Merging Historical and Recent Records of Seismicity to Better Define Earthquake Source Zones within the Anchorage Region

01HQGR0159
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Element I
Geophysics, seismology, source characteristics, seismotectonics

Investigations Undertaken:

This research concentrates on merging results of studies of historic and recent earthquakes to better define earthquake source zones in the Anchorage region (within ~100 km of Anchorage). The study involves 5 main tasks: 1) relocation and merging of recent seismicity (1971-present) recorded by the U.S. Geological Survey (1971-1988) and the Alaska Earthquake Information Center (1988-present), 2) relocation of older events (1928-1971) using recent events as master events, 3) waveform modeling studies of moderate (5.4<M<6.5) events occurring up to 15 years prior to the 1964 mainshock, 4) collection of intensity information for historic and recent earthquakes, and 5) Coulomb failure stress modeling studies of crustal events.

Ms. Claudia Flores worked as a research assistant on the earthquake relocation portion of this project. She had relocated crustal earthquakes within the Anchorage region (1988-2000) using HypoDD (Waldhauser and Ellsworth, 2000) and will present results of her research at the fall 2002 meeting of the American Geophysical Union.

In the summer of 2002 Ms. Flores was hired as a research assistant at Los Alamos National Laboratory, so Mr. Peter Murray was hired during the summer to assist with digitizing seismograms of moderate earthquakes occurring 15 years prior to 1964 within the Cook Inlet region. He also completed digitizing seismograms of pre-1964 mainshock events within the Kodiak Island region.

Dr. Doser completed relocation of older events using the master event technique in the spring 2002 as well as Coulomb failure modeling studies of the 1933 Upper Cook Inlet earthquake sequence and the 1984 Sutton earthquake. Results of this research were presented at the 2002 meeting of the Seismological Society of America. She has completed collection of all available intensity information and has begun developing intensity distance relationships for the Anchorage region. She also has begun reformatting phase data for the relocation of crustal events of the Anchorage region occurring between 1971 and 1988. In June 2002 she visited the U.S. Geological Survey in Menlo Park and presented results on analysis of changes in seismic moment rates before and after the 1964 Great Alaskan earthquake and their comparison to geologic moment rates. This research has been conducted in collaboration with Dr. Natasha Ratchkovski (Alaska Earthquake Information Center) and Dr. Peter Haeussler (USGS, Anchorage). A paper on seismicity within the Kodiak Island region following the 1964 mainshock was also accepted for publication by the Bulletin of the Seismological Society of America during the summer. In July she visited with USGS personnel in Anchorage to discuss future research plans as well as publication of collaborative results.

Results:

Task 1 (post-1964 relocations of crustal events)

The volume of phase data that had needed to be processed and reformatted has led us to focus on initial efforts on the relocation of crustal (<30 km) earthquakes during this study period. Results of our relocation of events occurring between 1988 and 2000 are shown in Figure 1. The brown lines denote faults and the red lines anticlines from Haeussler et al. (2001) and Haeussler (written commun., 2002). The relocations (black dots) show several interesting features including an east-west trending band of seismicity within Upper Cook Inlet near 61N and a northeast-southwest trending band of seismicity located south of the Castle Mountain fault (61.5N, 149.7W) along the axis of an anticlinal structure. A poster on these results (Flores and Doser, 2002) will be presented at the fall 2002 meeting of the American Geophysical Union. We are still reformatting data recorded from 1971-1988, but hope to have relocations completed by January 2002.

Task 2 (relocations of pre-1964 crustal earthquakes)

Relocations of pre-1964 seismicity was accomplished using the master event technique, with the 1933 Upper Cook Inlet earthquake used as the master event for crustal events closest to Anchorage. Figure 2 shows the relation of the earthquakes to linear maximum magnetic gradient boundaries mapped by Saltus et al. (2001). The gradient boundaries are often associated with faults or folds showing recent deformation (Saltus et al., 2001). We believe the 1933 sequence may represent faulting along one of these mapped structures.

