Studies of Benioff-Zone Earthquakes Within the Anchorage, Alaska, Region

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Element II
Seismology, source characteristics, seismotectonics

Investigations Undertaken:

The proposed research focuses on Benioff zone (lower plate) earthquakes of the Anchorage region (within ~150 km of Anchorage). Benioff zone earthquakes represent one of two important seismic source zones for the Anchorage region. Historically, these earthquakes have produced significant damage (intensities of VII to VIII) within the Anchorage urban region. Since these lower plate earthquakes have smaller magnitudes than events along the plate interface, they may also be expected to have shorter repeat times. The research builds upon previous teleseismic waveform modeling and relocation studies of large (M_w>6.0), historic (1928-1964) earthquakes and moderate (M_w>5.7), recent, earthquakes (1964-1988) in both the upper and lower plates, as well as ongoing detailed relocation studies of upper plate seismicity (1971-2001). The tasks to be accomplished for this study include: 1) detailed relocations of recent Benioff zone events (1964-present), with use of waveform cross correlation techniques for higher precision locations whenever possible, 2) regional waveform modeling and empirical Greens function analysis of recent moderate (M_w>5.0) earthquakes (1988-present) to determine focal mechanisms, seismic moments, stress drops, focal depths and fault rupture processes, 3) teleseismic and regional waveform modeling of $5.7<m_b<6.3$ Benioff zone earthquakes occurring up to 15 years prior to the 1964 mainshock, 4) examination of intensity data for historic and recent Benioff zone events to determine how these deeper events affect ground motion in the Anchorage region.

Ms. Annette Veilleux has worked as a research assistant on this project. She has completed relocation of Benioff zone earthquakes occurring within the Anchorage region between 1988 and 2000 using HypoDD (Waldhauser and Ellsworth, 2000) and presented initial results of her research at the fall 2003 Society of Chicanos and Native Americans in Science (SACNAS) meeting (Veilleux, 2003).

Dr. Doser completed relocation of older Benioff zone events occurring between 1971 and 1988. She has collected data from the International Seismological Centre (ISC) for Benioff zone events occurring between 1964 and 1971 and is presently reformatting these phase data for relocation. A master event technique will be used to relocate pre-1964 seismicity using suitable post-1970 earthquakes. She has completed collection of all available intensity information and has begun developing intensity distance relationships for the Anchorage region. Initial results of this research will be presented at the spring 2004 meeting of the Seismological Society of America.

A paper on changes of crustal seismic moment rates in the Anchorage region following the 1964 Great Alaska earthquake will be published in the Bulletin of the Seismological Society of America in early 2004. This research has been conducted in collaboration with Dr. Natasha Ratchkovski (Alaska Earthquake Information Center), Dr. Peter Haeussler (USGS, Anchorage), and Dr. Richard Saltus (USGS, Golden). A paper on the crustal seismicity of the Anchorage region (with former graduate research assistant Claudia Flores) is in preparation. Ms. Flores defended her M.S. thesis entitled "A Study of the Shallow Seismicity in the Anchorage Region, South-Central, Alaska" in June 2003. Results of the research will also be presented at the Fall 2003 meeting of the American Geophysical Union (Flores and Doser, 2003). In July Dr. Doser visited with scientists at the USGS, Anchorage to discuss these results, as well as future research plans.

<u>Results:</u>

Task 1 (post-1964 relocations of Benioff zone events)

Relocations of 3,038 earthquakes occurring in the Pacific plate at depths > 25 km between 1988 and 1998 are shown in Figure 1. Phase data obtained from the Alaska Earthquake Information Center was used in this analysis. The colors of the symbols reflect depth as indicated. The majority of earthquakes < 50 km depth are located in the northern portion of the study area and in Cook Inlet southwest of Anchorage. The deepest events (> 90 km) are located northwest of Cook Inlet and within Central Cook Inlet.

Figure 2 shows 4,539 events occurring between 1971 and 1988 that were relocated using phase data from the U.S. Geological Survey's data base. Note that there are considerably more events at depths < 50 km during this time period. This likely reflects stress redistribution in the Pacific plate following the 1964 Prince William Sound earthquake. Thus there appears to be a strong down-dip migration of seismicity through time. Deeper events (> 90 km) also appear to be more uniformly distributed along the slab during this time period.

