FINAL TECHNICAL REPORT

Award Number: 05HQGR0101

STUDIES OF CRUSTAL AND BENIOFF-ZONE EARTHQUAKES OF THE PRINCE WILLIAM SOUND AND SOUTHERN KENAI PENINSULA REGIONS, ALASKA

Diane I. Doser
The University of Texas at El Paso, Department of Geological Sciences, 500 W. University Ave., El Paso, TX 79968
(915)-747-5851 (office), (915)-747-5073 (FAX), doser@geo.utep.edu

Award Number: 05HQGR0101

STUDIES OF CRUSTAL AND BENIOFF-ZONE EARTHQUAKES OF THE PRINCE WILLIAM SOUND AND SOUTHERN KENAI PENINSULA REGIONS, ALASKA

Diane I. Doser
The University of Texas at El Paso, Department of Geological Sciences, 500 W. University Ave., El Paso, TX 79968
(915)-747-5851 (office), (915)-747-5073 (FAX), doser@geo.utep.edu

ABSTRACT:

This research focused on study of the seismicity (1964-2002) of two regions of the Prince William Sound asperity that ruptured during the 1964 great Alaska earthquake, the Prince William Sound (PWS) and southern Kenai Peninsula regions (SKP). Within the PWS region we relocated over 11,000 earthquakes. Comparison of the relocated seismicity and stress orientations obtained from first motion information suggests that rheological changes encountered at pre-existing suture zones within the upper North American plate serve to concentrate seismicity. The suture zones may also serve as conduits for the migration of fluid from the lower plate(s), especially in the region south of the Contact fault zone when sediment carried on the top of the subducted Pacific plate is pinched out by the subduction process. Slivers of oceanic material caught within the upper plate during past episodes of subduction may also be responsible for several regions of unusually clustered seismicity (e.g. Tazlina glacier region) that appear to extend from the upper plate across the plate interface into the lower plate. The shape of the plate interface appears to control the location of $M_w \geq 5.5$ earthquakes in both the upper and lower plate. Within the SKP region we relocated over 2,300 earthquakes. In this region shallow (<20 km) upper plate seismicity is sparse, with the exception of the southeastern and southwestern portions of the peninsula. The southeastern region of seismicity appears to be related to deformation near the edge of the Yakutat Block with maximum compressive stress oriented perpendicular to the edge of the block. Lower plate(s) seismicity (≥30 km) shows distinct northeast-southwest lineations. At depths of 30 to 40 km the maximum compressive stress strikes 310° and minimum compressive stress strikes 145° (downdip), a stress field optimally oriented for faulting along either southwest striking high angle reverse faults or moderate angle (~30°) normal faults. At depths > 40 km the maximum compressive rotates to a strike of 270° and minimum compressive stress to 100°, with stresses optimally oriented for faulting along south-southwest striking faults. The stress orientations from deeper seismicity are consistent with previous studies

Introduction:

This research concentrated on seismicity (1964-2002) of two regions of the Prince William Sound (PWS) asperity that ruptured during the 1964 great Alaska earthquake, the PWS region (59 to 62°N, 144 to 148°W) and southern Kenai Peninsula (SKP) region (59 to 60.2°N, 148 to 152°W) (Figure 1). Study of these regions was merged with research previously supported by NEHRP (2003-2005) that focused on Benioff-zone seismicity within 100 km of Anchorage. The tasks we proposed to accomplish in this study included: 1) detailed relocations of crustal and Benioff-zone earthquakes occurring between 1964 and 2002 in the PWS and SKP regions, 2) determination of stress field variation through inversion of first motion data, 3) examination of the relation of seismicity to known lithospheric structure and observed zones of plate interface locking and relaxation, and 4) integration of results with those obtained for the Anchorage region to obtain a comprehensive view of seismicity within the PWS asperity region since 1964.

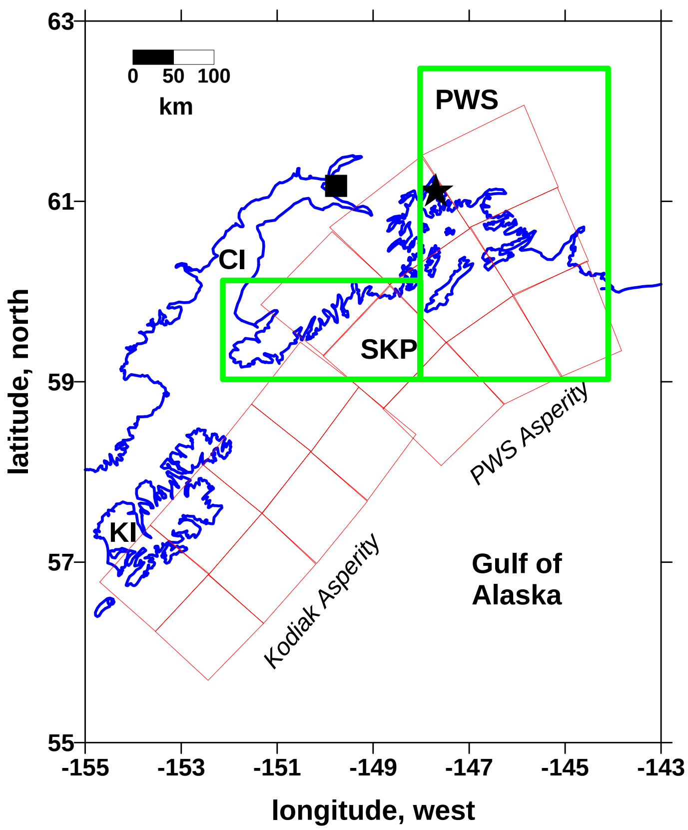

Figure 1 – South-central Alaska with SKP and PWS study areas (green boxes) and asperities associated with the 1964 great Alaska earthquake (red boxes). Star is epicenter of 1964 mainshock. Box is Anchorage. CI is Cook Inlet and KI is Kodiak Island.

Results:

We present the results of tasks 1-4 for the PWS region in a paper that has been submitted for an AGU Monograph on the "*Active Tectonics and Seismic Potential of Alaska*". A preprint of this paper may be found at the end of this technical report. We are still in the process of completing a manuscript that will discuss the completion of tasks 1-3 for the SKP region and their integration with previous studies of the central and northern Kenai Peninsula. Some of these results were presented in preliminary form at the spring 2007 meeting of the Seismological Society of America and are shown in the following figures.

Figure 2 shows the major features of the Kenai Peninsula. Relocated crustal seismicity (Figure 3) for the entire Kenai Peninsula indicates that there is very seismicity within the Kenai Peninsula. The concentration of crustal seismicity within the Prince William Sound region reflects the strong coupling between the Pacific plate, Yakutat block and North America plate. Crustal seismicity increases north of the Castle Mountain fault and within Cook Inlet. There is a moderate level of crustal seismicity near Seward and southeast of Homer. The seismicity near Seward may be related to interaction of the edge of the Yakutat block with the upper North American plate.