Task 3 (waveform modeling of moderate pre-1964 events)

Waveforms of moderate earthquakes were digitized during the summer 2002, but we have not begun our analysis of these records. We hope to compare seismograms of these moderate events with seismograms of larger events (with well determined source parameters) recorded at the same stations in an effort to determine if the moderate events exhibit similar waveform characteristics (especially depth phases) to the larger events. We hope to complete this analysis by March 2003.

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-distance information for all events is shown in Figure 3. Also shown are the median distance values for each intensity interval. Although data for the 1964 mainshock are shown (dark blue dots), median distances obtained using these data (magenta squares) are clearly anomalous (especially at the intensity 6 level), reflecting the great size of this event. If the 1964 data are excluded, however, there still appears to be an anomalous intensity-distance relationship (yellow triangles). These anomalous relationships may be reflective of the uneven population density within the Anchorage region or focal depth dependency. The 2000-2001 data (green triangles) appear to give the most reasonable intensity-distance relationship, but these are derived from a very limited number of small (Mw<5.5) events.

Task 5 (Coulomb failure stress modeling studies)

Results of Coulomb failure stress modeling for the 1933 earthquake sequence were shown in last year's annual report. Three of the five larger (M>5.0) aftershocks of this sequence fall within regions where δCFS > 0.1 bars, the δCFS threshold level for triggering of aftershocks that has been suggested by King et al. (1992) and Reasenberg and Simpson (1992). The two aftershocks that do not correspond to regions of higher δCFS could either have occurred on faults with different orientations than the mainshock or could be mislocated (mislocations of no more than 10 km would place the events within the higher δCFS regions). The modeling also suggested that the 1933 earthquake sequence did not raise δCFS in the vicinity of the Mw~7.0 1943 northern Cook Inlet earthquake (see Figure 2 for epicentral location). δCFS modeling for aftershocks of the 1984 Sutton earthquake (Figure 4) suggests the aftershocks are best explained by rupture along a 8 km long and 7 km wide fault that ruptured downward from the mainshock hypocenter (at 19 km). With this rupture geometry 100% of the aftershocks occurring at depths of 17 km or less are located within a region of δCFS > 0.1 bars (Figure 4a) and 74% of all aftershocks are located within the same region (Figure 4b).

Related Studies

In addition to progress toward our 5 tasks, we have conducted studies of seismic moment rates in the Anchorage region and completed a study of post-1964 mainshock seismicity of the Kodiak Island region. 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 presented at the fall 2002 meeting of American Geophysical Union and manuscript is in preparation for Seismological Research Letters or Geophysical Research Letters.

A paper on Kodiak Island seismicity since the 1964 mainshock is currently in press (Doser, Brown & Velasquez, 2002). The most intense seismicity and moment release in the Kodiak Island region occurred within the Pacific plate and along the plate interface of the southwestern edge of the Kodiak segment where slip during the 1964 mainshock was < 5 m. Few earthquakes have occurred within the North American plate. The intense seismicity in the southwestern portion of the region correlates well with the northern edge of a zone of high plate interface coupling detected by GPS/geodesy studies (Zweck et al., 2002) (dashed red line, Figure 5). Our studies suggest that during 1964-1974 faulting within the Pacific plate was characterized by normal and normal-oblique faulting. However, since 1974 reverse-oblique faulting has become more common in the Pacific plate. Seismic moment release in the Kodiak region is over 6 times greater than in the Prince William Sound-Cook Inlet region for the past 37 years, and we do not appear to see the decreases in seismic moment release as observed to the north. Unlike the Prince William Sound region, there is also a lack of down-dip migration of seismicity since 1964. Note that seismicity in the Prince William Sound-Cook Inlet region also clusters around the edges of the zone of highest interface coupling (dashed orange line, Figure 5). The few events with the region of highest coupling are immediate aftershocks of the 1964 sequence occurring within the North American crust. Events also appear to cluster around the zone of aseismic creep (blue line, Figure 5) as defined by GPS/geodesy studies.

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 1928-2001 time period in order to examine the nature of shallow crustal and deeper Pacific plate earthquake source zones near Anchorage. 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., W.A. Brown and M. Velasquez, Seismicity of the Kodiak Island region (1964-2001) and its relation to the 1964 great Alaska earthquake, in press, Bull. Seismol. Soc. Am., July 2002.