We have only begun to make cross sections to investigate spatial and temporal patterns within the region. We hope to add additional relocations from events occurring in 1964-1971 to further verify the down dip migration of seismicity through time following the 1964 mainshock.

Task 2 (regional waveform modeling, post-1983 events)

We are in the process of collecting digital waveform data for Pacific Plate events (M≥5.0) shown in red in Figure 3. Note that many of the events within Upper Cook Inlet have similar hypocenters so that they can be used in empirical Greens function analysis studies.

Task 3 (teleseismic and regional waveform modeling of events occurring between 1950-1964)

Teleseismic and regional waveform data have been collected for many suspected Pacific Plate events occurring 15 years prior to the 1964 mainshock, as well as for events occurring prior to the onset of digital recording (in ~1983) . Figure 3 shows all events of M≥5.0 occurring between 1950 in 1983 in blue. Note that many of the events occur either north or south of more recent earthquakes, which will hamper the use of the most recent events as empirical Greens functions for source parameter analysis of the older events.

Task 4 (analysis of intensity information)

We have collected intensity data for earthquakes occurring in the Anchorage region between 1964 and 1985 from the NOAA intensity web site. In addition, we have used zip code/internet response-based intensity information collected from the USGS's "Did You Feel It?" data archive (pasdena.wr.usgs.gov/shake/ak).

Intensity-median distance information for 8 events occurring in the study area between 1964 and 2002 is shown in Figure 4. With the exception of the 1964 mainshock (a plate interface event) and the August 1984 Sutton earthquake (a crustal event), all events occurred within the subducting Pacific Plate. The pattern of the fall-off of intensity with distance is very similar for the 1964 mainshock, the Pacific plate events in 1968 and July 1983, and the 1984 Sutton earthquake. All events have $M_w \geq 5.7$. In contrast, the three Pacific Plate events with $M_w \leq 5.1$ show a different fall-off. The 2002 events occurred nearly directly beneath Anchorage so that intensity variations may have been strongly controlled by near site effects, since many sites were nearly equidistant from the earthquakes. The March 1978 event was a 90 km deep event located on the western side of Cook Inlet. This location could skew intensity observations, since few people live west of the Inlet. However, the December 1968 event also occurred west of Cook Inlet at a depth of 86 km and appears to follow the fall-off pattern of other M_w>5.1 events. This suggests that the steeper fall-off for March 1978 may be controlled more by its lower magnitude. The September 1983 event (M_w=6.4) exhibits a fall-off in intensity that appears to mix aspects of the two dominant fall-off patterns. This event occurred very close to the hypocenter of the July 1983 event, but had a slightly different focal mechanism.

These preliminary results suggest that events of $M_w \geq 5.7$, regardless of position (crust, interface, subducted slab), may create similar amounts of shaking. This could make it difficult to use intensity information from historical events to help estimate event focal depth. The 2002 events may also serve as a good model for intensity fall-off for larger events occurring directly beneath Anchorage. We have also collected intensity data for events in the Alaska interior, Kodiak Island region, and southeastern Alaska with the hope we will be able to compare intensity fall-off between regions.

Related Studies

In addition to progress toward our four tasks outlined above, we have conducted studies of seismic moment rates in the Anchorage region and have studied the crustal seismicity of the Denali fault zone (1912-1988). Our seismic moment rate calculations show a factor of 1000 decrease in moment rates following the 1964 mainshock. We then used geologic information on structures within Cook Inlet basin (e.g. Haeussler et al., 2000) to estimate a regional geologic moment rate. Since it is difficult to estimate the amount of horizontal offset that has occurred along these structures, our geologic moment rates could underestimate the true rates by up to 70%. Nevertheless, the geologic moment rate is only 4 to 10 times lower than the pre-1964 mainshock seismic moment rate. This suggests that the 1964 mainshock has significantly slowed regional crustal deformation. If we compare the geologic moment rate to the post-1964 mainshock rate, the moment rate deficit over the past 36 years is equivalent to a Mw 6.5 to 6.8 earthquake. This highlights the difficulty in using seismicity in the decades following a large megathrust earthquake to adequately characterize long-term crustal deformation. These results will be published in the Bulletin of the Seismological Society in February 2004.