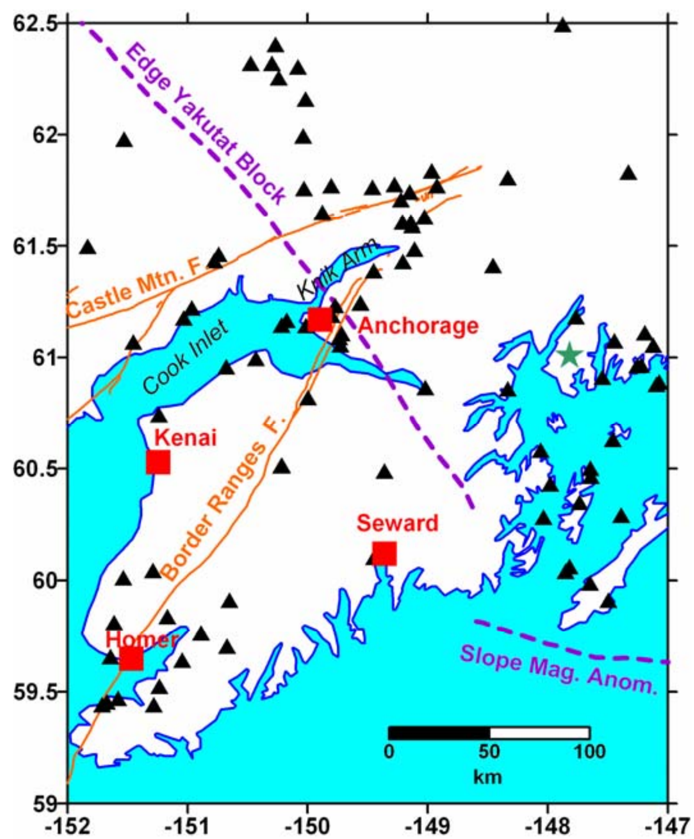

Figure 2 – Major population centers (red squares), seismograph stations (triangles), and faults of the Kenai Peninsula region. Dashed purple lines represent edges of the Yakutat block as defined by Eberhart-Phillips et al. (2006).

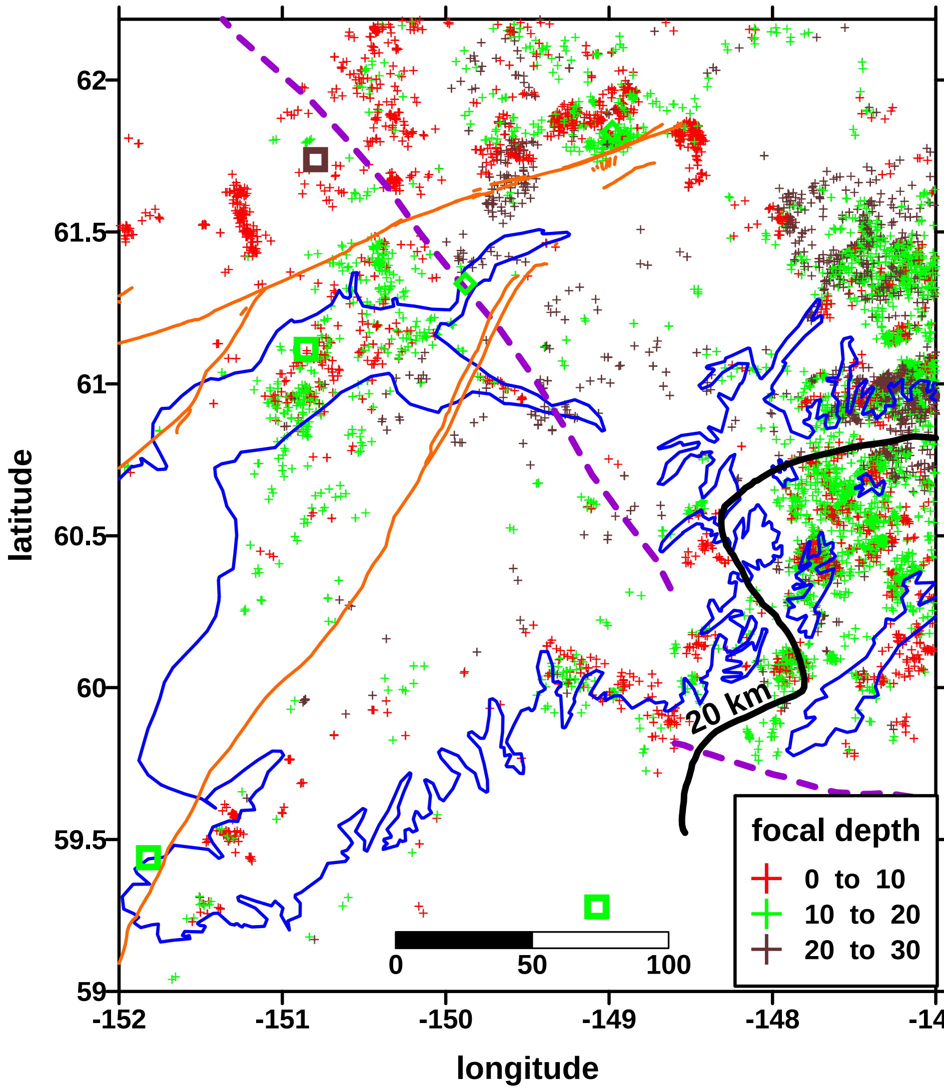

Figure 3 – Relocated crustal seismicity of the Kenai Peninsula 1971-2001. Color reflects focal depth. The solid line is the 20 km depth to the plate interface within PWS as imaged by Brocher et al. (1994). Boxes are magnitude > 5.0 earthquakes occurring between 1918 and 1964.

Figure 4 shows relocated Benioff-zone seismicity. Note that there is little seismicity within the SKP east of 150.5°W. Events appear to cluster at depths of 30 to 40 km in the region just east of Kachemak Bay. To the west many events appear to delineate northeast-southwest trending structures within the downgoing Pacific plate.

A series of north-south and east-west oriented cross sections (locations shown in Figure 5) are shown in Figure 6. Earthquakes located within 12 km of these cross sections have been projected onto the cross section lines. The east-west oriented cross sections illustrate the change in the dip of the slab from a very shallow dip (A-A') in the north to steeper dips (B-B' and C-C'). There is a marked increase in the concentration of seismicity just north of the edge of the Yakutat block (see A-A' and E-E'). Note the unusual cluster of seismicity observed in C-C' and D-D'. This is a region where a high velocity zone has been imaged in the tomographic studies of Eberhart-Phillips et al. (2006).

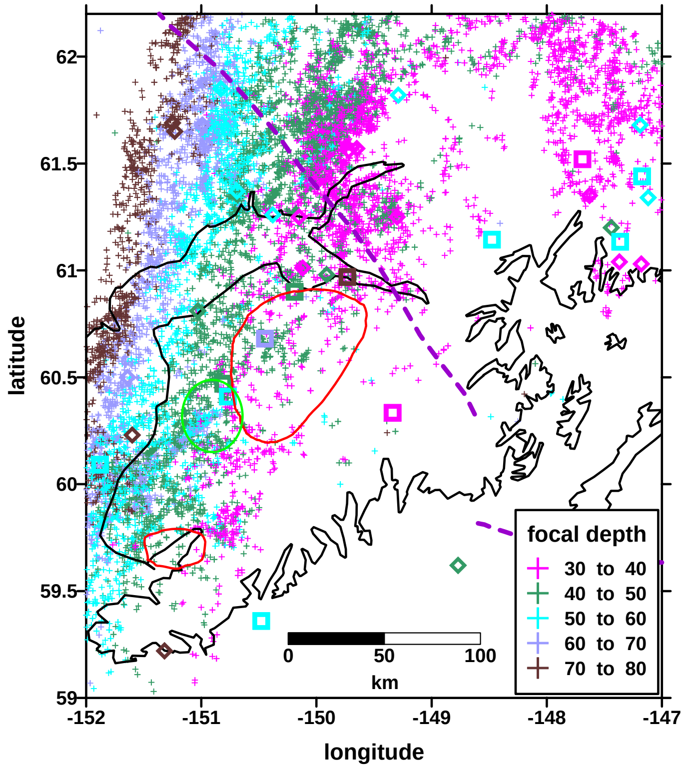

Figure 4 – Relocated Benioff-zone seismicity 1971-2001. Boxes are M>5.0 earthquakes occurring between 1918 and 1964, diamonds are M>5.0 events occurring since 1964. Red ovals represent zones of uplift from Cohen and Freymueller (1997) and green oval is a cluster of unusual seismicity observed beneath the Caribou Hills/Lake Tustumena region.