Doser, D., M. Velasquez, W. Brown, and A. Veilleux, Large (Mw>5.5) intraplate slab earthquakes (1928-2000) of the Prince William Sound region, Alaska, in Kirby, S., K. Wang and S. Dunlop (eds.), The Cascadia Subduction Zone and Related Subduction Systems-Seismic Structure, Intraslab Earthquakes and Processes, and Earthquake Hazards, U.S. Geological Survey Open File Report 02-328, 103-106., 2002.

Flores, C., and D.I. Doser, Preliminary results of double difference relocations in the Anchorage region, submitted to Fall 2002 meeting, Amer. Geophys. Union.

Doser, D.I., N. Ratchkovski and P. Haeussler, Changes in crustal seismic deformation rates associated with the 1964 great Alaska earthquake, submitted to Fall 2002 meeting, Amer. Geophys. Union.

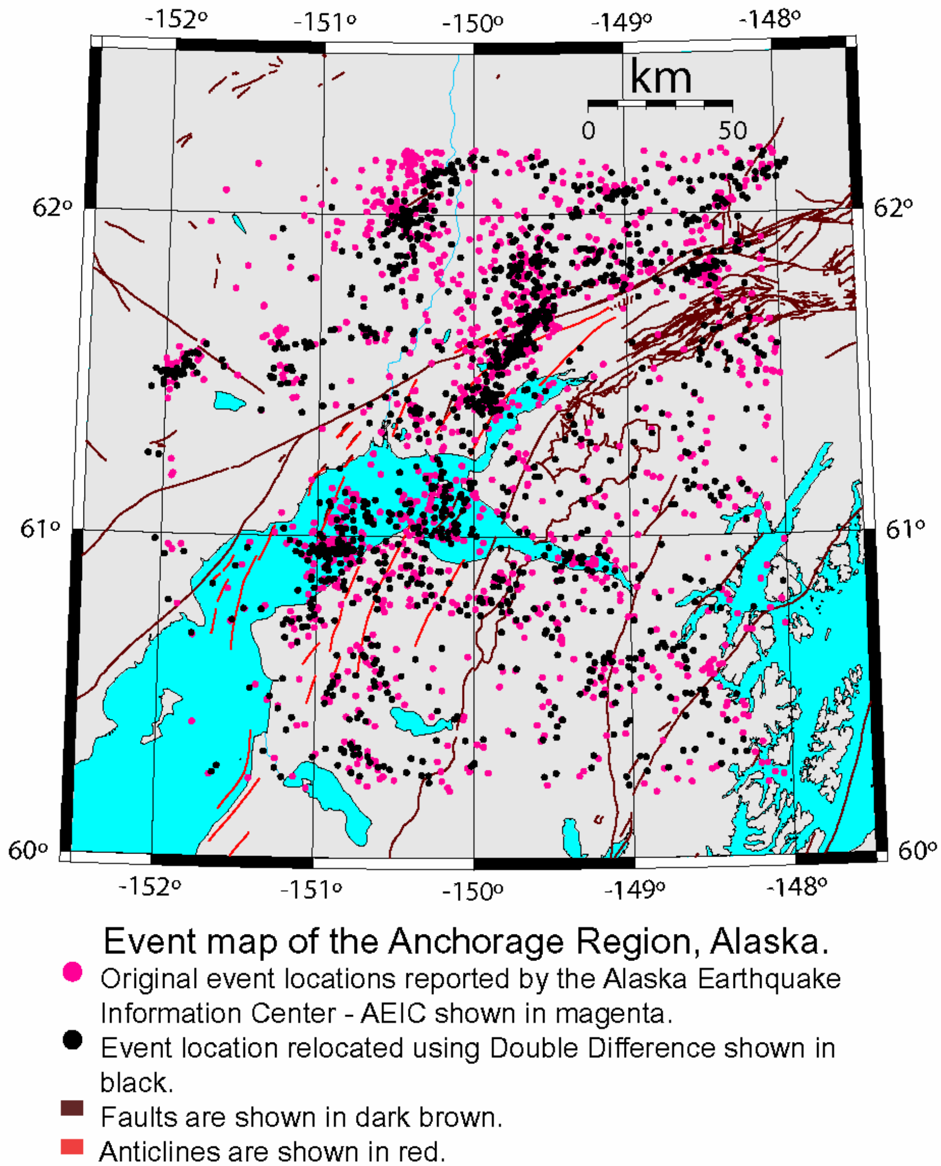
Doser, D.I. and C. Flores, Analysis of crustal seismicity (1933-1943) near Anchorage, Alaska and implications for seismic hazard from crustal earthquake sources, Seismological Research Letters 73, 220, 2002.