A paper on historical seismicity of the Denali fault zone is in preparation for a special issue of the Bulletin of the Seismological Society of America. The paper concentrates on seismicity prior to 1971, although we have relocated earthquakes occurring between 1971 and 1998. For pre-1971 events we used the bootstrap relocation technique of Petroy and Wiens

(1989). Figure 5 shows the relocations for 1912-1971. In addition to the relocations, we conducted waveform modeling for events of M>6.0.

The waveform modeling and earthquake locations suggest that most M>6.0 events occurred on strike-slip or reverse faults located either south or north of the Denali fault. A magnitude 6.5 event in 1929 (Figure 5) appears to have occurred within the subducting slab at a depth of ~ 60 km. Events in 1962 appear to have occurred upon a reverse fault that may be the extension of the Pass Creek fault. A magnitude 6.9 event in 1932 appears to be a deeper event (~30-40 km) along a left-lateral strike-slip fault. Of considerable interest is the July 7, 1912 earthquake (M~7.2). We have relocated it to the vicinity of the Denali fault, although its 95% confidence ellipse is very large (Figure 5). We have attempted to locate seismograms for this event in several data archives, however, to date have been only able to obtain records from Riverview, Australia. Surface wave amplitudes observed on these seismograms are not inconsistent with rupture along the Denali fault. If the 1912 event actually occurred on the Denali fault, this may explain why the portion of the Denali fault located between the October 2002 Nenana Mountain rupture zone and the November 2002 Denali rupture zone was relatively aseismic during the 2002 sequence.

Non-technical Summary:

This study focuses on earthquake hazards of the Anchorage, Alaska region. Major tasks in the study are to relocate and merge hypocentral data for the 1950-2001 time period in order to examine the nature of deeper Pacific plate earthquake source zones near Anchorage and model seismic waveforms to better understand seismic sources within the Pacific plate. We will also compile intensity information for earthquakes in the region, which will provide insight into variations in ground shaking and their relationship to local geologic conditions.

Reports Published:

Doser, D.I., N. Ratchkovski, P. Haeussler, and R. Saltus, Changes in crustal seismic deformation rates associated with the 1964 great Alaska earthquake, in press, Bull. Seismol. Soc. Amer., 2003.

Flores, C., and D.I. Doser, A study of shallow seismicity (1971-1999) in the Anchorage region, Alaska, abstract, to be present at Fall 2003 meeting, Amer. Geophys. Union.

Veilleux, A.M., Seismicity of the subducting slab, Upper Cook Inlet, south-central Alaska, annual meeting, Soc. For Adv. Of Chicanos and Native Amer. in Science, Albuquerque, NM, 2003.

Availability of Data Sets:

Copies of phase data and intensity data that are being used in the analysis will be available in paper or digital form. First motion data and waveform data are also available in digital form. Contact the principal investigator, Dr. Diane Doser, for more details at (915)-747-5851 or doser@geo.utep.edu.

