(state-funded report done by contract)

EARTHQUAKE HAZARDS IN THE ALASKA TRANSPORTATION CORRIDORS

FINAL REPORT

by

L.D. Gedney, S.A. Estes and D.L. Marshall

Geophysical Institute
University of Alaska
Fairbanks, Alaska 99701

March 1983

Prepared for

STATE OF ALASKA
DEPARTMENT OF TRANSPORTATION AND PUBLIC FACILITIES
DIVISION OF PLANNING AND PROGRAMMING
RESEARCH SECTION
2301 Peger Road
Fairbanks, Alaska 99701

TABLE OF CONTENTS

Abstract

Based on observations made by modern seismographic networks since 1967, and taking into consideration historical records of large Alaskan earthquakes in the past, it is judged that the hazards faced by transportation corridors in different areas of the state increase in approximately the following order: (1) the Circle area, including the Steese and Elliott Highways, which contains a portion of the Tintina fault, now largely dormant; (2) The Rampart seismic zone, in which notable historic seismic activity occurred only in 1968 and 1969, but which contains the Yukon River bridge, a portion of the Dalton Highway, Manley Hot Springs Road, and Tanana; (3) The Glennallen area, bisected by the Castle Mountain fault. This zone includes the southern Richardson Highway and portions of the Border Ranges fault system; (4) The Cantwell area. This segment contains the Central Parks Highway and the Denali Highway. The principal tectonic element is the central portion of the Denali fault; (5) The Fairbanks area, an active seismic zone containing the northern Richardson and northern Parks Highways. This area contains an almost continually active area extending from near Harding Lake to Fox; (6) The Valdez area, with the southernmost section of the Richardson Highway and the Edgerton Highway. This segment contains the epicentral area of the great earthquake of 1964, the Chugach Mountains, and portions of the Border Ranges fault system; (7) The Kenai area. The Kenai Peninsula, with the Seward Highway and the peninsular road net is highly seismically active and overlies an active subduction zone; (8) The Talkeetna area, which contains Anchorage, Palmer and the southern Parks Highway. It is not unlikely that this will be the site of the Alaska mainland's next major earthquake.

Introduction

The seismic activity recorded in Alaska varies greatly depending on location. It is common knowledge that we can expect the most damaging earthquakes to occur around the southern coastal margins, while the northernmost areas are almost (but not quite) earthquake-free.

There is good reason for this. Since the early 1960's, it has been understood that the North Pacific oceanic plate is gradually moving to the northwest and impinging on the Alaska mainland. As it does so, it occasionally produces great earthquakes when the accumulated strain overcomes the intrinsic strength of the rocks of faults along which the differential movement occurs. Famous examples include the Lituya Bay earthquakes of 1958, during which the Pacific plate abruptly slid sideways against southeast Alaska, and the disastrous "Anchorage" earthquake of 1964, when the intruding plate underthrust the south-central portion of Alaska from a point extending from Prince William Sound southwestward to near southern Kodiak Island.

Some details of how this plate interaction occurs are now reasonably well understood.

For one, the principal tectonic offsets in Alaska appear to have occurred along a number of very large lateral faults which traverse the state roughly from east to west. From the north, these are the Kobuk, the Tintina, the Denali, and the Castle Mountain faults (St. Amand, 1957; Grantz, 1966; Richter and Matson, 1971; Forbes et al, 1976). From some of the work that has been done, one of the more interesting aspects to arise is that it appears that relative offset along these major systems has been transferred sequentially from the northernmost to the southernmost, with a gradation of seismic activity in between (Gedney and VanWormer, 1974).

This means, in essence, that one can expect to find a higher degree of seismicity within the state from north to south. Indeed, this is what we observe today. While the south-central area of the state is highly seismically active, and the central interior moderately so, activity dies out rapidly to the north.

At this point, it would be well to point out that this study does not include the Aleutian Islands. The Aleutians are active, but there are few roads there, few recording stations, the population density is low, and there is little risk to human life.

We are also excluding southeast Alaska for the simple regrettable reason that there are insufficient recording stations there (operated by any agency) to warrant a serious hazard study. Even so, it is well known that the Queen Charlotte fault system extending northward from the coast of British Columbia is a serious earthquake threat and has produced a number of magnitude 8 events since the turn of the century.

In addition, we have not included studies of the road networks around the Seward Peninsula, or of the Denali fault between Delta Junction and the Canadian border. In the first case, the reason is that data for a reasonable statistical estimate do not exist, and in the latter case, it is because the area (surprisingly, perhaps) simply doesn't produce enough earthquakes to even attempt an analysis (Gedney and Estes, 1982).

Finally, there is the Mt. McKinley (Denali) area. This is a very seismically active region, producing many earthquakes each year. But in terms of seismic risk to transportation facilities, the danger is very small. The reasons for this are that almost all earthquakes are deep (around 100 kilometers), and that the principal epicentral area is relatively distant from the Parks Highway and population centers. In the years since 1966 when this laboratory first started to request "Felt Reports" from local residents, very few have been received from McKinley Park Headquarters, and the ones that were could usually be attributed to earthquakes that had happened further to the south.

All in all, south-central Alaska and the Central Interior are the areas of major concern, for the reasons that not only do they contain the overwhelming majority of the state's transportation corridors, but they also produce the most earthquakes (Fig. 1, p. 32). The segments of the state described in the paragraphs that follow were established based on information that has been learned about Alaskan seismicity over the past 20 years. Although the segmentation may seem arbitrary in cases, the breakdown represents a reasonable approximation of seismic risk related to the various tectonic elements involved. Figure 1 also shows the geographic boundaries of the areas chosen for individual treatment. It bears pointing out not all of the epicenters displayed in Figure 1 were used in the following sections -- about three-fourths of these have been deleted because of reduced confidence levels in their determination. While Figure 1 shows the locations of all the earthquakes actually on record for this part of Alaska, Figure 2 (p. 33), indicating the better-located earthquakes since 1967, gives a clearer indication of the events used in drawing up most of the maps and cross-sections presented (for an explanation of the criteria used in selecting events, refer to the section "Explanation of Figures" on p. 28). Figure 2 also shows the outlines of the areas chosen for the broad cross-sections of seismic activity across the entire study area shown in Figures 3 (p. 34) and 4 (p. 35).

Returning to Figure 1, we have labeled the individual areas dealt with, as: (1) The Rampart seismic zone; (2) The Circle seismic zone; (3) The Fairbanks seismic zone; (4) The Cantwell seismic zone; (5) The Talkeetna seismic zone; (6) The Glennallen seismic zone; (7) The Valdez seismic zone, and; (8) The Kenai seismic zone.

Physical description and seismic history of study areas

The following section is based largely on the U.S. Department of Commerce series "Earthquake History of the United States", on the report by Davis and Echols (1962), and on various internal studies of the Geophysical Institute. In this summary only potentially damaging earthquakes of magnitude 6.0 or greater are included. The physical boundaries of the individual areas are indicated on the accompanying figures.

(1) The Rampart seismic zone (Figs. 5, p. 36; 6, p. 37; 7, p. 38; 8, p. 39).

Although this area is traversed by the Kaltag fault, this tectonic feature has exhibited little seismicity in the historic past. Epicenters of earthquakes measuring 6.0 and 6.3 have been recorded on 25 May 1950 at 65.5 degrees north, 151.5 degrees west, and on 10 May 1958 at 65.0 degress north, 152.5 degrees west, respectively.

Owing to the scant seismographic coverage at the time, however, these locations must be regarded as suspect.

One event occurred on 29 October 1968 which makes it appear that this area may pose a genuine seismic threat. This was a magnitude 6.5 earthquake which occurred at latitude 65.4 degrees north, 150.1 degrees west, caused some minor damage at Rampart and was widely felt over a radius of 500 kilometers. Aftershock and focal mechanism studies revealed that a potentially active left-lateral fault exists along a lineament coinciding with the Minook Creek Valley (Gedney et al., 1969). Subsequently, construction of the Yukon River bridge was slowed when it was discovered that the foundation of pier #4 rested on fault gouge, and redesign was necessitated. The location of the bridge lies on a direct line with the aftershock alignment following the 1968 earthquake.

(2) The Circle seismic zone (Figs. 9, p. 40 and 10, p. 41).

This is an area through which both the Steese and Elliott Highways pass. The Tintina fault goes through the northeast quadrant. Since 1967, a number of moderate earthquakes, ranging in magnitude up to 5.0, have been located in the vicinity of this fault, particularly in the Crazy Mountains region, but it is an area presenting so little potential of damage by earthquakes to structures that we do not even include cross-sections in the figures (cross-sections were made, but revealed little).

(3) The Fairbanks seismic zone (Figs. 11, p. 42; 12, p. 43; 13, p. 44; 14, p. 45).

One of the most seismically active areas of Alaska is centered near Fairbanks. Although few faults have been mapped on the surface, it appears certain from seismological studies that a right-lateral fault extends from near Harding Lake to north of the city near Fox (Gedney et al., 1980). In addition, there is a mapped fault stretching from near Nenana northward along the edge of the Minto Flats (Beikman, 1978).

Historical damaging earthquakes include:

Date	Lat(N)	Long(W)	Magnitude
27 Aug 04	64.7	151.0	7.7

07 Jul 12	64.0	147.0	7.4
21 Jan 29	64.2	147.9	6.2
04 Jul 29	64.2	147.9	6.5
22 Jul 37	64.7	146.7	7.3
07 Oct 47	64.5	146.0	6.5
16 Oct 47	64.5	148.6	7.0
21 Jun 67	64.7	147.4	6.5

The most recent sequence of earthquakes near Fairbanks began on 31 December 1981 when a magnitude 5.2 event and aftershock series occurred 25 miles south of the city (Gedney et al., 1982). The central interior area between the Alaska Range and the Yukon-Tanana uplands should be considered as an area of major hazard to transportation facilities.

(Note added in editing: The Badger Road area 10 miles southeast of the city experienced an earthquake swarm on 15 April 1983 which included a magnitude 5.0 event and resulted in widespread minor damage in the area, with one minor injury).

(4) The Cantwell seismic zone (Figs. 15, p. 46; 16, p. 47; 17, p. 48).

The boundaries that we have selected to include the Cantwell seismic zone contain within them the central Parks Highway, the central Richardson Highway and the entire Denali Highway. This is an area of moderate seismic risk, and many small earthquakes are felt. Significant historical earthquakes include those occurring on 16 October 1947 at 63.8 degrees north, 148.1 degrees west. This was a magnitude 7.0 event, but the actual epicenter is in doubt and it may have been much closer to Fairbanks. Another earthquake of magnitude 6.3 occurred 19 August 1948, near 63.0 degrees north, 150.0 degrees west, and many aftershocks were felt in Cantwell. This was before reliable recording systems were installed in interior Alaska and the depths of these earthquakes are not accurately known. They were probably relatively deep (greater than 50 km). Note on Figure 16 (p. 47) that the shallower portions of the downgoing Pacific slab are obvious in the western part of the area.

(5) The Talkeetna seismic zone (Figs. 18, p. 49; 19, p. 50; 20, p. 51).

This area includes the southern Parks Highway and the population centers of the Matanuska-Susitna Valley. It is probably most susceptible of all to damage from earthquakes in the future (see section on "Interpretation" which begins on p. 18). The record, which is almost certainly incomplete, includes the following earthquakes:

Date	Lat(N)	Long(W)	Magnitude
27 Apr 33	61.3	150.5	7.0
13 Jun 33	61.0	151.0	6.2
19 Jun 33	61.2	151.5	6.0
23 Oct 36	61.1	149.2	7.0
30 Jul 41	61.0	151.0	6.3
03 Nov 43	61.8	151.0	7.3
25 Jun 51	61.0	150.1	6.3
09 May 62	62.0	150.1	6.0
20 Oct 62	61.1	149.7	6.2

(6) The Glennallen seismic zone (Figs. 21, p. 52; 22, p. 53; 23, p. 54).

This seismic zone contains some striking topographic features, including the Castle Mountain fault rift along which the western Glenn Highway runs and the northern escarpment of the Chugach Mountains. It also includes much of the Talkeetna Mountains, and a large portion of the southern Richardson Highway. On 2 August 1934 a magnitude 6.0 earthquake occurred at 61.5 degrees north, 147.5 degrees west, and on 3 April 1964 an earthquake of similar magnitude was recorded at 61.6 degrees north, 147.6 degrees west. The latter earthquake was probably a northern aftershock of the "Good Friday" earthquake of 27 March.

Seismic activity occurs sporadically throughout the Talkeetna Mountains. A particularly active area lies just south of Tazlina, on the northern flanks of the Chugach Range.

From Figure 21 (p. 52), however, it is evident that the seismic activity drops substantially in the Lake Louise area east of the Talkeetna Mountains to a level of almost zero risk.

The cross-section shown in Figure 22 (p. 53) shows no obvious association between seismicity and the Castle Mountain fault, although it points out again the upper portions of the northwestward dipping subduction zone of the Pacific plate, and the intense zone of activity on the northern flanks of the Chugach Range near the Tazlina Glacier.

(7) The Valdez seismic area (Figs. 24, p. 55; 25, p. 56; 26, p. 57).

This area contains the southern Richardson Highway corridor, the Edgerton Highway and a major portion of the "Contact" fault system between the north Pacific and American plates. Within it lies the initial epicentral zone of the major 1964 Alaska earthquake.

Recorded earthquakes include:

Date	Lat(N)	Long(w)	Magnitude
22 Sep 11	60.5	149.0	6.9
04 Jan 33	61.0	148.0	6.3
02 Aug 34	61.5	147.5	6.0
27 Mar 64	61.0	147.8	8.4
30 Aug 66	61.3	147.5	6.0

Parenthetically, it should be stated that there were many aftershocks exceeding magnitude 6.0 which followed the 1964 earthquake, but that most of these occurred to the southwest of this zone (added in editing -- two earthquakes of magnitude 6.0 or greater occurred in this area on 12 July and 7 September, 1983).

(8) The Kenai seismic zone (Figs. 27, p. 58; 28, p. 59; 29, p. 60).

The Kenai Peninsula overlies an active seismic zone which produces not only myriads of earthquakes, but also the volcanic activity observed along western Cook Inlet. The peninsula is riding on top of the flexed zone of the Pacific plate as it is being bent to underthrust the southern portion of the Alaska Range on the western shore of the inlet. The peninsular road net, including the Seward Highway, can be threatened at any time by major earthquakes. The western escarpment of the Kenai Mountains is an obvious tectonic fault.

Historic earthquakes include:

Date	Lat(N)	Long(W)	Magnitude
24 Dec 31	60.0	152.0	6.3
11 Oct 40	59.5	152.0	6.0
05 Dec 42	59.5	152.0	6.3
27 Sep 49	59.8	149.0	7.0
03 Oct 54	60.0	151.0	6.8
24 Jan 58	60.0	152.0	6.3
26 Dec 59	59.9	151.9	6.3

It should be understood that the locations for these earlier earthquakes can be taken as only approximate, because of the lack of local seismographic coverage in the state.

In tabulating the number of felt and damaging earthquakes that have been documented in these areas in recorded history, the following points should be kept in mind: (1) The number of reports received by any recording agency depends largely on the population density within the specified area; (2) Even though an earthquake may have been widely felt in an area, the facilities for reporting these incidents to authorities vary widely depending on location; (3) Some areas experience so many earthquakes that residents feel it unnecessary to make felt reports; and, (4) During the periods when seismographic instrumentation was minimal in the state, the same earthquake may have been jointly assigned to adjoining areas. Under these circumstances, Table 1, following, probably is a gross underestimation of the number of felt and damaging earthquakes that have actually occurred. Nevertheless, the table contains all the information on public record, and provides an easily understandable summary of the earthquake potential in southcentral and interior Alaska. The data date from the turn of the century.

TABLE 1

Area	Felt Earthquakes	Damaging Earthquakes
(1) Rampart	27	1
(2) Circle	20	3
(3) Fairbanks	101	9
(4) Cantwell	30	0
(5) Talkeetna	129	7
(6) Glennallen	6	3
(7) Valdez	69	5
(8) Kenai	75	12

Data reduction

In 1949, Gutenberg and Richter (c.f.) published their landmark paper "Seismicity of the Earth and Associated Phenomena." Here, it was first disclosed that a linear relationship seemed to exist between the logarithm of the cumulative number of earthquakes occurring in particular areas of the world and their respective magnitudes. They expressed this relationship as:

$$\text{Log } N = a - bM.$$

In this expression, N represents the number of earthquakes of magnitude greater than or equal to magnitude M during a specified period of time. The constants a and b are thought to be representative of the stress conditions existing in the area under investigation. Henceforth, these constants will be referred to as the a-intercept and the b-slope.

For example, if N is measured on the y-axis and M on the x-axis, the slope b, of the line plotted relating the logarithm of the cumulative number of earthquakes as measured on the y-axis relative to earthquake magnitude on the x-axis will lessen as the relative number of larger earthquakes in an area increases with respect to the smaller. For an example of such a plot see Figure 30 (p. 61).

The a-intercept is valuable in comparing the absolute number of earthquakes occurring in areas of similar size -- the higher the a-intercept, generally speaking, the greater the number of earthquakes. B-slopes in different seismic areas around the world have been found by numerous investigators to average around 1.0. It is generally thought that low b-slopes presage an area characteristic of one potentially seismically hazardous, while high b-slopes are indicative of areas undergoing continual seismic relief, such as in an aftershock zone.

Mogi (1963) was one of the first to attempt relating these quantities to conditions within a stressed seismic zone. Among his conclusions, derived largely from laboratory studies, was that low b-slopes were often related to highly stressed areas in which many small fractures occurred before final failure. At the opposite end of the spectrum were such sequences as aftershock series, during which very high b-slopes were observed, representing many small earthquakes relative to few large.

These observations have been duplicated on rock samples in laboratories by American seismologists including works by Scholz (1968), Wyss (1973), Scholz et al. (1973), and Wyss and Lee (1973).

We have used the seismological data that have been collected since 1967 to obtain relative b-slopes and a-intercepts of the various seismic zones of Alaska through which the major transportation corridors pass, in order to approximate the relative seismic risk in each.