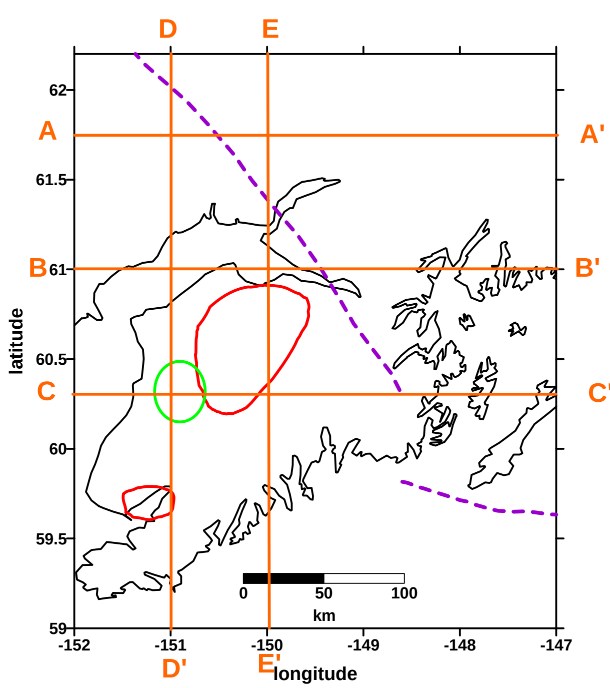

Figure 5 – Location of cross sections shown in Figure 6.

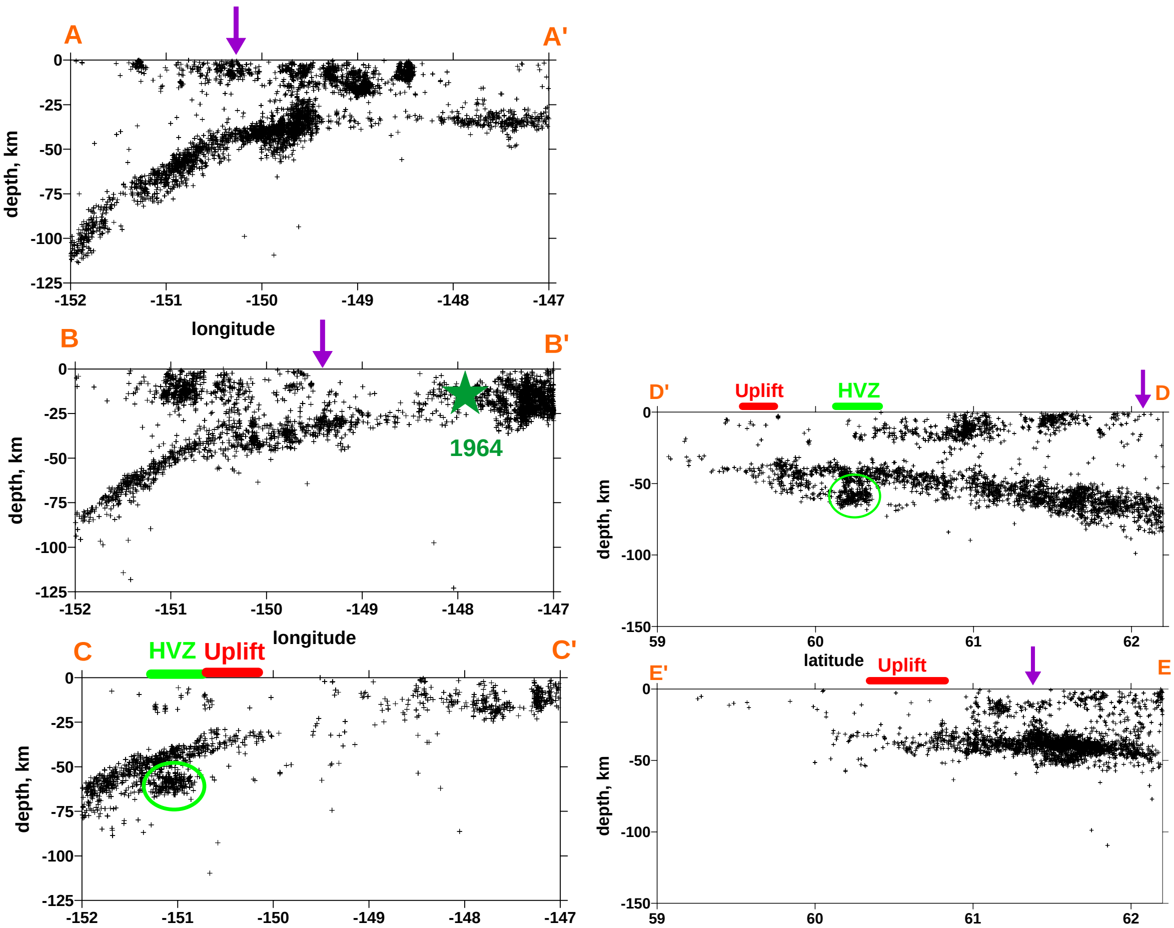

Figure 6 – East-west and north-south cross sections (see Figure 5 for locations). Seismicity within ± 12 km of the cross section lines have been projected on to the profiles. Purple arrows indicate edge of Yakutat block. Red bars indicate zones of uplift (Cohen and Freymueller, 1997) and green bars high velocity zone imaged by Eberhart-Phillips et al. (2006). Star is hypocenter of the 1964 mainshock. Green ellipses indicate unusual cluster of seismicity seen in Figure 4.

It is useful to compare the relocated seismicity to features of the Bouguer gravity field (Figures 7 and 8). Figure 7 shows the relation of crustal earthquakes to the gravity field. Earthquakes in PWS cluster around gravity highs. These highs represent ophiolite sequences and ultramafic rocks, suggesting that rheological differences in the upper plate may serve to concentrate stress, and hence seismicity. The crustal seismicity east of Seward correlates well with the gravity high related to the Resurrection Bay ophiolite sequence. Crustal seismicity within Cook Inlet appears to be confined to a gravity low associated with the north Cook Inlet basin. This is not surprising considering at least some of the seismicity appears to be directly associated with faults and folds of major basin structures (e.g. Flores and Doser, 2005). North of the Castle Mountain fault seismicity is associated with structures that form the edges of the Susitna Basin. We hope to conduct further wavelength and strike filtering of the gravity data to search for specific structures that correlate with observed trends in crustal seismicity. We will also compare the crustal seismicity to features of the magnetic field.

Figure 8 compares Benioff-zone seismicity to low pass filtered gravity data. Here we have passed only wavelengths > 20 km. The inception of slab events in the western Kenai Peninsula correlates well with the edge of a gravity low that strikes to the northeast. Seismicity at the northeastern end of Kachemak Bay (east of Homer) may be related to a cross structure seen in the gravity contours. Seismicity northeast of Anchorage appears to wrap around a gravity low that might indicate a change in lower crustal upper plate structure or structure in the upper portion of the subducting Yakutat block. Part of this gravity low correlates with a region of high velocity imaged by Eberhart-Phillips et al. (2006).

