Revised Seismicity and Revised Fault Plane Solutions for the Queen Charlotte Islands Region

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Abstract

Epicentre locations in the Canadian Earthquake Data File for the Queen Charlotte Islands region from 1900 to 1980 have been reviewed and a number of changes made which are documented here. The revised seismicity pattern shows a strong correlation with the Queen Charlotte fault scarp with little, if any, seismicity on other major fault systems of the Queen Charlotte Islands. The distribution of large earthquakes along the Queen Charlotte fault suggests that two major seismic gaps may be present. There have been no earthquakes confirmed to be in Hecate Strait or Queen Charlotte Sound. Fault plane solutions for the region have been recalculated with additional data and show a combination of thrusting and strike-slip faulting in the south, changing to a predominantly strike-slip environment in the north.

Résumé

On a examiné certains renseignements du fichier de données sur les tremblements de terre au Canada, soit l'emplacement des épicentres dans la région des îles Reine-Charlotte pour la période allant de 1900 à 1980, et on a effectué quelques changements dont fait état le présent document. La révision des caractéristiques de la séismicité dans la région montre une solide corrélation entre les mouvements séismiques et l'escarpement de faille Reine-Charlotte et la faible amplitude des phénomènes séismiques, si toutefois il s'y en déroule, dans les zones des autres principaux systèmes de failles des îles Reine-Charlotte. La répartition des tremblements de terre qui ont secoué de vastes régions le long de la faille Reine-Charlotte laisse croire à la présence de deux discontinuités séismiques importantes. On ne possède aucune preuve que des tremblements de terre se sont produits dans le détroit d'Hécate ou dans le bassin Reine-Charlotte. En tenant compte de données supplémentaires, on a établi de nouveau la direction des plans de failles dans la région et on a constaté l'existence de charriages et de décrochements ponctuels le long des lignes de failles au sud et de glissement de zones entières au nord.

A. INTRODUCTION

The tectonic setting of the Queen Charlotte Islands and southeast Alaska (Figure 1) is dominated by the proximity of the active boundary between the Pacific Plate and the America Plate, generally referred to as the Queen Charlotte Fault in this region (e.g. Wilson, 1965). South of the Queen Charlotte Islands, off Queen Charlotte Sound, there is a complex triple junction region (eg. Riddihough et al., 1980; Davis and Riddihough, 1982) between the Pacific/America boundary and the subduction regime of Vancouver Island (eg. Riddihough and Hyndman, 1976; Riddihough, 1977). Recent examinations of the seismicity of the Queen Charlotte Islands region (Milne et al., 1978; Hyndman and Weichert, 1982) have accepted at face value the epicentres compiled into the Canadian Earthquake Data File and previously published fault plane solutions. This study investigates the completeness and accuracy of epicentres and fault plane solutions in the region, introduces revisions, and draws some new conclusions.

There are two major seismotectonic problems to be addressed in the Queen Charlotte Islands region. The first is the exact location of the seismicity. A plot of epicentres from the Canadian Earthquake Data File shows most of them concentrated around the postulated trace of the Queen Charlotte fault, but some events are significant distances from the main grouping (eg. Figure 2, taken from Milne et al., 1978). Thus, is all the seismicity along the fault or are earthquakes occurring elsewhere in the region? More specifically, could one of the main inland faults such as the Rennell Sound fault, the Louscoone Inlet fault or the Sandspit fault (Figure 3) be active or are there any active faults under Hecate Strait or Queen Charlotte Sound?

The second major questions to be addressed is that of the earthquake mechanisms. Global tectonic models of the region (Minster et al, 1974; Minster et al, 1978; Chase, 1978) suggest that in the region of the Queen Charlotte Islands, the Pacific plate and the American plate interact at an angle that is oblique to the strike of the Queen Charlotte fault (Figure 3). This angle is very small at the north end of the fault in southeast Alaska, but becomes more pronounced in the Queen Charlotte Islands region and is most oblique in the southern Queen Charlotte Islands, south of 53^o N, where the shelf break strikes significantly more to the east. These plate interaction models suggest there is convergence in the Queen Charlotte Islands region which must be accommodated in some way. It may be that the Queen Charlotte Islands are overriding the Pacific Plate. Seismic reflection profiles (Srivastava, 1978; Chase et al., 1975) suggest that some element of underthrusting may be present. Thus the second question to be asked is if any net convergence in this region can be detected in the earthquake focal mechanisms.

To investigate earthquake locations in the Canadian Earthquake Data File for the Queen Charlotte Islands region, epicentres were examined for the period from 1900 to 1980. A literature search was performed to seek all published epicentres other than those in standard catalogues. Two key papers (Tobin and Sykes, 1968; Kelleher and Savino, 1975) were found which relocated a number of earthquakes in the region by recomputing earlier epicentres using the raw data published by the International Seismological Summary (ISS). These epicentres were evaluated against the epicentres in the data file and substituted in many cases. In addition to these epicentres, all other events for which sufficient data existed in the ISS, USCGS bulletins or Canadian bulletins were recalculated. The results for all earthquakes of magnitude 5 and greater are shown in Figure 4 and all revisions are listed in Tables I and II. In addition to epicentres, all previously published fault plane solutions in the region were compiled and examined in detail. Their accuracy and relevance to the tectonic setting is discussed in the last section.

B. EARTHQUAKE LOCATIONS

(1) Larger Earthquakes

The continental shelf break is very sharp adjacent to the Queen Charlotte Islands and southeast Alaska and appears to mark the trace of the Queen Charlotte fault within a few kilometers. The revised epicentres for events larger than magnitude 5 show much more of a concentration along the Queen Charlotte fault than did the epicentres in the Canadian Earthquake Data File (compare Figures 2 and 4). Opposite the Queen Charlotte Islands a second lower scarp exists about 20 km seaward of the main scarp (eg. Hyndman and Ellis, 1981). Although it cannot be ruled out, there is no suggestion here that the lower scarp is seismically active. Because the shelf break is so sharp the epicentres of earthquakes in this region give a feeling for how accurate earthquake locations are. For instance, most of the large earthquakes that are located from a good distribution of world wide data have epicentres within a few kilometers of the shelf break (Figure 4). As events become smaller, the distribution of stations reporting becomes less evenly distributed in azimuth and east-west accuracy becomes a problem. In earlier years, often Saskatoon, Saskatchewan (SAS), 1600 km distant, was the only station providing east-west control unless the event was large enough to record at Ottawa (OTT) and stations along the east coast of United States. In more recent years, even though readings are very accurate, the large number of stations in North America at a narrow range of azimuths make the epicentres susceptible to errors in the earth model, again affecting east-west control. The drawing of the epicentres to the east of their true location is a common result. A good example of this is shown in Hyndman et al. (1978).

When trying to estimate the best epicentres for earthquakes that occurred before 1950, there are three main choices: the ISS epicentres, the epicentres published by Gutenberg and Richter (1949) and epicentres computed using P arrival times listed in the ISS. When the earthquake is large and has been recorded by stations well distributed in azimuth and distance then the three epicentres are all reasonably close together (i.e. within 100 km of each other). When fewer data are available epicentres can vary by hundreds of kilometers. For example consider the different epicentres for the May 26, 1929 event (M = 7) and the July 1, 1930 event (M = 5.7) shown in Figure 5.

In almost all cases the ISS solutions can be considered to be the poorest. They were calculated using arrival times mailed from various stations and the aim was to locate the earthquakes in the correct part of the globe rather than pursue the best epicentre. Often epicentres were assigned to one previously computed in the region rather than computing a new epicentre. Travel time curves and computational methods improved through time and thus the later ISS epicentres are more accurate. Even though Milne selected Gutenberg and Richter (1949) epicentres for most Queen Charlottes events in his report on historical west coast seismicity (Milne 1956), ISS epicentres are the ones that were most commonly compiled into the present Canadian Earthquake Data File. There appears to be no reason for this other than the availability of the ISS catalogues.

Gutenberg and Richter produced epicentres for most major earthquakes in the world in their volume Seismicity of the Earth, first published in 1949. They had the benefit of ISS epicentres, worked with original records from California stations and used readings from selected seismograph stations known to have reliable time control. They used both P and S information and had a good set of travel time curves to work with. Thus, their epicentres are usually more reliable than those published by the ISS. They quote their epicentres in most cases to the nearest 1/2 degree or 1/4 degree (i.e. about ± 50 km or ± 25 km).

To be weighed against the Gutenberg and Richter epicentres are epicentres that have been computed with modern computer programs using P arrivals listed in the ISS. All P arrival data can be used, but all data is not equally reliable and thus erroneous readings may severely prejudice the solution. Low gain seismographs often made identification of the first onset of P arrivals difficult and resulted in a lot of late picks. Slow paper speed (commonly 10 or 15 mm per minute) and difficulty in maintaining accurate time often made timing errors large.

For example, the two closest stations to the Queen Charlotte Islands region, Sitka and Victoria, which have considerable influence on most solutions, are typical. Sitka had a Bosh-Omori seismograph from 1904 to 1932 which had a static magnification of 10 and a paper speed of 15 mm per minute. In 1932 it was replaced by Wenner instruments with a static magnification of 1000. It was not until the 1960's that a modern high gain short period station with 60 mm per minute paper speed was established. In a 1920 bulletin the timing accuracy of Sitka was listed as ± 10 seconds and did not improve to the order of ± 1 second until some time in the 1930's. Victoria had good time control of ± 1 second almost from the beginning but the fastest paper speed on any instrument was 8 mm per minute until the first high gain short period station was established in July of 1948. The first seismograph at Victoria, a Milne installed in late 1898, had a static magnification of about 7. A Weichert (static magnification of 70) was added in 1917 and Milne-Shaw seismographs (static magnification of 300) were added in 1922.

Epicentres for many earthquakes in the region have been computed by Tobin and Sykes (1968) and Kelleher and Savino (1975). For this study all earthquakes prior to 1948 in the Queen Charlottes region were recomputed as well as any later event that had not been previously recomputed or that showed significant deviation (generally greater than 50 km) from the Gutenberg and Richter (1949) epicentres. The program EPDET (Weichert and Newton, 1970) was used with the JB travel time tables. Considerable experimentation was done to determine the stability of the solution and the dependence on certain stations in order to assess the reliability of the epicentre calculated. This was done by eliminating the largest residuals one by one, paying attention to the fact that late picks are more likely on low gain seismograms. It was usually found that by the time all the remaining stations had residuals which were less than about 3 seconds, adding or subtracting a few stations made very little difference to the location or the origin time. This was then considered to be a stable solution. Some solutions would not converge to one location and in these cases the Gutenberg and Richter solution was chosen as the best estimate over the computer calculated solution because they had the advantage of S information to restrict the origin time. All changes are documented in Table I.

(2) Completeness and Accuracy

Some comment on the completeness and accuracy of the revised Queen Charlottes data set is warranted. A summary of these characteristics is made in Table III, but the table should only be used as a guide as there are exceptions and some boundaries are not well defined. Before the ISS started its annual summary in 1917, epicentres were very poorly defined and many earthquakes went unlocated. However no earthquakes larger than magnitude 7 could have escaped detection in the Queen Charlottes region since the founding of the Victoria seismograph station in late 1898. After 1917 ISS processing should insure that all earthquakes of magnitude 6 and greater should have been detected and located in the region. As short period Benioff seismometers were deployed around North America in the 1930's the location threshold moved down to the 5.5 level. Certainly this was the case by 1940 but the year 1940 is not significant and the 5.5 threshold may have been reached a few years sooner. The accuracy during this time period is roughly ± 50 km.

The establishment of a modern high gain seismograph in Victoria in 1948 made an improvement in the location capability in the Queen Charlottes area although, because of station reliability, it was not until two companion stations were established at Alberni (ALB) and Horseshoe Bay (HBC) in 1951 that a reading from the southern Vancouver Island region could be guaranteed. The effect of having at least one high quality arrival from the southern Vancouver Island region decreased the error along the Queen Charlotte fault (roughly in a northwest-southeast direction) to better than ± 25 km. The error perpendicular to the fault still remained the order of 50 km for all but the largest (greater than M = 6.5) events. The location threshold was also dropped at this time to about magnitude 5 for the Queen Charlotte Islands although some magnitude 5 events may still have not been located immediately to the north in southeast Alaska even though they would have been recorded on several stations.

The most significant improvement for earthquake location in the region was made when the Fort St. James seismograph station (FSJ) was established in central British Columbia in 1965. This lowered the complete detection threshold to magnitude 4 and reduced the east-west error to the same order as the north-south error (about ± 25 km). It must be emphasized again that this estimate is only for events above the completeness threshold. While smaller events may have been located from time to time, uncertainty in phase identification can give rise to much larger errors (see discussion in next section).

The establishment of a station on the Queen Charlotte Islands in 1970 increased the detection capability but did not significantly decrease the location threshold below the 1965 level as clear readings at FSJ and PHC are still the limiting factor.

There are only three earthquakes located significantly east of the Queen Charlotte fault in Figure 4, two are poorly located aftershocks of the 1949 earthquake (see Figure 10) and the third is the December 21, 1936 (M=6) earthquake which appears to be significantly east of the Queen Charlotte fault (near 53N, 132W in Figure 4). With an error of ± 50 km this earthquake could actually be on the Queen Charlotte fault. The location for this event is suspicious, for although the solution appears to be well defined at the given location, a likely aftershock, occurring 24 minutes later, locates with the same degree of precision immediately to the west on the Queen Charlotte fault scarp. It should be emphasized that the error estimates in Table III apply only to events over the magnitude thresholds indicated and smaller events, though they may occasionally have enough readings to be located, can have considerably larger uncertainty. For example, the Nov. 16, 1923 earthquake (M=5) shown at 53.5N, 133W in Figure 4 probably has an uncertainty the order of ± 100 km.

(3) Smaller earthquakes 1951-1980

Up until now, I have been discussing larger events that are located with international networks, generally events larger than magnitude 5.

After 1951 some earthquakes smaller than magnitude 5 were located in the Queen Charlotte Islands region but the locations have large uncertainties (± 50 km or more in some cases). When Fort St. James (FSJ) station was established in central British Columbia in 1965, it became possible in conjunction with Port Hardy (PHC) on northern Vancouver Island, to routinely assign epicentres to events magnitude 4 and larger. The accuracy of these epicentres was improved with establishment of a seismograph station on the Queen Charlotte Islands in 1970. Epicentres for smaller events could be calculated in some instances, although this is dependent on the noise conditions at the individual seismograph stations. Most epicentres after 1965 locate along the Queen Charlotte fault, but three small earthquakes had epicentres significant distances to the east of the Queen Charlotte fault (Figure 6). These three events were subjected to a detailed study.

(a) Calibrating events

In order to investigate whether the small events on the Queen Charlotte Islands were actually located there or were mislocated Queen Charlotte fault events, several larger well located reference events were used to understand what phases were likely to be visible at each of the 3 closest seismograph stations and what time variations could be expected from the standard travel time curves for the arrival time of each phase at each station. In order to insure well located calibrating events, only ones with epicentres close to the Queen Charlotte fault scarp and solutions with small RMS residuals were selected. The seismograms of these events were examined to establish the character of arrivals at each station, accurately pick Pn, Pg, Sn and Sg arrivals and establish station corrections at the 3 closest stations that recorded the smaller events. The seismograms of the smaller events were then examined to see if incorrect picks could have been made when the original processing was done. The earthquakes were then relocated using the station corrections from the calibrating events (see Figure 6).

The calibrating events were selected so that they were large enough to have all phases recorded at PHC and FSJ but small enough that the onset of S phases would not be lost at PHC and FSJ. This effectively limited the magnitude range from 3 3/4 (if the background noise was low) to about 4 3/4. Another criterion used to ensure well located events were chosen was that the epicentres were near the Queen Charlotte fault and that the 3-station solution (QCC, PHC, FSJ) was not too different from the published EPB solution. Arrivals were picked by comparing seismograms from several earthquakes with the same epicentral area.