Before presenting Table 2 (p.17), which contains the parameters of least-squares fits to the data, we make the following explanations:

(1) When trying to compute accurate b-slopes, it should be

understood that some cutoff levels must be established where magnitudes are considered. For instance, it is possible that many smaller magnitude earthquakes, while being recorded accurately by nearby stations, may be missed entirely by stations that are more distant from the epicentral region. For this reason, we have normalized the data for all the separate sectors investigated to include only those earthquakes of magnitudes ranging between 2.5 and 4.5. This insures that almost no earthquake of meaningful magnitude has escaped detection in recording, and also that the occasional larger earthquake (such as the magnitude 6.5 Rampart earthquake) does not have undue influence on the findings. Because of "rolloff" at the lower magnitude levels due to diminished detection capabilities, and "jumps" in the data at the higher end owing to occasional larger earthquakes, deletion of these events preserves the most linear part of the data, which is the best indicator of the true background seismic level.

For a graphic illustration of why this policy was adopted, please refer again to Figure 30 (p. 61).

(2) The numbers in Table 2 have also been normalized taking into account the operating periods of the stations involved in data collection. In most cases, this period includes only that from September, 1967 to March, 1981 (more recent data have not yet been properly collated). An exception is that the major Rampart earthquake of 1968 and its aftershock sequence have not been included. It was felt that this would impart too much bias to the final results. In addition, there

have been periods of network down-time which may have influenced the results. For this reason these brief periods have been accounted for in the calculations and the normalizing process.

(3) We have also normalized the figures for differences in total area. One could not say that an area 10,000 square kilometers in size would equate with a neighbor twice that size if they both experienced one magnitude 7 earthquake during a year. For this reason, each of the eight study areas have been normalized to 25,000 square kilometers. This approximates the size of the different areas, which range from a maximum of 38,400 square kilometers for the Kenai seismic zone to 19,980 square kilometers for the Rampart seismic zone.

TABLE 2

This listing contains the recurrence parameters a and b as determined by least-squares fits to the data with the root-mean-square errors given under "RMS." The column labeled "Total No." gives the number of earthquakes recorded in the individual areas during the study period, and under "No. Used" is given the number of earthquakes between magnitudes 2.5 and 4.5 (inclusive) which were used in the computations.

Area	a	b	RMS	Total No.	No. Used	Period
(1) Rampart	4.48	0.995	0.03	1938	790	10/69-03/81
(2) Circle	3.28	0.861	0.06	897	193	09/67-03/81
(3) Fairbanks	5.72	1.090	0.04	6603	733	03/69-03/81
(4) Cantwell	5.02	0.872	0.02	2890	741	10/67-03/81
(5) Talkeetna	5.44	0.928	0.07	3378	1605	09/67-03/81
(6) Glennallen	4.12	0.969	0.05	1989	744	09/67-03/81
(7) Valdez	5.07	0.866	0.05	1375	617	09/67-03/81
(8) Kenai	5.17	0.888	0.09	1543	937	09/67-03/81

Interpretation

Recalling the relationship log N = a - bM, we can invert the results shown in Table 2 to calculate the expected recurrence intervals of earthquakes based on the data collected since 1967.

TABLE 3

Expected Magnitude Recurrence Intervals (yrs)

Area	4	5	6	7
(1) Rampart	0.32	3.12	30.9	305
(2) Circle	1.46	10.60	76.9	558
(3) Fairbanks	0.04	0.54	6.6	81
(4) Cantwell	0.03	0.22	1.6	12
(5) Talkeetna	0.02	0.15	1.2	11
(6) Glennallen	0.57	5.31	49.4	460
(7) Valdez	0.02	0.18	1.3	10
(8) Kenai	0.02	0.19	1.4	11

In this example, we present the values for only magnitudes 4,5,6, and 7, but the process could be continued indefinitely in either direction. That is, we could as easily compute the expected recurrence interval of an earthquake of magnitude 10 as we could for one of -10. Of course, both these values would be absolutely meaningless, and we have confined ourselves to the range of potentially damaging earthquakes which are plausible over most of south central and interior Alaska. In any event, the figures merely hint at the relative seismic risk in each of the areas, and must not be taken to represent the three-decimal-point accuracy indicated. We will now briefly discuss what the findings of this report seem to indicate for each of the seismic zones involved.

(1) Rampart seismic zone

On the whole, the epicenters presented in this report seem to bear little correlation with mapped tectonic faults. An exception to this is the Rampart earthquake zone, which coincides almost exactly with the sharp rift of the Minook Creek Valley. But this is an exception in itself, because the Minook Creek Valley does not appear on any geologic map with which we are familiar as a mapped fault. Had it not been for the earthquake sequence of 1968, this are would probably be classified today as being an area of low seismic risk. In consideration of these earthquakes, although in spite of the relatively low elements of risk suggested by Table 3, we must consider it to be the locale of at least a magnitude 7.0 earthquake in the foreseeable future. In any event, the risk to any transportation facilities, save the Yukon bridge, is small.

(2) Circle seismic zone.

The Circle area approximates the northeasternmost extent of Alaska's principal continental seismic zone. To the north of here, seismicity gradually dies out to an inconsequential level. There seems to be some relationship between seismicity and the Tintina fault in the Crazy Mountains area, but the extremely low a-intercept in Table 2 and the low recurrence parameters in Table 3 seems to rule it out as a region of serious seismic threat.

(3) Fairbanks seismic zone.

The Fairbanks area is one frequented by felt earthquakes, and it is certain that several seismically active faults exist, although they have never been mapped on the ground. One reason that so many earthquakes are felt is that it is fairly densely populated, but nonetheless it is seismically active by any standard. In 1937 magnitude 7.3 earthquake occurred 40 miles southeast of the city and rockslides blocked the Richardson ahighway for several days. In 1967, a series of magnitude 6.0 earthquakes occurred 10 miles to the southeast, and resulting landslides blocked the newly constructed Chena Ridge Road. The very high value of the a-intercept found in Table 2 for the Fairbanks seismic zone must be attributed in part to a relatively dense concentration of local seismographic stations and the attendant detection of many smaller events. But in spite of the relatively low recurrence parameters shown in Table 3, because of the importance of the transportation networks passing through the area and its past history of damaging earthquakes, it must be considered a seismic hazard of the first degree, capable of producing earthquakes at least as large as magnitude 7.5.

(4) Cantwell seismic zone.

The Cantwell area derives much of its seismicity as a "spinoff" from the much more active, but much deeper earthquake zone lying beneath Mt. McKinley (Denali) to the west. Although it includes a major portion of the Denali fault which lies along the central portion of the Alaska Range, the major contribution of seismicity from a visible tectonic feature seems to come from the Hines Creek strand of the Denali, which passes near Healy to the north. In actuality, most of the seismic activity in the area is probably due not so much to lateral offset along these major faults as to underthrusting of the Pacific plate at considerable depths. The entire area overlies a "corner" of the north Pacific lithospheric plate as it is being rammed in the Alaska sub-continent. Because of the depth of most earthquakes here, and in view of the few reports of damage, we judge this to be an area of fairly low seismic risk, although its tectonic setting and the values in Table 3 do not rule out the possibility of an earthquake of at least magnitude 8.0. The values in Table 3 indicate that it is a potential candidate for a major earthquake.

(5) Talkeetna seismic zone.

Taking all things into consideration, of the areas covered by this report, the Talkeetna seismic zone seems to be the one waiting for a major earthquake to happen. Although the Valdez and Kenai areas are also subject to very large earthquakes, seismic strain in these regions was largely released during the great earthquake of 1964, and will probably take 100 years or more to build back to the level that could produce another earthquake of that magnitude. Talkeetna, on the other hand, was at the very northern extension of the rupture zone associated with the 1964 earthquake, and just as with cracks in a sheet of metal, stress concentrates at the very end of cracks in the crustal material, and it is there where the next failure is most likely to occur. The number of felt and damaging reports, the high a-intercepts, the number of earthquakes, the short recurrence intervals, and the tectonic setting all combine to signal the Talkeetna area as being a likely site for Alaska's next major inland earthquake.

(6) Glennallen seismic zone.

Even though the Castle Mountain fault passes squarely through this area, the historic level of seismicity, coupled with low computed recurrence interval values and a low a-intercept, rate it as only a moderate seismic risk. Although not comparable to its neighbors in this respect, it could still produce a respectable earthquake in the magnitude 7.5 range. One aspect that is coming into sharper focus as debate on the Susitna project continues, is that the little-mapped Talkeetna Mountains may contain more faults than suspected. This information has been gained largely through satellite observations, but the suspected faults apparently pose little seismic hazard. The northeastern part of the region, in particular, seems to be tectonically stable at the present.

(7) Valdez seismic zone.

The titles "Valdez" and "Trans-Alaska Pipeline" are practically synonomous to almost everyone. But so are the titles "Valdez" and the "Good Friday Earthquake" to anyone who was living in Alaska on March 27, 1964. From the figures that we have derived, it is evident that the Valdez area is still prone to major earthquakes in the future. The difference now is that (as stated in the Talkeetna section) it will probably take a time interval of something on the order of a century for the stress levels to build to the point where another earthquake such as that in 1964 can occur. Intermittent smaller events are inevitable.

(8) Kenai seismic zone.

The low b-slope levels indicated, the high a-intercept, and the frequent recurrence intervals in the Kenai Peninsula area since 1967 indicate a high level of seismic risk. However, just as with the Valdez area, it is unlikely that it will experience another great earthquake again for at least another 100 years. Earthquakes associated with the plate being underthrust beneath the peninsula, however, can still be expected to occur at a steady pace although these will probably be at a tolerable magnitude level until at least the middle of the 21st century. As seen in Figures 27 (p.58) and 28 (p.59), the present activity is diffuse and cannot be directly associated with any tectonic element, except possibly the suggestion of a slight downward migration of earthquakes in the western part which can be attributed to the subduction zone.

Summary

Combining the findings of seismological investigations obtained over the last 20 years with historical observations, our subjective estimations as to the relative earthquake risk in the different seismically active areas encompassing the major transportation corridors of the state are as follows:

(1) In the areas covered by the present transportation corridors, seismic risk increases from a mimimum near Circle to a maximum in the Matanuska-Susitna Valley.

(2) Transportation facilities in central interior Alaska are exposed to occasional major seismic damage. This is borne out by damage to the transportation networks that has been experienced in the past and the high incidence of earthquakes that continue to the present.

(3) Transportation corridors crossing the Alaska Range are subject to moderate seismic damage over extended periods of time. These are not felt at present to be a major area of concern.

(4) Those sections of the southern Richardson and western Glenn Highways east of the headwaters of the Matanuska River face little seismic hazard. From the point where the Glenn Highway enters the Matanuska River Valley to Palmer, the risk is relatively high.

(5) Seismic strain in the Valdez and Kenai Peninsula areas was largely released during the 1964 earthquake. Although many moderate earthquakes can be expected in these seismic zones in the near future, it is unlikely that a major earthquake will

recur here during this century.

(6) In our opinion, the most likely site for the next major mainland Alaska earthquake lies somewhere along the transportation corridor between Anchorage and Broad Pass. High recurrence parameters in the area and vulnerable geologic setting both point to this possibility.

REFERENCES

Beikman, H.M., Preliminary Geologic Map of Alaska, Department of Interior, U.S. Geol. Surv., 1978.

Davis, T.N. and C. Echols, A Table of Alaskan Earthquakes, 1788-1961, Report UAG-R131, Geophysical Institute, University of Alaska, 1962.

Forbes, R.B., H. Pulpan and L. Gedney, Seismic risk and the Denali fault, Prepared for Gulf State Engineering Company, Geophysical Institute, University of Alaska, 52 pp., 1976.

Gedney, L., E. Berg, H. Pulpan, J. Davies and W. Feetham, A field report on the Rampart, Alaska earthquake of October 29, 1968, Bull. Seism. Soc. Am., V. 59, pp. 2619-2624, 1969.

Gedney, L. and J. VanWormer, Tectonic lineaments and plate tectonics in southcentral Alaska, Proceedings of the First International Symposium on the New Basement Tectonics, Utah Geological Association Publication No. 5, pp. 27-34, 1974.

Gedney, L., S. Estes and N. Biswas, Earthquake migration in the Fairbanks, Alaska seismic zone, Bull. Seism. Soc. Am., V. 70, pp. 873-884, 1980.

Gedney, L. and S. Estes, A recent earthquake on the Denali fault in the southeast Alaska Range, Alaska Division of Geological and Geophysical Surveys Geologic Report 73, pp. 51-54, 1982.

Grantz, A., Strike-slip faults in Alaska, Department of Interior, U.S. Geol. Surv., Open file report 852, V. 5, 82 pp., 1966.

Gutenberg, B. and C. Richter, Seismicity of the earth and related phenomena, Princeton University Press, 1949.

Mogi, K., Some discussions on aftershocks, foreshocks, and earthquake swarms--the fracture of a semi-infinite body caused by an inner stress origin and its relationship to earthquake phenomena (third paper), Bull. Earthquake Research Inst., Tokyo, V. 41, pp. 615-658, 1963.

Richter, C., Elementary Seismology, 768 pp., Freeman Press, 1958.

Richter, D. and N. Matson, Quaternary faulting in the eastern Alaska Range, Geol. Soc. Am. Bull., V. 82, pp. 1529-1540, 1971.

Scholz, C., The frequency-magnitude relation of microfracturing in rock and its relation to earthquakes, Bull. Seism. Soc. Am., V. 58, pp. 399-415, 1968.

Scholz, C., L. Sykes and Y. Aggarwal, Earthquake prediction: a physical basis, Science, V. 181, pp. 801-810, 1973.

St. Amand, P., Geological and geophysical synthesis of the tectonics of portions of British Columbia, the Yukon Territory, Geol. Soc. Am. Bull., V. 68, pp. 1343-1370, 1957.

Wyss, M., Towards physical understanding of the earthquake frequency distribution, Geophys. J., V. 31, pp. 341-359, 1973.

Wyss, M. and W. Lee, Time variations of the average earthquake magnitude in central California, Stanford University Pub. Geol. Sci., V. 13, pp. 24-42, 1973.

Explanation of figures

Figure 1 (p.32) includes all epicenters that have been recorded since 1967. These include some very unreliable epicenters computed on the basis of "readings" from perhaps as few as three seismographic stations.

The remaining figures consisting of maps and cross-sections present data that have been much more carefully selected on the basis of the following criteria:

(1) Reliable readings from five or more stations were available.
(2) The root-mean-square errors of the computer-generated solutions did not exceed 1.0 second.
(3) Neither ERH nor ERZ exceeded 10 kilometers (these are acronyms for the largest expected horizontal and vertical deviations, respectively, of the true solution within a one-standard deviation ellipsoid).

* *

Figure 1 (p.32). Printout of all earthquakes, regardless of solution quality, recorded since 1967. The eight study areas indicated in bold outline.

Figure 2 (p.33). Printout of best solutions (as judged from the criteria outlined above) with areas of cross-sections printed in Figures 3 and 4 outlined.

Figure 3 (p.34). Cross-section A-A' of total area looking northwest. Evidence of dipping seismic zone to the southwest is apparent. Horizontal areas of seismic zones included in report are indicated in top of figure. These appear to overlap because of oblique azimuth of view.

Figure 4 (p.35). Cross-section B-B' of overall study area looking northeast. Section gives good view of dipping subduction zone. As in Figure 3 horizontal extent of individual study areas is shown at top of figure.

Figure 5 (p.36). Epicentral plot of earthquakes in the Rampart seismic zone since 1967. Minook Valley rift closely follows aftershock zone of 1968 Rampart earthquake. Little activity is noted along the Kaltag or Tintina faults.

Figure 6 (p.37). Cross-section looking to the north-northeast along the Minook Valley rift.

Figure 7 (p.38). Cross-section looking to the west-northwest across the Minook Valley rift.

Figure 8 (p.39). Number of earthquakes by month recorded in the Rampart seismic zone. The peak during 1968 and 1969 was the result of a major earthquake in October, 1968. Little data were recorded in the area prior to 1967. There were also breaks in data collection between July, 1976 and March, 1977, and also between January and June of 1980.

Figure 9 (p.40). Epicentral plot of earthquakes in the Circle seismic zone since 1967. Well-located earthquakes in this area are rare. Although some seem to be related to the Tintina fault system, earthquake hazards can be considered as being minimal.

Figure 10 (p.41). Number of recorded earthquakes between 1967 and 1981 in the Circle area. Data between July, 1976 and November, 1977 are unavailable, as are data between January and June of 1980.

Figure 11 (p.42). Epicentral plot of earthquakes in the Fairbanks seismic zone since 1967. Concentration of earthquakes southeast of Fairbanks is believed to be the product of a right-lateral fault extending from near Harding Lake to north of Fairbanks to near Fox. The Minto Flats northwest of Nenana also produce frequent earthquakes as does the Gold King Creek area on the north flank of the Alaska Range.

Figure 12 (p.43). Fairbanks cross-section A3-A3' looking northeast.

Figure 13 (p.44). Fairbanks cross-section B3-B3' looking northwest. Potential fault may be indicated by thick vertical cluster near left center of figure.

Figure 14 (p.45). Number of earthquakes by month recorded in the Fairbanks seismic zone. Although 1967 marked a time that the Fairbanks area had its most intense seismic activity for 30 years, the relatively few earthquakes shown on this graph for that period are indicative of the meager instrumental network at the time. The rising peaks in the following years are graphic evidence of the upgrading of the system. No data are provided for the periods between July and December, 1976 and January and July of 1980.

Figure 15 (p.46). Epicentral plot of earthquakes in the Cantwell seismic zone since 1967. Epicenters are not obviously related to well-known mapped faults. The most active area is north of the Hines Creek strand of the Denali. This most likely indicates the northernmost terminus of the subducting Pacific slab.

Figure 16 (p.47). Cantwell Cross-section A4-A4' looking northeast. The upper portion of the downgoing Pacific slab is apparent, but earthquakes at these depths pose little hazard.

Figure 17 (p.48). Number of recorded earthquakes in the Cantwell seismic zone since 1967. Data between July and October, 1976 and January and July of 1980 are unavailable.

Figure 18 (p.49). Epicentral plot of earthquakes in the Talkeetna seismic zone. Flanking the western escarpment of the Talkeetna Mountains, overlying an active subduction zone, and lying near the end of the breakage zone of the 1964 earthquake, the Talkeetna area is probably the most prone among the study areas to a major earthquake in the foreseeable future.

Figure 19 (p.50). Talkeetna cross-section A5-A5' looking northeast. The subduction zone is apparent.

Figure 20 (p.51). Number of recorded earthquakes in the Talkeetna seismic zone since 1967. Data from April to July of 1980 are unavailable.

Figure 21 (p.52). Epicentral plot of earthquakes in the Glennallen seismic zone. The Talkeetna Mountains to the west and the Tazlina Glacier area on the northern flanks of the Chugach Range are conspicuously active compared with the lowlands around Lake Louise to the northeast.