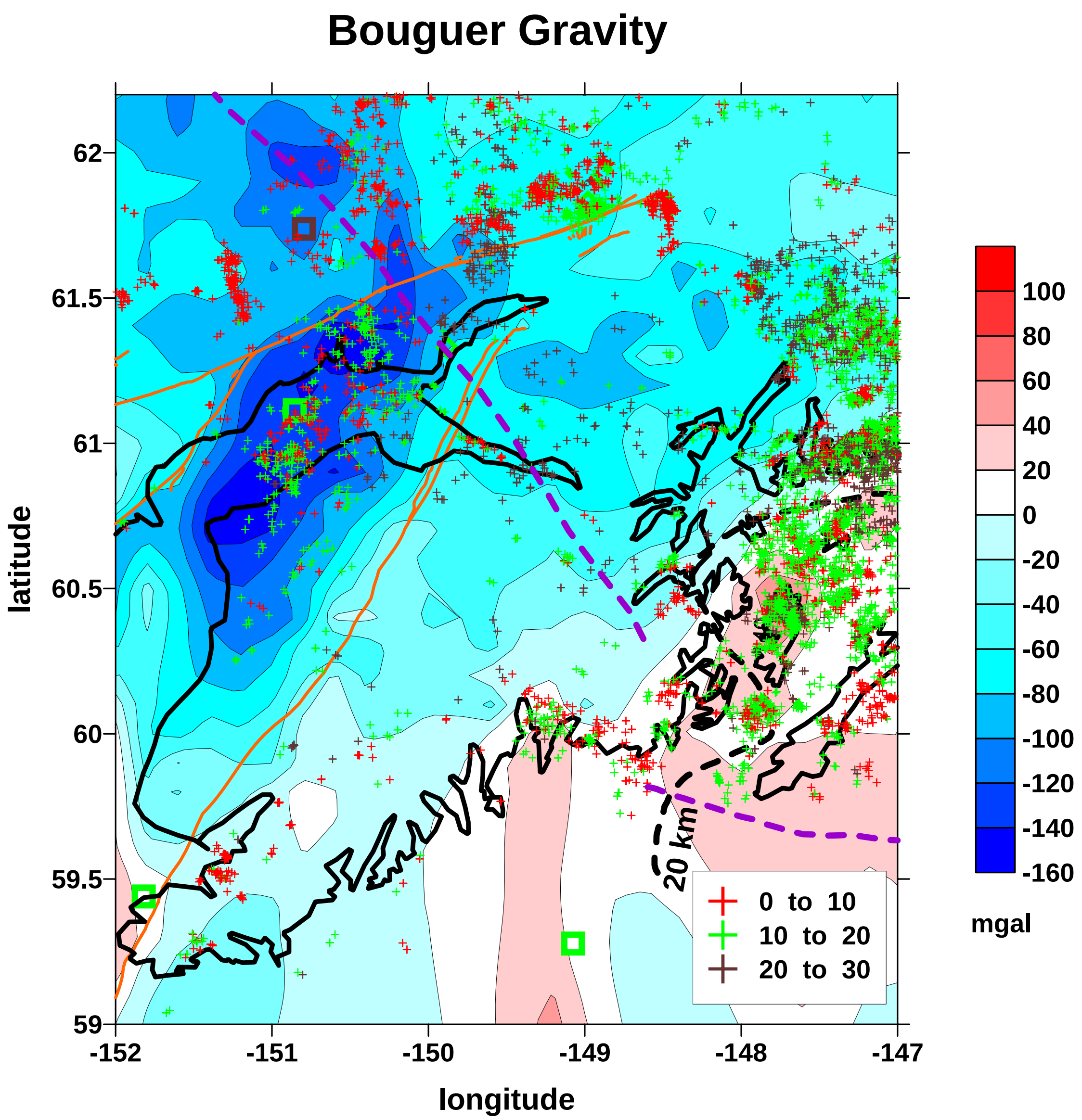

Figure 7 – Crustal seismicity compared to Bouguer gravity. Bouguer gravity data from U.S. Geological Survey website (2006).

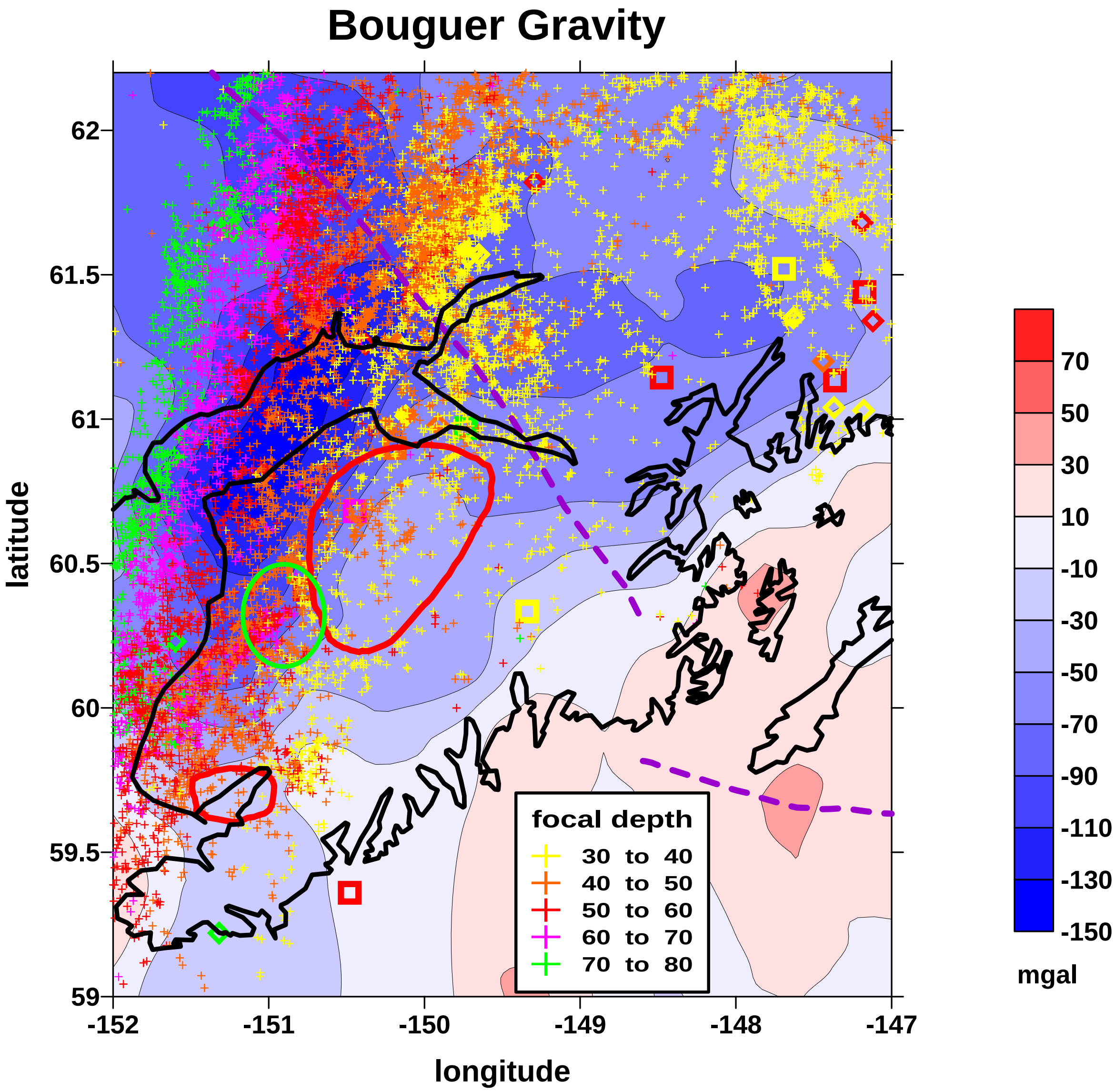

Figure 8 – Low pass filtered (wavelengths < 20 km rejected) gravity data compared to Benioff zone seismicity.