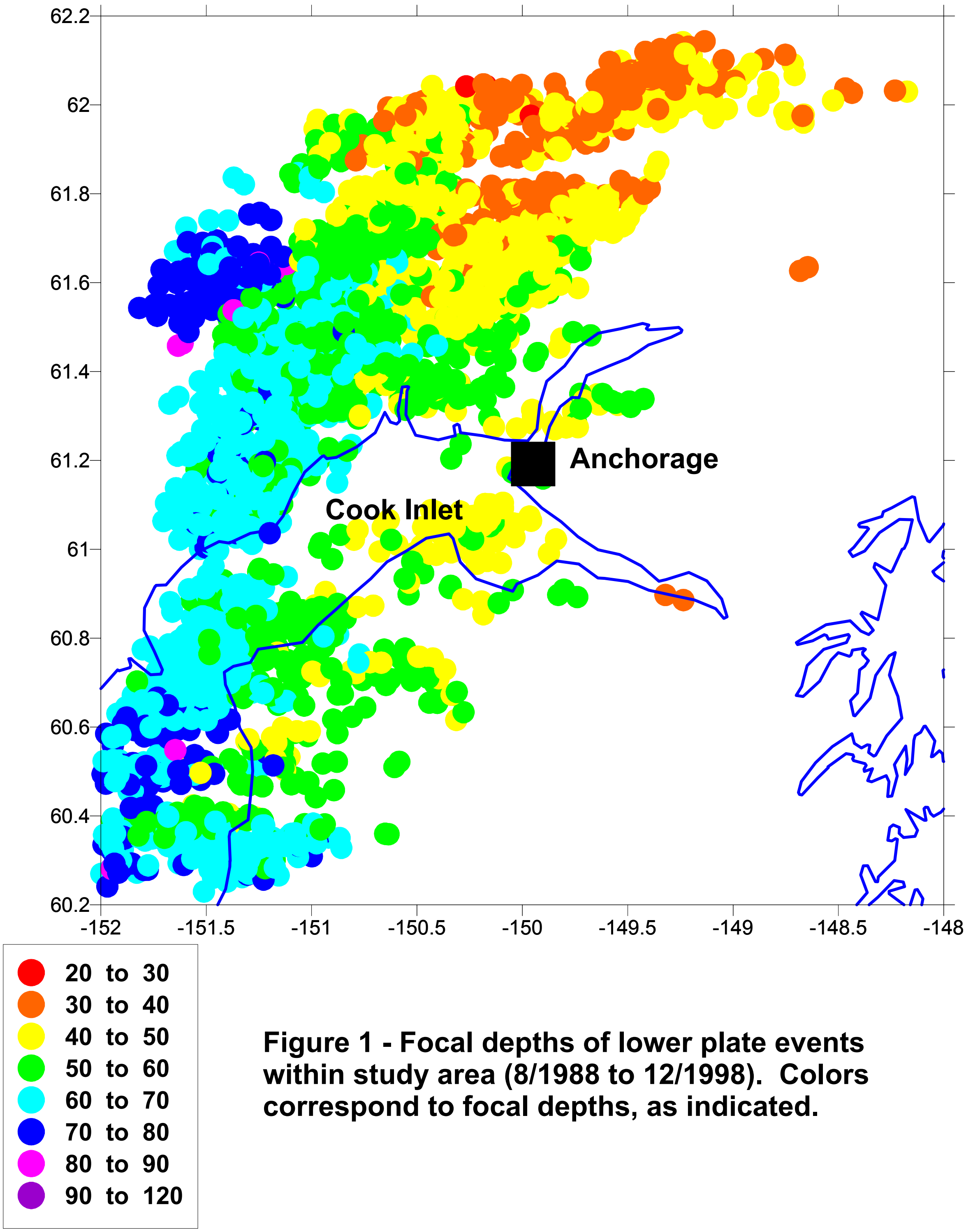

Figure 1 - Focal depths of lower plate events within study area (8/1988 to 12/1998). Colors correspond to focal depths, as indicated.