Figure 22 (p.53). Glennallen cross-section A6-A6' looking northeast. Again we notice the Pacific slab down-dipping to the northwest and the conspicuous cluster beneath the Tazlina Glacier.

Figure 23 (p.54). Number of recorded earthquakes in the Glennallen seismic zone since 1967. Data from April to July of 1980 are unavailable, although there was a surge of activity during the last part of 1980.

Figure 24 (p.55). Epicentral plot of earthquakes in the Valdez seismic zone. Although always potentially hazardous, the aftershock zone of the 1964 earthquake has become diffuse and largely indistinguishable.

Figure 25 (p.56). Valdez cross-section A7-A7' looking northeast. There is little to be gained from this cross-section, except that it can be noted that the upper margin of the downgoing Pacific plate begins to gently dip to the west. Offset along this interface was the mechanism producing the 1964 earthquake.

Figure 26 (p.57). Number of recorded earthquakes in the Valdez seismic zone. Of all the areas which we have investigated in the progress of this report, this and the Kenai area are the only ones for which we have substantial data prior to 1967. This, of course, is because of the 1964 earthquake and its aftershocks. There are no data available between April and August of 1980.

Figure 27 (p.58). Epicentral plot of earthquakes in the Kenai seismic zone. The Kenai Peninsula displays no obvious connection between surficial tectonic elements and epicentral locations. Almost all the earthquakes occurring within this region are related to the downgoing slab.

Figure 28 (p.59). Kenai cross-section A8-A8' looking northeast. The diffuse arrangement of hypocenters gives only scant hint of the well-defined Benioff subduction zone that extends to the west under Cook Inlet.

Figure 29 (p.60). Number of recorded earthquakes in the Kenai seismic zone. As with the Valdez area, the Kenai seismic zone shows a sharp peak in activity in 1964. No data are available for the period between April and June of 1980.

Figure 30 (p.61). Sample b-slope plot showing recurrence parameters in area 1 (Rampart) during study period. Linear magnitude interval between 2.5 and 4.5 was chosen for this and all other study areas.

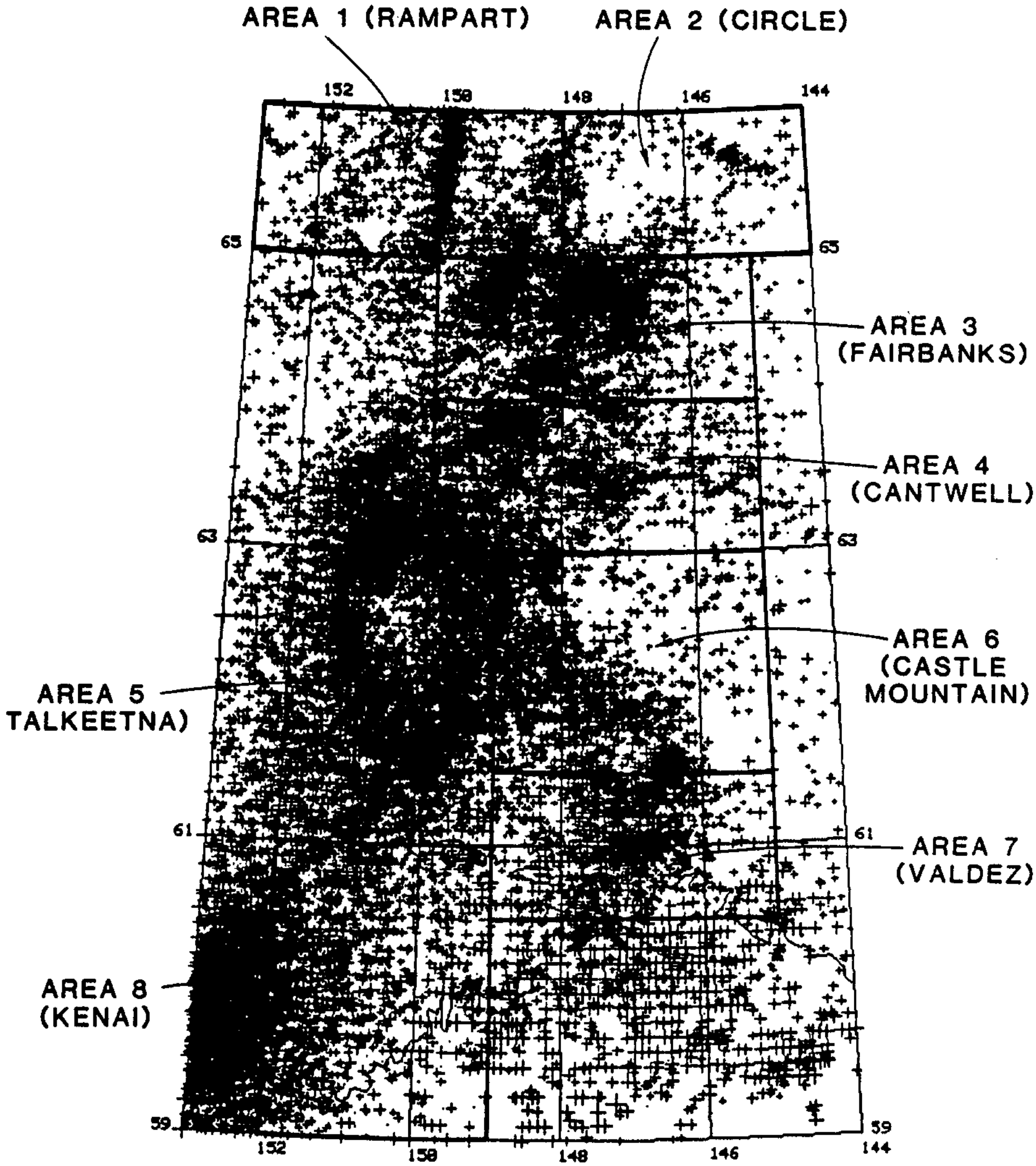

Figure 1. Printout of all earthquakes, regardless of solution quality, recorded since 1967. The eight study areas are indicated in bold outline.

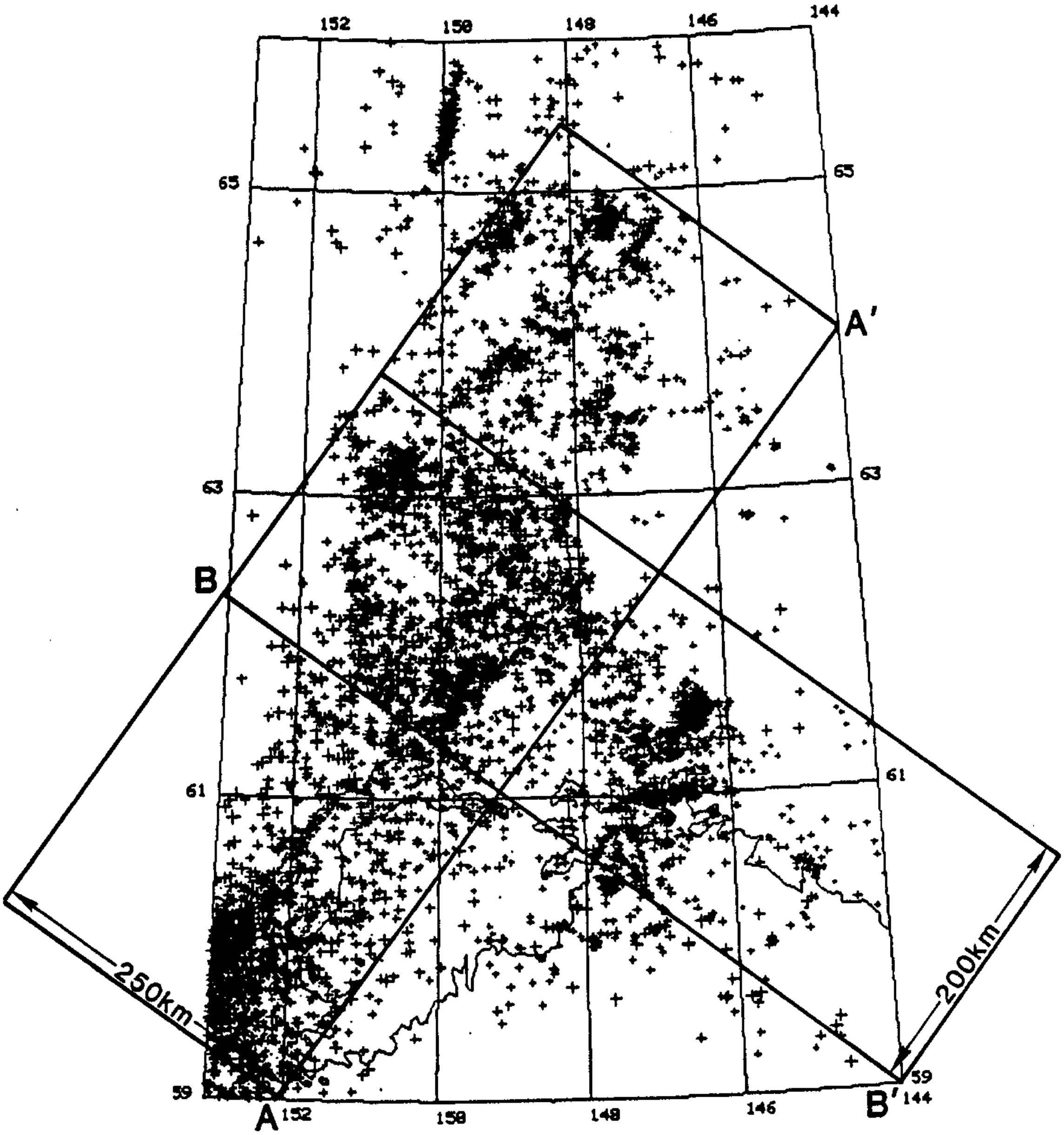

Figure 2. Printout of best solutions (as judged from the criteria outlined above) with areas of cross-sections printed in Figures 3 and 4 outlined.

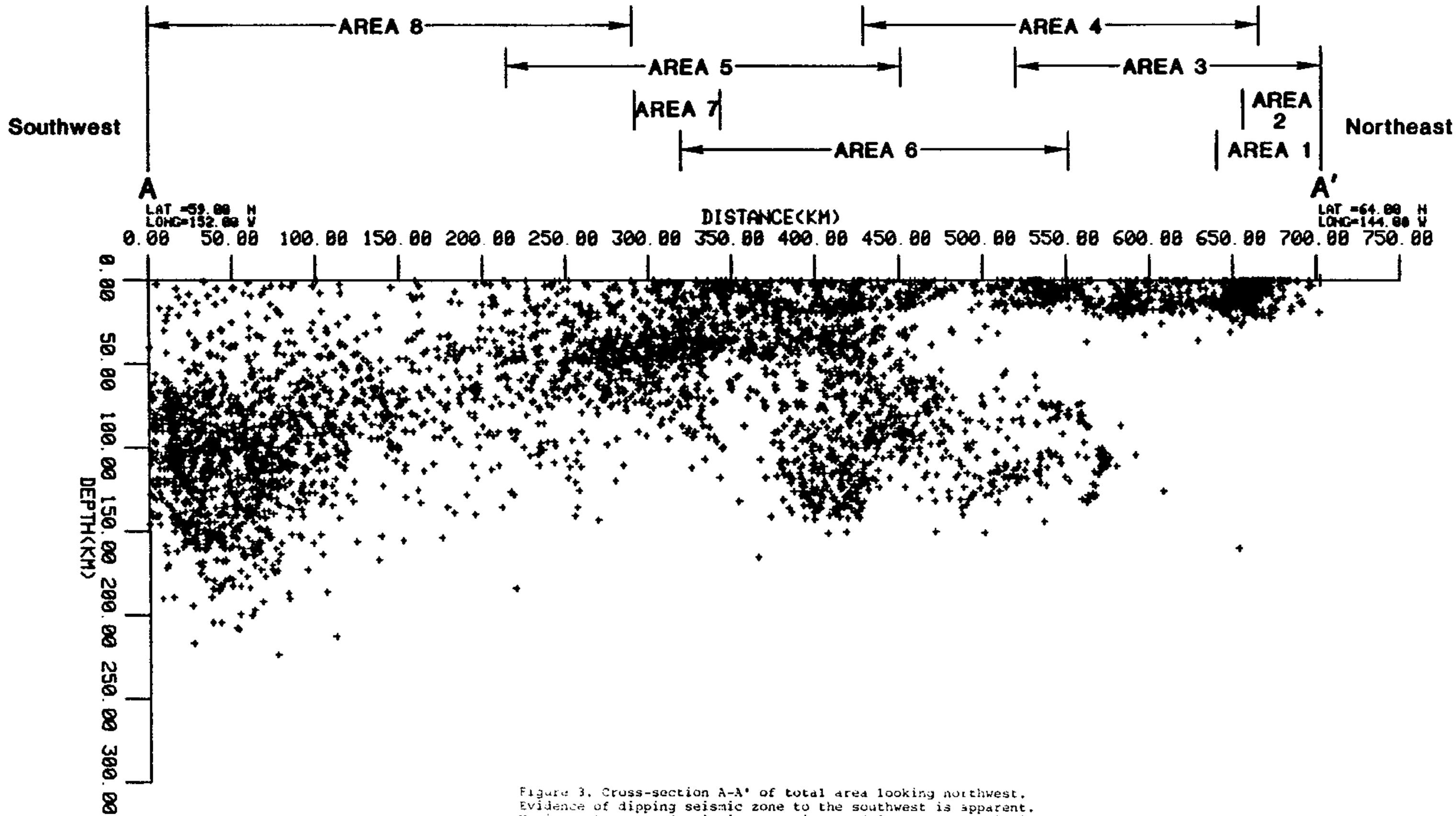

Figure 3. Cross-section A-A' of total area looking northwest. Evidence of dipping seismic zone to the southwest is apparent. Horizontal areas of seismic zones included in report are indicated at top of figure. These appear to overlap because of oblique azimuth of view.

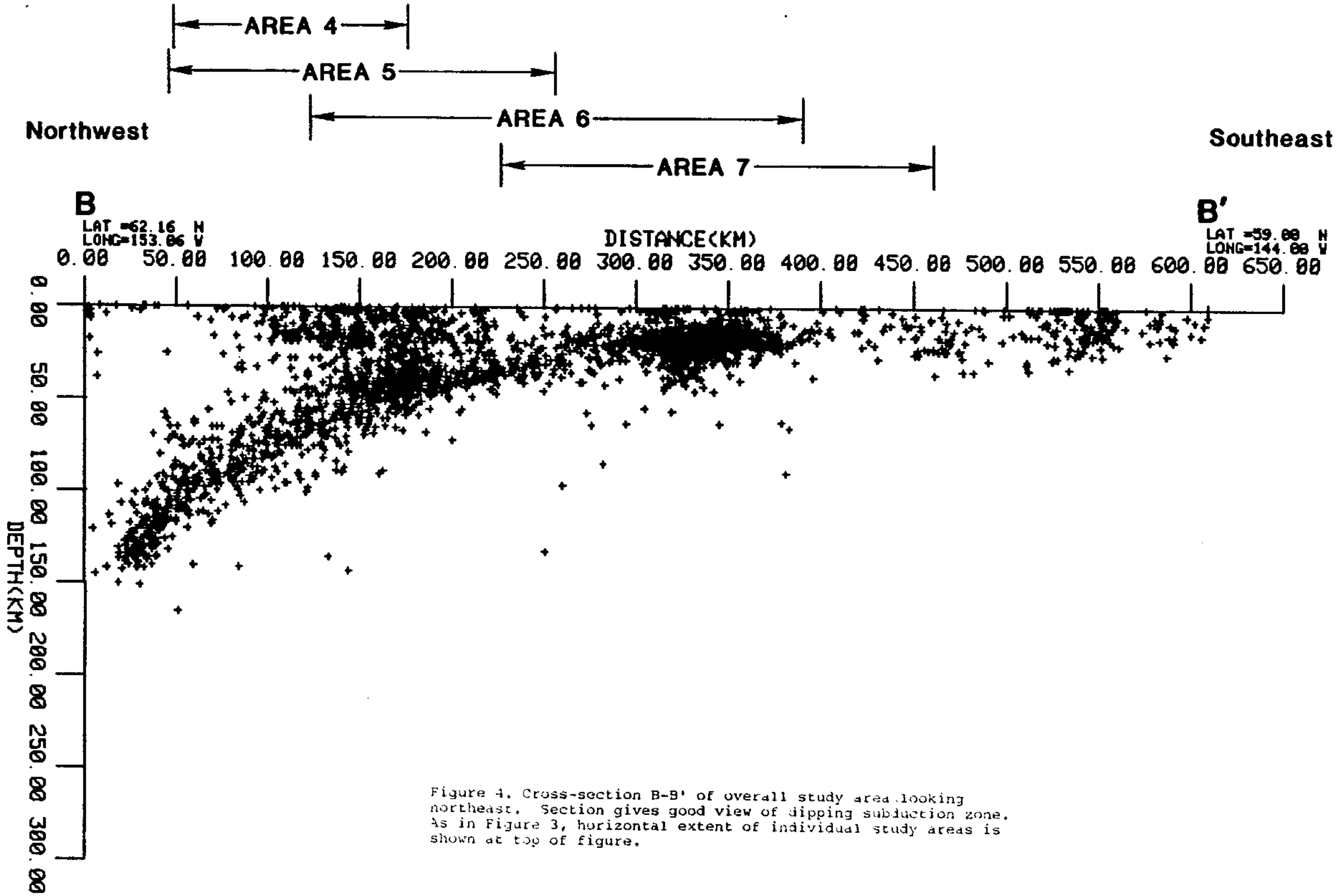

Figure 4. Cross-section B-B' of overall study area looking northeast. Section gives good view of dipping subduction zone. As in Figure 3, horizontal extent of individual study areas is shown at top of figure.