We have used first motion data from groups of earthquakes within the SKP region to invert directly for stress field orientation using the program of Robinson (1999). We lacked sufficient, high quality data to obtain any stress directions for crustal events. However, we did obtain good results for several clusters of events located at depths of 40 to 60 km within the region north of Kachemak Bay. Integrating these results (Figure 9) with stress results for the subducting plate from studies by Veilleux and Doser (2007) for the northern Cook Inlet region, Doser et al. (2007) for the PWS region and moment tensor information from the Alaska Earthquake Information Center, indicates that in the southernmost Kenai Peninsula the direction of maximum compressive stress is oriented parallel to the direction of plate convergence (purple arrow). Northwest of Kachemak Bay the direction begins to rotate toward the west and northwest, while in the northern portion of the peninsula and Cook Inlet it begins to rotate toward the northeast. As the edge of the Yakutat block is approached the maximum stress is generally oriented perpendicular to the edge.

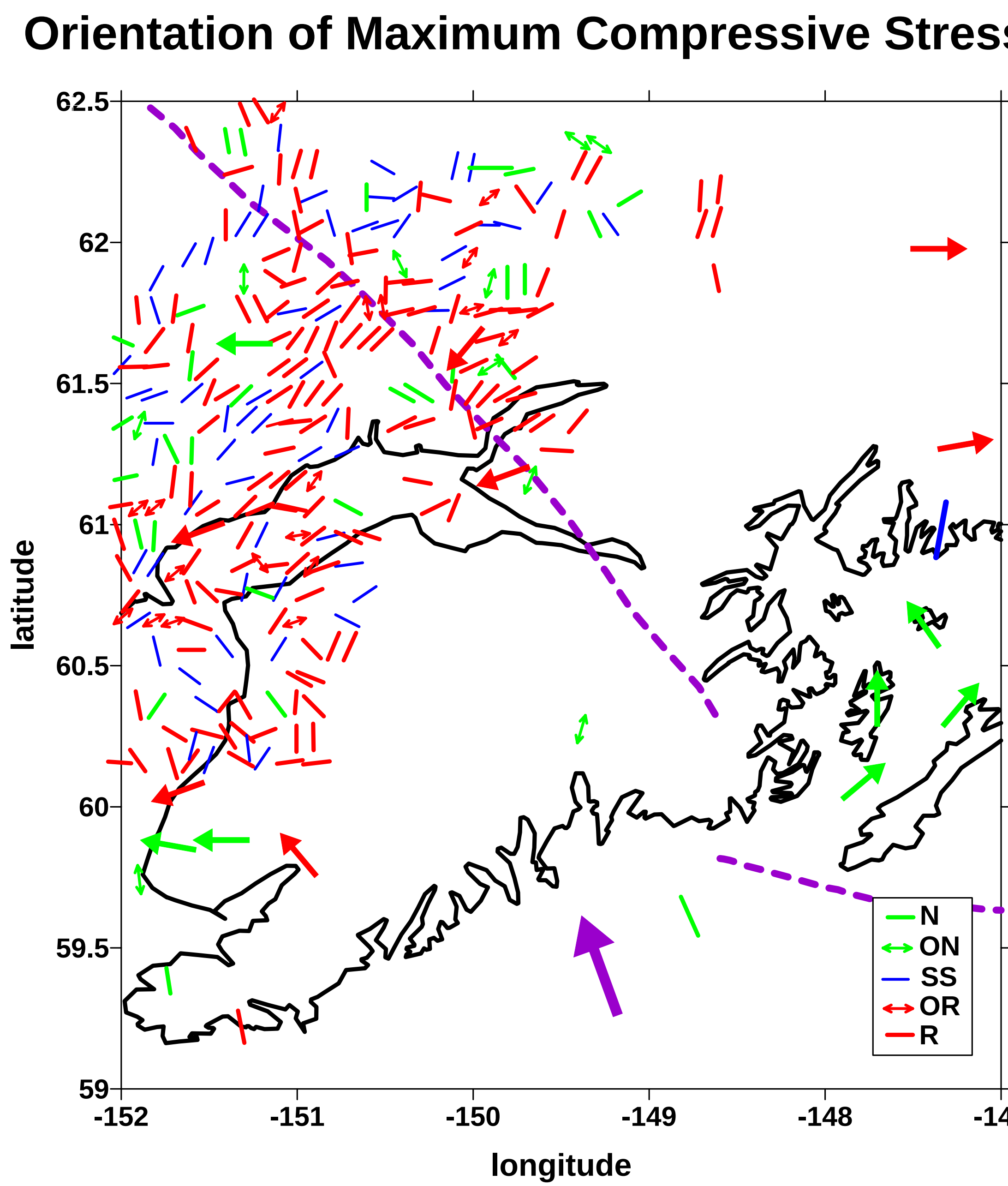

Figure 9 – Orientation of the direction of maximum compressive stress from inversion of first motion data (medium size arrows) and individual focal mechanisms (small symbols). Large arrow indicates direction of plate convergence from DeMets and Dixon (1999). Color indicates normal/oblique normal (green), reverse/oblique reverse (red) and strike-slip (blue) faulting.

Related Studies

Several other recent studies of earthquakes of south-central Alaska have been completed to help provide a comprehensive picture of the tectonics and seismic hazards of the region. Specific papers on these studies are summarized below.

The results of a previously funded NEHRP study on the seismicity of the Benioff-zone near Anchorage were published in the *Bulletin of the Seismological Society of America* (Veilleux and Doser, 2007). The relocated seismicity reveals important details of the subducting Pacific plate and Yakutat blocks including clustering of seismicity within the Pacific plate mantle, northeast and northwest striking near vertical faults within the Pacific plate crust, and a region of intense deformation associated with the southwestern edge of the Yakutat block. Stress analyses from the direct inversion of first motion data and from inversion of focal mechanisms for 713 events indicates a rotation of the maximum compressive stress direction from a trench parallel direction (northeast) in the southwestern portion of the study area to an east-west direction near the southwestern edge of the Yakutat block located just north of Anchorage. Regions of the Pacific plate mantle that produced M_w>6.4 earthquakes in 1934 and 1954 continue to be seismically active.

Doser (2006) published a study in *Pure and Applied Geophysics* of the relocation of 18 events occurring prior to 1918 within south-central Alaska using a bootstrap relocation technique. Locations of events within the Yakutat region suggest that the 1899 great earthquake sequence began on 4 September with a M_S=7.9 event within the area of the Pamplona fault zone/western Transition fault zone, rupturing the western portion of the North American/Pacific plate interface between Icy Bay and Cape Suckling. A M_S=7.4 event on 10 September appears to have ruptured the offshore portion of the plate interface to the east of the 4 September event. This was followed by a M_S=8.0 event that likely ruptured the onshore and down-dip portion of the plate interface between Icy Bay and Yakutat Bay. A M_S=7.0 event in 1908 may have ruptured a small portion of the plate interface between the 4 September and 10 September events. Events occurring between 1911 and 1916 in the Prince William Sound region appear to be slab events occurring in similar locations to more recent seismicity. Within the Kodiak region the 1900 earthquake of M_S=7.7 has a location consistent with rupture of the Kodiak asperity which also ruptured during the 1964 great Alaska earthquake. Other large magnitude Kodiak events appear to be associated with regions of recent seismicity, including the Karluk Lake area of southwestern Kodiak Island and the Albatross Basin located offshore southeast of Kodiak Island. Space-time seismicity patterns since 1899 indicate that magnitude 6 to 7 events have occurred with regularity in the Kodiak Island region, that there has been a lack of magnitude ≥ 6 events in the Prince William Sound region since 1964, and that the Yakutat region has remained notably quiescent at the magnitude ≥ 6 level.