Doser, D.I. and C. Flores, Crustal earthquake source zones within the Anchorage, Alaska region, Eos Trans. Amer. Geophys. Union, v.82 no. 47, F927, 2001.

Availability of Data Sets:

Copies of phase data and intensity data that will be used in the analysis will be available in paper or digital form. First motion data and waveform data will also be 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. Relocated events (using HypoDD) of the Anchorage region (1988-2000).



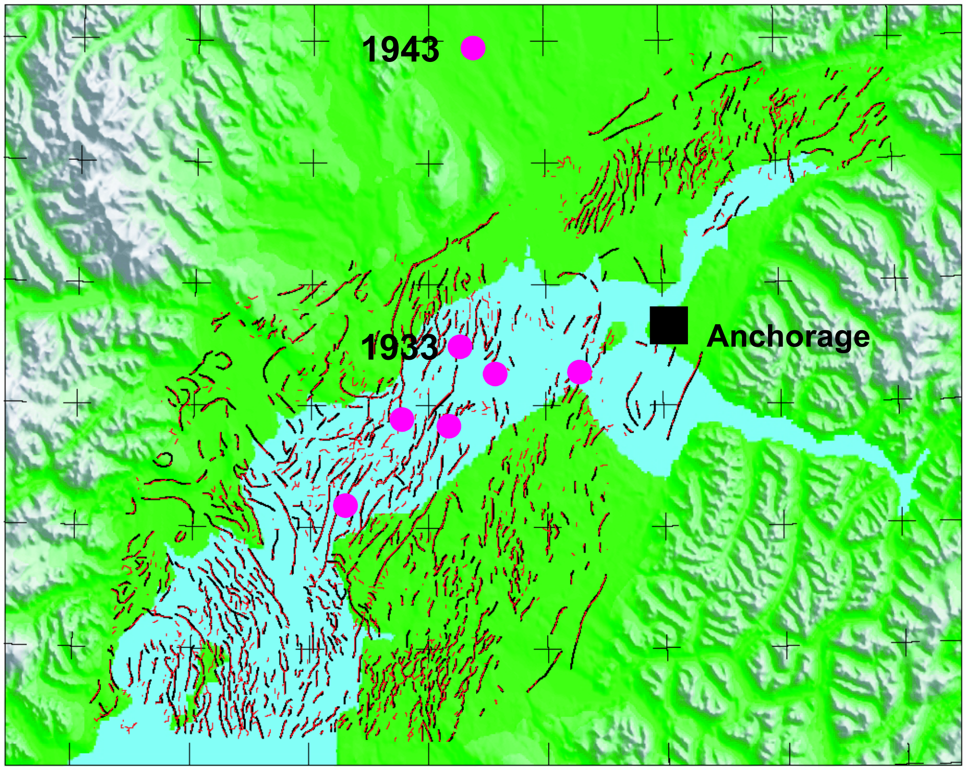


Figure 2. Relocated earthquakes (1933-1943) in Anchorage Region.
Lines show linear maximum magnetic gradient boundaries.