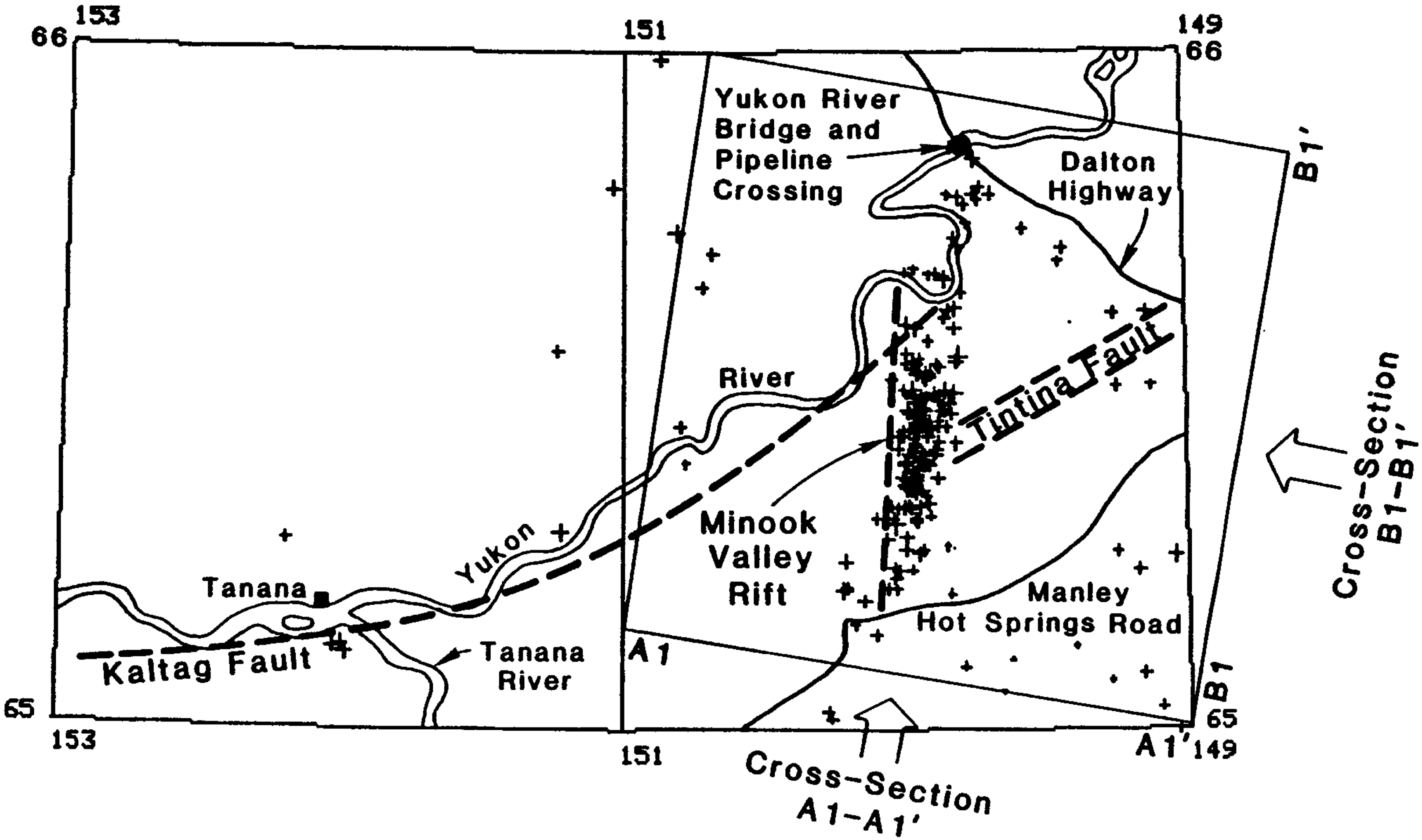

Figure 5. Epicentral plot of earthquakes in the Rampart seismic zone since 1967. Minook Valley rift closely follows aftershock zone of 1968 Rampart earthquakes. Little activity is noted along the Kaltag or Tintina faults.

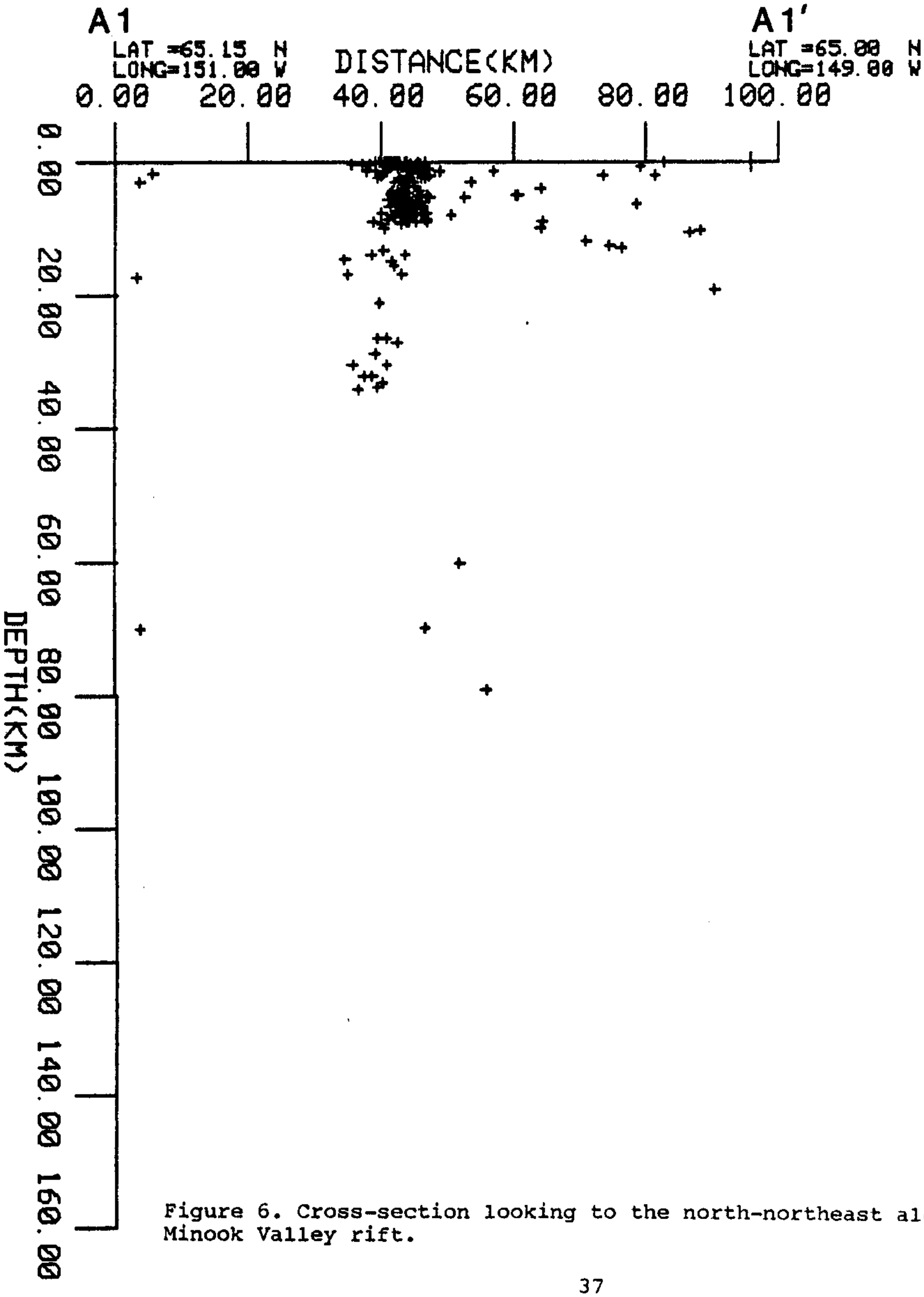

Figure 6. Cross-section looking to the north-northeast along the Minook Valley rift.

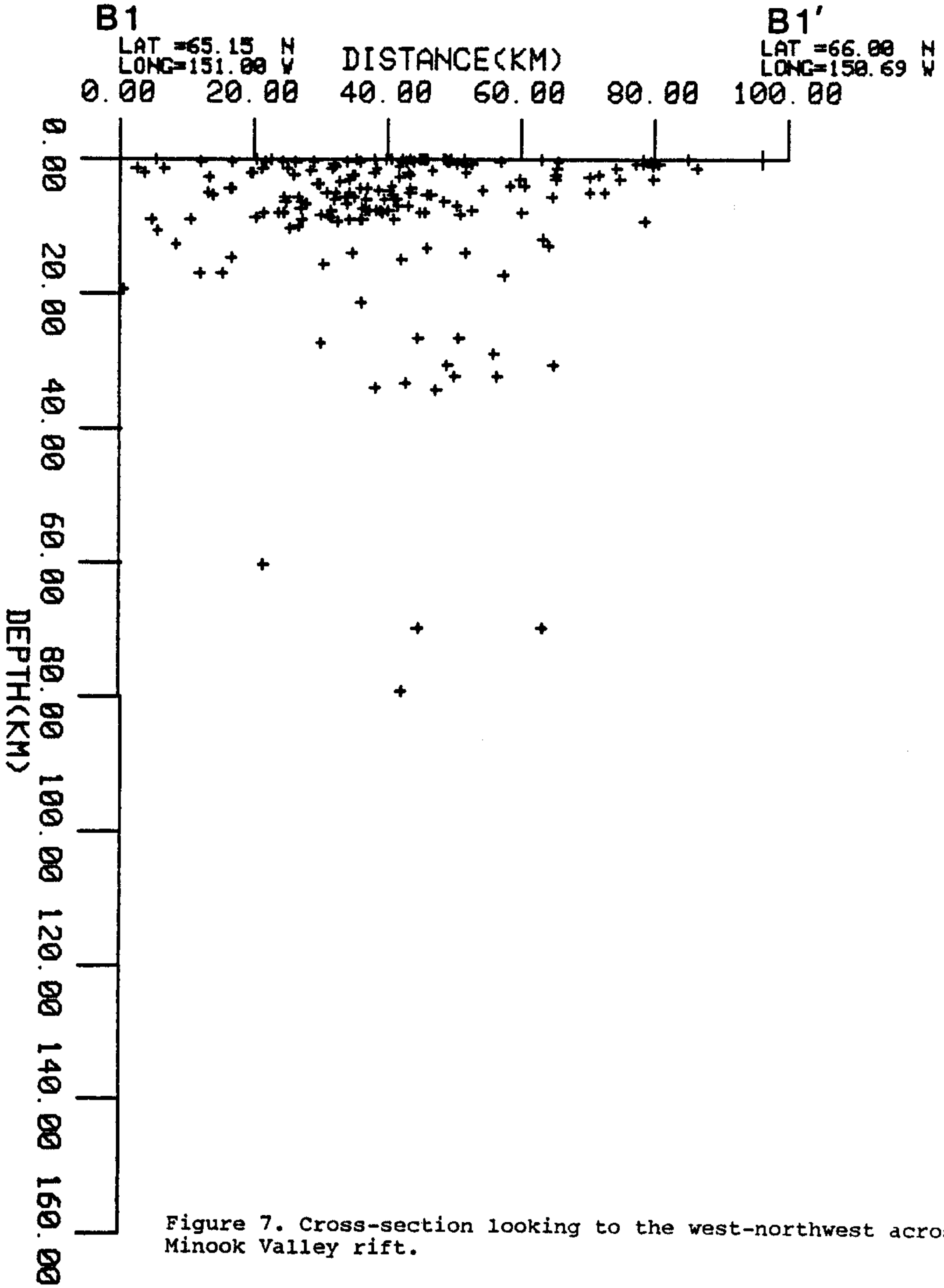

Figure 7. Cross-section looking to the west-northwest across the Minook Valley rift.

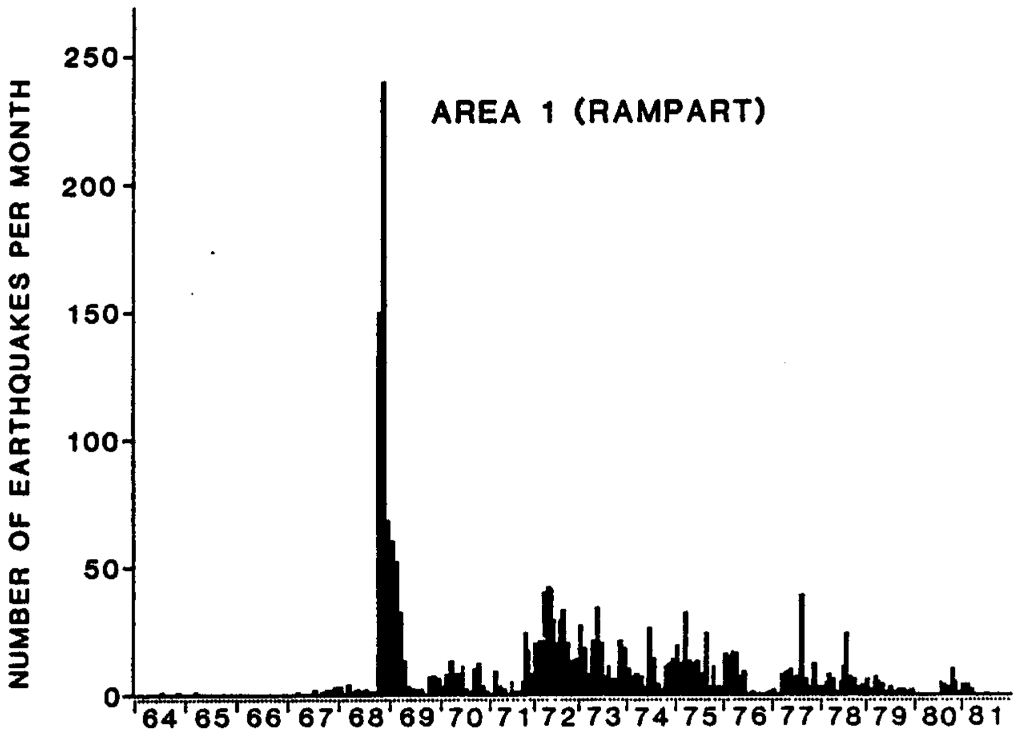

Figure 8. Number of earthquakes by month recorded in the Rampart seismic zone. The peak during 1968 and 1969 was the result of a major earthquake in October, 1968. Little data were recorded in the area prior to 1967. There were also breaks in data collection between July 1976 and March 1977, and also between January and June of 1980.

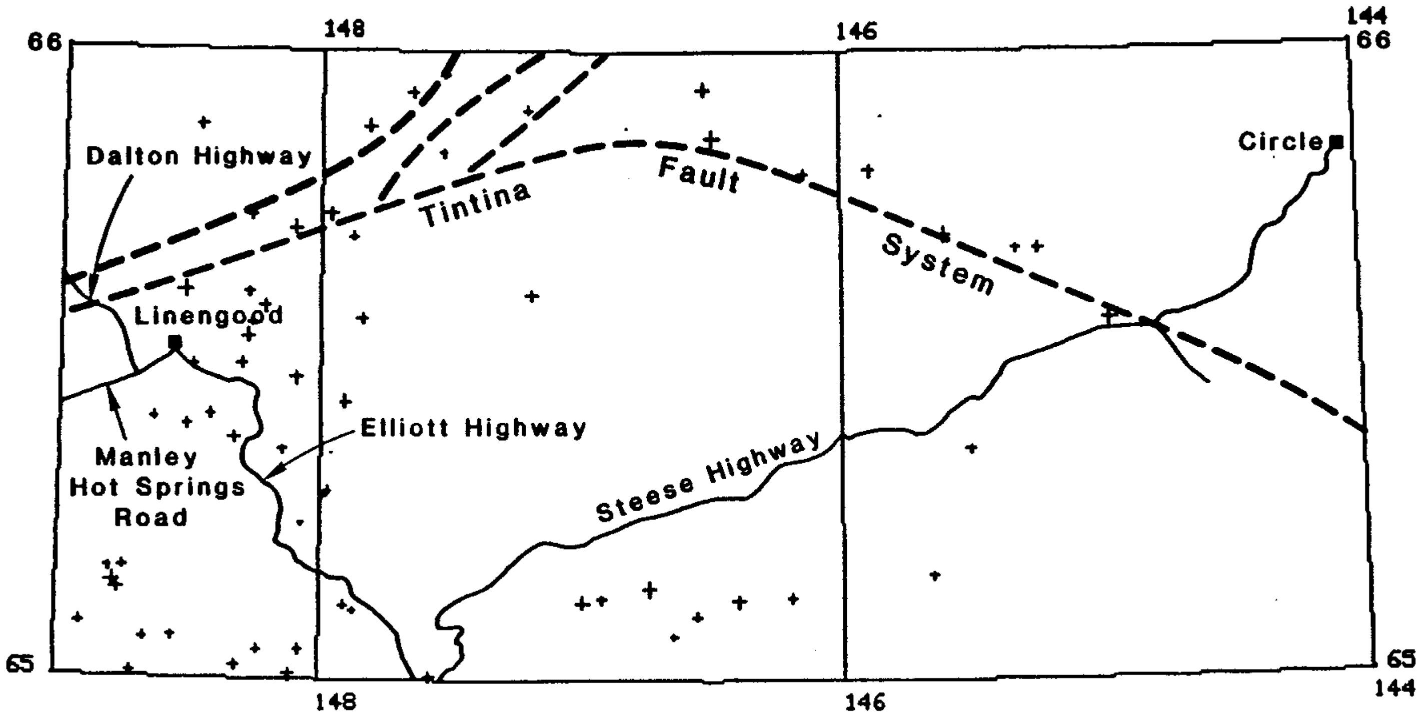

Figure 9. Epicentral plot of earthquakes in the Circle seismic zone since 1967. Well-located earthquakes in this area are rare. Although some seem to be related to the Tintina fault system, earthquake hazards can be considered as being minimal.

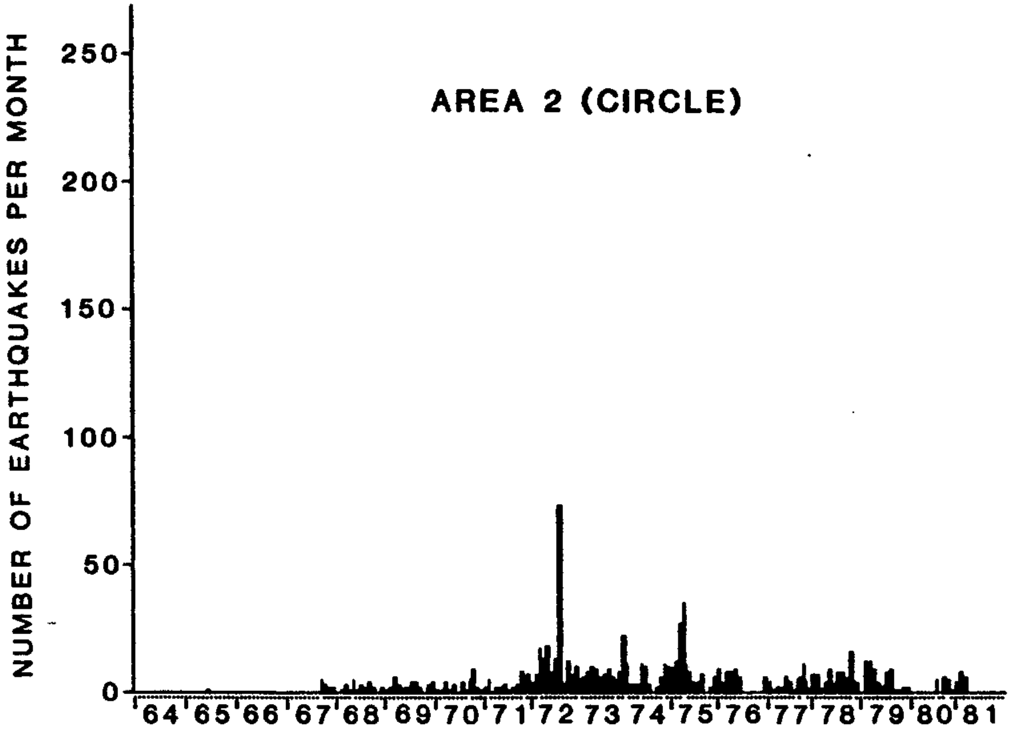

Figure 10. Number of recorded earthquakes between 1967 and 1981 in the Circle area. Data between July 1976 and November 1977 are unavailable, as are data between January and June of 1980.