For the northern Queen Charlottes Pn, Pg and Sg are identified readily on FSJ whereas only Pn and Sn can be picked on PHC. Moving to the southern Queen Charlottes, again Pn, Pg and Sg are the phases that can be picked on FSJ but the arrival picked as Pg, though always impulsive, seems to be unreliable. This variability of arrival times of Pg by several seconds compared to other phases was not just restricted to the three calibrating events used, but was also noticed in several other events that were considered for calibrating events. The reason is not clear but could be caused by variation in crustal structure or focal depth. The southern calibrating events show Pn and Sn clearly on PHC but Sg is a recognizeable impulsive arrival as well and is usually the largest phase on the seismograms. Moving even farther south to the region of the aftershocks of the magnitude 7 June 24, 1970 earthquake (Figure 9), Sn becomes indistinct and there are several P phases after Pn so that Pn and Sg are the only phases that can be picked reliably. This change of phases with the latitude of the epicentre has been a source of error in correctly identifying phases on PHC for Queen Charlotte fault zone earthquakes, especially for smaller earthquakes where only the larger phases are visible.

The calibrating events were used to investigate the effect of crustal model on epicentre solutions. The standard EPB model consists of a 36 km layer of 6.2 km/s material over an 8.2 km/s halfspace, both with a Poisson's ratio of approximately 0.25. A seismic experiment was conducted in 1970 setting off explosions in Bird Lake on the Queen Charlotte Islands and recorded on the mainland. The resulting model (Forsyth et al., 1974) consists of an effective Pn velocity of 8.0 km/s, an effective Pg velocity at the distance of FSJ of 6.2 and a crustal thickness of about 30 km. A Poisson's ratio of 0.25 was assumed and the model was used to locate the calibrating events. In most cases, the RMS error was reduced slightly (by 0.1 or 0.2 s) and the epicentre moved by less than 2 km. Since the improvements with the Bird Lake model were not great, it was decided to use the standard model and generate stations corrections equivalent to the residuals observed. (Tables IV and V).

(b) Sandspit Fault

There are two events, occuring in 1974 and 1975, which have epicentres significantly east of the Queen Charlotte fault (Figure 6). They were investigated to see if they were mislocated Queen Charlotte fault events or possibly Sandspit fault events. The revised epicentres, calculated using station corrections and only high quality arrivals picked after examining the original seismograms, are also located in the same vicinity, significantly east of the extension of the Sandspit fault (Figure 6). The S and P arrivals at both QCC and FSJ are such that the events could be located as indicated or on the Queen Charlotte fault near Tasu. The earthquakes are too small ($M_L = 3.3, 3.7$) to be recorded well at PHC and only one phase stands out on the record. By analogy with the northern Queen Charlottes calibrating events (Table V) the largest phase should be Sn. This interpetation is used to give the locations shown in Figure 6. However, as there are no other epicentres located on the Queen Charlotte Islands and QCC and FSJ suggest locations either near the east coast of the Islands or near the Queen Charlotte fault, some uncertainty must be attached to epicentres that depend on an unconfirmed phase.

Unlocated events recorded at Queen Charlotte Island stations were routinely reported from 1970 to 1976, first at Sandspit station (SSC) and after mid-1971 at Queen Charlotte City station (QCC). All events which had S-P times that indicated epicentres inland of the Queen Charlotte fault (see circles of detection in Figure 7) were tabulated to give an indication of possible seismicity along the Sandspit fault. Because the central Queen Charlotte Islands are an active logging area, the total number of events was expected to include a number of road construction blasts. The events were thus plotted to indicate time of day and as can be seen in Figure 7, the daytime hours are heavily blast contaminated. Four small events were detected in 6 years outside of working hours ranging in magnitude from 0.8 to 1.8. If this rate is extrapolated to include the daytime hours, an event rate of about 1 microearthquake per year is indicated. This is lower than or equal to the background level of microseismicity observed at most seismograph stations in the Canadian Cordillera and does not suggest any activity on the Sandspit fault.

(c) Queen Charlotte Sound

The Canadian Earthquake data file lists locations for 21 earthquakes on the continental shelf of Queen Charlotte Sound since 1951. These events were examined in detail to see if their epicentres were the best estimate possible. In most cases the earthquakes were found to be significantly mislocated and were relocated elsewhere. The problem was usually one of east-west control. The original epicentres and the revised epicentres are shown in Figure 8.

For all events original work sheets were examined to see the stations and phases used to locate the earthquake. For events prior to 1965 USCGS bulletins were also checked for any additional data and the combined data sets were processed with the same crustal model and computer program (CANSES) that has been used for events 1972 and later in western Canada. The main problem is that in this period, prior to the establishment of FSJ, east-west control is poor. The three closest stations PHC, ALB and VIC (and only ALB and VIC prior to 1962) are almost in a straight line pointing at the region. Only when events are large enough to record on Penticton (PNT) or stations in the northwestern United States is some degree of east-west control available. The epicentres of most pre-1965 events moved out of Queen Charlotte Sound when located with the CANSES computer program and the standard crustal model, but the epicentres of 3 small events in September, 1963 remained. These events all have P and S phases identified at PHC and P arrivals only identified at VIC, ALB and PNT. The data as presented on the work sheets suggested little room for improvement. However, when the seismograms were examined, the arrivals were found to be so small as to be uncertain by several 10's of seconds in some cases. At Port Hardy (PHC) these events appear similar and have similar S-P intervals to events in a large swarm that occurred west of Vancouver Island from the period Aug. 30 to Sept. 10 (see Milne and Smith, 1966) and thus were removed from Queen Charlotte Sound.

All of the epicentres after 1965 move out of Queen Charlotte Sound when relocated. The main problem here is correctly identifying phases on FSJ, particularly the S phases. An S phase if correctly identified, even if its onset is uncertain by several seconds, is usually sufficient to provide east-west control, and for all of the cases here, move the epicentre to the west out of Queen Charlotte Sound. The correct identification of phases is complicated as events from the Queen Charlotte fault have P_g and S_g as the most prominent phases on the FSJ seismogram, while events on the Revere-Dellwood Fracture zone have P_n and S_n as the most prominent phases with P_g and S_g very difficult to identify. When dealing with earthquakes near the background noise level it is difficult to pick phases correctly without a larger reference event from the region.

FSJ seismograms and in some cases PHC seismograms were examined for most of the post 1965 events with the Queen Charlottes calibrating events and well located offshore events used as reference events. This helped considerably in correct phase identification. Some post 1965 epicentres still have larger residuals than well located events in the region and thus may not yet be the best solutions. It would probably be necessary to re-examine all seismograms to insure optimum solutions, however the main concern here was correct east-west control to determine if there was any seismicity in Queen Charlotte Sound. This objective has been satisfied and all earthquakes previously thought to be in the Sound have been relocated to the region of the steep continental slope or to the deep ocean.

Other than the revised events discussed in this section on smaller earthquakes, most events in the region of the Queen Charlotte Islands since 1965 are expected to be well located (ie. better than ± 25 km) if they are magnitude 4 or larger (Table III). These events are plotted in Figure 9 and, similar to Figure 4, show most epicentres located close to the scarp marking the Queen Charlotte fault.

(4) Focal depth of Queen Charlotte Islands earthquakes

There is very little information on focal depths for Queen Charlotte Islands' earthquakes because there are no close seismograph stations to calculate depths directly. A microearthquake survey (Hyndman and Ellis, 1981) suggested depths of 20-25 km for several small events along the Queen Charlotte fault. Routine processing of larger earthquakes by the ISC suggests shallow depths, generally less than 30 kilometers, but reliable depth cannot be calculated in this way unless the data are very carefully selected. Depth calculations using the reflection off the earth's surface pP can be very accurate and thus a search was made through the ISC for any events having well defined pP depth calculations. Only 4 were found and they are listed in Table VI. These should be considered as maximum depths as pP phases identified at some stations may well be pwP, reflection off the surface of the ocean, which would give deeper depths because the low water velocity is not taken into account in standard pP depth calculations by the ISC (e.g. see Mendiguren, 1971; Frolich, 1982). This is particularly likely for events south of the Queen Charlotte islands that are surrounded by water such as the 1970 and 1976 events listed in Table VI.

C. THE LARGEST EARTHQUAKES, RUPTURE ZONES AND SEISMIC GAPS

1) The May 26, 1929 earthquake

The magnitude of the 1929 earthquake was computed by Gutenburg and Richter (1954) to be 7, which is confirmed if the felt area estimated from newspaper reports is used to compute a magnitude from Topozada's (1975) relationship. The epicentre is constrained by a world-wide distribution of seismograph stations with a good range of distance and azimuth. The main source of errors in the solution are the timing and measuring uncertainties associated with seismograms of 1929 vintage. The epicentre was recomputed using P arrival times listed in the ISS and considerable experimentation was done varying the combinations of stations. All reasonable solutions fall within a rectangle defined by ± 50 km perpendicular to the Queen Charlotte fault and ± 25 km along the fault from the preferred epicentre which is identified in Figure 10. This places the epicentre to the south of the 1970 magnitude 7 earthquake in this region (Figure 10). There are no located aftershocks for this event but they would have had to have been at least magnitude 5 1/2 to be routinely reported by the ISS in 1929.

Milne estimated the epicentre for the 1929 earthquake to be in Hecate Strait near the central Queen Charlotte Islands on the basis of felt reports (Milne, 1956) and some calculations (Milne, 1963). There is no evidence in the calculations done here to support this and all other published epicentres (ISS, Gutenberg and Richter, 1949; Kelleher and

Savino, 1975) are also south of the Queen Charlotte Islands. The descriptive information listed by Milne (1956) can be misleading if the Modified Mercalli scale (e.g. Richter, 1958) is used to interpret the large landslides in the central region of the Queen Charlottes. Very high Modified Mercalli intensities result suggesting proximity to the epicentral region. A detailed study of the landslides associated with the 1946 Vancouver Island earthquake (M_s =7.3) has shown that in the steep and high rainfall west coast terrain, large landslides can occur in regions of Modified Mercalli VI and greater (Mathews, 1979). The only observation reported by Milne (1956) that is definitely indicative of an intensity higher than VI is at Rose Harbour near the southern tip of the Queen Charlotte Islands where a chimney was knocked down (Modified Mercalli VII). All of the felt and damage observations as reported by Milne (1956) are consistent with a magnitude 7 earthquake south of the Queen Charlotte Islands at the location indicated here.

2) The August 22, 1949 earthquake

The August 22, 1949 earthquake, which had a magnitude of 8.1, is the largest earthquake that has occurred in Canada in historic times. Gutenberg and Richter (1949) computed the magnitude (M_s) for the earthquake and it was judged to be well defined by Geller and Kanamori (1977) who examined the original work sheets. Tobin and Sykes (1968) relocated the larger aftershocks of this event. The earthquake ruptured the Queen Charlotte fault for at least 250 kilometres as indicated by the length of the zone defined by the better located aftershocks of Tobin and Sykes (1968). The rupture length may have been up to 470 km if a poorly located event near 56°N on August 26 and two earthquakes also near 56°N occurring on October 31, more than two months after the mainshock are considered to be aftershocks (Figure 10).

The locations of the aftershocks of this earthquake were investigated with the teleseismic epicentre program EPDET, starting with ISS P arrivals and using JB tables and zero focal depth as Tobin and Sykes (1968) had done. Improved epicentre solutions for several events were found by eliminating stations with the largest residuals, but several very poorly located epicentres remain (aftershocks are plotted in Figure 10). The main problem for these events is that the recording stations are all in a narrow azimuth range to the southeast which gives very poor control perpendicular to the Queen Charlotte Fault. Stable solutions cannot be found as adding or subtracting a station from the data set changes the location of the epicentre by tens of kilometers. Because it was found that most teleseismic solutions became stable when all residuals above 3 seconds were eliminated, a 3 second cutoff was used here as well to determine the solutions in Table I.

Magnitudes (M_L) were estimated for most of the aftershocks from Victoria (VIC) short period vertical Benioff seismograph using the nomogram of Gutenberg and Richter (1942). The day of the mainshock and the day following are missing from EPB seismogram storage so magnitudes for events on these days were estimated from the number of P arrivals in the ISS by comparing the number of P arrivals with aftershocks for which seismograms were available. Hodgson, in unpublished notes made when examining the original seismograms of this earthquake, scanned the records for aftershocks up to the end of September and identified nineteen. It is interesting to note that he did not include in his list the event on August 26 at 05:25 near 56°N nor the event on September 20 at 12:18 that has a poorly defined epicentre significantly east of the Queen Charlotte fault near latitude 53°N (see Figure 10). The September 20 event looks very different from the other aftershocks on the Victoria seismogram. A complete list of possible aftershocks with revised locations and magnitudes is given in Table VII. All events above about magnitude 4-1/2 would have been identified on the Victoria seismograms.

The revised aftershock locations suggest the aftershock zone extends a little farther south than that indicated by Tobin and Sykes (1968) and Kelleher and Savino (1975) and that the rupture zone is about 300 km long if the events at 56°N are considered to be unrelated (Figure 10). If these events are not aftershocks then a significant seismic gap exists from 54 1/2° N to 56° N (Kelleher and Savino, 1975) where the aftershocks from the July 31, 1972 Sitka earthquake begin ($M_s = 7.6$).

3) The June 24, 1970 earthquake

This earthquake has magnitude ($M_s = 7$) reported by USCGS on 2 observations and a magnitude ($M_s = 7.4$) reported by Moscow on 25 observations. Berkeley (M = 6.25 - 6.5) and Pasadena (M = 6.5 - 7) report somewhat lower values. The felt area estimated from intensity reports (Horner et al., 1975) suggests a magnitude of about 6 3/4, but this is unreliable because the earthquake occurred at 6 a.m. local time and many people may have been asleep and thus did not observe the low intensity levels that are necessary to accurately define the total felt area. The original seismograms from the closest stations, Sandspit

(SSQ), Port Hardy (PHC) and Fort St. James (FSJ) were examined for the aftershocks of this event to see if more precise locations could be calculated to define the fault area. Unfortunately, this is not possible for most aftershocks for several reasons: there are some key events that have their onsets buried in the coda of previous events, PHC arrivals are very emergent and the S arrivals at FSJ cannot be picked for the larger aftershocks which have reliable P phases at PHC.

However, for three aftershocks, arrival times for both Pn and Sg phases could be picked at SSQ, PHC and FSJ. These events were located using the station corrections derived from the southern Queen Charlottes calibrating events (see section on Calibrating Events and Table IV) and locate about 40 kilometres south of the epicentres listed in the Canadian Earthquake Data file (which are ISC epicentres). Relative locations were done between the mainshock and these aftershocks using only Pn arrivals at SSQ, PHC and FSJ and assuming all differences in arrival times were due to distance distribution along the fault. This shows an aftershock zone extending about 20 km southwest from the mainshock epicentre. S-P intervals of unlocated aftershocks at SSQ show a variation from 20 to 24 seconds which is equivalent to an aftershock zone of about 35 kilometers, mainly south of the epicentre. Both these observations suggest the rupture was south from the epicentre and not bilateral.

What is clear from observing the lengths of the aftershock zones of the largest events is that a significant seismic gap, the order of 75 kilometers long, exists along the southern Queen Charlotte Islands between the southernmost known aftershocks of the 1949 earthquake and the aftershock zone of the 1970 earthquakes (Figure 10). This gap has persisted for at least 80 years and would require an earthquake of about 7.5 to fill it completely (Rogers, 1982).