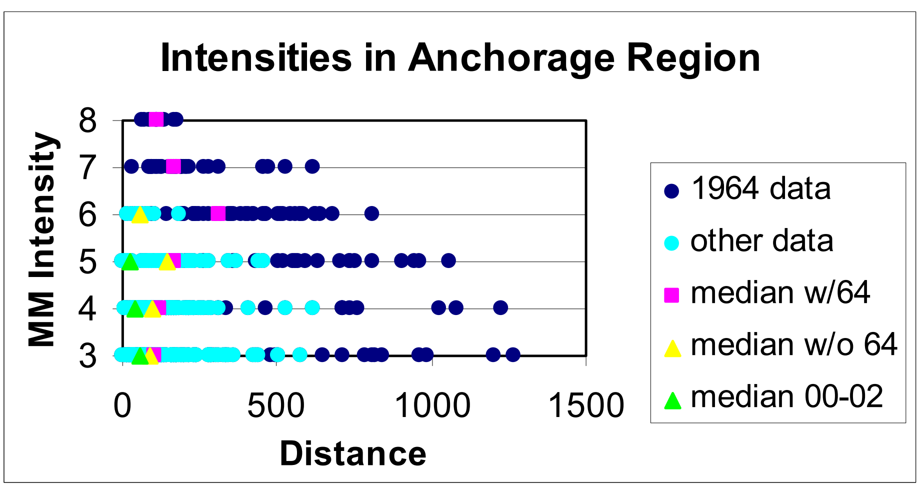


Figure 3: Intensity information for earthquakes occurring from 1964-2002 in the Anchorage region. Blue symbols are intensity data points, squares and triangles are median distance values for each intensity unit as indicated.