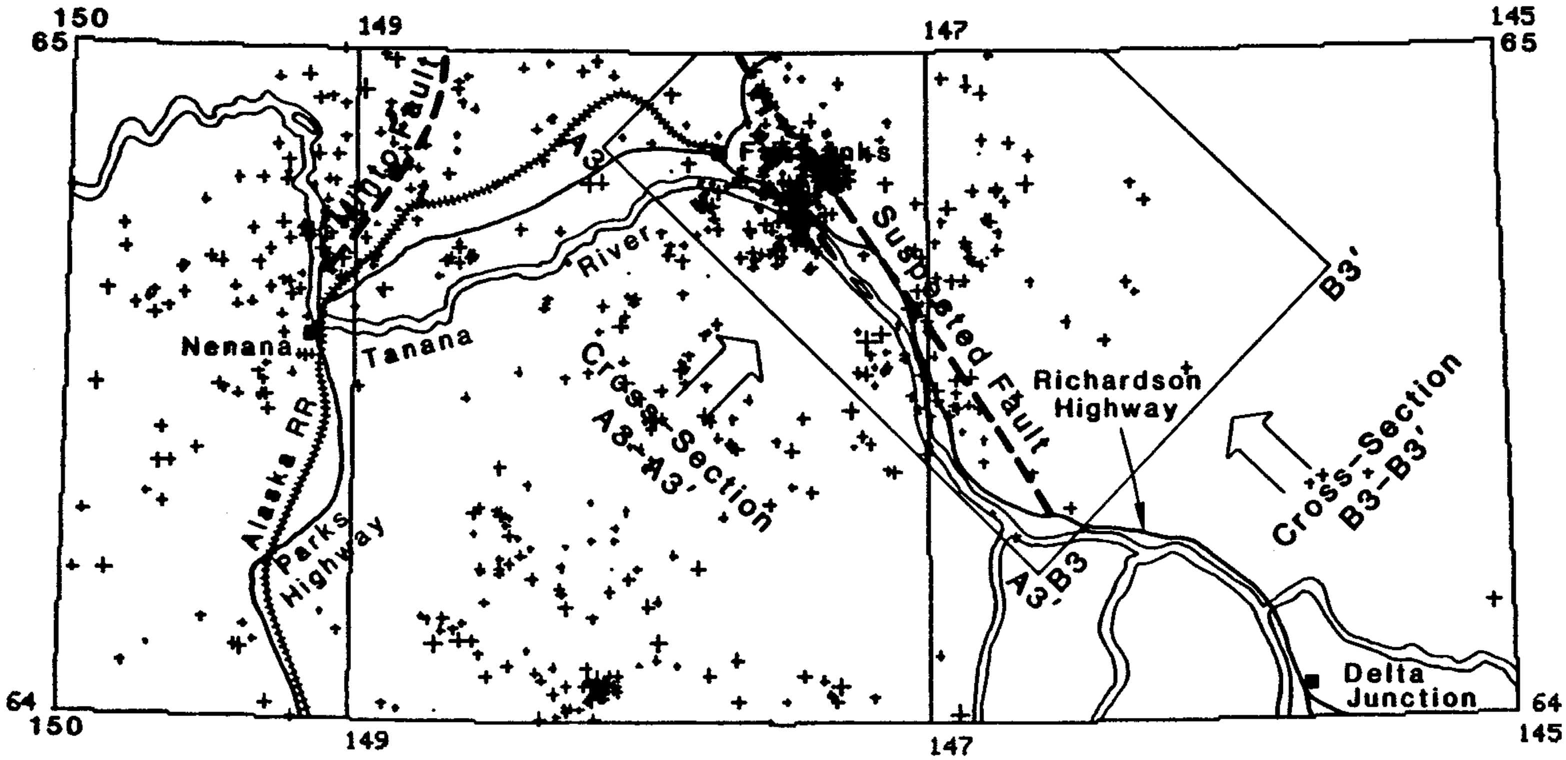

Figure 11. Epicentral plot of earthquakes in the Fairbanks seismic zone since 1967. Concentration of earthquakes southeast of Fairbanks is believed to be the product of a right-lateral fault extending from near Harding Lake to north of Fairbanks near Fox. The Minto Flats northwest of Nenana also produce frequent earthquakes, as does the Gold King Creek area on the north flank of the Alaska Range.

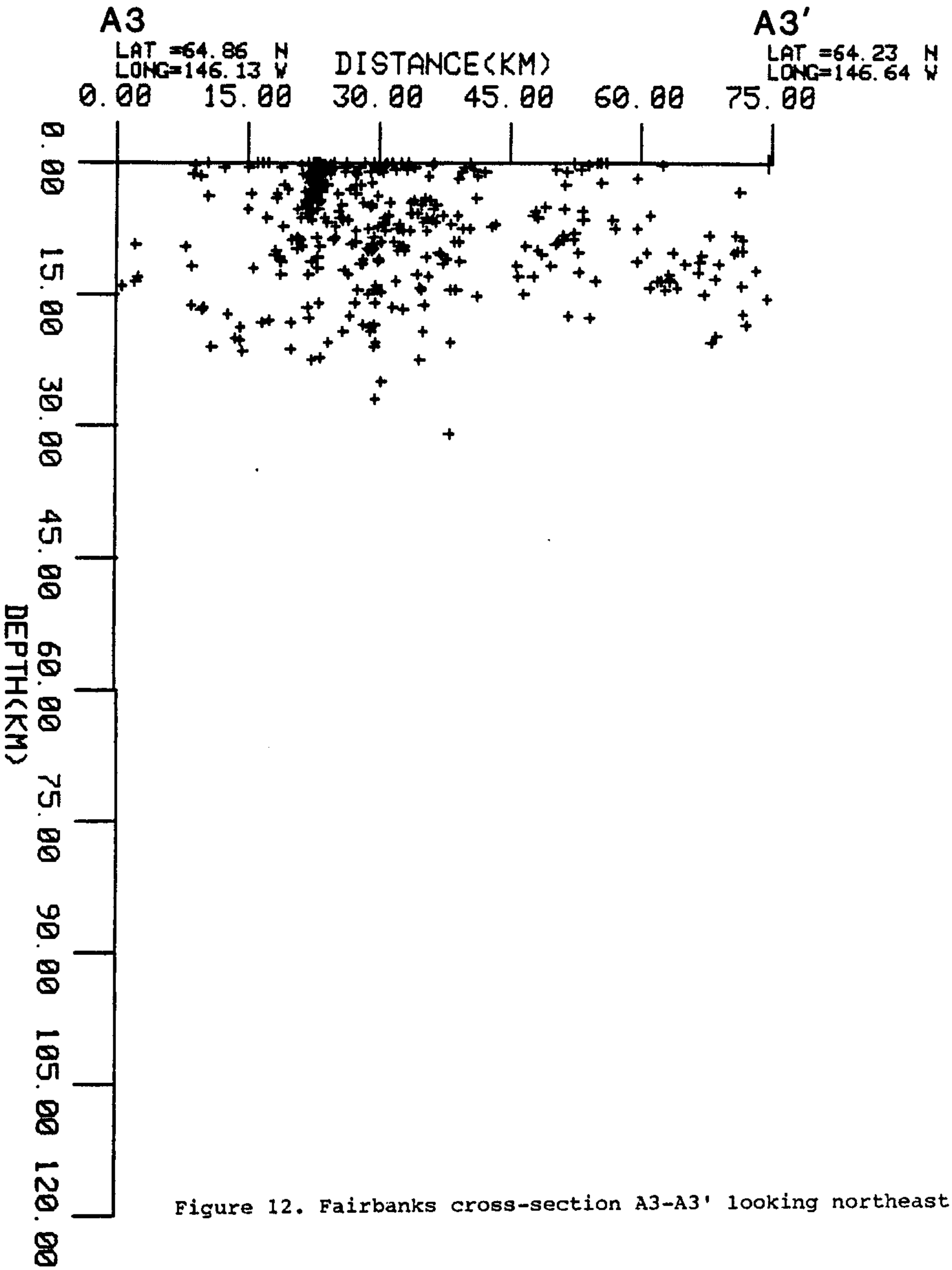

Figure 12. Fairbanks cross-section A3-A3' looking northeast.

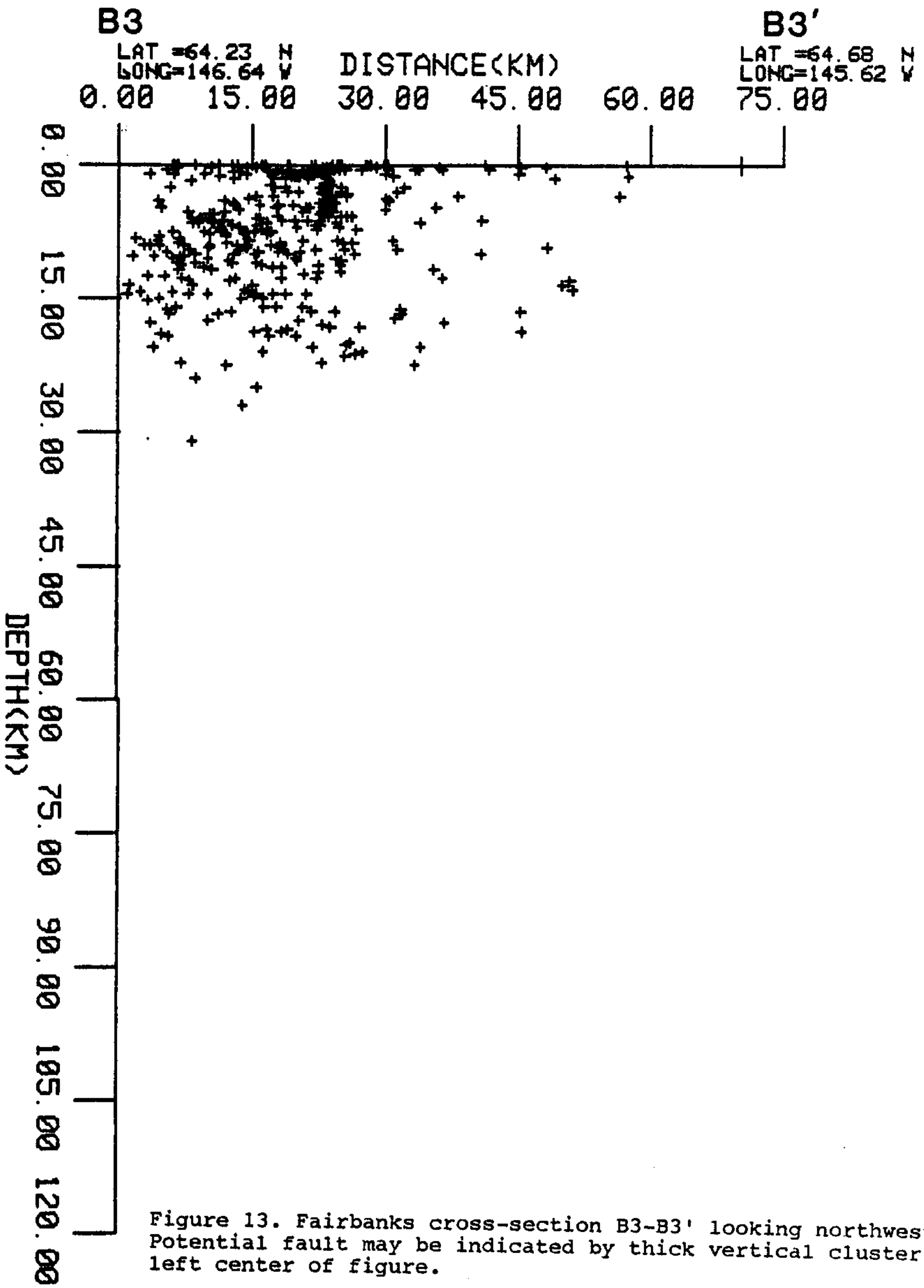

Figure 13. Fairbanks cross-section B3-B3' looking northwest. Potential fault may be indicated by thick vertical cluster near left center of figure.

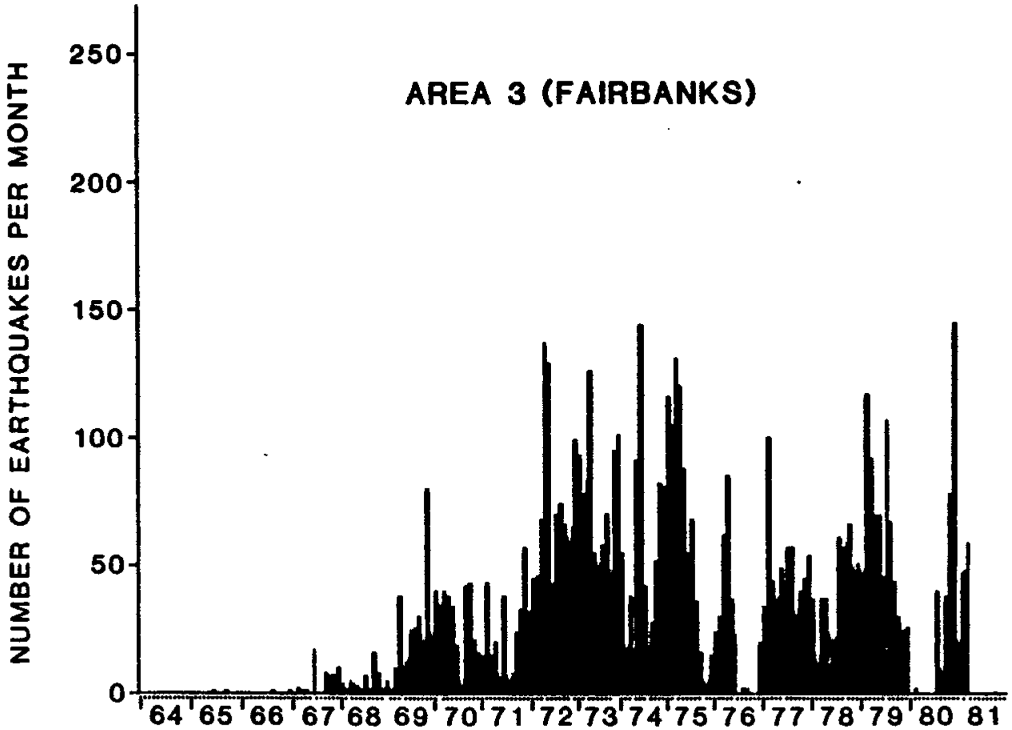

Figure 14. Number of earthquakes by month recorded in the Fairbanks seismic zone. Although 1967 marked the time that the Fairbanks area had its most intense seismic activity for 30 years, the relatively few earthquakes on this graph shown for that period are indicative of the meager instrumental network at the time. The rising peaks in the following years are graphic evidence of the upgrading of the system. No data are provided for the periods between July and December 1976 and January and July of 1980.

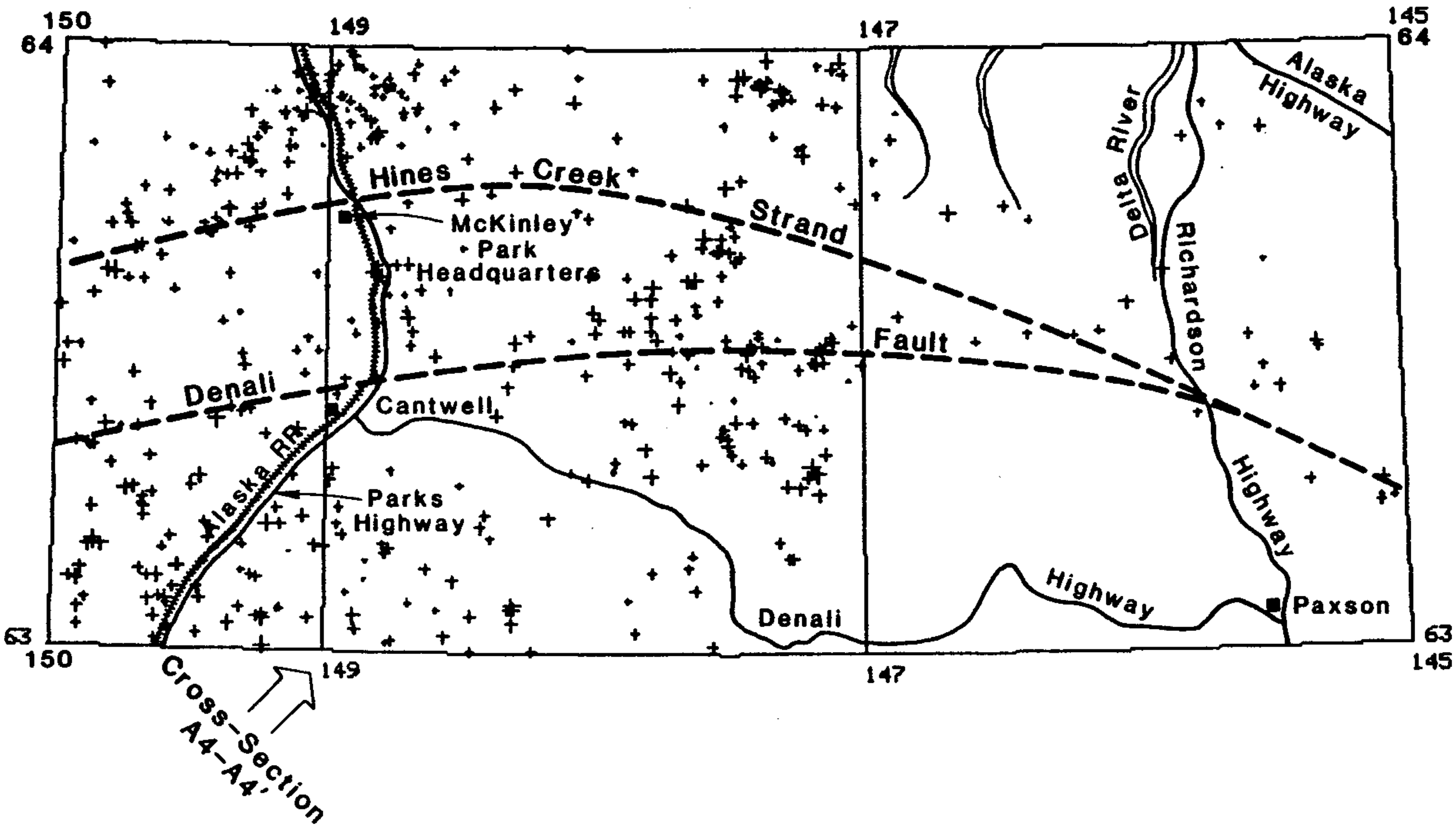

Figure 15. Epicentral plot of earthquakes in the Cantwell seismic zone since 1967. Epicenters do not seem to be especially related to well-known mapped faults. The most active area is north of the Hines Creek strand of the Denali. This most likely indicates the northernmost terminus of the subducted Pacific slab.