Doser et al. (2007) conducted a study of seismicity in the Bering Glacier region of south-central Alaska located between Icy Bay and Cape Suckling to investigate the relationship of seismicity to glacial processes. These results will soon be published in *Tectonophysics*. The study was based on the relocation of over 1000 earthquakes of magnitude > 0.1 occurring between 1973 and 2001 in the Bering Glacier region of southern Alaska. The results indicate that much of the seismicity in the region is occurring within the North American plate in a zone where an inferred structure, which lies beneath Bering Glacier, intersects the Chugach-St. Elias fault system. Stress-field analysis indicates that the events in the Bering Glacier surge reservoir region are likely occurring on northeast-trending thrust faults, consistent with previous modeling that suggested thrust faulting would be enhanced in regions of ice draw down. There also appears to be a stress field compatible with either high-angle normal or reverse faulting in regions located northwest of the Bering Glacier. This may indicate localized complexities in interactions between the Bering Glacier structure and the Chugach-St. Elias fault system.

We have just initiated a new study of southeast Alaska seismicity funded by NEHRP that started June 1, 2007. In mid-June Dr. Doser visited colleagues at the Pacific Geoscience Centre in Sydney, BC, Canada to discuss the results of relevant Canadian studies, collect pertinent data sets and insure continued cooperation throughout the study.

We are continuing our studies of the source processes of Benioff zone earthquakes using empirical Greens function techniques. This allows us to begin to examine events with magnitudes as small as 4.5 to 5. Annette Veilleux began a study of several earthquakes near Anchorage as part of her dissertation work and Alejandro de la Peña complete a study of several PWS events as part of his MS thesis. A more comprehensive study funded by NEHRP will begin in September 2007. We have been working with Dr. Chris Stephens of the USGS to collect strong ground motion information for events of interest. Dr. Doser has also been operating a broadband seismograph station on the central Kenai Peninsula for about a year with hopes of using some of the collected data for this study.

Reports Published:

Doser, D.I., A. de la Peña, and A.M. Veilleux, Seismicity of the Prince William Sound region and its relation to plate structure and the 1964 great Alaska earthquake, submitted for American Geophysical Union Monograph on "*Active Tectonics and Seismic Potential of Alaska*", March 2007.

Doser, D.I., Wiest, K.R., and J.M. Sauber, Seismicity of the Bering Glacier region and its relation to tectonic and glacial processes, in press, *Tectonophysics*, April 2007.

Veilleux, A.M., and D.I. Doser, Studies of Wadati-Benioff zone seismicity of the Anchorage, Alaska region, *Bull. Seismol. Soc. Am. 97*, 52-62, 2007.

Doser, D.I., Relocation of earthquakes (1899-1917) in south-central Alaska, *Pure and Appl. Geophys. 163*, 1461-1476, 2006.

Availability of Data Sets:

Copies of phase data, first motion data, and potential field 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.

Bibliography

Brocher, T.M., G.S. Fuis, M.A. Fisher, G. Plafker, M.J. Moses, J.J. Taber, and N.I. Christensen (1994). Mapping the megathrust beneath the northern Gulf of Alaska using wide-angle seismic data, *J. Geophys. Res.* **99**, 11,663-11,686.

Cohen, S.C., and J.T. Freymueller (1997). Deformation of the Kenai Peninsula, Alaska, *J. Geophys. Res.* **102**, 20,479-20,488.

DeMets, C., and T.H. Dixon (1999). New kinematic models for Pacific-North America motions from 3 Ma to present, 1: Evidence for steady motion and biases in the NUVEL-1A model, *Geophys. Res. Lett.* **26**, 1921-1924.

Eberhart-Phillips, D., D.H. Christensen, T.M. Brocher, R. Hansen, N.A. Ruppert, P.J. Haeussler and G.A. Abers (2006), Imaging the transition from Aleutian subduction to Yakutat collision in central Alaska, with local earthquakes and active source data, *J. Geophys. Res, 111,* B11303, doi:10.1029/2005JB004240.

Flores, C.F., and D.I. Doser, D.I. (2005). Shallow seismicity of the Anchorage, Alaska region (1964-1999), *Bull. Seism. Soc. Amer*. **95**, 1865-1879.

Robinson, R. (1999). Get Stress: A Computer Programme for Inverting First Motion Observations to a Regional Stress Tensor, Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, 7 pp. (copy of software available at ftp.gns.cri.nz/pub/robinson/ getstress).

U.S. Geological Survey (2006). Alaska gravity data base (2006). http://wrgis.wr.usgs.gov/docs/gump/morin/alaska/gravity/gravity.html

The following pages are a preprint of “Seismicity of the Prince William Sound region and its relation to plate structure and the 1964 great Alaska earthquake”, a paper that was submitted for consideration for publication in a monograph of the American Geophysical Union on *Active Tectonics and Seismic Potential of Alaska* in March 2007.

Seismicity of the Prince William Sound Region and Its Relation to Plate Structure and the 1964 Great Alaska Earthquake

Diane I. Doser[1], Alejandro de la Peña[1], and Annette M. Veilleux[1]

[1]Department of Geological Sciences, University of Texas at El Paso, El Paso, Texas USA

We have relocated over 11,000 earthquakes within the Prince William Sound region of south-central Alaska where oblique subduction of the Pacific plate and Yakutat blocks beneath North America occurs at an angle of 3°. Subduction of the Yakutat block creates a major asperity at the subduction interface, which slipped during the 1964 Great Alaska earthquake. Comparison of relocated seismicity and stress orientations obtained from first motion information suggests that rheological changes encountered at pre-existing suture zones within the upper plate serve to concentrate seismicity. The suture zones may also serve as conduits for the migration of fluid from the lower plate(s), especially in the region south of the Contact fault zone when sediment carried on the top of the subducted Pacific plate is pinched out by the subduction process. Slivers of oceanic material caught within the upper plate during past episodes of subduction may also be responsible for several regions of unusually clustered seismicity (e.g. Tazlina glacier region) that appear to extend from the upper plate across the plate interface into the lower plate. The shape of the plate interface appears to control the location of $M_w \geq 5.5$ earthquakes in both the upper and lower plate

1. Introduction

The Prince William Sound (PWS) region of south-central Alaska is a site of complex subduction of the Yakutat block and Pacific plate beneath North America

(Figure 1). Seismic reflection/refraction studies [*Brocher et al.,* 1994] show the subduction interface dips about 3° beneath much of PWS. The overlying North American plate consists of a series of terranes that have been sutured to North America since the late Cretaceous [*Fuis and Plafker,* 1991]. The 1964 Great Alaska earthquake nucleated within this region of complex geology with slip of over 20 m [*Johnson et al*., 1996; *Ichinose et al*., 2006] occurring along the subduction interface.

We compare relocated seismicity occurring between 1971 and 2001 within the PWS region to seismic refraction/reflection studies [e.g. *Brocher et al*., 1994; *Fuis et al.,* 1991], seismic tomography studies [*Eberhart-Phillips et al*., 2006], geodetic studies [*Zweck et al*., 2002] and gravity information in an effort to determine how upper and lower plate structure controls the location of seismicity. We invert first motion data to determine the variations in the regional stress field and its relation to regional structures.

