. Nearby recordings of P-wave first-motions are particularly useful when the local velocity structure is not well known, as is the case for the southern Kenai Peninsula. Further work is planned to improve this velocity model. For example, travel times recorded along the Kenai Peninsula from well-timed blasts along the Seward Highway north of Turnagain Arm during 1982 will help to constrain the velocity stucture. The refined velocity model, improved station control, and application of relative relocation techniques will aid in resolving the relationship between the shallow crustal activity and the mapped faults.

REFERENCES

Beikman, H. M., compiler, 1980, Geological map of Alaska: U. S. Geological Survey, scale 1:2,5000,000.

Bischke, R. E., 1974, A model of plate margins based on the recent tectonics of Shikoku, Japan: Journal of Geophysical Research, v. 79, p. 4845-4857.

Fogleman, K. A., Stephens, C. D., Lahr, J. C., Rogers, J. A., Cancilla,, R. S., Tam, Roy, Freiberg, J. A., and Melnick, J. P., Catalog of earthquakes in southern Alaska, April-June 1980: U. S. Geological Survey Open-File Report 83-14, 54 p.

Hastie, L. M., and Savage, J. C., 1970, A dislocation model for the 1964 Alaska earthquake: Bulletin of the Seismological Society of America, v. 60, p. 1389-1392.

Lahr, J. C., 1980, HYPOELLIPSE/MULTICS, A computer program for determining local earthquake hypocentral parameters, magnitude, and first-motion pattern, U. S. Geological Survey Open-File Report 80-59, 59 p.

Lahr, J. C., and Stephens, C. D., 1980, Review of earthquake activity and current status of monitoring in the region of the Bradley Lake Hydroelectric Project, Kenai Peninsula, Alaska: U. S. Geological Survey Open-File Report 81-736, 33p.

Lahr, J. C., and Stephens, C. D., 1983, Eastern Gulf of Alaska seismicity: Final report to the National Oceanic and Atmospheric Administration for July 1, 1975 through September 30, 1981: U. S. Geological Survey Open-File Report 83-592, 48 p.

Melosh, H. J., and Fleitout, L., 1982, The earthquake cycle in subduction zones: Geophysical Research Letters, v. 9, p. 21-24.

Minster, J. B., and Jordan, T. H., 1978, Present day plate motions: Journal of Geophysical Research, v. 83, p. 5331-5354.

Plafker, George, 1969, Tectonics of the March 27, 1964, Alaska earthquake, U. S. Geological Survey Professional Paper 543-I, 74 p.

Stephens, C. D., Lahr, J. C., and Rogers, J. A., 1982, Review of earthquake activity and current status of seismic monitoring in the region of the Bradley Lake Hydroelectric Project, southern Kenai Peninsula, Alaska: November 27, 1980 - November 30, 1981: U. S. Geological Survey Open-File Report 82-417, 26 p.

Woodward-Clyde Consultants, 1979, Reconnaissance geology Bradley Lake Hydroelectric Project: submitted to the Department of the Army, Alaska District, Corps of Engineers, Anchorage, Alaska.

APPENDIX: INTENSITY SCALE USED BY NEIS

MODIFIED MERCALLI INTENSITY SCALE OF 1931

Adapted from Sieberg's Mercalli-Cancani scale, modified and condensed.

I. Not felt - or, except rarely under especially favorable circumstances. Under certain conditions, at and outside the boundary of the area in which a great shock is felt: sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced; sometimes trees, structures, liquids, bodies of water, may sway--doors may swing, very slowly.

II. Felt indoors by few, especially on upper floors, or by sensitive, or nervous persons. Also, as in grade I, but often more noticeably: sometimes hanging objects may swing, especially when delicately suspended; sometimes trees, structures, liquids, bodies of water, may sway, doors may swing, very slowly; sometimes birds, animals, reported uneasy or disturbed; sometimes dizziness or nausea experienced.

III. Felt indoors by several, motion usually rapid vibration. Sometimes not recognized to be an earthquake at first. Duration estimated in some cases. Vibration like that due to passing of light, or lightly loaded trucks, or heavy trucks some distance away. Hanging objects may swing slightly. Movements may be appreciable on upper levels of tall structures. Rocked standing motor cars slightly.

IV. Felt indoors by many, outdoors by few. Awakened few, especially light sleepers. Frightened no one, unless apprehensive from previous experience. Vibration like that due to passing of heavy or heavily loaded trucks. Sensation like heavy body striking building or falling of heavy objects inside. Rattling of dishes, windows, doors; glassware and crockery clink and clash. Creaking of walls, frame, especially in the upper range of this grade. Hanging objects swung, in numerous instances. Disturbed liquids in open vessels slightly. Rocked standing motor cars noticeably.