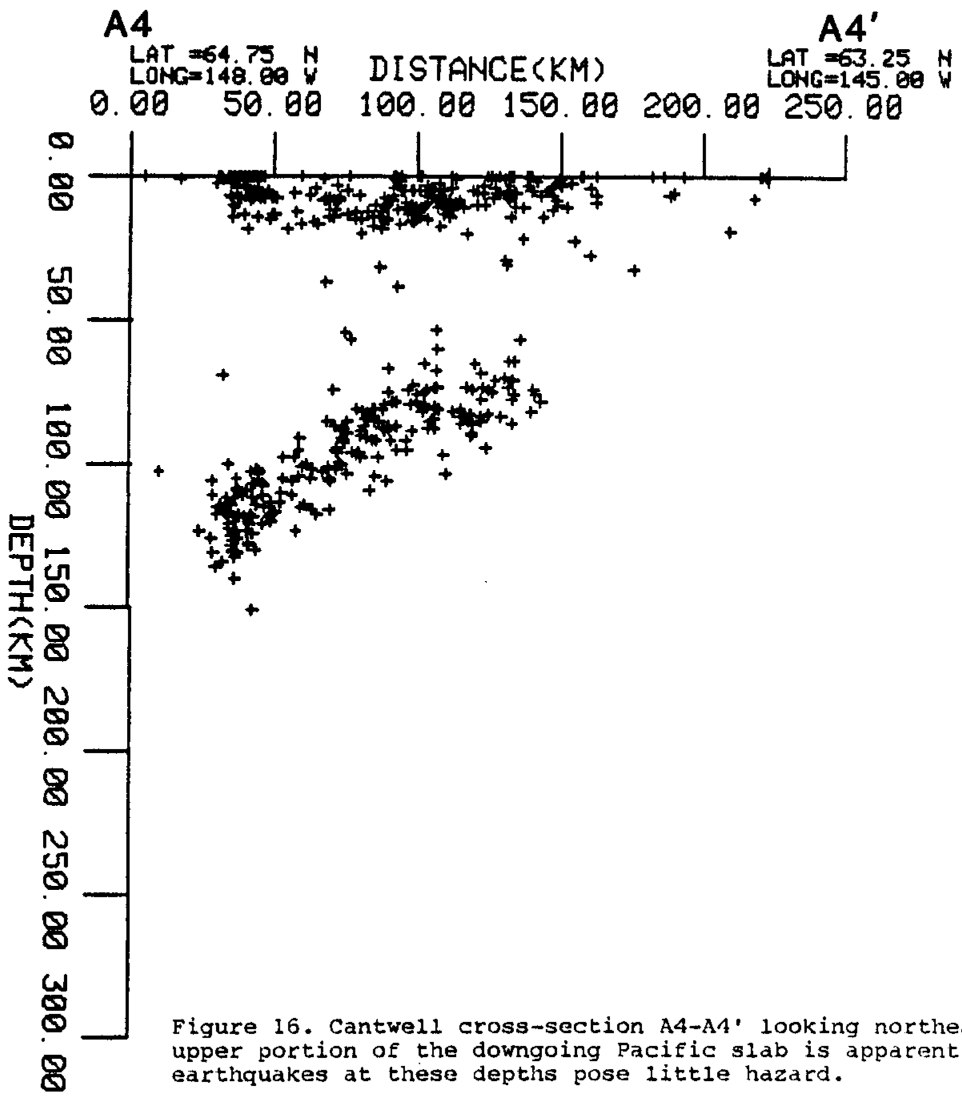

Figure 16. Cantwell cross-section A4-A4' looking northeast. The upper portion of the downgoing Pacific slab is apparent, but earthquakes at these depths pose little hazard.

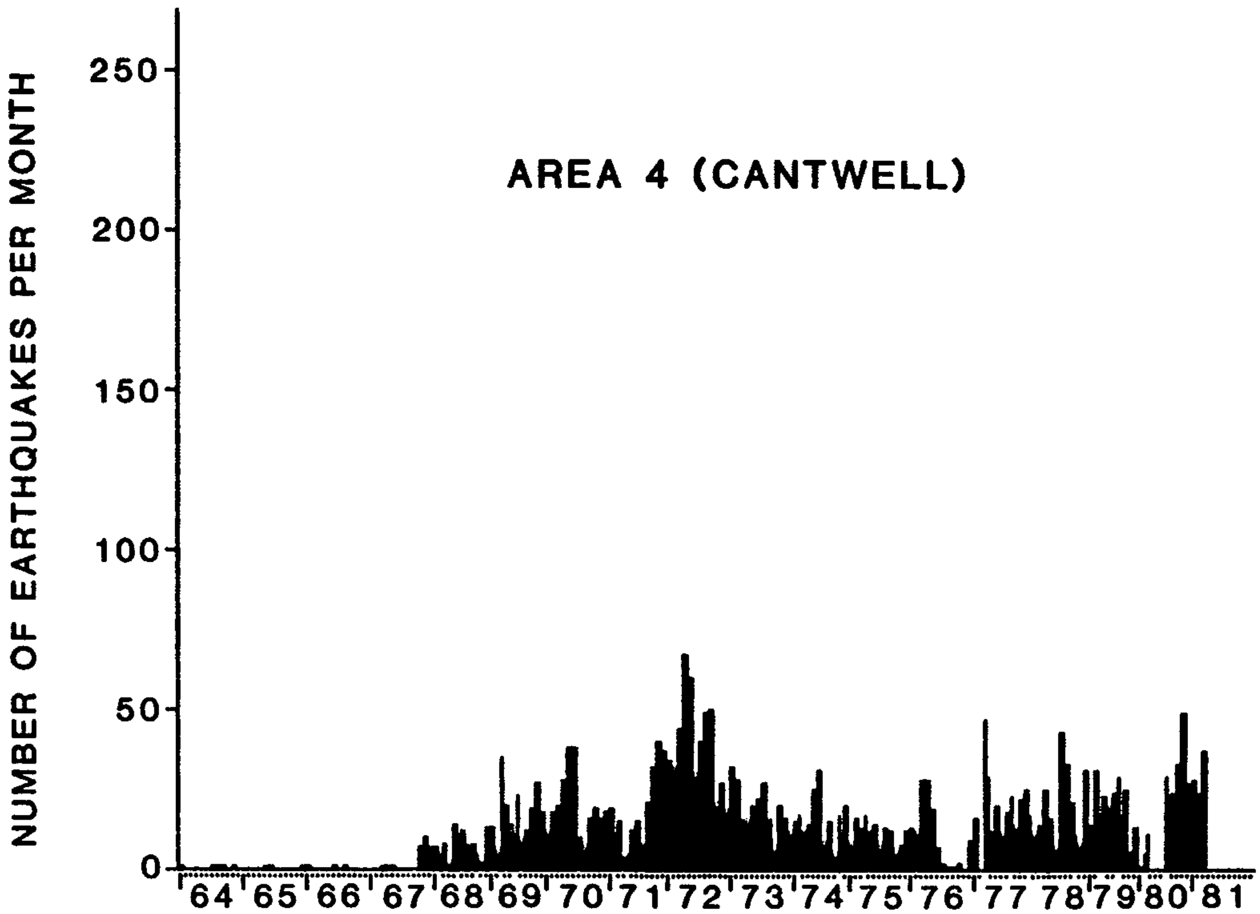

Figure 17. Number of recorded earthquakes in the Cantwell seismic zone since 1967. Data between July and October 1976 and January and July 1980 are unavailable.

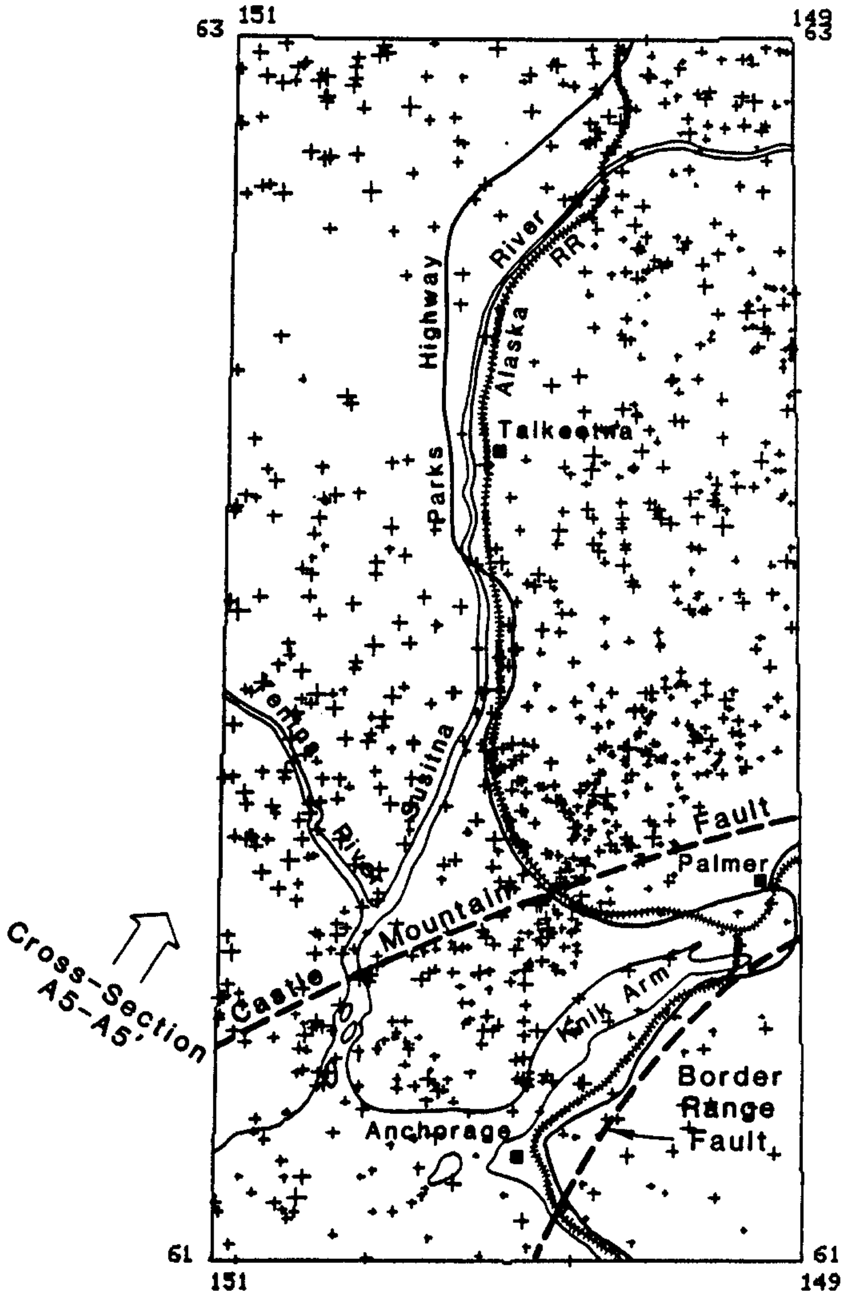

Figure 18. Epicentral plot of earthquakes in the Talkeetna seismic zone. Flanking the western escarpment of the Talkeetna Mountains, overlying an active subduction zone, and lying near the end of the rift generated by the 1964 earthquake, the Talkeetna area is probably the most prone among the study areas to a major earthquake in the foreseeable future.

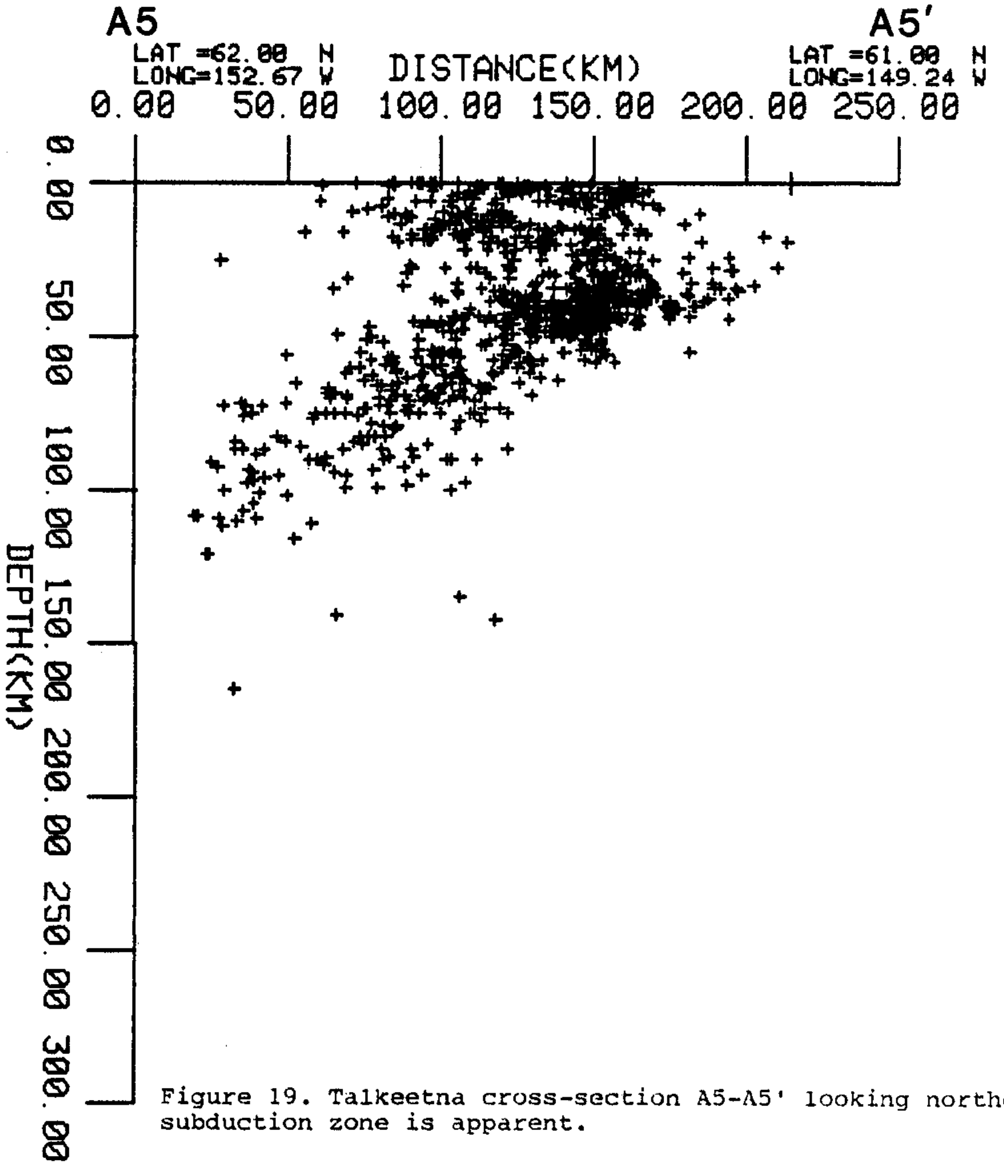

Figure 19. Talkeetna cross-section A5-A5' looking northeast. The subduction zone is apparent.

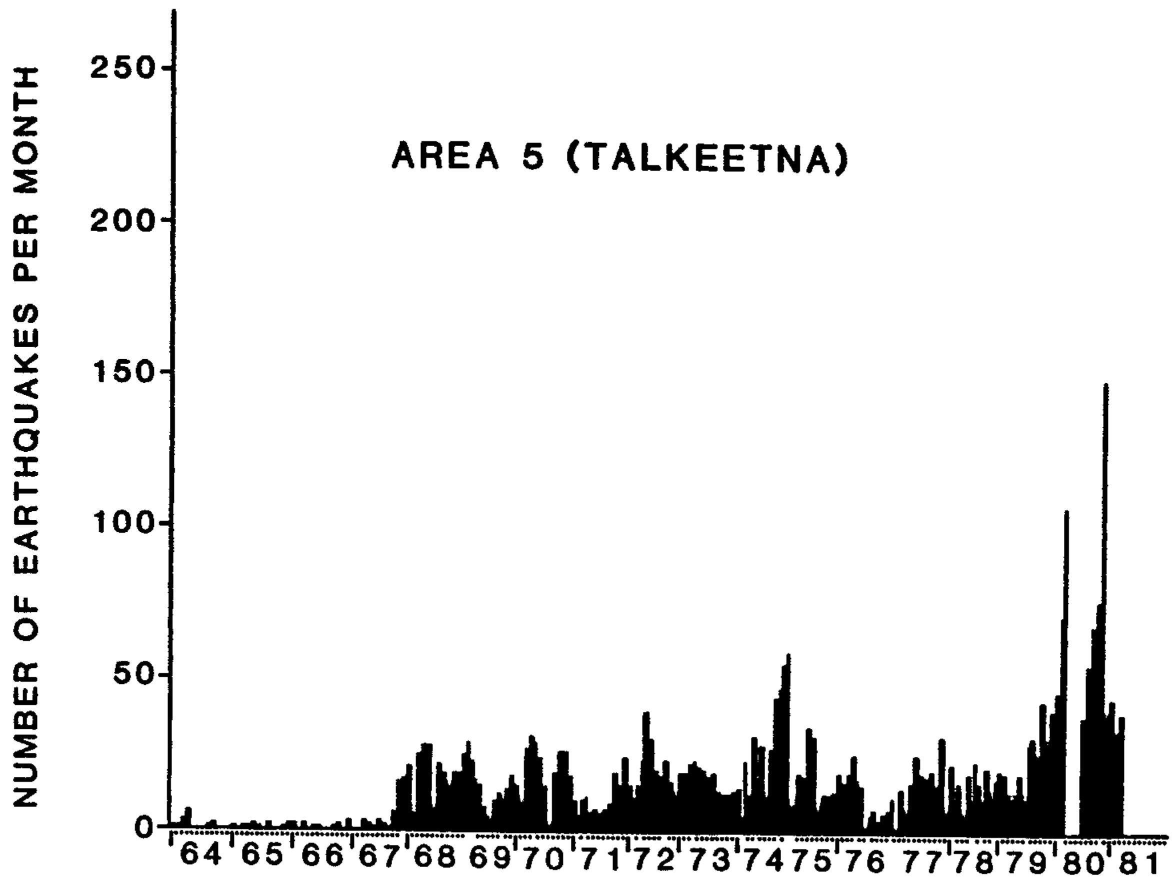

Figure 20. Number of recorded earthquakes in the Talkeetna seismic zone since 1967. Data from April to July 1980 are unavailable.