Our goal is to better understand how structure within this complex subduction zone controls the location of upper and lower plate seismicity. These regions have historically experienced magnitude 6 to 7 events that have shorter recurrence intervals than plate interface earthquakes. Thus better characterization of the likely source zones for these earthquakes are required for improving seismic hazard estimates for the south-central Alaska region.

2. Previous Studies of Seismicity

The first comprehensive study of seismicity of the PWS region was conducted by *Page et al.* [1989]. They relocated seismicity occurring between 1971 and 1986 using a velocity model calibrated to the seismic refraction studies of *Fuis et al.* [1987]. Their results were the first to indicate the subducted Yakutat block and Pacific plate appear to be continuous across the region. Focal mechanisms suggested least compressive stress was oriented down-dip in the subducting plate(s) with north-south oriented maximum compression within the overriding plate. The study also noted an unusual clustering of seismicity beneath the Tazlina Glacier region (Figure 1) that appears to extend across the plate interface.

Ratchkovsky et al. [1998] used the joint hypocenter determination method to relocate seismicity at depths ≤ 50 km occurring between 1988 and 1996 within a larger region of south-central Alaska. They suggested that an observed 15-20 km seismicity gap north of PWS represents a boundary between two blocks within the subducting Pacific plate. Focal mechanisms within the subducting plate(s) showed WNW-ESE oriented T-axes, indicating down-dip extension, even at shallow depths. They found very few thrust events located either along the plate interface or within the upper plate.

Lu et al. [1997] inverted focal mechanisms information for stress field orientation in PWS using larger (M_S~5) and smaller magnitude earthquakes. They inverted all events occurring from 0 to 40 km, not differentiating between lower and upper plate events. In both cases they found near horizontal minimum compressive stress oriented WNW-ESE. Maximum compressive stress had a NNE-SSW strike, but varied from near horizontal (larger events) to near vertical (smaller events) plunge.

Studies of larger magnitude (>5.5) earthquakes occurring for the past 80 years [*Doser and Brown*, 2001; *Doser et al.,* 1999] suggest that the Tazlina Glacier and Columbia Bay regions (Figure 1) have been persistently active. Much of the lower plate seismicity since 1928 appears to cluster immediately downdip of the 1964 asperity. Upper plate seismicity in PWS increased in the 5 years following the 1964 mainshock, however, overall moment release in the PWS region has decreased by a factor of at least 7 since the 1964 mainshock [*Doser et al*., 2006].

3. Analysis techniques

In this study we use the double difference (HypoDD program) relocation technique of *Waldhauser and Ellsworth* [2000] with the velocity model of *Fogelman et al.* [1993]. Phase data from October 1971 to July 1988 were obtained from the U.S. Geological Survey (K. Fogelman, written comm., 2001) and from August 1988 to December 2001 from the Alaska Earthquake Information Center (AEIC) (N. Ruppert, written comm., 2001). We relocated at total of 11,490 events (Figure 2) with a maximum separation distance of events within a cluster set at 10 km. A minimum of 8 observations were required for each event pair.

First motion polarity information was inverted directly for the stress field orientation using GetStress [*Robinson*, written commun., 1999, ftp.gns.cri.nz/pub/robinson/getstress]. Only events with more than 8 first motion observations were used in analysis. Data were selected in rectangular volumes that were bounded by gaps in seismicity. The first motion data were randomly resampled 1000 times to determine the range of stress orientations consistent with the first motion data and their 95% confidence intervals. Only those regions having 95% confidence intervals for stress axes that covered less than 15° of the focal sphere were used in the final analysis.

4. Results

4.1 Relocations

Relocated seismicity is shown in Figure 2 for four depth ranges. Figure 3 compares relocated seismicity with several of the seismic refraction/reflection interpretations of *Brocher et al*. [1994]. The locations of the seismic lines are indicated in Figure 1. Figure 4 shows examples of north-south and east-west oriented cross sections of seismicity (indicated by arrows in Figure 1) that were used to construct a contour map of the top of the subducted plate (shown in Figure 5). Figure 6 compares seismicity to Bouguer gravity anomalies, while Figure 7 shows the results of inversion of first motion data for stress field orientations.

The four depth ranges of Figure 2 were selected to emphasize variations in seismicity with crustal structure. Focal mechanisms of $M_w \geq 5.0$ earthquakes occurring between 1928 and 2006 are also shown. The dashed line is the Slope Magnetic Anomaly (SMA), which represents the southern edge of the subducted Yakutat block [*Griscom and Sauer*, 1990]. The bold gray lines in Figure 2 are the Contact and Border Ranges fault zones that represent suture zones between the Prince William and Chugach and the Chugach and Peninsular terranes, respectively, that were accreted to North America during previous episodes of subduction and convergence (e.g. *Fuis and Plafker*, 1991).

Seismicity in Figure 2a (0 to 15 km depth) predominantly occurs within the North American plate, since the depth to the plate interface is ~14 km at the SMA. Focal mechanisms and stress inversion results (Figure 7a) suggest that much of the central PWS offshore seismicity appears to be associated with thrust and reverse faulting. Northward dipping thrust and reverse faults appear to be imaged in several cross sections, including Figure 3a (110-120 km), Figure 3b (20 to 30 km), Figure 4a (60.2°N) and Figure 4b (60.4-60.6°N). The seismicity located southeast of Montague Island, including a number of M_w>5 aftershocks of the 1964 event, is likely associated with the Patton Bay fault system (bold gray line, Figure 2a) that moved up to 17 m [*Ichinose et al*., 2007] during the 1964 mainshock. Shallow seismicity intensifies within western and northern PWS (Figure 2a). *Eberhart-Phillips et al.* [2006] noted that this increase in seismicity appears to be related to stronger seismic coupling along the plate interface as modeled by *Zweck et al.* [2002]. Black arrows on Figures 3 and 4 indicate the limits of the zone where *Zweck et al.* [2002] have determine a coupling coefficient ≥ 0.5. Onshore seismicity is concentrated within the Copper River delta, Columbia Bay, and Tazlina Glacier regions.

Figure 2b (15 to 25 km depth) represents seismicity near the subduction interface between the Yakutat block and the North American plate. Focal mechanisms of larger events indicate reverse and thrust faulting above the plate interface and normal faulting below the plate interface. *Fisher et al.* [2005; 2006] suggest that the concentrated seismicity occurring in northern Knight Island and northern Montague Island may be related to underthrusting of slices of the Yakutat block onto the North American plate (e.g. Figure 3a, 140-190 km; Figure 3b 60 km). Seismicity in the Columbia Bay and Valdez regions is concentrated near the southern edge of the Contact fault. *Eberhart-Phillips et al.* [2006] have speculated that rheological changes across the Contact fault may serve to concentrate stress in this region. If we extrapolate the seismic refraction results of the *Fuis et al.* [1991] for the southern Richardson Highway line ~ 50 km to the west to the central PWS (Figure 3c) it appears that the interpreted edge of the Kula plate coincides with an increase in seismicity observed in the Valdez region north of the Contact fault (V, Figure 3). The structure along this cross section (Figure 3c) also indicates that the layer of sediment located above the Pacific plate and separating it from the Yakutat block pinches out somewhere near the Contact fault system. As this pinch-out occurs fluids should be expelled from the sediments and their migration along the Contact fault system may serve to increase seismicity within this region. The northern edge of shallower seismicity (0 to 25 km depth, Figures 2a and 2b) appears to be controlled by the Border Ranges fault system, suggesting the older suture zones serve to concentrate stresses and/or fluid movement through the North American plate.