D. FOCAL MECHANISMS

Focal mechanisms that have been published for earthquakes in the region of the Queen Charlotte Islands are listed in Table VIII. To the north, along southeast Alaska primarily strike-slip and thrusting events are observed. The sense of relative motion calculated from the mechanism solutions corresponds closely with expected relative plate motion in the region (Perez and Jacob, 1980). In the Queen Charlottes area focal mechanisms have been published for the great 1949 earthquake (M = 8.1) (Hodgson and Milne, 1951; Wickens and Hodgson, 1967), the 1970 earthquake (M = 7) south of the Charlottes and an aftershock (Chandra, 1974), and a 1976 earthquake (M = 6) also south of the Charlottes (Wetmiller and Horner, 1978). Other than for the 1949 event, the published solutions for these earthquakes do not correspond in azimuth to the local strike of the Queen Charlotte fault or in direction of motion to the motion predicted by plate tectonics (Chase, 1978; Minster and Jordan, 1978). All of these mechanisms are reexamined in this section.

To the south of the Queen Charlotte fault, in the complex triple junction region leading to the Explorer spreading centre, the published mechanisms are not well constrained but suggest strike-slip and a combination of strike-slip and normal faulting (Hodgson and Storey, 1954; Chandra, 1974). There are also mechanisms for some smaller earthquakes in this region presented by Gallagher (1969) in his PhD thesis. However, they are so poorly constrained that they are not useful for tectonic modelling.

The location of the Queen Charlotte Islands relative to the distribution of seismographs on the globe effectively limits the size of earthquake for which a well defined focal mechanism can be calculated by the P nodal method. Because of the orientation of the Queen Charlotte fault, the southern extension of the fault plane is usually well constrained because it bisects the network of stations in California. The northern extension which passes through Alaska is not well constrained. The only operating station in central Alaska for much of this century was College (COL) and in recent times it is the only one with long period data. Thus, there is often only one station to restrict the position of the fault plane and since it is quite close to the nodal plane it often does not have an impulsive P arrival. To accurately define the azimuth of the faulting and to give information on the dip, the earthquake must be large enough to record well in Europe. This is illustrated in Figure 11. The minimum magnitude is about 6 and even this is pushing the limit if there is a high microseismic noise level in Europe. All events likely to produce good solutions are examined here.

1) The August 22, 1949 earthquake ($M_s = 8.1$)

The focal mechanism of the 1949 earthquake was studied originally by Hodgson and Milne (1951). Hodgson later gathered together a large number of seismograms to study this event. He re-examined previous first motions and thirteen new first motions were read. Eight of the polarities read for the original solution were reversed due to information about revised seismograph polarities or because of a reading difference with Milne who read most of the original records. Three readings were added from bulletins and this data set was processed by computer program and published as a revised solution in the Wickens and Hodgson (1967) catalogue.

Extensive notes made by Hodgson on the seismograms as well as tracings of the beginings of most of them were examined to obtain a feeling for the quality of the data. Those readings which were impulsive and for which there was no doubt were given full weight in the processing. All doubtful readings for whatever reason, as well as all readings from bulletins were given one half weight. Three more readings from bulletins were found and added to the Hodgson data set. The data were processed using a version of Wickens' original program (Wickens and Hodgson, 1967) with all arrivals in the Pn distance range restricted to an angle of emergence from the focal sphere of 55°. While restricting the angle of emergence of rays in the P_n distance range is correct procedure for most earthquakes (because the rupture surface is above the Moho) it is not clear that this is appropriate for large earthquakes on oceanic transforms which may also have some seismic rupture in the mantle portion of the lithosphere (Burr and Solomon, 1978). In any case, changing the positions of the P_n rays on the focal sphere does not alter the solutions of any of the Queen Charlotte fault events sufficiently to affect any of the conclusions drawn here.

The fault plane solution for the 1949 event (Figure 11) is almost identical to that of Wickens and Hodgson (1967). The azimuth of the northwest striking plane corresponds exactly to the strike of the fault at the latitude of the epicentre. The dip of the fault is very steep and well constrained by a number of European stations that have good quality readings. The motion is mainly strike-slip with a small thrust component. The net horizontal motion during this earthquake is significantly different (15°) from the latest estimates of Pacific-American motion in the region predicted by plate interaction models (Minster et al, 1978, Chase 1978). If the plate interaction models are correct, then there is a component of convergence along the fault at this latitude not taken up by this earthquake, that must be taken up by some other means.

(2) The June 24, 1970 earthquake ($M_s = 7$)

A solution for this earthquake was previously published by Chandra (1970) who used a combination of P first motion and S polarization data. It appears that S polarization angles, which are difficult to define precisely, are exerting undue influence on his solution. A solution can be found using his P data alone which has fewer incorrect P first motions and is not significantly different in S wave radiation pattern. The addition of 66 additional short period P polarities from the ISC (weighted at 1/2 weight in the solution) confirm the P only solution. Superior P only solutions have been found for several of Chandra's solutions where he has used his P and S algorithm (e.g. Rogers, 1976; Perez and Jacob, 1980) suggesting the relative weights he used for P and S data may need to be revised.

The northwest-southeast fault plane for this earthquake represents a combination of strike-slip and thrust faulting with strike-slip being the dominant type. The strike of the fault plane in the optimum solution produced by the computer program has a more north-south orientation (by 19°) than the local strike of the continental shelf break of N40°W (presumably the Queen Charlotte fault) . The maximum dip of the fault is well constrained demanding a significant thrust component. The fault plane can be rotated counterclockwise 19° to correspond to the strike of the continental shelf by making five additional station polarities incorrect. All of these stations are near the nodal plane and thus the quality of the solution does not degrade significantly, but the horizontal projection of the fault motion vector becomes significantly different from the horizontal motion predicted by plate tectonics (Figure 12).

The horizontal motion vector depends on the azimuth of the fault plane and sweeps out a range from N14°W for the optimum solution to N27°W for the solution constrained to the azimuth of the shelf break. The predicted motion vector for the Pacific-America interaction at the epicentre from recent plate models (Minster et al., 1978; Chase, 1978) is N18°W, in the middle of the range. If the horizontal motion vector is made to correspond to the plate interaction vector, as Mackenzie (1969) suggests it should for interplate earthquakes, then a solution can be found within the same minimum chosen by the computer program. This is thus the preferred solution as it is both the optimum division of the data set and satisfies the plate tectonic constraint. The surface projection of the fault plane is still about 10° from the local orientation of the shelf break, but is very similar to the trend of microearthquakes recorded by ocean bottom seismographs immediately to the south of this earthquake (Hyndman and Rogers, 1981). The dip of the fault plane is 50° (Figure 13).

(3) June 24, 1970: Foreshock and Aftershock

Chandra (1974) published a poorly constrained solution for the largest aftershock (M = 5.2) of the June 24, 1970 earthquake. Also, a foreshock (M = 5) occurring 5 and one half hours before the mainshock has 38 first motions listed in the ISC. As mentioned before, because of the relative location of the Queen Charlotte Islands with respect to the distribution of world wide seismograph stations, these events are too small to provide well constrained solutions. However, when the solution of the main shock is superimposed on these data sets it can be seen that they are likely to have similar mechanisms involving right lateral strike slip faulting with a significant thrust component (Figure 14).

(4) The February 23, 1976 earthquake (M_s = 6.0)

This earthquake is a magnitude 6 event immediately to the south of the 1970 earthquake sequence. A very poorly constrained solution with 20 percent incorrect data was published by Wetmiller and Horner (1978) using first motions read from short period stations in the Canadian network and selected data published in the NEIS *Earthquake Data Report*. In order to better define the solution, microfilm was examined for all available short and long period seismograms from the World Wide Standard (WWSS) network and all Canadian long period stations. This resulted in 27 first motions of high reliability. Also, data from the University of California (Berkeley) *Bulletin of Seismograph Stations* was included (at one half weight) as it showed a clear division in the California stations which unambiguously spans a nodal plane. The solution is shown in Figure 15. Adding readings from the ISC and lower quality polarities read from the WWSS network does not result in a clearer definition of the dip of the nodal planes. This earthquake is too small to read reliable first motions at most European stations and as such is just below the magnitude limit necessary to obtain a well constrained solution. Nevertheless, there is a sufficient distribution of stations with reliable readings to see that this earthquake cannot have a fault plane dipping to the east at an angle as shallow as in the 1970 events (Figures 13 and 14). This earthquake has a much shallower focal depth than the 1970 event (Table VII) and thus probably represents faulting in the upper crust.

(5) Summary of Fault Plane Solutions

The only well defined fault plane solutions in the Queen Charlotte Islands region are those for the August 22, 1949 earthquake (M_s=8.1) and the June 24, 1970 earthquake (M_s=7). These are shown in Figure 16 superimposed on the seismicity map of the region. The fault plane solution of the 1949 earthquake (Figure 11) represents almost pure strike-slip faulting on a near vertical plane. The strike is consistent with the local strike of the Queen Charlotte fault but the horizontal motion vector is significantly different (15^o) from the latest estimates of the Pacific/America interaction direction (Minster et al., 1978; Chase, 1978). On the other hand, the 1970 earthquake has a combined strike-slip and thrust mechanism (Figure 13) which is consistent with the predicted Pacific/America motion, but the strike of the 1970 fault plane is about 10^o different from the probable trend of the Queen Charlotte fault. The fact that the horizontal motion vector of the 1970 earthquake is consistent with the recent plate interaction models suggests the models are representative of Pacific/America motion in the Queen Charlotte Islands area. The implication of this in the region of the 1949 earthquake is that there is a significant amount of convengence perpendicular to the strike of the Queen Charlotte fault that was not taken up during the rupture of that earthquake and must be taken up in some other way.

E. CONCLUSIONS

The revised seismicity pattern shows a strong correlation with the Queen Charlotte fault scarp with little, if any, seismicity on other major fault systems of the Queen Charlotte Islands indicating all Pacific/American motion occurs along the Queen Charlotte fault. There have been no earthquakes confirmed to be in Hecate Strait or Queen Charlotte Sound. The distribution of large earthquakes along the Queen Charlotte fault suggests that two major seismic gaps are present. Fault plane solutions for the region have been recalculated with additional data and show a combination of thrusting and strike-slip faulting in the south, with horizontal motion parallel to the Pacific-American vector, changing to a predominantly strike-slip environment in the north.

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TABLE I

Changes to Canadian Earthquake Data File in the Queen Charlotte Islands Region (50°N-57°N)

(The first line contains the present Data File solution, the second line contains revised parameters. Other changes to the Data File in the Queen Charlotte Islands region are documented in Rogers 1980. Any changes here supercede those in Rogers, 1980.)

1920	Mar. 29	05 07 53.	50.5	129.5	6.4
		05 07 51.8	50.6	129.87	
	Recalculated with ISS data				
1921	Apr. 10	13 40 16.	53.2	133.7	6.5
		13 40 16.	54.	134.	
	Gutenberg and Richter (1949) solution				
1923	Nov. 16	04 15 35.	53.	131.	5.0
		04 15 25.	53.5	133.	
	Poorly constrained solution. Origin time is restricted with California data.				
1924	Mar. 30	00 08 56.	50.5	129.5	6.0
		00 08 56.	50.	130.24	
	Gutenberg and Richter (1949) solution				
1927	Oct. 25	17 59 14.0	56.4	136.0	5.0
			57.67	136.07	
	This aftershock of Oct. 24 earthquake is moved from ISS epicentre of mainshock to Tobin and Sykes (1968) epicentre of mainshock. It has not been recomputed.				

1927	Nov. 12	21 56 12.0	56.4	136.0	5.0
			57.67	136.07	
	As above.				
1927	Nov. 21	15 13 50.0	56.4	136.0	5.0
			57.69	136.07	
	As above.				
1927	Dec. 31	19 06 45.0	56.4	136.0	5.0
		19 07 03.5	59.33	136.22	
	Tobin and Sykes, 1968.				
1929	Mar. 01	07 31 13.7	50.79	129.74	6.1
		07 31 13.	50.5	130.75	
	Gutenberg and Richter (1949) solution.				
1929	May 26	22 39 54.0	52.8	129.5	7.0
		22 39 58.5	51.51	130.74	
	Recalculated with ISS data				
1930	Jul. 01	01 09 13.0	51.5	133.3	5.5
		01 09 18.1	52.49	132.04	5.7(M_s)
	Recalculated with ISS data. Magnitude from Gutenberg and Richter, 1949.				

1936	Dec. 21	19 03 13.0	52.9	131.6	6.0
		19 03 13.9	52.93	131.75	

Recalculated with ISS data.

1936	Dec. 21	19 27 59.0	52.9	131.6	5.0
		19 26 55.0	52.51	132.05	

Recalculated with ISS data.

1945	Aug. 02	20 44 45.0	53.9	132.1	6.2
		20 44 46.2	53.87	133.35	6.3(M_s)

Recalculated with ISS data. Magnitude rounded up from Gutenberg and Richter (1949) value of 6-1/4.

1947	Apr. 27	11 08 41.0	56.0	140.5	5.0
		11 08 55.8	55.32	137.80	

Kelleher and Savino, 1975.

1948	Feb. 28	01 58 06.0	53.9	132.1	6.5
		01 58 07.9	53.37	132.73	

Recalculated with ISS data.

1949	Aug. 22	04 01 12.0	53.75	133.25	8.0
		04 01 12.2	53.62	133.27	8.1(M_s)

Tobin and Sykes, 1968. Magnitude from Gutenberg and Richter (1949).

1949	Aug. 23	02 59 19.0	53.8	133.2	5.0
		02 59 06.1	55.08	134.01	

Recalculated with ISS data.

1949	Aug. 23	19 37 30.	52.6	132.1	5.0
		19 37 33.0	52.42	131.87	

Recalculated with ISS data.

1949	Aug. 23	19 43 35.	52.6	132.1	5.5
		19 43 35.0	52.64	132.10	5.0(M_L)

Recalculated with ISS data. Magnitude estimated from number of P arrivals.

1949	Aug. 24	22 37 13.	56.2	132.1	5.5
		22 37 13.1	52.78	132.11	4.9(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1949	Aug. 26	05 25 58.0	56.0	135.0	4.0
		05 25 57.5	56.08	135.27	4.9(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1949	Aug. 26	22 39 29.0	54.5	136.0	5.5
		22 39 37.2	54.67	133.88	5.0(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1949	Aug. 27	21 30 41.0	52.6	132.1	5.0
		21 30 47.0	53.05	132.74	5.3(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1949	Sept. 05	06 54 06.0	53.8	133.2	5.0
		06 54 10.0	53.62	132.97	4.9(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1949	Sept. 12	14 37 46.0	55.8	132.0	5.0
		14 37 48.6	55.16	132.57	5.0(M_L)

(Recalculated with ISS data. Magnitude calculated from VIC.

1949	Oct. 31	01 39 28.0	56.0	136.0	6.7
		01 39 29.5	56.05	135.69	6.2(M_s)

Tobin and Sykes, 1968. Magnitude calculated from VIC and Gutenberg and Richter (1949) value of 6-1/4.

1949	Oct. 31	02 32 09.0	56.0	136.0	5.0
		02 32 11.3	56.02	135.91	5.1(M_L)

Tobin and Sykes, 1968. Magnitude calculated from VIC.

1950	Aug. 08	05 11 55.0	54.5	136.0	4.5
		05 12 04.0	54.92	134.58	5.0(M_L)

Kelleher and Savino, 1975. Magnitude estimated from number of ISS arrivals.

1950	Sept. 28	21 47 01.0	54.5	134.5	5.5
		21 47 02.4	54.32	134.63	

Kelleher and Savino, 1975.