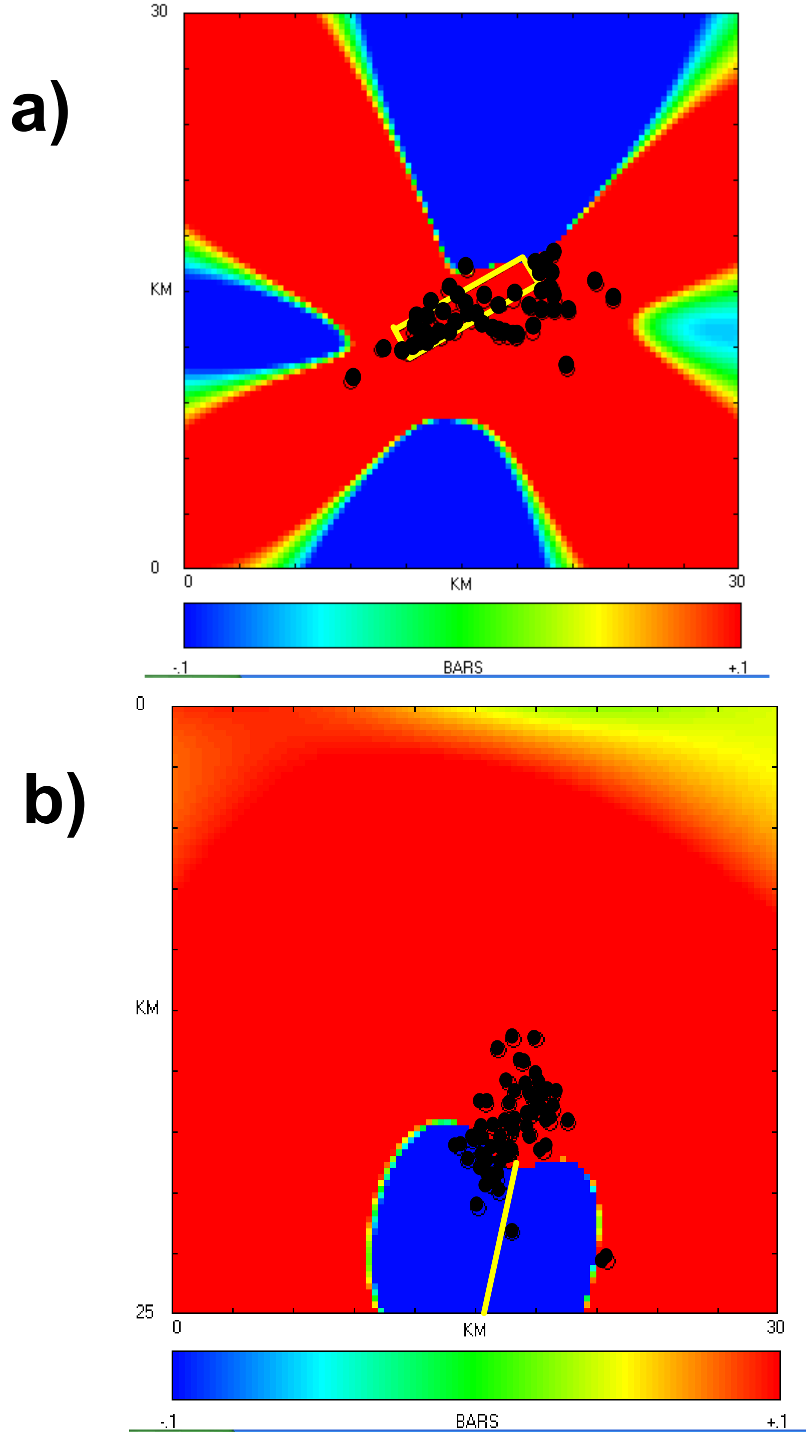


Figure 4. DCFS models of 1984 Sutton mainshock. Fault plane is indicated by yellow line, aftershocks by black dots. Red indicates regions of DCFS>0.1 bar (a) Map view. (b) cross section along fault dip.

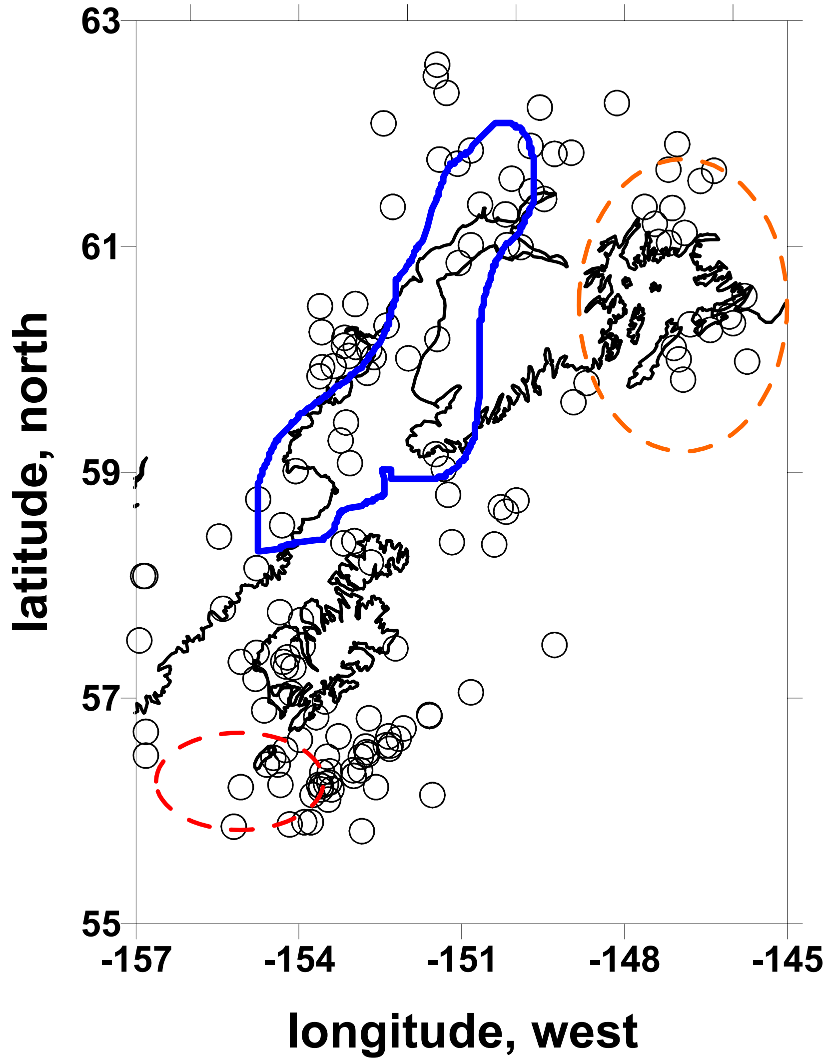


Figure 5. Mw>5.5 earthquakes 1964-2002 (squares) in epicentral region of 1964 great Alaskan earthquake. Red and orange dashed lines indicate regions of high interface coupling. Blue line denotes region of aseismic slip along plate interface (from Zweck et al., 2002).