V. Felt indoors by practically all outdoors by many or most: outdoors direction estimated. Awakened many, or most. Frightened few--slight excitement, a few ran outdoors. Buildings trembled throughout. Broke dishes, glassware, to some extent. Cracked windows--in some cases, but not generally. Overturned vases, small or unstable objects, in many instances, with occasional fall. Hanging objects, doors, swing generally or considerably. Knocked pictures against walls, or swung them out of place. Opened, or closed, doors, shutters, abruptly. Pendulum clocks stopped, started or ran fast, or slow. Moved small objects, furnishings, the latter to slight extent. Spilled liquids in small amounts from well-filled open containers. Trees, bushes, shaken slightly.

VI. Felt by all, indoors and outdoors. Frightened many, excitement general, some alarm, many ran outdoors. Awakened all. Persons made to move unsteadily. Trees, bushes, shaken slightly to moderately. Liquid set in strong motion. Small bells rang--church, chapel, school, etc. Damage slight in poorly built buildings. Fall of plaster in small amount. Cracked plaster somewhat, especially fine cracks chimneys in some instances. Broke dishes, glassware, in considerable quantity, also some windows. Fall of knick-knacks, books, pictures. Overturned furniture in many instances. Moved furnishings of moderately heavy kind.

VII. Frightened all--general alarm, all ran outdoors. Some, or many, found it difficult to stand. Noticed by persons driving motor cars. Trees and bushes shaken moderately to strongly. Waves on ponds, lakes, and running water. Water turbid from mud stirred up. Incaving to some extent of sand or gravel stream banks. Rang large church bells, etc. Suspended objects made to quiver. Damage negligible in buildings of good design and construction, slight to moderate in well-built ordinary buildings, considerable in poorly built or badly designed buildings, adobe houses, old walls (especially where laid up without mortar), spires, etc. Cracked chimneys to considerable extent, walls to some extent. Fall of plaster in considerable to large amount, also some stucco. Broke numerous windows, furniture to some extent. shook down loosened brickwork and tiles. Broke weak chimneys at the roof-line (sometimes damaging roofs). Fall of cornices from towers and high buildings. Dislodged bricks and stones. Overturned heavy furniture, with damage from breaking. Damage considerable to concrete irrigation ditches.

VIII. Fright general--alarm approaches panic. Disturbed persons driving motor cars. Trees shaken strongly--branches, trunks, broken off, especially palm trees. Ejected sand and mud in small amounts. Changes: temporary, permanent; in flow of springs and wells; dry wells renewed flow; in temperature of spring and well waters. Damage slight in structures (brick) built especially to withstand earthquakes. Considerable in ordinary substantial buildings, partial collapse: racked, tumbled down, wooden houses in some cases; threw out panel walls in frame structures, broke off decayed piling. Fall of walls. Cracked, broke, solid stone walls seriously. Wet ground to some extent, also ground on steep slopes. Twisting, fall, of chimneys, columns, monuments, also factory stacks, towers. Moved conspicuously, overturned, very heavy furniture.

IX. Panic general. Cracked ground conspicuously. Damage considerable in (masonry) structures built especially to withstand earthquakes: Threw out of plumb some wood-frame houses built especially to withstand earthquakes; great in substantial (masonry) buildings, some collapse in large part; or wholly shifted frame buildings off foundations, racked frames; serious to reservoirs; underground pipes sometimes broken.

X. Cracked ground, especially when loose and wet, up to widths of several inches; fissures up to a yard in width ran parallel to canal and stream banks. Landslides considerable from river banks and steep coasts. Shifted sand and mud horizontally on beaches and flat land. Changed level of water in wells. Threw water on banks of csnals, lakes, rivers, etc. Damage serious to dams, dikes, embankments. Severe to well-built wooden structures and bridges, some destroyed. Developed dangerous cracks in excellent brick walls. Destroyed most masonry and frame structures, also their foundations. Bent railroad rails slightly. Tore apart, or crushed endwise, pipe lines buried in earth. Open cracks and broad wavy folds in cement pavements and asphalt road surfaces.

XI. Disturbances in ground many and widespread, varying with ground material. Broad fissures, earth slumps, and land slips in soft, wet ground. Ejected water in large amounts charged with sand and mud. Caused sea-waves ("tidal" waves) of significant magnitude. Damage severe to wood-frame structures, especially near shock centers. Great to dams, dikes, embankments often for long distances. Few, if any (masonry) structures remained standing. Destroyed large well-built bridges by the wrecking of supporting piers, or pillars. Affected yielding wooden bridges less. Bent railroad rails greatly, and thrust them endwise. Put pipe lines buried in earth completely out of service.

XII. Damage total--practically all works of construction damaged greatly or destroyed. Disturbances in ground great and varied, numerous shearing cracks. Landslides, falls of rock of significant character, slumping of river banks, etc., numerous and extensive. Wrenched loose, tore off, large rock masses. Fault slips in firm rock, with notable horizontal and vertical offset displacements. Water channels, surface and underground, disturbed and modified greatly. Dammed lakes, produced waterfalls, deflected rivers, etc. Waves seen on ground surfaces (actually seen, probably, in some cases). Distorted lines of sight and level. Threw objects upward into the air.