1954	Jun. 22	19 09 56.0	54.5	132.5	5.0
		19 09 53.8	54.17	133.63	4.5(M_L)

Recalculated. Magnitude estimated from VIC.

1954	Jul. 15	13 24 35.0	54.0	138.0	3.6
		13 24 34.5	53.57	133.46	4.5(M_L)

Tobin and Sykes, 1968. Magnitude estimated from number of arrivals in ISS.

1956	Feb. 19	02 18 09.0	51.3	130.6	6.8
		02 18 00.6	51.61	131.37	6.5(M_s)

Tobin and Sykes, 1968. Magnitude from B.C.I.S.

1956	Nov. 17	20 27 15.	54.5	134.0	6.5
		20 27 17.2	54.55	133.67	6.4(M_s)

Tobin and Sykes, 1968. Magnitude from B.C.I.S.

1957	Mar. 24	08 22 23.0	50.0	127.7	6.0
		08 22 22.5	50.85	130.36	6.2(M_s)

Tobin and Sykes, 1968. Magnitude from B.C.I.S.

1958	Apr. 09	06 15 12.0	56.5	139.0	4.7
		06 15 11.6	56.14	139.23	5.3(M_s)

Tobin and Sykes, 1968. Magnitude from Moscow (in BCIS).

1959	Dec. 26	10 59 56	51.1	129.6	3.8
		10 59 33.6	51.51	131.50	
	Recalculated with EPB data				
1960	Aug. 05	08 45 35.9	51.24	129.69	4.6
		08 45 37.5	50.88	130.09	
	Recalculated with EPB data				
1963	Mar. 30	00 34 36.2	51.00	129.58	4.1
		00 34 40.5	50.88	129.65	
	Recalculated with EPB data				
1963	June 23	13 11 45.0	51.3	129.80	4.5
		13 12 05.4	50.31	127.74	
1963	Sep. 1	22 07 28.0	51.4	129.6	2.7
		22 07 34.5			
	Part of an offshore swarm this day (see Milne and Smith, 1966). Arrivals are too small for accurate identification. Omit epicentre from data file.				
1963	Sep. 1	23 55 47.0	51.60	129.10	2.7
		23 55 46.2			
	As on Sept. 1 at 22 07.				
1963	Sep. 2	03 46 15.0	51.5	129.0	3.7
		03 45 40.8	52.09	131.49	4.2(M_L)
	Recalculated with EPB data				
1963	Sep. 2	14 12 48.0	52.0	129.5	4.2
		14 12 52.3			3.0(M_L)
	As on Sept. 1 at 22 07 and 23 55.				

1963	Nov. 20	01 13 44.	53.4	130.6	4.0
		01 13 52.3	52.17	130.97	

Relocated with EPB and USCGS data.

1964	Apr. 01	12 45 43.0	51.4	129.7	3.5
		12 45 42.1	51.22	130.00	

Recalculated with EPB data

1964	May 10	13 44 02.0	51.4	129.2	4.1
		13 44 06.7	51.06	129.47	

Recalculated with EPB data

1965	Apr. 22	10 11 48.0	51.6	129.3	2.2
		10 11 35.9	51.56	130.61	

Recalculated with EPB data

1967	Mar. 05	11 11 02.0	51.2	129.5	3.8
		11 11 02.4	50.83	129.79	

Recalculated with EPB data

1968	Feb. 15	18 27 30.0	51.35	129.68	3.8
		18 27 29.2	51.14	130.14	

Recalculated with EPB data

1968	Jun. 18	05 37 57.0	51.1	129.0	4.1
		05 37 47.6	50.72	130.26	

Recalculated with EPB data

1970	Feb. 19	08 09 18.	53.3	132.3	4.0
		08 09 16.3	52.84	132.49	

Phases repicked and recomputed with station corrections

1970	Jun. 24	13 09 08.	51.74	131.0	6.7
		13 09 11.3	51.77	130.76	7.0(M_s)

ISC solution preferred. Magnitude an estimate from ISC magnitude reports.

1970	Jun. 24	17 16 53	51.94	130.3	3.3 (mb)
		17 16 49.9	51.58	130.45	

Phases repicked and recomputed with station corrections

1970	June 24	19 10 15.	51.95	130.5	3.9 (mb)
		19 10 13.6	51.56	130.42	

Phases repicked and recomputed with station corrections

1970	Jun. 29	02 26 40.	51.99	130.3	3.7
		02 26 37.6	51.68	130.44	

Phases repicked and recomputed with station corrections

1970	Aug. 11	20 56 50.0	52.0	130.0	3.0
		20 56 36.9	51.54	130.23	

Recalculated with EPB data

1971	Jun. 29	06 28 54.0	51.2	129.6	4.2
		06 28 26.9	51.03	129.68	

Recalculated with EPB data

1973	Mar. 28	06 23 07.0	51.19	129.69	3.9
		06 23 05.6	50.74	129.89	
	Recalculated with EPB data				
1973	Oct. 11	12 13 57.0	51.22	129.48	3.1
		12 13 44.4	50.76	130.58	
	Recalculated with EPB data				
1974	May 25	14 00 47.0	51.53	129.46	3.1
		14 00 40.3	50.70	130.45	
	Recalculated with EPB data				
1974	Jun. 19	11 17 55	53.86	132.15	3.3
		11 17 52.8	53.97	132.02	
	Recalculated with EPB data and station corrections				
1975	Sep. 28	00 33 59	53.66	132.18	3.7
		00 34 00.5	53.70	132.03	
	Recalculated with EPB data and station corrections				

TABLE II

Earthquakes to be added to the Canadian Earthquake Data File

1949	Aug 22	09 15 21.4	54.96	133.43	$4.5(M_L)$
	Tobin and Sykes, 1968. Magnitude estimated from number of P arrivals.				
1949	Sept. 02	01 31 15.5	54.22	133.61	$4.6(M_L)$
	Tobin and Sykes, 1968. Magnitude calculated from VIC.				
1949	Sept. 12	08 36 03.5	54.87	134.32	$4.9(M_L)$
	Tobin and Sykes, 1968. Magnitude calculated from VIC.				
1949	Sept. 20	12 18 06.4	52.87	131.32	$5.1(M_L)$
	Recalculated with ISS data. Magnitude calculated from VIC.				

Table III
Completeness and accuracy of the revised data set.

Completeness Magnitude threshold	Year	Accuracy*
7	1899	± 100 kilometers
6.5	1917	± 50 kilometers
6	1917	
5.5	1940±	
5	1951±	± 50 km (east-west) ± 25 km (north-south)
4.5	1965	± 25 km
4	1965	

*Accuracy estimates apply only to events above the magnitude threshold for complete detection.

Table IV

Residuals from Southern Queen Charlottes Calibrating Events

	STN	Pn	P_1	S_n	S_1
1)	QCC		+0.4		+0.4
	PHC	-2.2	+0.5	-1.3	+2.3
	FSJ	+1.0	+5.9		-1.0
2)	QCC		-1.5		+1.8
	PHC	-2.1	+2.3	-1.6	+1.6
	FSJ	+0.5	+0.5		-1.5
3)	QCC		not recording		
	PHC	-2.7		-1.1	+2.0
	FSJ	+1.3	+2.4		-1.9

Average Residuals*

QCC		(-0.6)		(+1.1)
PHC	-2.3		-1.5	+2.0
FSJ	+0.9	(+2.7)		-1.5

Three station solutions:

1)	1975	Feb 14	12 15 04.8	52.67	132.07	3.8
2)	1976	May 13	07 11 42.6	52.79	132.31	4.8
3)	1978	Jul 11	03 04 50.0	52.64	132.00	4.1

*Values considered unreliable as station corrections are bracketed.

Table V

Residuals from Northern Queen Charlottes Calibrating Events

	STN	Pn	P_1	S_n	S_1
4)	QCC		-2.1		
	PHC	-1.4		+2.5	
	FSJ	+2.3	-0.4		-1.0
5)	QCC		-3.2		
	PHC			+2.6	
	FSJ	+0.8	+0.9		-1.1

Average Residuals*

STN	Pn	P_1	S_n	S_1
QCC		-2.7		
PHC	(-1.4)		+2.6	
FSJ	+1.6	(+0.2)		-1.1

Three station solutions:

4)	1972	Jun 17	23 50 24.4	54.29	133.55	4.3
5)	1976	Oct 15	20 29 30.7	54.36	133.86	3.8

*Values considered unreliable as station corrections are bracketed.

TABLE VI

pP depths for Queen Charlotte Fault earthquakes*

Date	Time	Lat(N)	Long(W)	Mag	Depth(km)
1970 Jun 24	13 09 11.3	51.8	130.8	7	22 ± 0.7
1976 Feb 23	15 14 15.1	51.4	130.6	6.0	6 ± 0.8
1978 Jul 11	02 55 50.0	52.7	132.0	5.1	10 ± 1.4
1979 Jul 11	12 28 04.0	55.2	134.0	5.1	9 ± 1.0

* Depths and standard errors are from the ISC. These should be considered maximum depths as pP phases may actually be pwP, the reflection of the ocean surface.

TABLE VII

Revised Parameters for 1949 Earthquake and Possible Aftershocks

(Focal depth restricted to zero in all calculations)

Date	Time	Lat(N)	Long(W)	Magnitude[1]	Quality[2]
Aug 22	04 01 12.2	53.62	133.27	8.1(Ms)	
Aug 22	09 15 21.4	54.96	133.43	4.5	P
Aug 22	12 22 05	not located			
Aug 22	13 40 20	not located			
Aug 23	02 59 06.1	55.08	134.01	5.0	P
Aug 23	19 37 33.0	52.42	131.87	5.0	
Aug 23	19 43 35.0	52.64	132.10	5.0	
Aug 23	20 24 31.1	52.69	132.23	6.4(Ms)	
Aug 24	02 37 21	not located			
Aug 24	09 20 00	not located			
Aug 24	12 42 39	not located			
Aug 24	21 51 41	not located		5.0	
Aug 24	22 37 13.1	52.78	132.11	4.9	
Aug 26	05 25 57.5	56.08	135.27	4.9	P
Aug 26	22 39 37.2	54.67	133.88	5.1	
Aug 27	21 30 40.7	53.05	132.74	5.3	
Sep 02	01 31 15.5	54.22	133.61	4.6	P
Sep 05	06 54 10.0	53.62	132.97	4.9	
Sep 12	08 36 03.5	54.87	134.32	4.9	P
Sep 12	14 37 48.6	55.16	132.57	5.0	P
Sep 18	11 59 00	not located		4.8	
Sep 20	12 18 06.4	52.87	131.32	5.1	P
Oct 31	01 39 29.5	56.05	135.69	6.25(Ms)	
Oct 31	02 32 11.3	56.02	135.91	5.1	

[1] Magnitudes after Aug 24 at 21 hrs are M_L values estimated from Victoria seismograms. Seismograms were not available for earlier events but magnitudes were estimated from the number of P arrivals in the ISS where possible.

[2] P indicates a poorly constrained epicentre solution

TABLE VIII

Published Fault Plane solutions for earthquakes in the vicinity of the Queen Charlotte Fault

North of the Queen Charlotte Islands

1927 Oct 24	Stauder, 1959; Wickens and Hodgson, 1967	strike-slip
1949 Oct 31	Hodgson and Storey, 1954; Wickens and Hodgson, 1967	thrust
1958 Jul 10	Stauder, 1960; Wickens and Hodgson, 1967	strike-slip
1972 Jul 30	Chandra, 1974; Perez and Jacob, 1980	strike-slip
*1972 Aug 15	Perez and Jacob, 1980	strike-slip
*1972 Aug 04	Chandra, 1974	thrust
1973 Jul 01	Chandra, 1974; Perez and Jacob, 1980	thrust
1973 Jul 03	Chandra, 1974; Perez and Jacob, 1980	strike-slip

Queen Charlottes Islands Region

1949 Aug 22	Hodgson and Milne, 1951; Wickens and Hodgson, 1967	strike-slip
*1970 Jun 24	Chandra, 1974	strike-slip
*1970 Jun 24	Chandra, 1974	strike-slip
*1976 Feb 23	Wetmiller and Horner, 1978	strike-slip

Triple Junction Region, south of the Queen Charlotte Islands

*1948 Dec 31	Hodgson and Storey, 1954; Wickens and Hodgson, 1967	strike-slip
*1964 Mar 31	Tobin and Sykes, 1968; Chandra, 1964	strike-slip
*1971 Mar 13	Chandra, 1974	strike-slip

*Poorly constrained solutions

List of Figures

Figure 1	Tectonic setting of the Queen Charlotte Islands.
Figure 2	Epicentres in the Canadian Earthquake Data file to the end of 1975. (From Milne et al., 1978)
Figure 3	Major faults, plate interaction direction and bathymetry.
Figure 4	Epicentres magnitude 5 and greater (1900 to 1980) with revisions from Tables I and II.
Figure 5	Various epicentres for the May 26, 1929 earthquake (M = 7) and the July 1, 1930 earthquake (M = 5.7).
Figure 6	Epicentres inland of the Queen Charlotte fault since 1965. Open circles indicate original epicentre, solid circles indicate revised epicentres. Stars are calibrating events used to generate station corrections and to identify phases.
Figure 7	Sandspit fault event rate. Histogram shows events that have S-P intervals indicating they are inland of the Queen Charlotte Fault as indicated by the circles around the seismograph stations.
Figure 8	Revisions for epicentres in Queen Charlotte Sound. Open circles are original epicentres, solid circles are revised epicentres. Three poorly located events do not have revised epicentres but based on appearance they are believed to be part of a swarm in the deep ocean. All of the revised epicentres occurring before 1965 (12 of the 21 events) are poorly constrained.
Figure 9	All events since 1965, magnitude 4 and greater from the Canadian Earthquake data file. Only a few of these events have been relocated. Epicentres are expected to be within 25 km of true locations except for those in the bottom right of the figure where phase misidentification can lead to larger errors.
Figure 10	Major earthquakes along the Queen Charlotte Fault Zone and the extent of their aftershock zones. Circles are possible 1949 aftershocks. Shaded circles are poorer solutions. Two possible seismic gaps are identified. The northern gap may not exist as the northern end of the 1949 aftershock zone is not well defined. The southern gap has not experienced any major earthquakes in at least the 80 years.
Figure 11	August 22, 1949, Mechanism solution lower hemisphere projection. Position of key stations are indicated on the focal sphere.

Figure 12	Dashed line represents shelf break (presumeably the orientation of the Queen Charlotte Fault) and dashed arrow represents plate interaction direction. Solid arrow is horizontal projection of relative motion vector from P nodal solution and solid line is surface intersection of the fault plane. (a) is the optimum computer solution, (b) adjusts the horizontal motion vector to coincide with the plate motion vector with the same data division as in (a), (c) restricts the azimuth of the fault plane to have the same orientation as the shelf break but forces some observations to be incorrect.
Figure 13	June 24, 1970 mechanism solution. A large number of compressional arrivals in Europe and the Canadian arctic necessitate a thrust component in the solution.
Figure 14	June 24, 1970 mechanism solution superimposed on data of a foreshock and an aftershock. Note that the data although insufficient to produce well constrained solutions is consistent with a thrusting component in the solution.
Figure 15	February 23, 1976 mechanism solution. The dip of the fault plane is not well controlled, but it cannot have a dip to the east as shallow as the 1970 earthquake in Figure 13.
Figure 16	Position of the only well defined fault plane solutions in the Queen Charlotte Islands region. The northern solution is for the August 22, 1949 (M=8.1) earthquake (Figure 11) and the southern one is for the June 24, 1970 (M=7) earthquake (Figure 13).