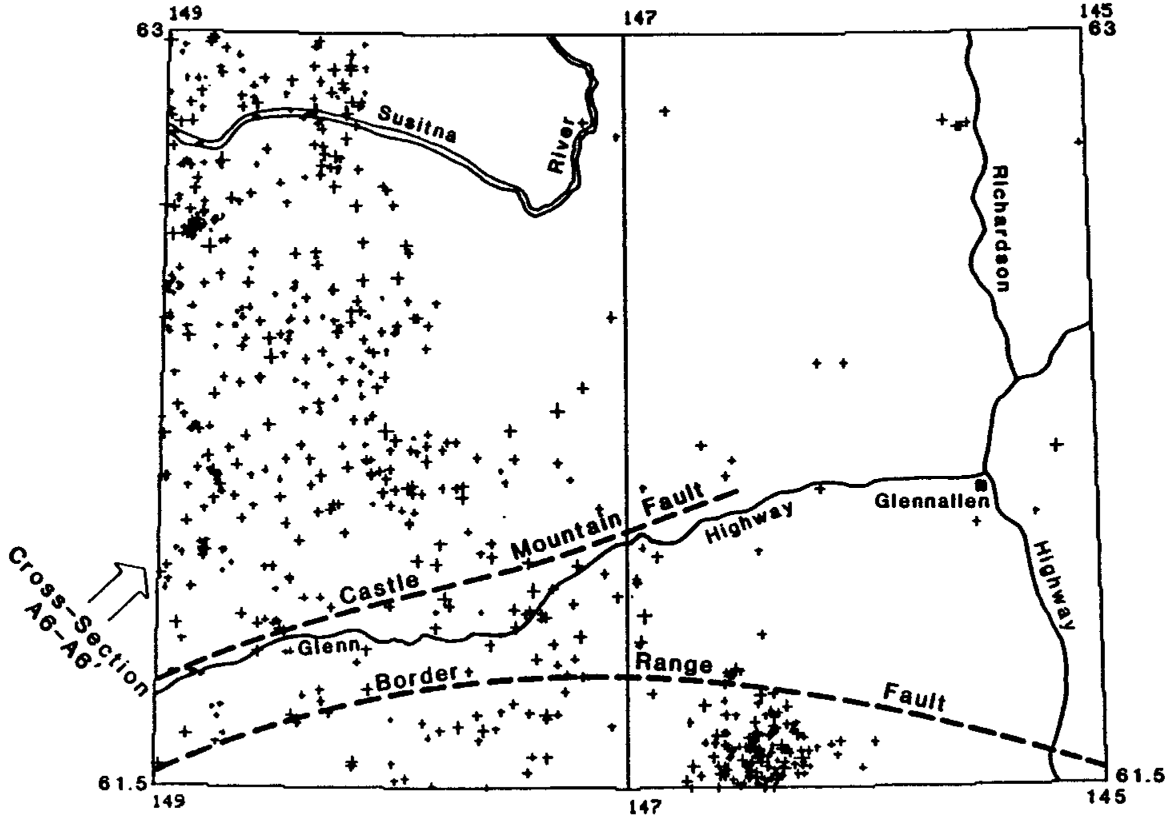

Figure 21. Epicentral plot of earthquakes in the Glennallen seismic zone. The Talkeetna Mountains to the west and the Tazlina Glacier area on the northern flanks of the Chugach Range are conspicuously active compared with the lowlands around Lake Louise to the northeast.

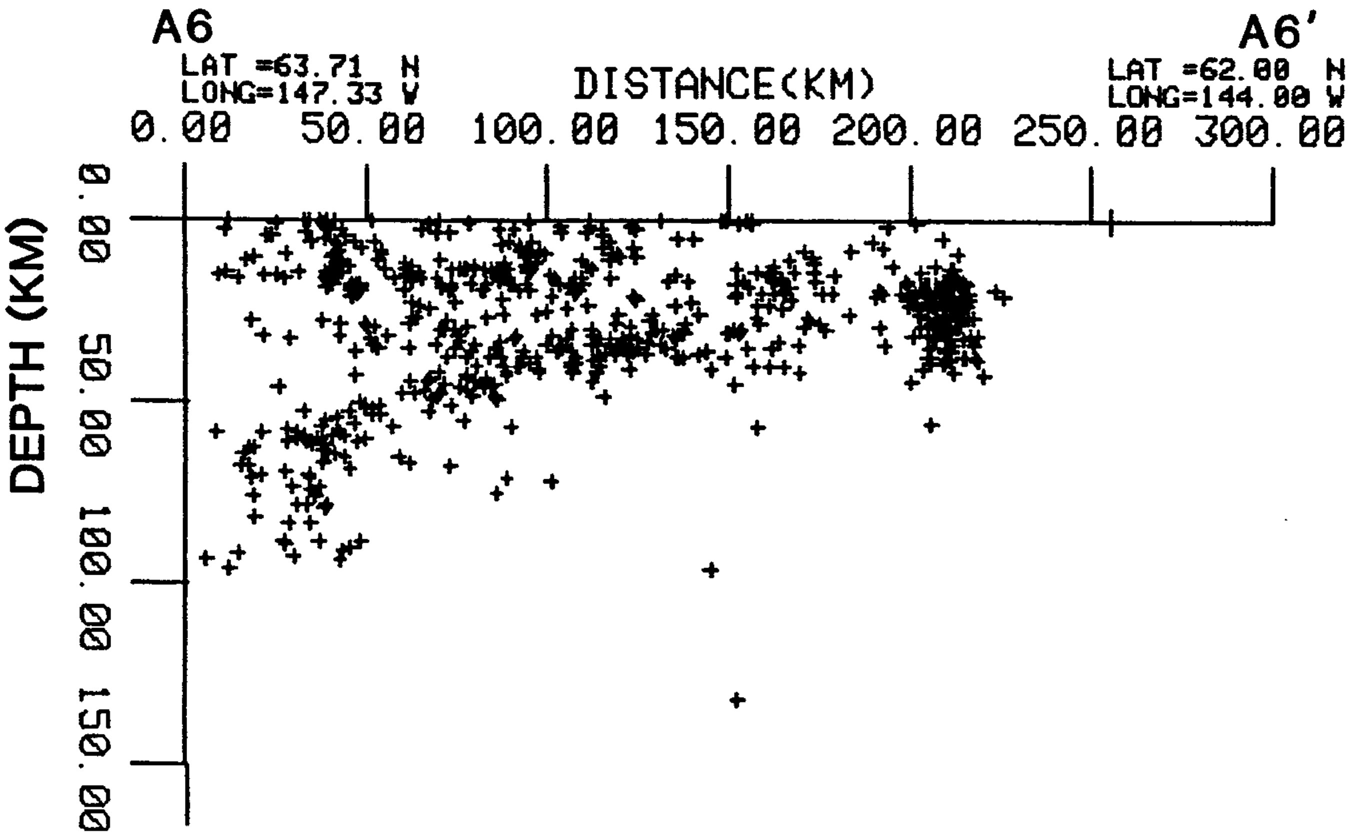

Figure 22. Glennallen cross-section A6-A6' looking northeast. Again we notice the Pacific slab down-dipping to the northwest and the conspicuous cluster beneath the Tazlina Glacier.

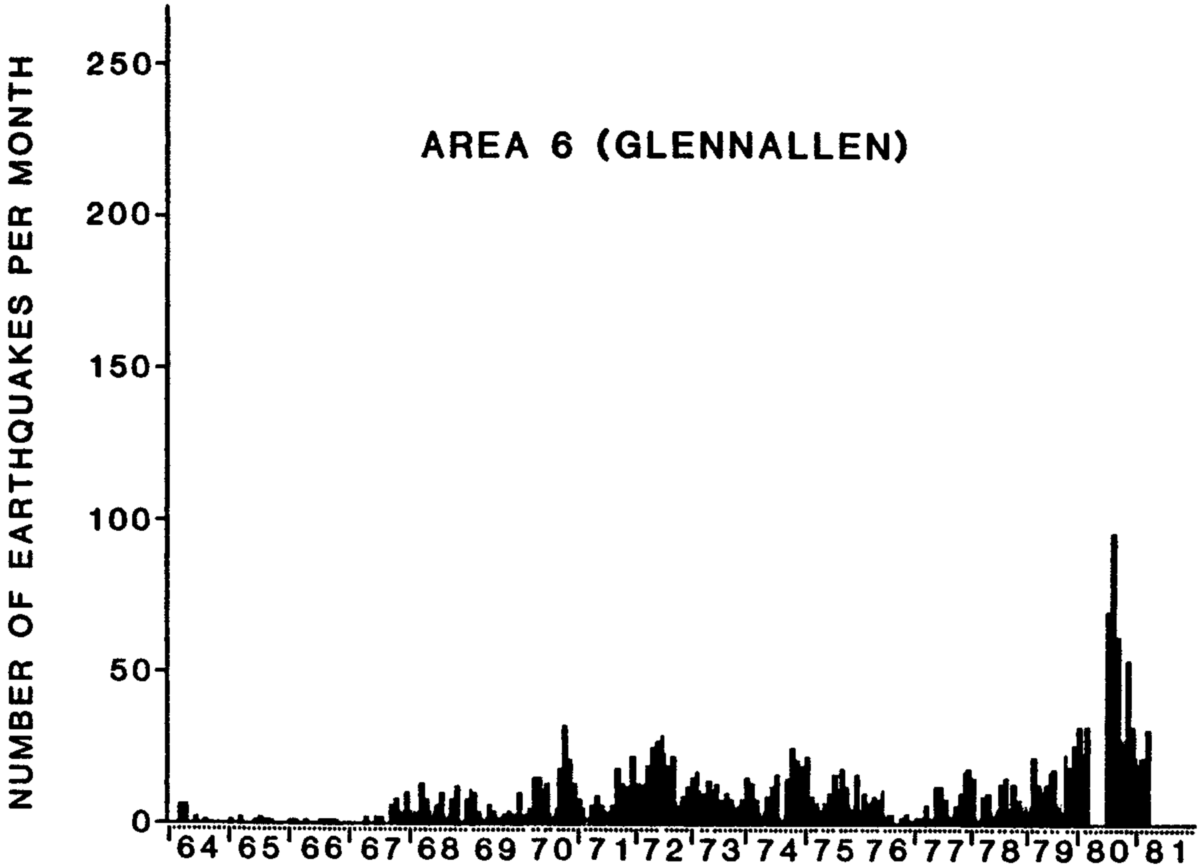

Figure 23. Number of recorded earthquakes in the Glennallen seismic zone since 1967. Data from April to July 1980 are unavailable, although there was a surge of activity during the last part of 1980.

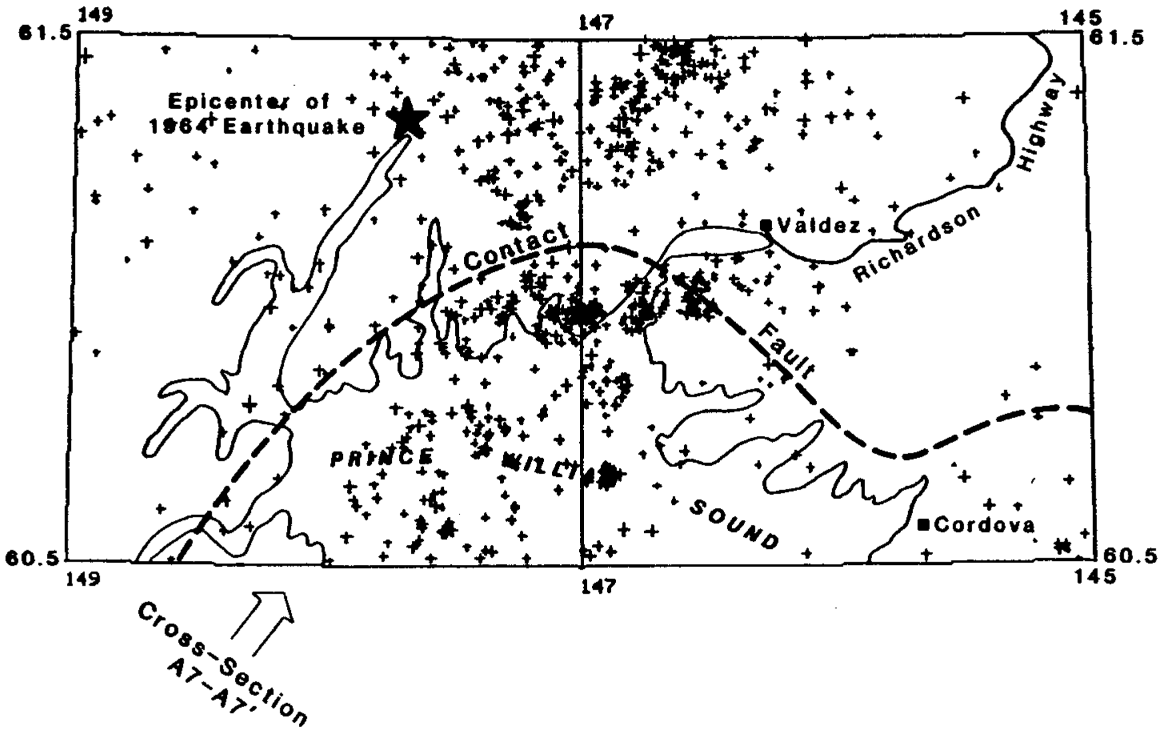

Figure 24. Epicentral plot of earthquakes in the Valdez seismic zone. Although always potentially hazardous, the aftershock zone from the 1964 earthquake has become diffuse and largely indistinguishable.

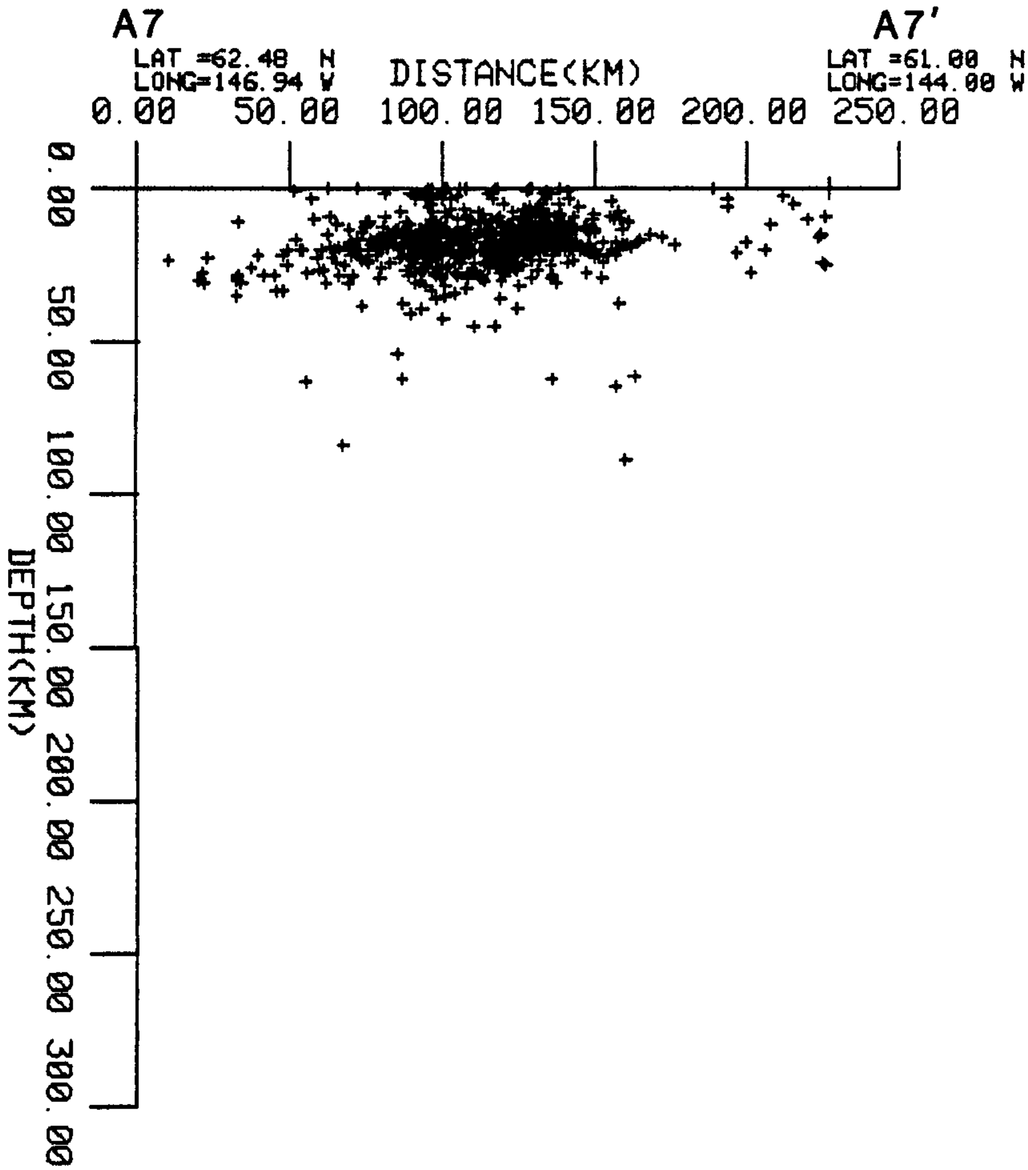

Figure 25. Valdez cross-section A7-A7' looking northeast. There is little to be gained from this cross-section, except that it can be noted that the upper margin of the downgoing Pacific slab can be observed to begin gently dipping down to the west. Offset along this interface was the mechanism producing the 1964 earthquake.