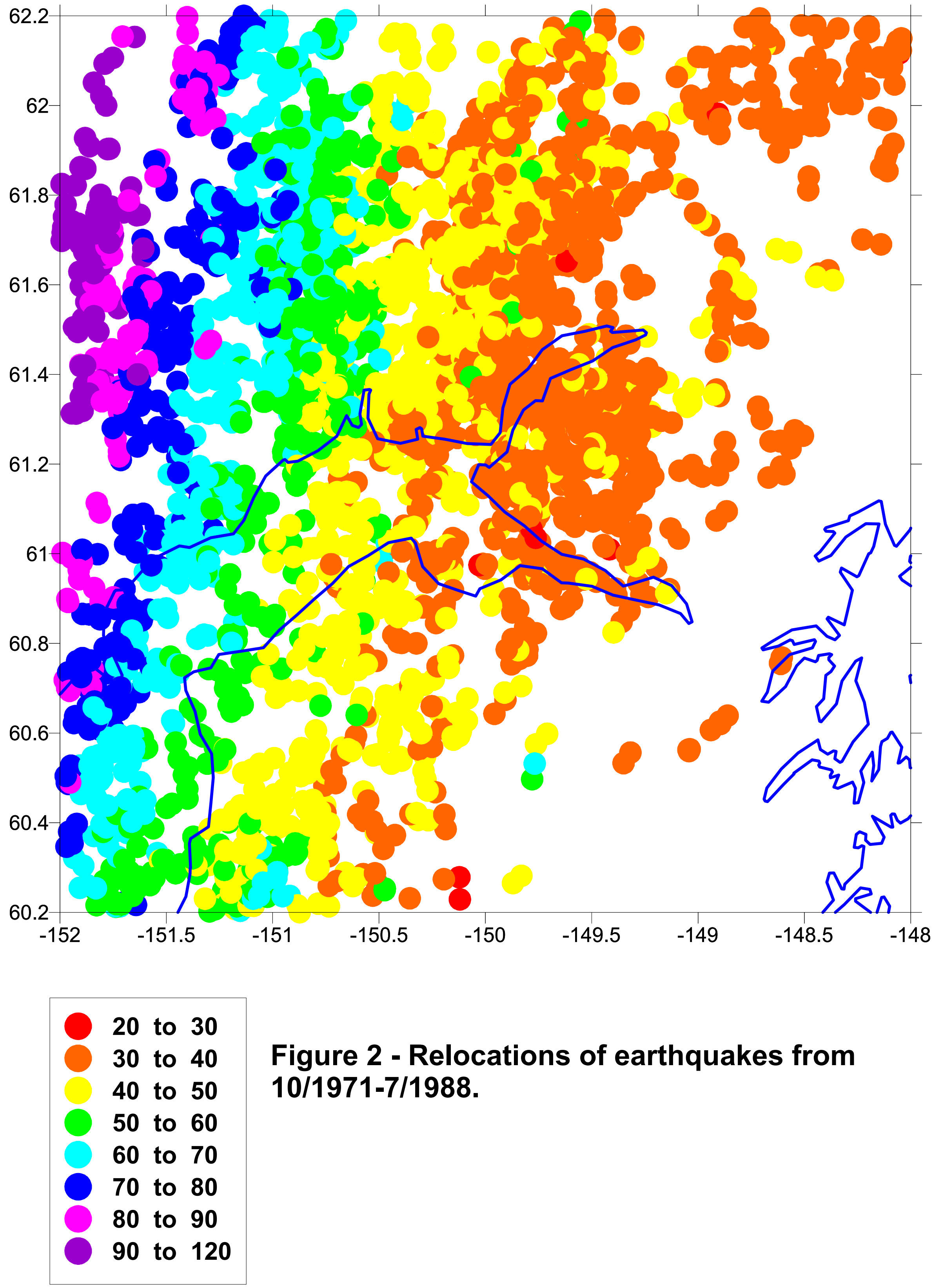

Figure 2 - Relocations of earthquakes from 10/1971-7/1988.