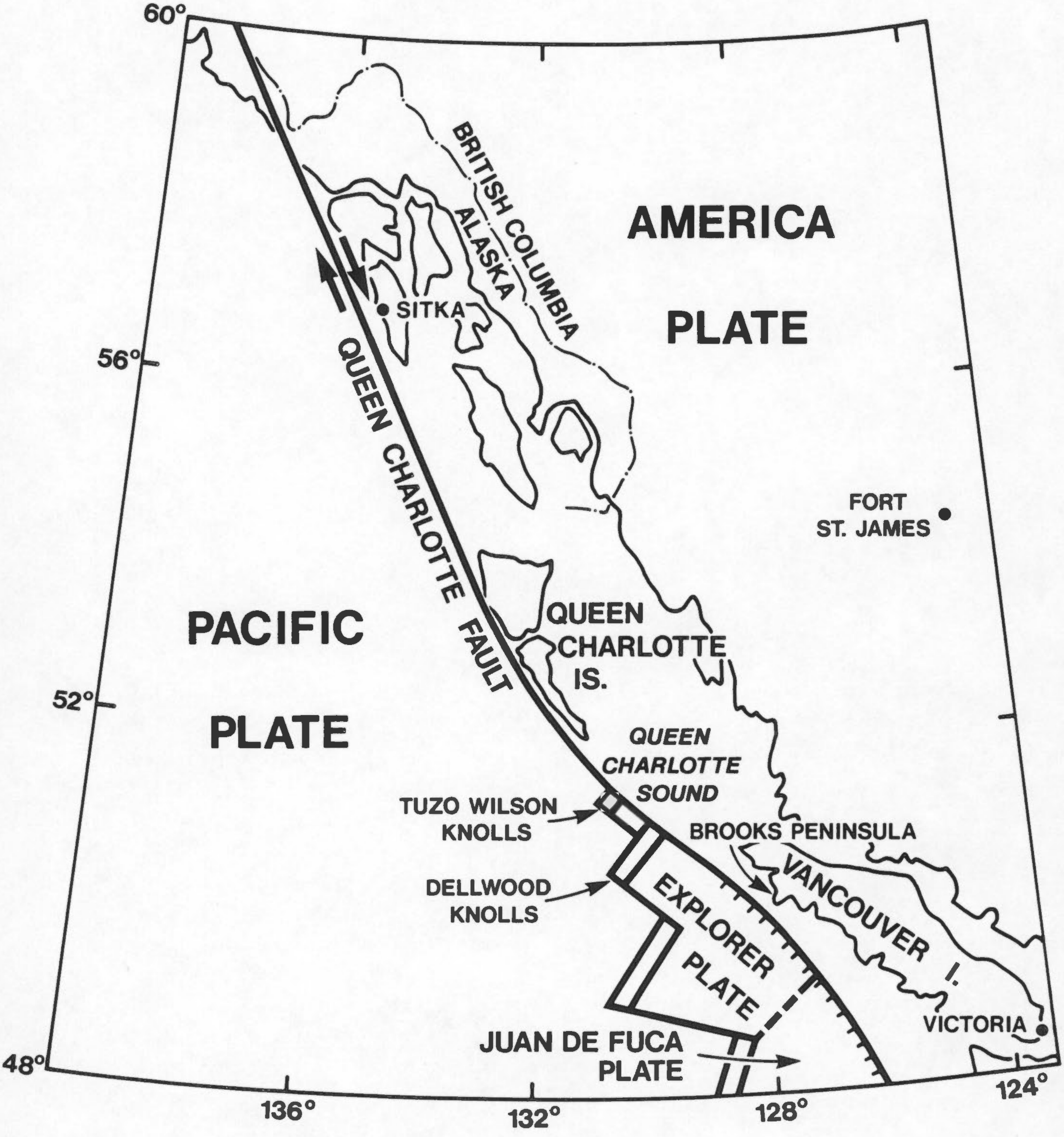

60°
56°
52°
48°
136°
132°
128°
124°
BRITISH COLUMBIA
ALASKA
AMERICA
PLATE
SITKA
QUEEN CHARLOTTE FAULT
FORT
ST. JAMES
PACIFIC
PLATE
QUEEN
CHARLOTTE
IS.
QUEEN
CHARLOTTE
SOUND
TUZO WILSON
KNOLLS
BROOKS PENINSULA
DELLWOOD
KNOLLS
EXPLORER
PLATE
VANCOUVER
I.
VICTORIA
JUAN DE FUCA
PLATE

Figure 1

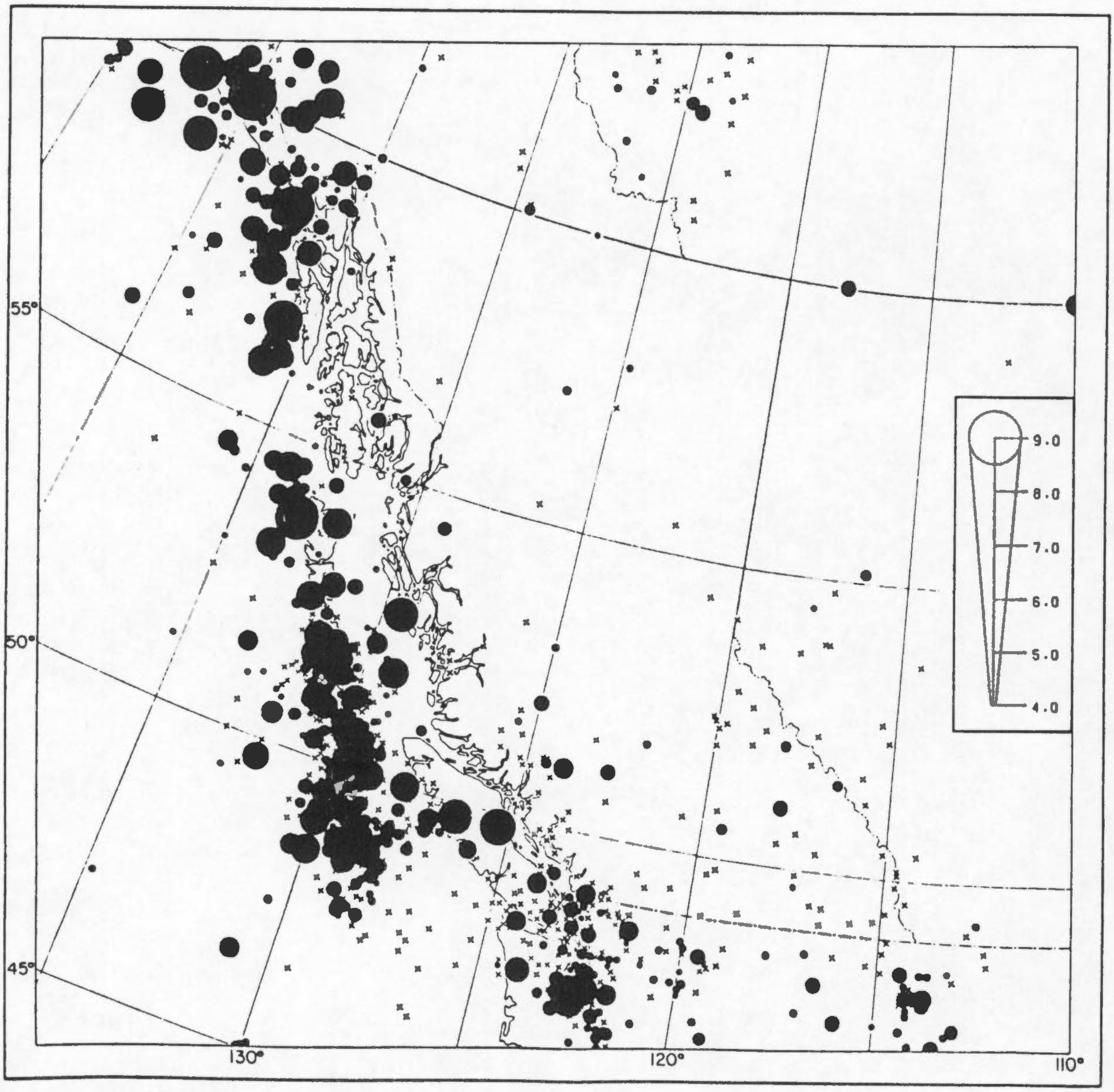


Figure 2

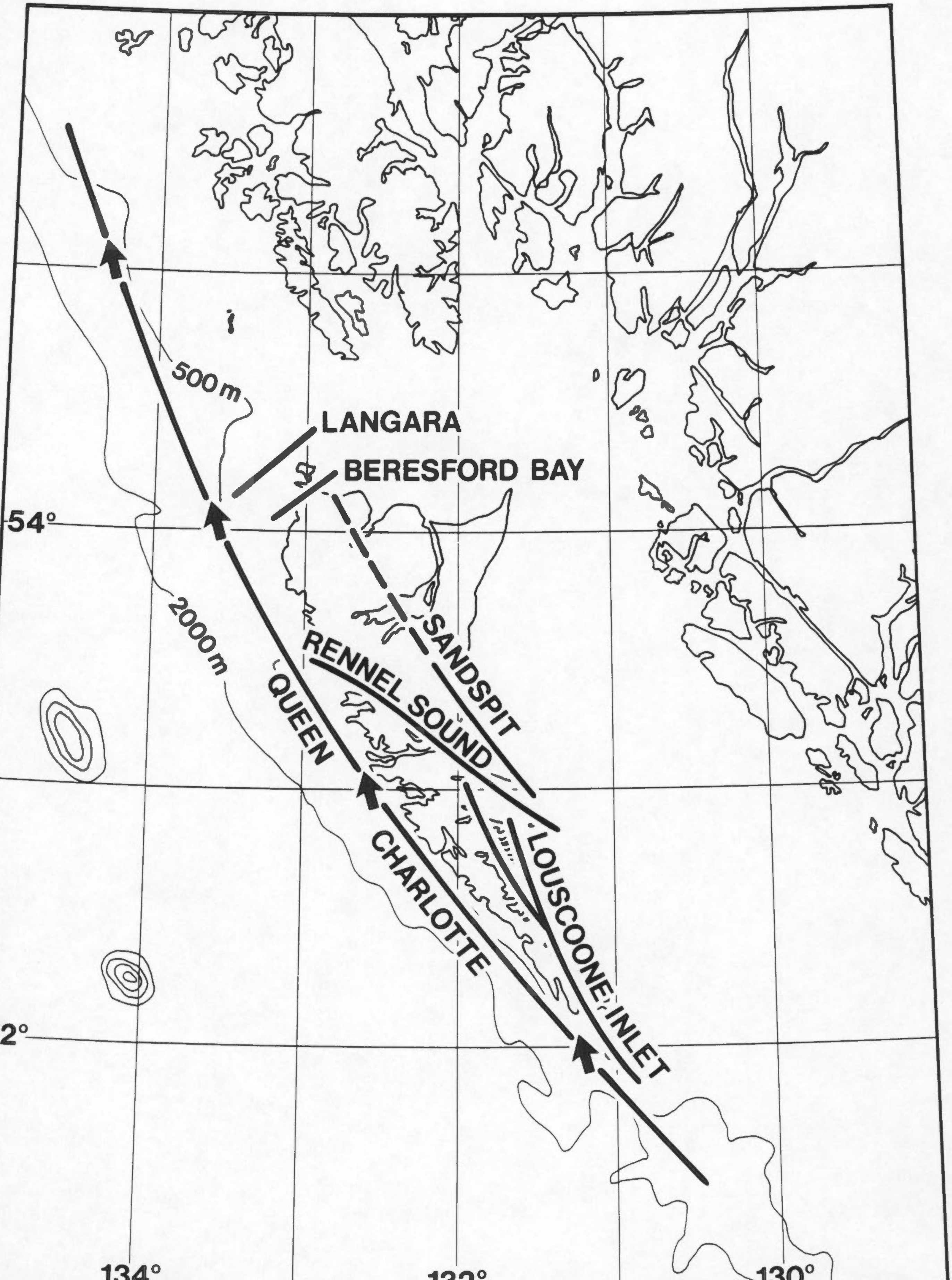
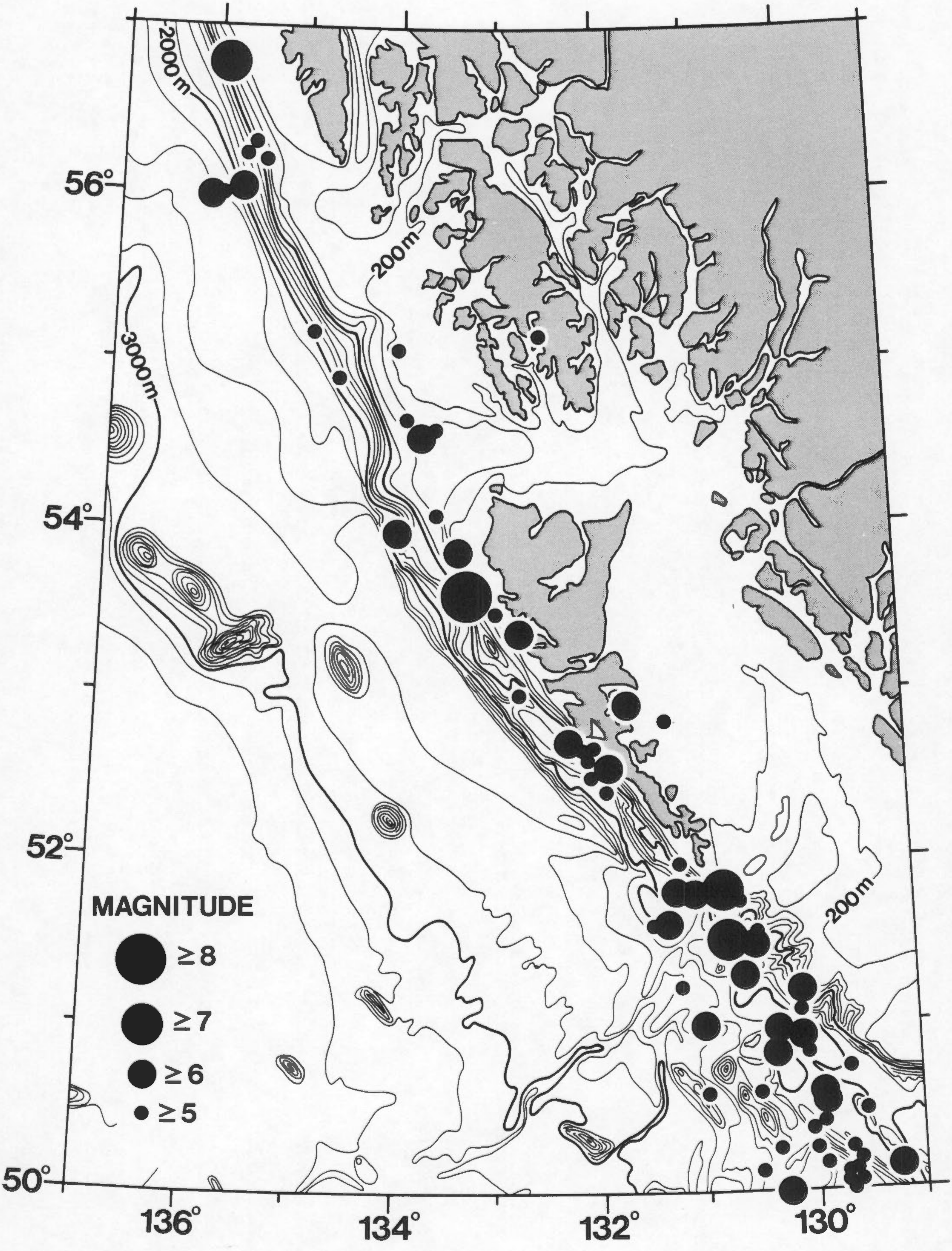