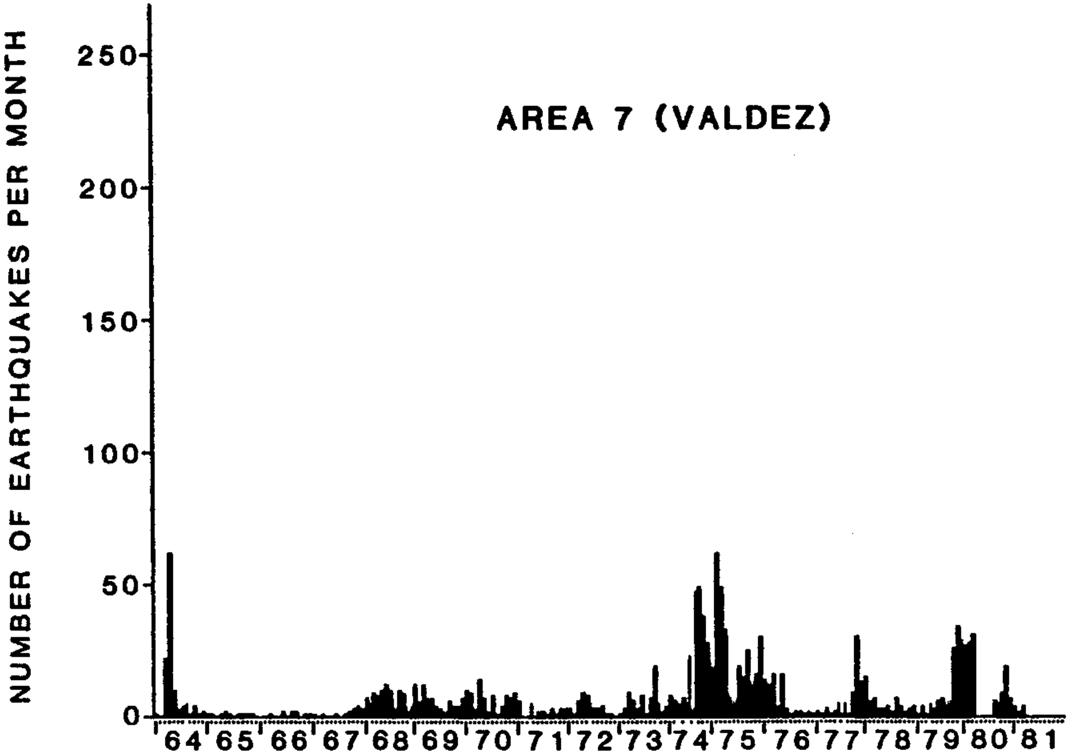

Figure 26. Number of recorded earthquakes in the Valdez seismic zone. Of all the areas which we have investigated in the progress of this report, this and the Kenai area are the only ones for which we have substantial data prior to 1967. This, of course, is because of the 1964 earthquake and it's aftershocks. There are no data available between April and August of 1980.

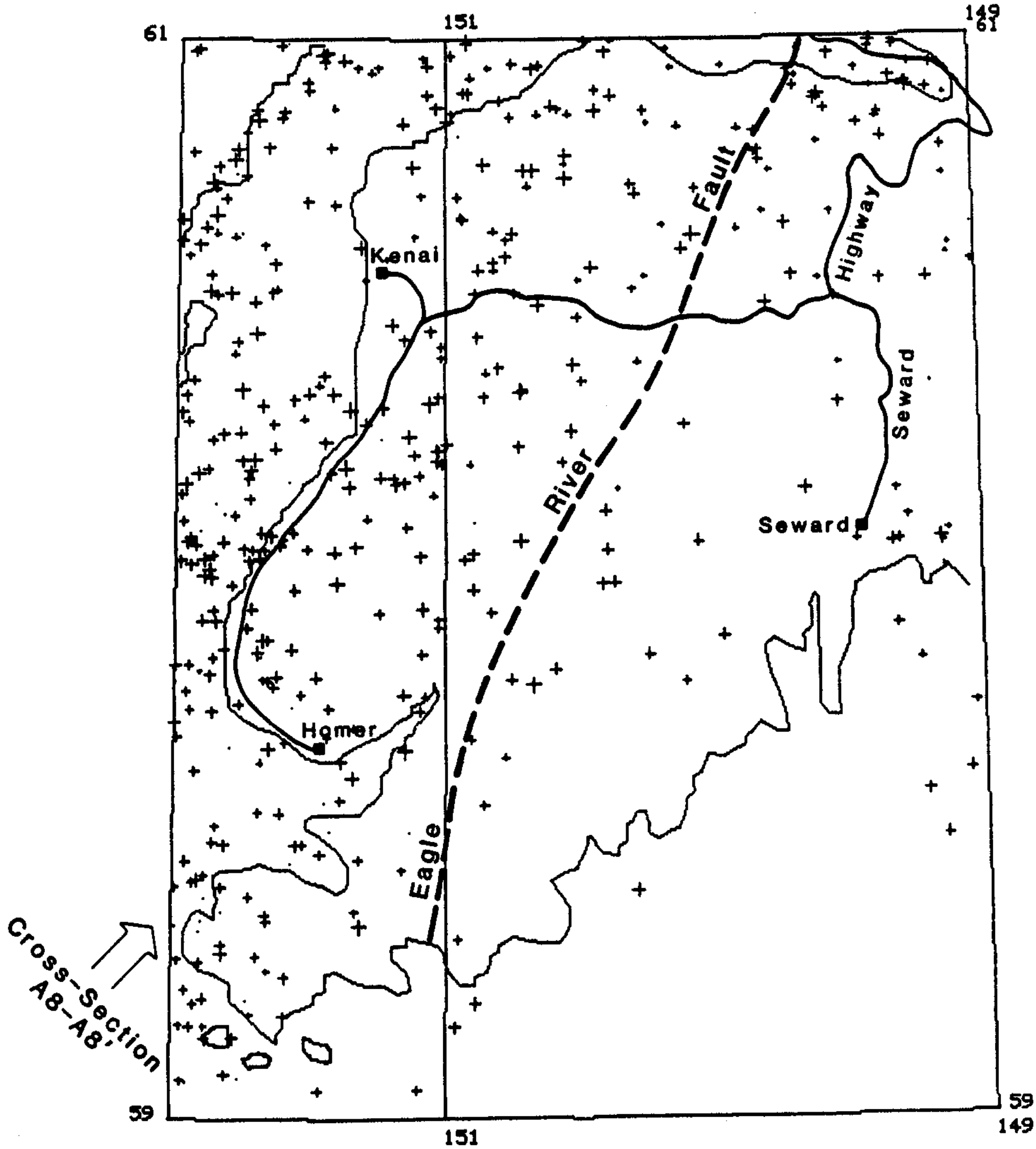

Figure 27. Epicentral plot of earthquakes in the Kenai seismic zone. The Kenai Peninsula displays no obvious connection between surficial tectonic elements and epicentral locations. Almost all the earthquakes occurring within this region are related to the downgoing slab.

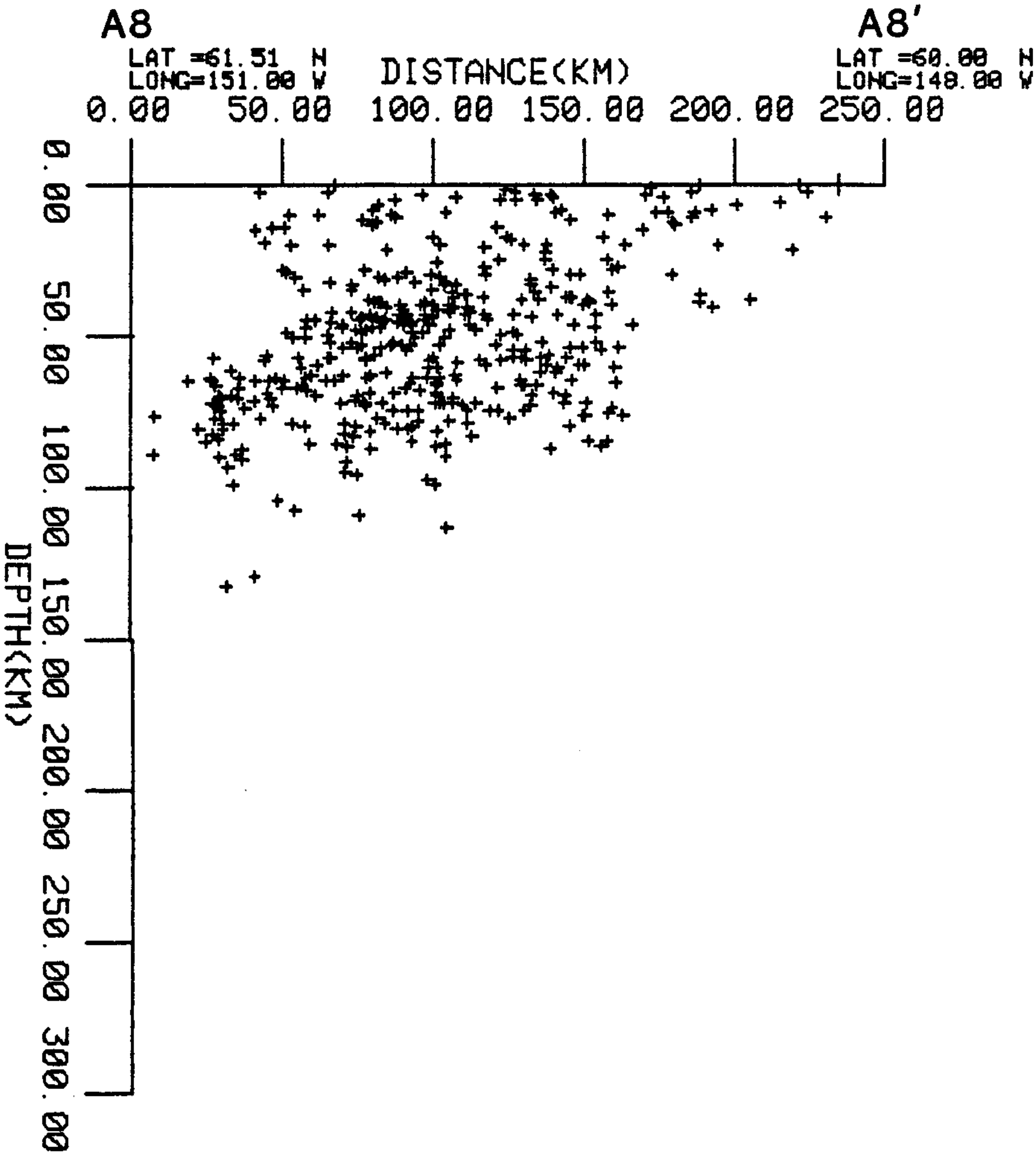

Figure 28. Kenai cross-section A8-A8' looking northeast. The diffuse arrangement of hypocenters gives only scant hint of the well-defined Benioff subduction zone that extends to the west under Cook Inlet.

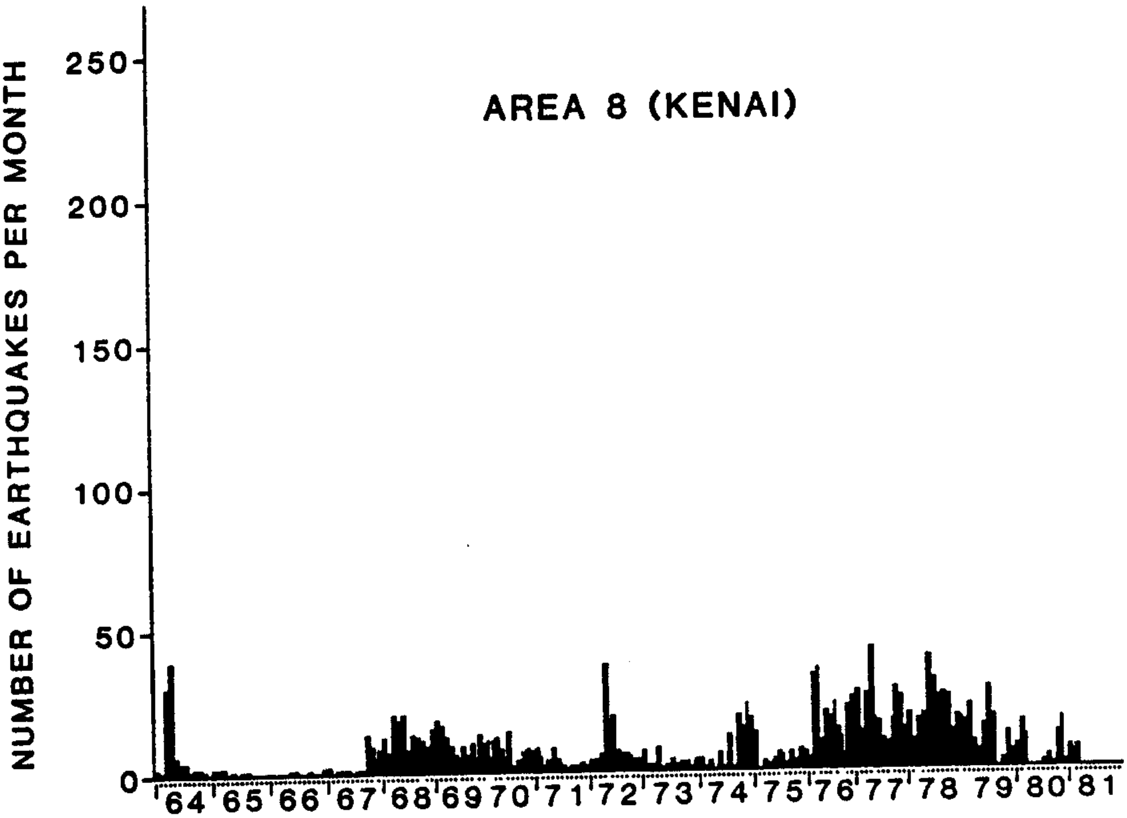

Figure 29. Number of recorded earthquakes in the Kenai seismic zone. As with the Valdez area, the Kenai seismic zone shows a sharp peak in activity during 1964. No data are available for the period between April and July of 1980.

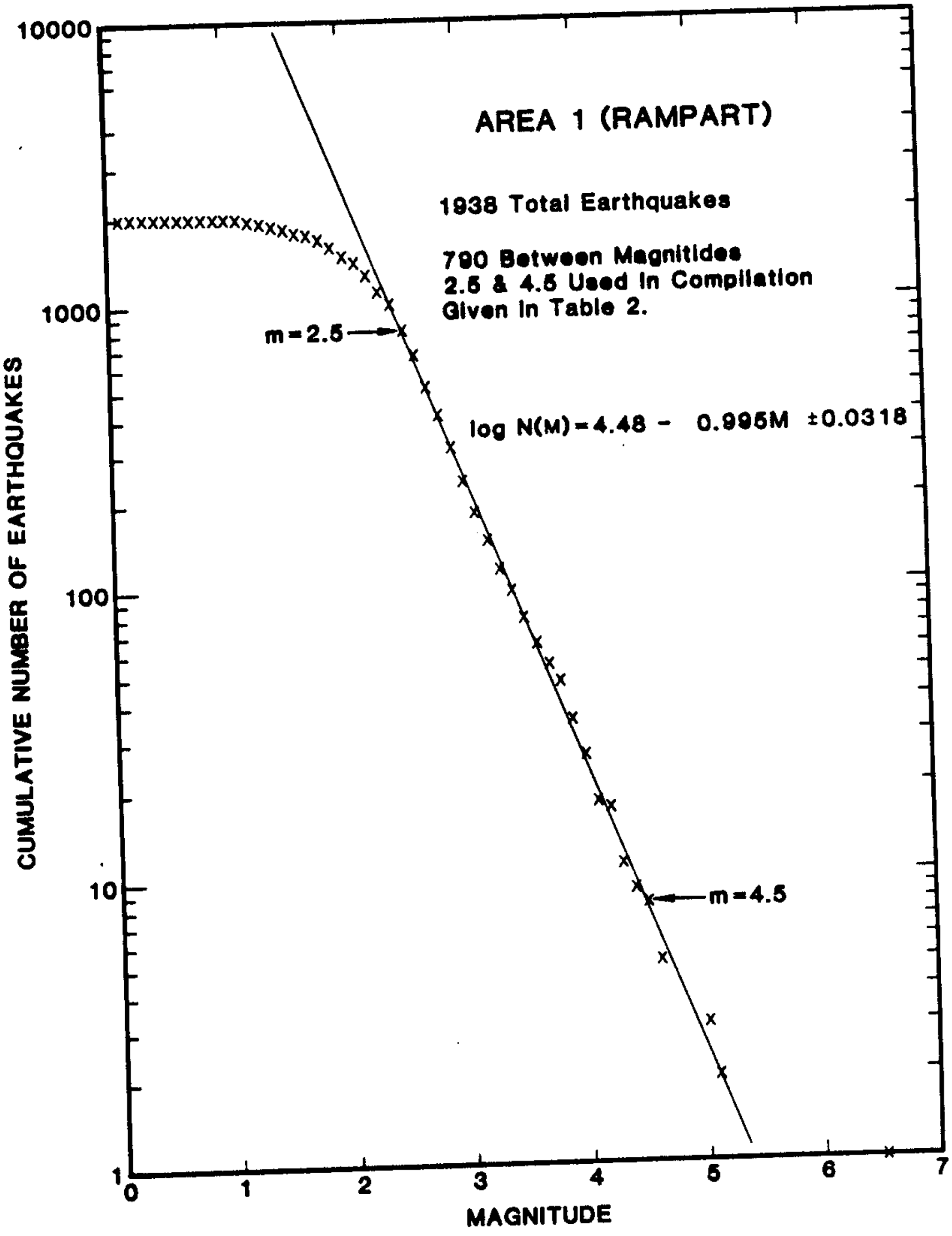

Figure 30. Sample b-slope plot showing recurrence parameters in area 1 (Rampart) during study period. Linear magnitude interval between 2.5 and 4.5 was chosen for this and all other areas used in study.