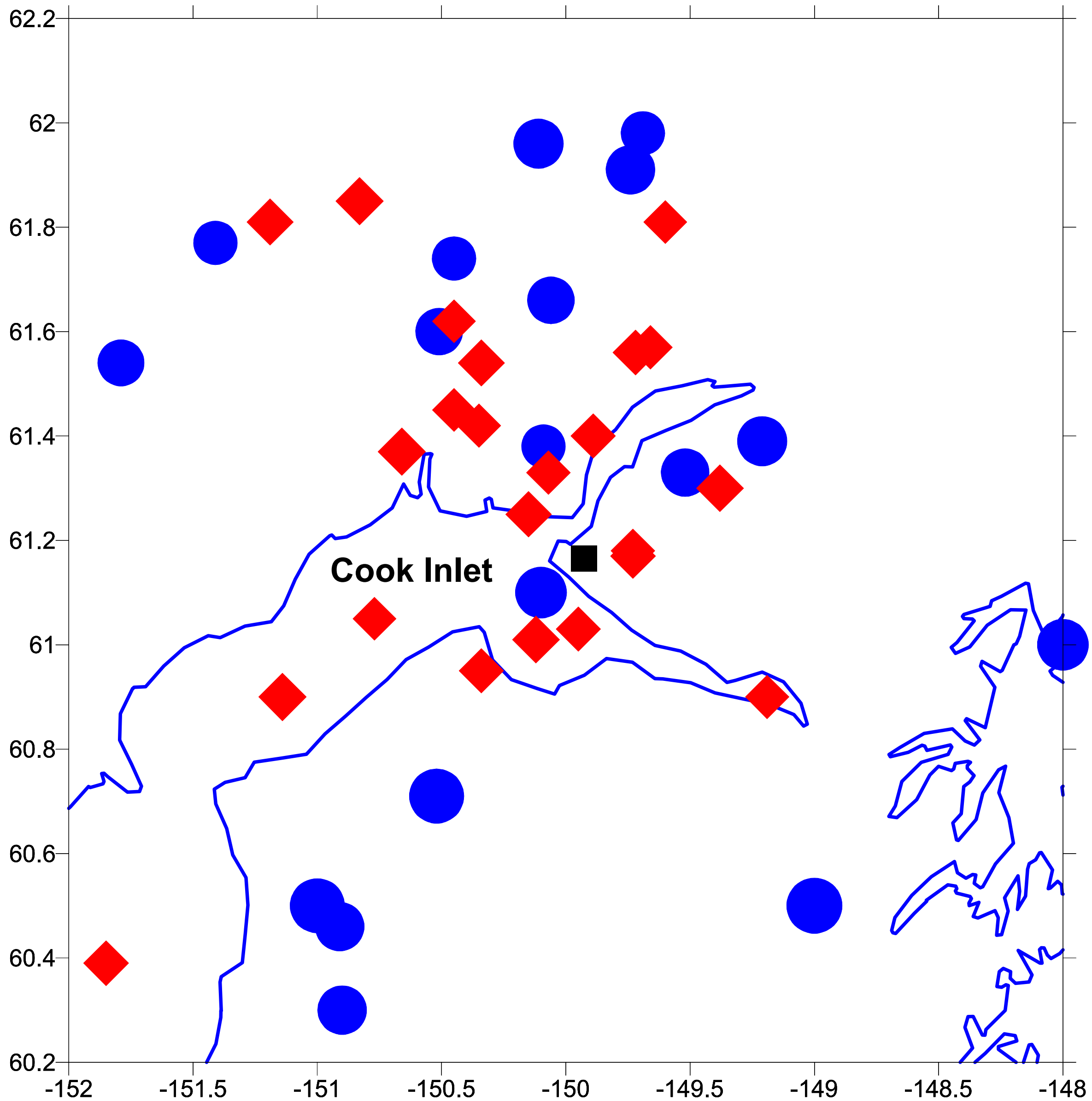

Figure 3 - M>=5.0 events for waveform modeling studies. Red symbols are post-1982 events, blue symbols are pre-1983 events. Event size is scaled to magnitude. Black square indicates Anchorage.