LANGARA
BERESFORD BAY
500 m
2000 m
SANDSPIT
RENNEL SOUND
QUEEN
CHARLOTTE
LOUSCOONE INLET
54°
52°
134°
132°
130°

Figure 3



-2000 m
2000 m
3000 m
200 m
200 m
56°
54°
52°
50°
136°
134°
132°
130°
MAGNITUDE
≥ 8
≥ 7
≥ 6
≥ 5

Figure 4

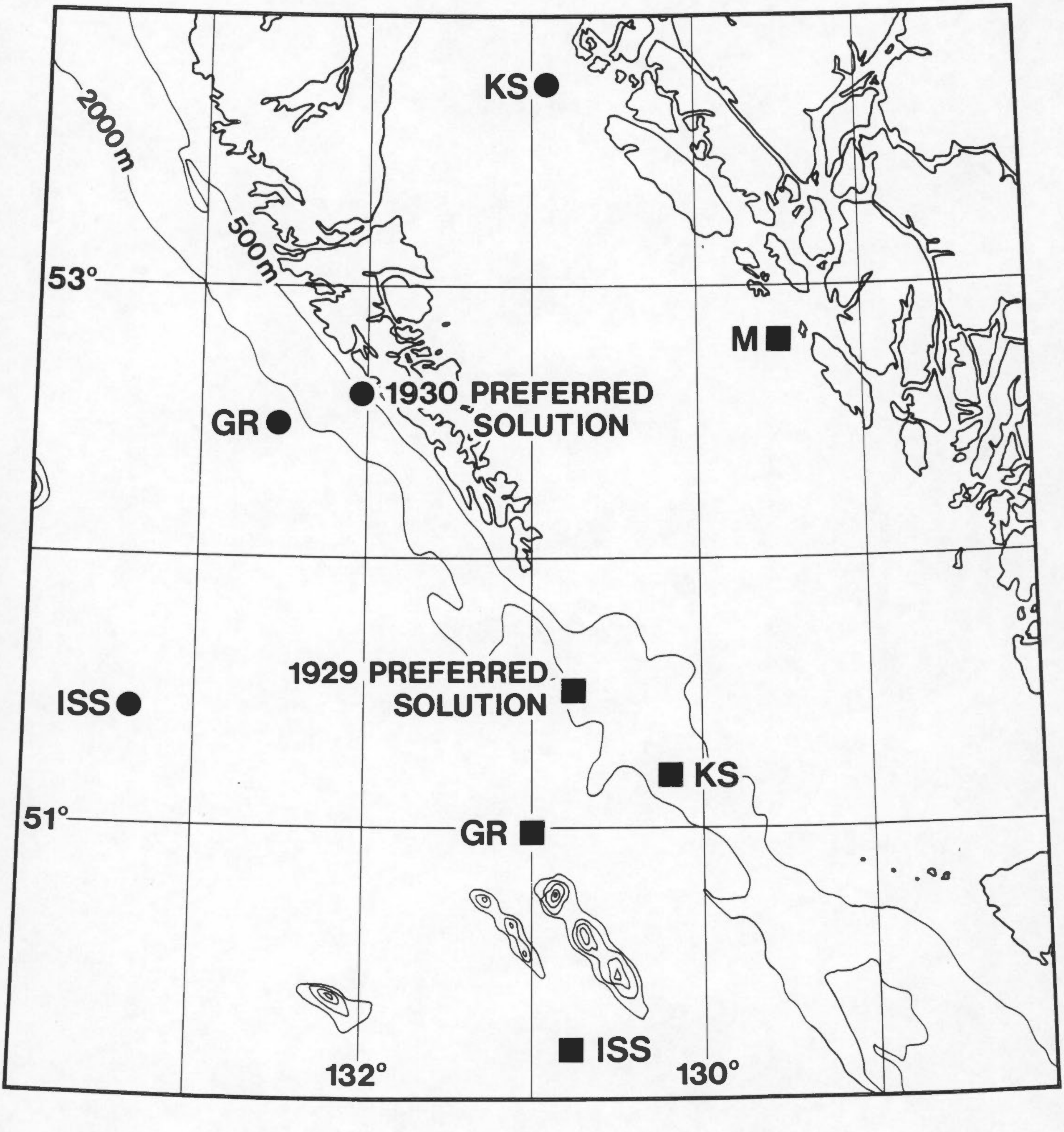

KS
2000m
500m
53°
M
1930 PREFERRED SOLUTION
GR
1929 PREFERRED SOLUTION
ISS
KS
51°
GR
ISS
132°
130°

Figure 5

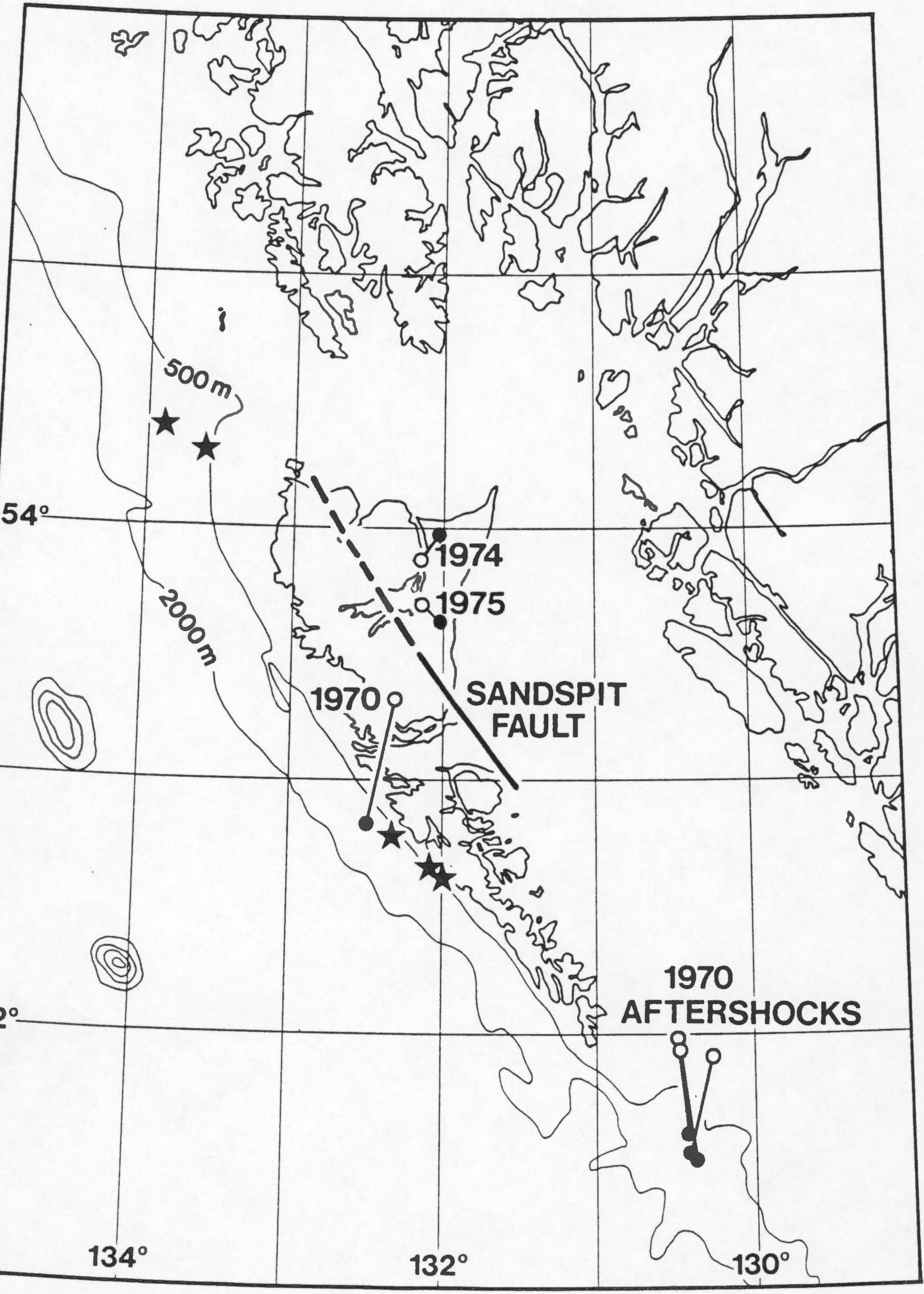
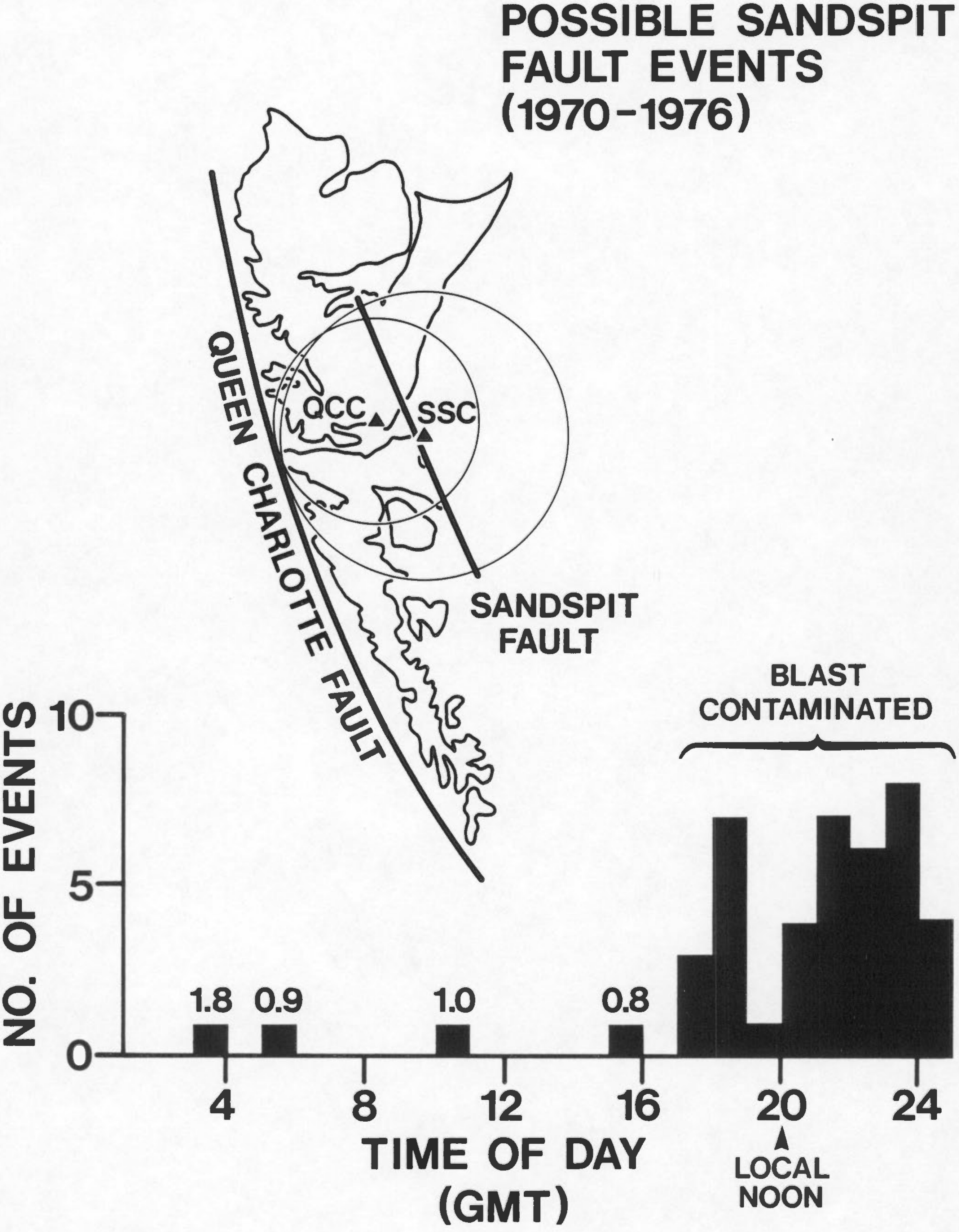

500 m
2000 m
54°
52°
134°
132°
130°
1974
1975
1970
SANDSPIT
FAULT
1970
AFTERSHOCKS

Figure 6



POSSIBLE SANDSPIT FAULT EVENTS (1970-1976)

Figure 7

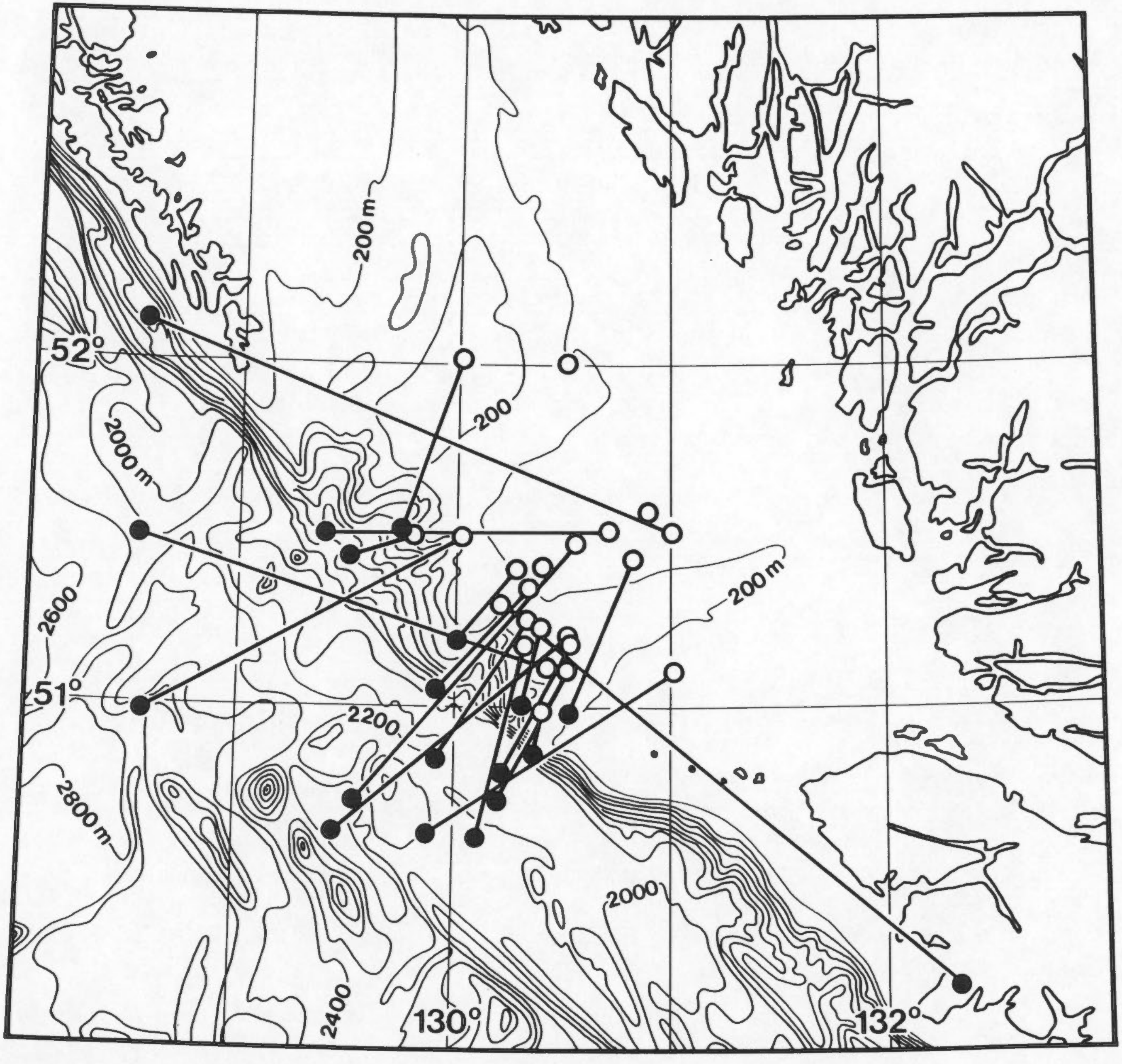


Figure 8

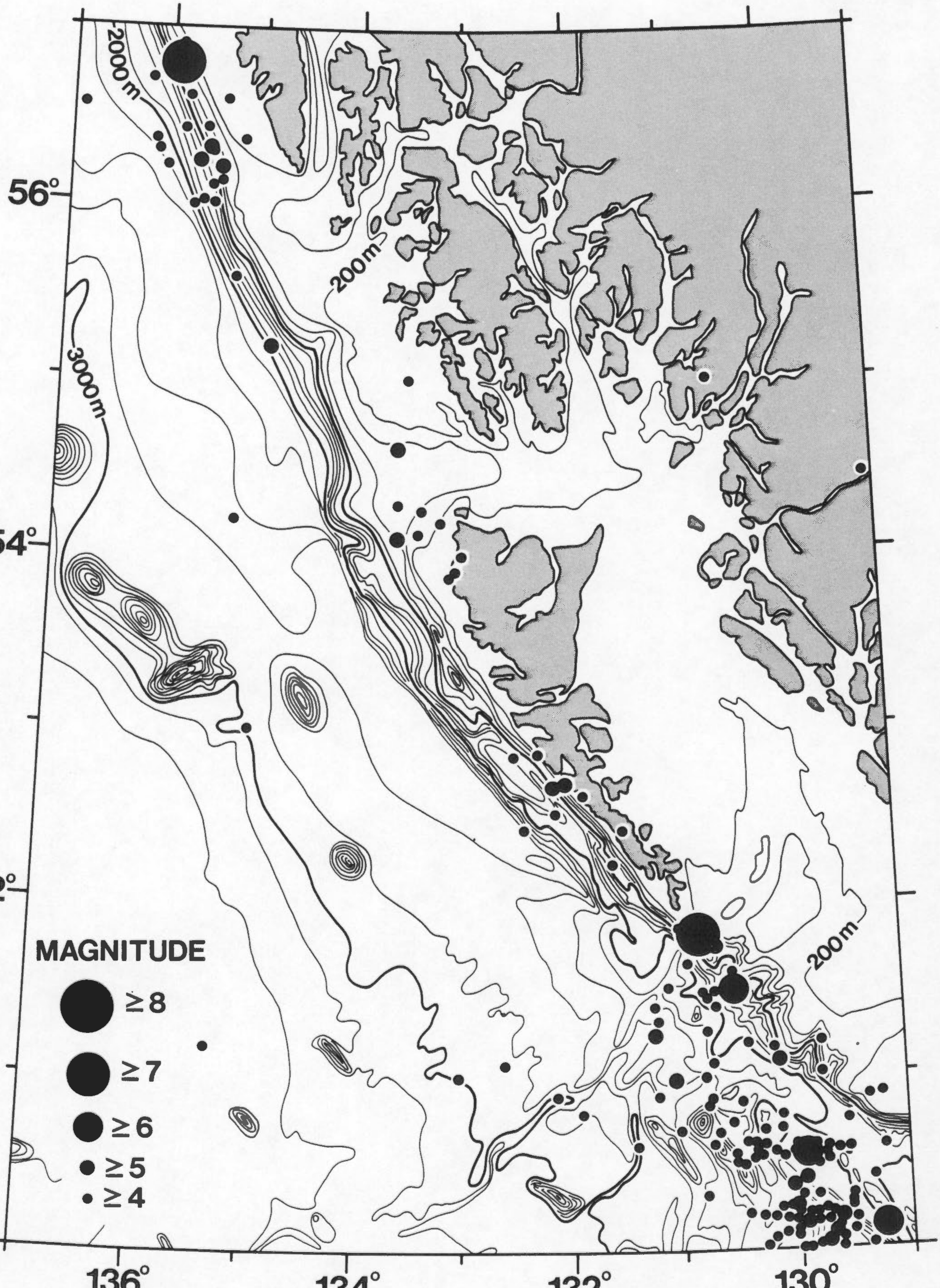

2000m
200m
3000m
200m
56°
54°
52°
50°
136°
134°
132°
130°
MAGNITUDE
● ≥8
● ≥7
● ≥6
● ≥5
● ≥4

Figure 9

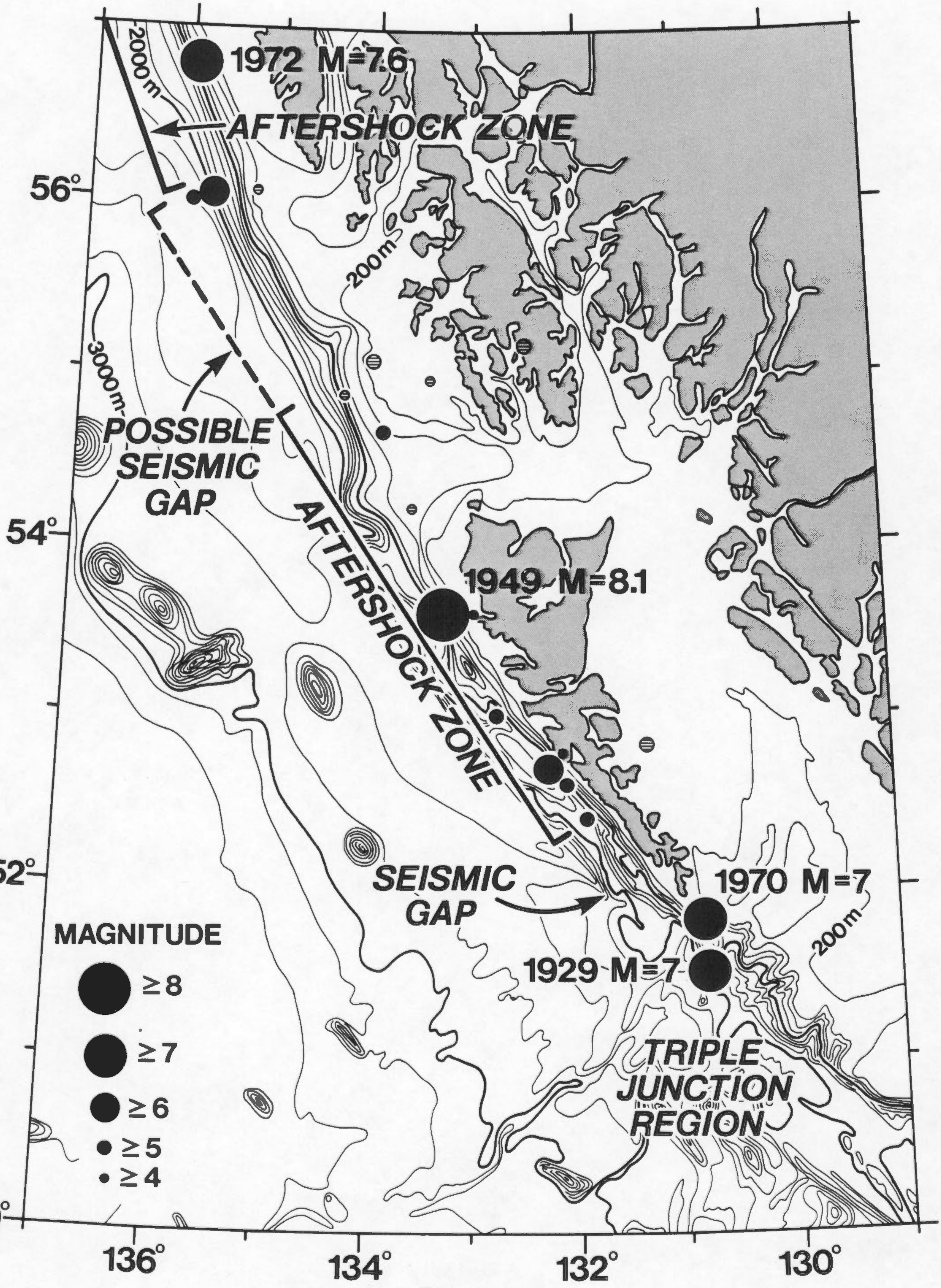
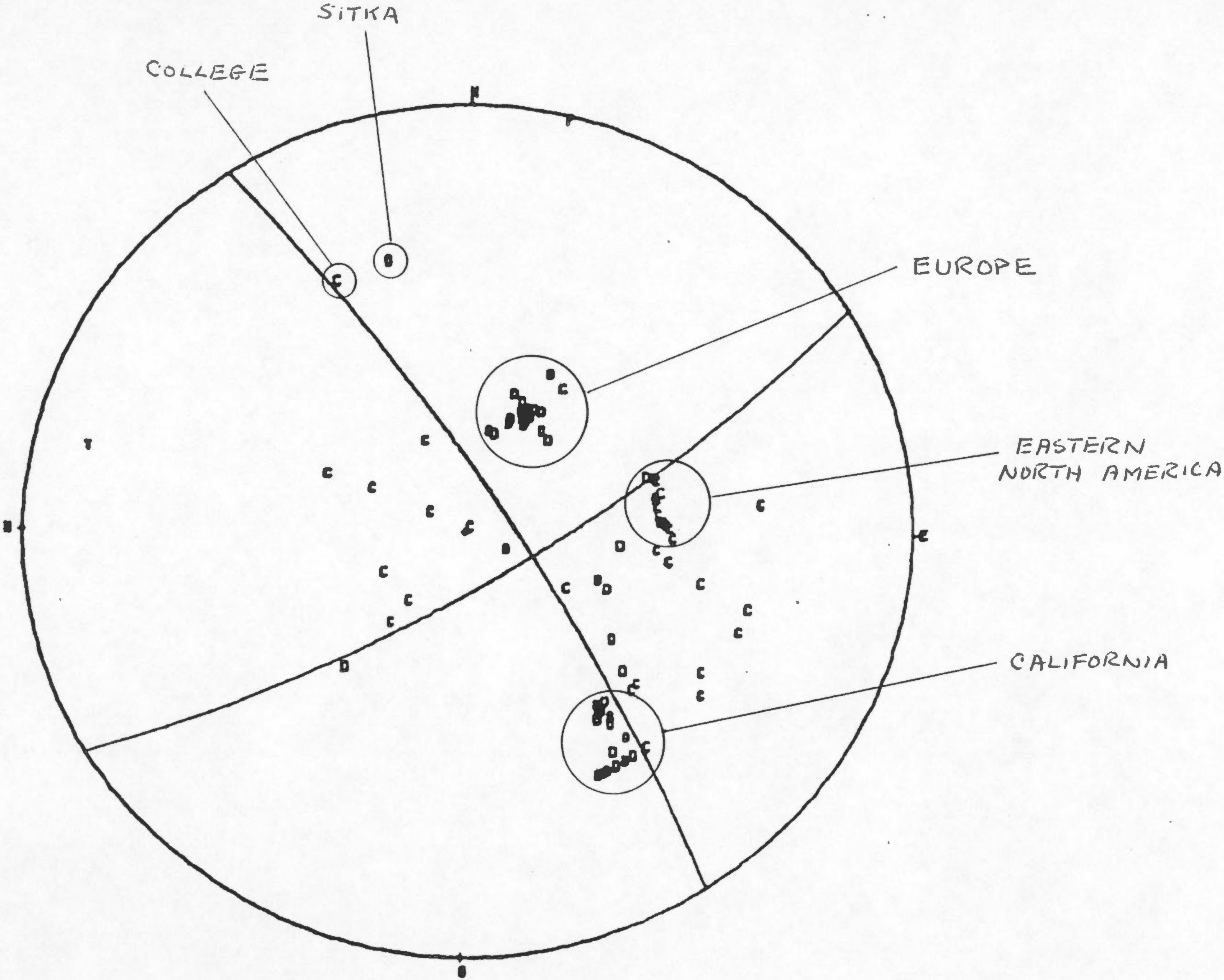

1972 M=7.6
2000 m
AFTERSHOCK ZONE
56°
200 m
3000 m
POSSIBLE
SEISMIC
GAP
54°
1949 M=8.1
AFTERSHOCK ZONE
52°
SEISMIC
GAP
1970 M=7
200 m
1929 M=7
MAGNITUDE
≥ 8
≥ 7
≥ 6
≥ 5
≥ 4
TRIPLE
JUNCTION
REGION
50°
136°
134°
132°
130°