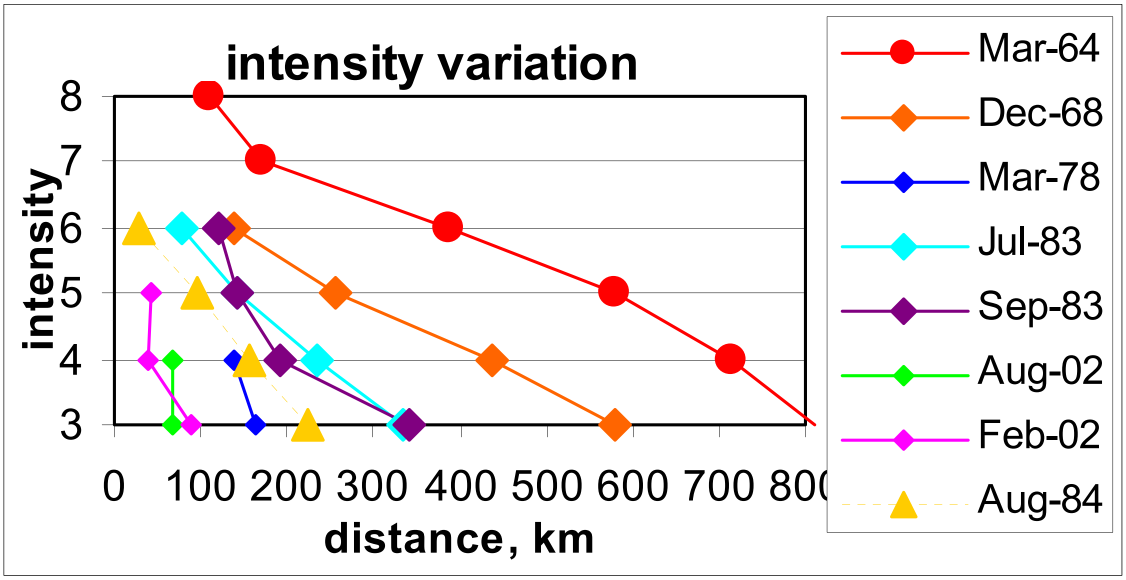

Figure 4 – Median intensity versus distance for events of the study area. Symbol size scaled to magnitude. The 1984 earthquake is a crustal event, the 1964 earthquake is a plate interface event, and all others are within the subducted Pacific plate.

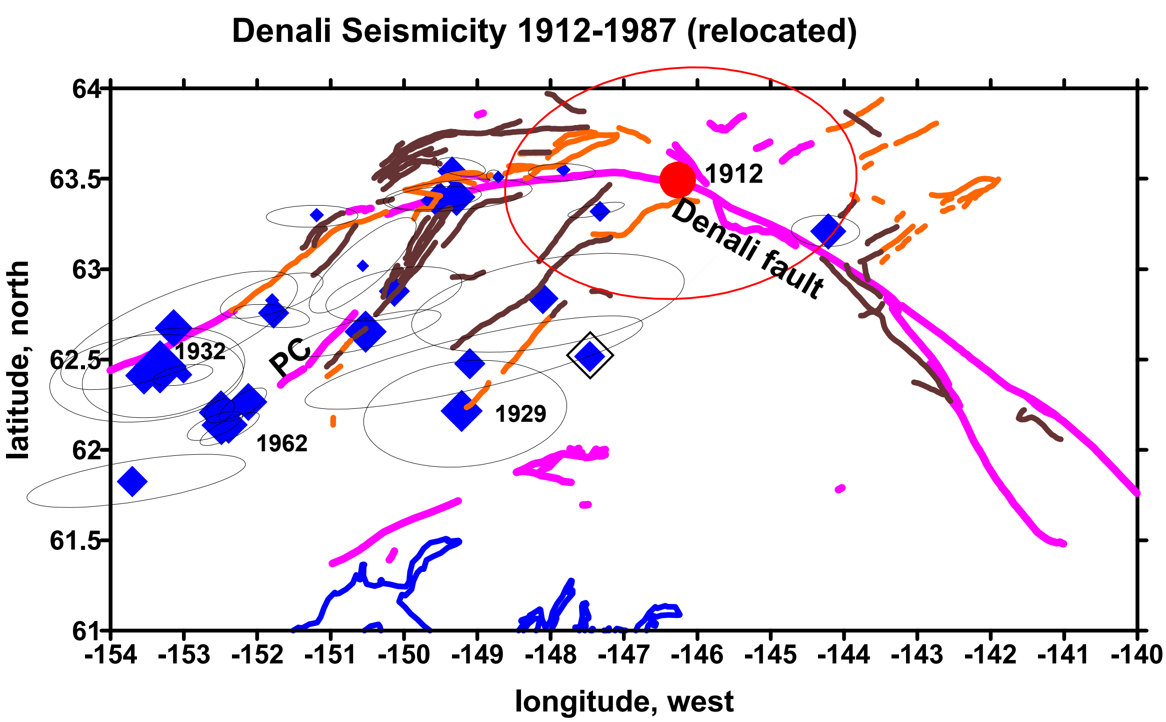

Figure 5 - Relocated earthquakes of the Denali fault system. Error ellipses indicate 95% confidence intervals. Events of interest are labled by date. Magenta lines are Holocene to late Pleistocene age faults, orange are Neogene faults, and brown are pre-Neogene faults from Plafker et al. (1994). PC=Pass Creek fault