Figure 10



SITKA
COLLEGE
EUROPE
EASTERN NORTH AMERICA
CALIFORNIA
N
E
S
W

Figure 11

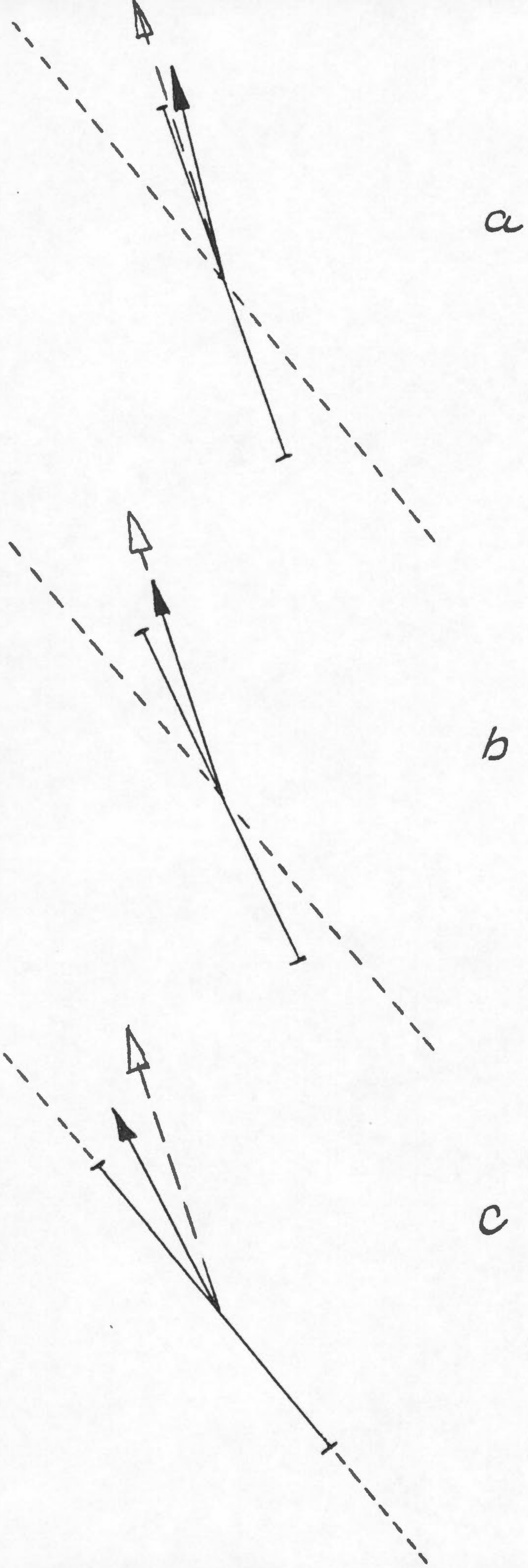


Figure 12

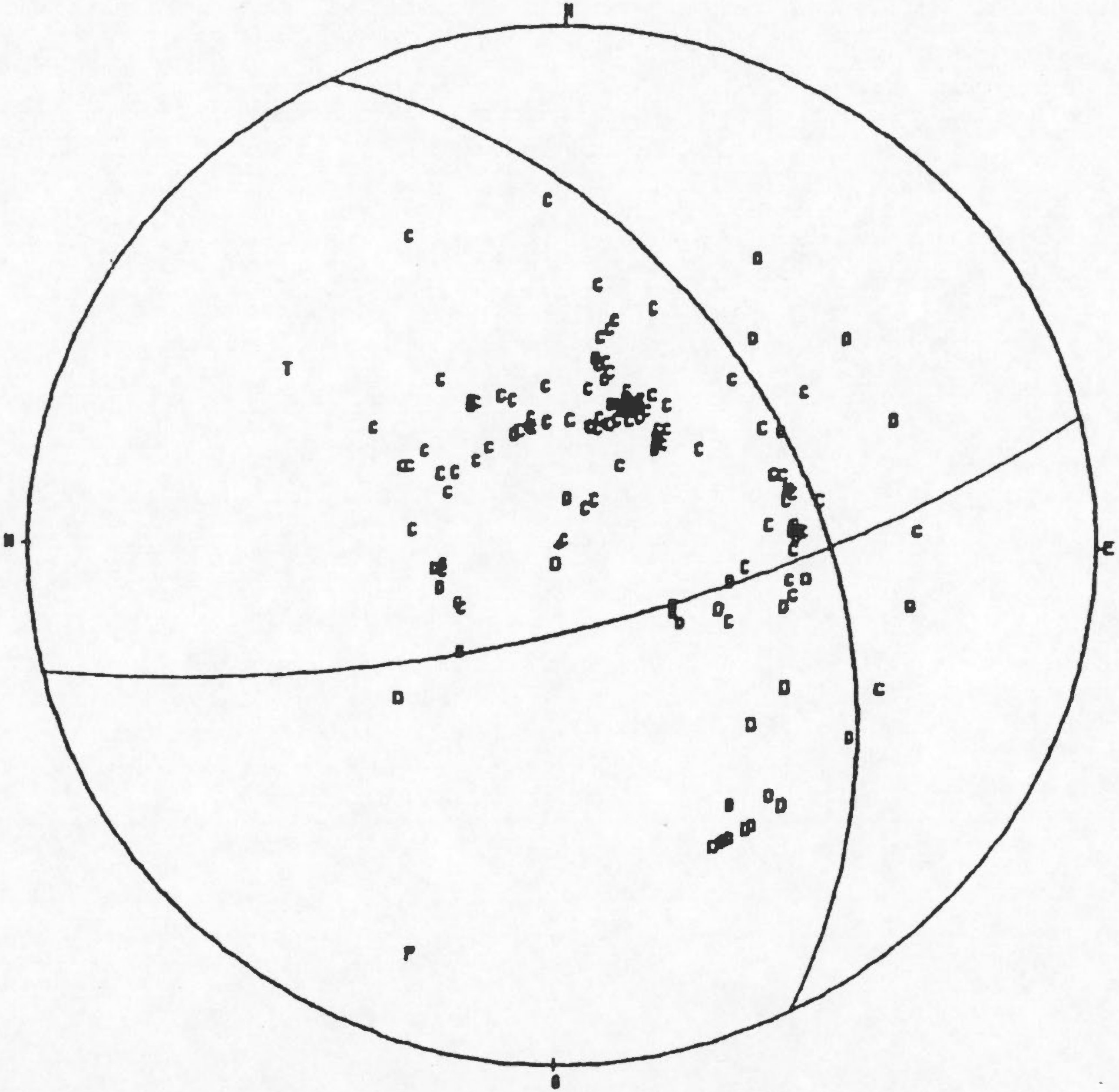
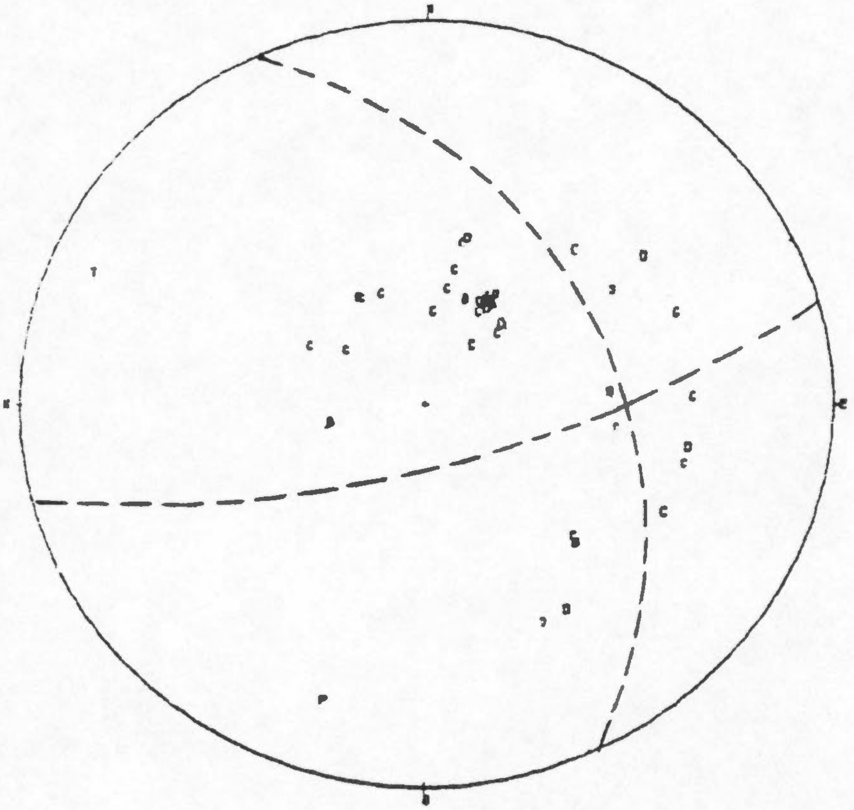


Figure 13

FORESHOCK



AFTERSHOCK

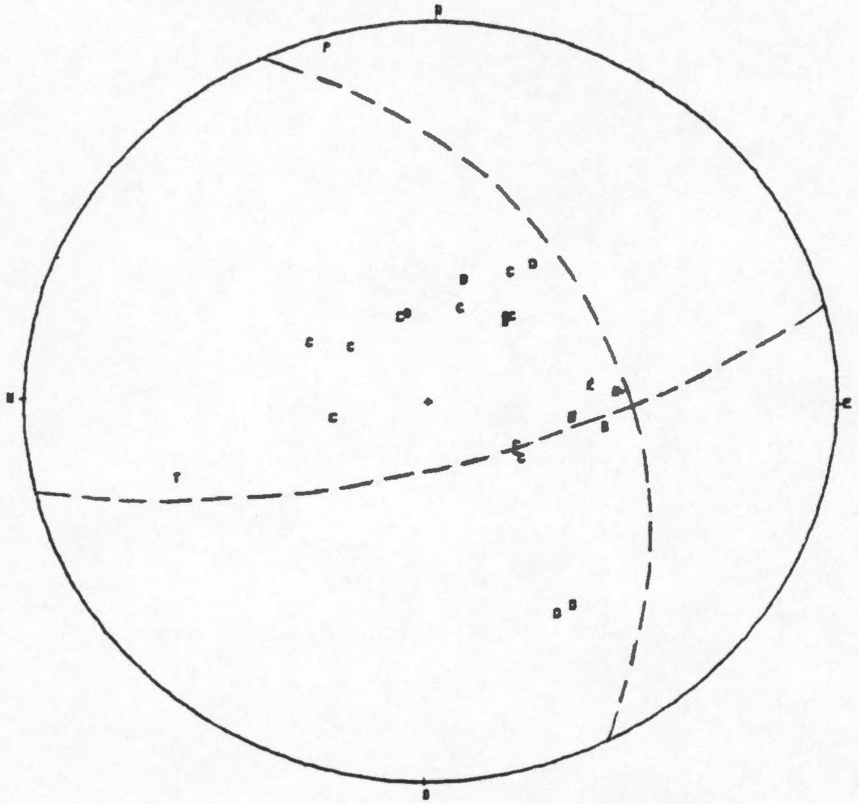


Figure 14

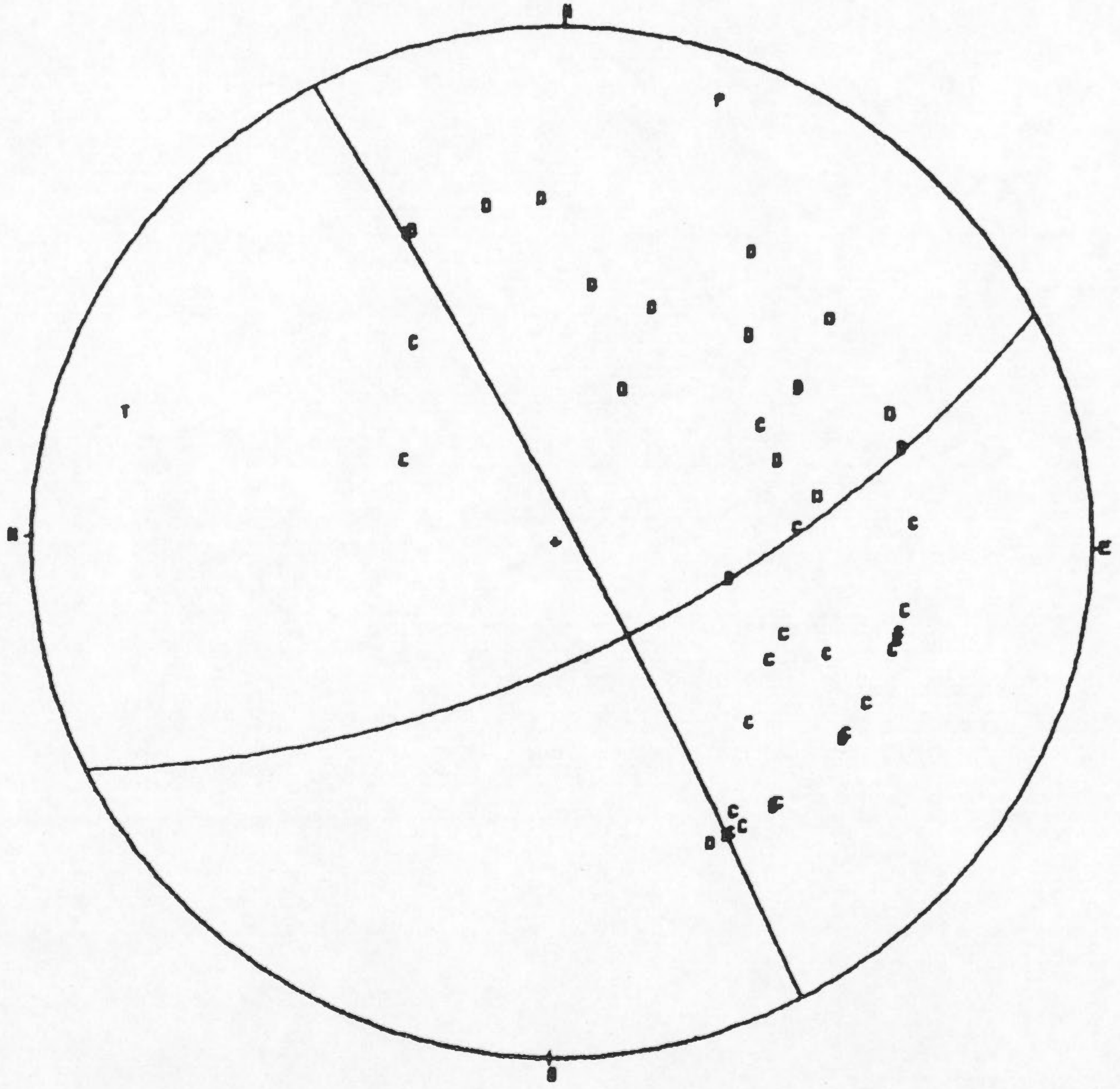
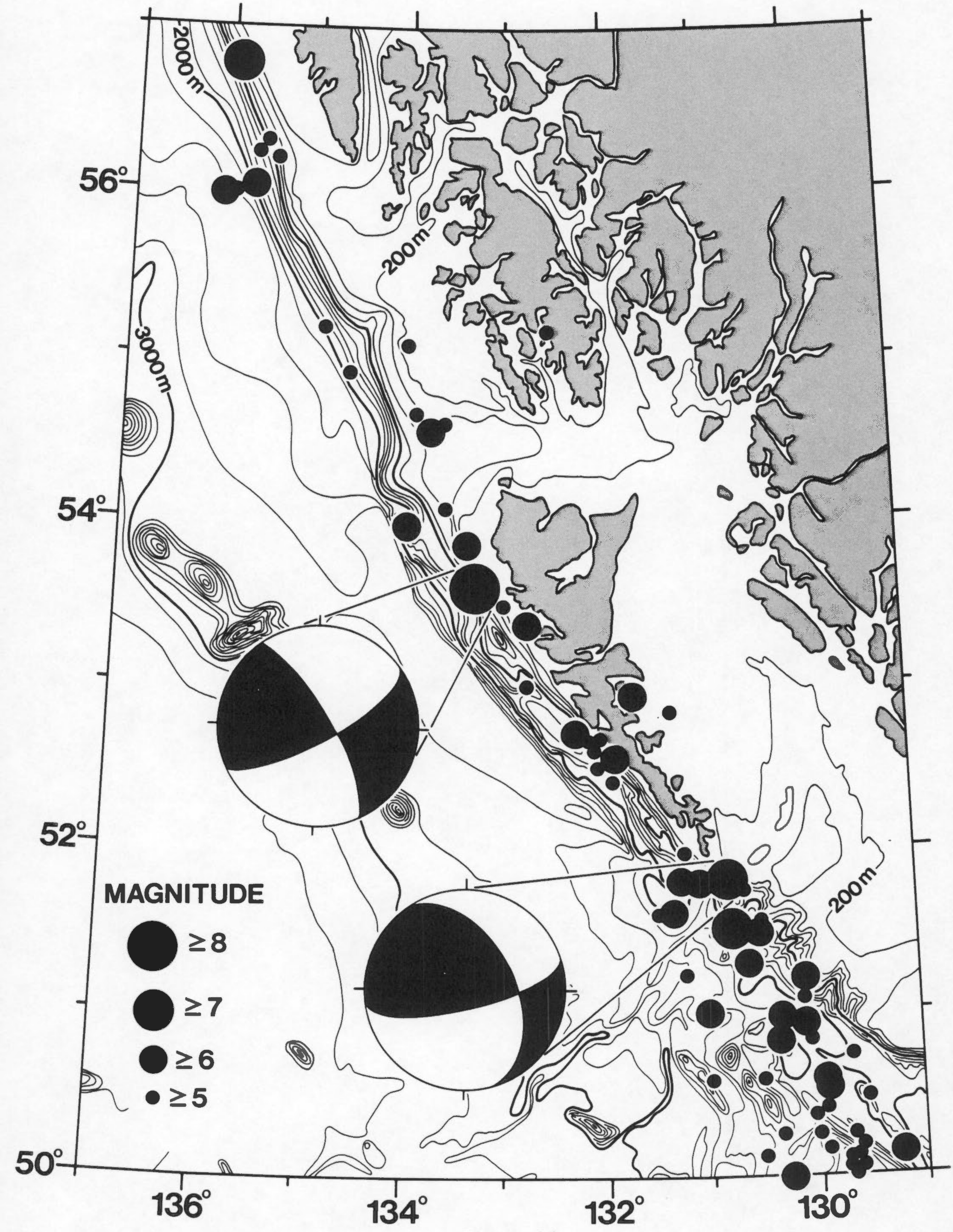


Figure 15



2000m
200m
3000m
56°
54°
52°
50°
136°
134°
132°
130°
200m
MAGNITUDE
≥ 8
≥ 7
≥ 6
≥ 5

Figure 16