The seismicity of Figure 2c (25 to 35 km) occurs below the plate interface in the Columbia Bay and Valdez regions. Note that this region of seismicity is also located downdip of the pinched out Pacific plate sediment (Figure 3c). *Page et al.* [1989] suggest that the 1983 Columbia Bay earthquake sequence (which includes the largest magnitude event occurring within PWS since the 1964 aftershock sequence, the M_w=6.5 July 1983 earthquake) (Figure 2c and Figure 4b at 61°N) likely involved faulting within the crust and mantle of the Pacific plate. As noted previously by *Page et al.* [1989] and *Ratchkovsky et al.* [1998], the Tazlina Glacier cluster (Figures 2c, 3c, 4d) extends across the plate interface. Figure 3c suggests that interaction between a subducted remnant of the Kula plate and the presently subducting plates could produce this unusual pattern of seismicity. The M_w=7.0 1928 earthquake (the largest magnitude event to have occurred in the PWS region in the 40 years prior to 1964 mainshock) appears to have ruptured the lower portion of the Yakutat block in a region near northern Montague Island that has remained seismically active (Figure 3a at 155 km; Figure 4d near 147°W).

Most events shown in Figure 2d (35 to 50 km) are located below the plate interface. The larger magnitude earthquakes are occurring on normal faults, with mechanisms indicating downdip (NW-SE) extension north of 61.5°N. Greater components of strike-slip motion are observed to south of 61.5°N. In contrast, slab events occurring at the same depth range located to the west in Cook Inlet exhibit reverse-oblique faulting [*Veilleux and Doser*, 2007].

4.2 Shape of the Subducted Slab

We constructed a series of north-south and east-west cross-sections through the PWS region in order to determine the depth to the plate interface. Cross sections were spaced 10 km apart and seismicity within 5 km of the cross section was projected onto each cross section line. Examples of these cross section lines are shown in Figure 4. The plate interface was interpreted to lie near the cessation of shallow, upper plate seismicity or the initiation of intense lower plate seismicity. The bold dashed gray lines in Figure 4 indicate where we have estimated the location of the plate interface. Black triangles on some cross sections indicate the points where the plate interface contours of *Brocher et al.* [1994] (based on seismic refraction/reflection studies) intersect the cross sections. Note that in some regions (e.g. Figures 4a and 4d) there is 4 to 5 km of uncertainty in the depth to the plate interface.

Figure 5 indicates points where depths to the plate interface were estimated (plusses) along with a contour map (bold lines) based on these measurements. The contour map was generated by interpolating individual measurements to a grid with a 25 km spacing and then smoothing the results. This map agrees well with *Brocher et al.'s* [1994] interface contours (bold gray dashed lines) within offshore and northern PWS. The contours on our interface map steepen more rapidly in western PWS than the contours based on *Brocher et al.* [1994] and could represent an edge effect of our analysis. We are currently working to relocate all seismicity between eastern PWS and western Cook Inlet to better define the shape of the western portion of the plate interface. The limited data suggest a smoother shape to the plate interface at depths > 20 km (Figure 5). *Zweck et al.*'s [2002] strongest zone of locking (coupling coefficient ≥ 1.0) is indicated by the black dashed line and closely follows the northern edge of the 20 km interface depth contour.

Figure 5 suggests that upper plate $M_w \geq 5.0$ earthquakes (open diamonds) are primarily concentrated in the region located above a sharp bend in the plate interface. Lower plate events (black symbols) are concentrated in the region near a bend in the 20 km depth contour and to the northwest. Although poorly constrained, the epicenters of $M_S > 7$ earthquakes occurring between 1906 and 1916 [*Doser*, 2006] (black stars, Figure 5), and the 1928 earthquake (largest black square) suggest this pattern of seismicity may be a permanent feature throughout the earthquake cycle. Note that the epicenter of the 1964 mainshock (gray star, Figure 5) and the highest amount of slip on the PWS asperity as modeled by *Ichinose et al.* [2007] (X in Figure 5) occur near the edge of the 20 km depth contour. The zone of maximum slip also corresponds to the location of the southwestern corner of the subducting Yakutat block as imaged by *Eberhart-Phillips et al.* [2006].

4.3 Relation of Relocated Seismicity to Potential Field Data

Fisher et al. [2005; 2006] have noted a correlation between seismicity in western PWS and the occurrence of ultramafic rocks imaged by magnetic and gravity data. Both *Fisher et al.* [2005; 2006] and *Ichinose et al.* [2007] have noted the correspondence between maximum slip in the 1964 mainshock (X, Figure 6a) and a free air gravity low located within central and western PWS.

We compare upper plate (depth < 15 km) seismicity to the complete Bouguer gravity [*http://wrgis.wr.usgs.gov/docs/gump/morin/alaska/gravity/gravity.html*] in Figure 6a and lower plate (depth $\geq$15 km) seismicity to low pass filtered Bouguer gravity in Figure 6b. The gravity data were gridded at a ~10 km interval.

In Figure 6a the contours of high Bouguer gravity correspond well with the shape of the plate interface (black dashed lines). A gravity high in the Knight Island region is related to ultramafic rocks [*Bradley et al*., 2003]. Seismicity clusters around and on top of this high and another high located east of Naked Island. The northeast-southwest trend of seismicity in the Columbia Bay and Tazlina Glacier regions appears to follow the strike of the gravity contours. A majority of the seismicity within the Copper River delta is associated with a sharp bend in the Bouguer gravity contours. The epicenter of the 1964 mainshock is located near the edge of a gravity low associated with the College Fiord region. These relationships suggest a strong correlation between rheologic changes and seismicity within the upper plate.

Lower plate seismicity in the Columbia Bay and Valdez regions (Figure 6b) cuts across gravity contours, but much of the deeper seismicity north of 61°N is restricted to the region between the -20 and -60 mGal contours. *Eberhart-Phillips et al.* [2006] indicate a small region of either thinner crust or higher velocity crust (~35 km to the 7.5 km/sec isovelocity surface, as denoted by the ellipse, Figure 6b) that appears to be surrounded by seismicity. They also have determined that the crust is slightly thicker or has a lower velocity (~50 km to the 7.5 km/sec isovelocity surface) in the vicinity of College Fiord corresponding to the Bouguer low observed in Figure 6b. It is possible the change in thickness or density of the crust led to nucleation of the 1964 rupture in this region.

4.4 Variations in Stress Field

Table 1 summarizes the results of the inversion of first motion data for stress field orientations in the PWS region. The boxes in Figure 7 indicate regions selected for analysis based on the hypocentral clustering of events. Bold black lines in Figure 7 indicate maximum compressive stress directions; dashed gray lines are minimum compressive stress directions. The bold arrow indicates Pacific-North America plate motion [*DeMets and Dixon*, 1999]. The lengths of the lines are proportional to plunge. We attempted to investigate stress field changes in the Tazlina Glacier region in 5 km intervals, however only data for the shallowest (0 to 25 km) and deepest (> 40 km) regions gave consistent directions.

Upper plate data for central PWS (Figure 7a) indicate reverse faulting with northwest-southeast oriented near horizontal maximum compressive stress in the Copper River delta and east of Montague Island regions. South of Hinchibrook Island, the maximum compressive stress rotates to NNE-SSW but remains horizontal. Both these directions are significantly rotated from the Pacific-North American plate motion direction. Focal mechanisms of larger offshore events (Figure 2a) are generally consistent with these two stress orientations. The Tazlina region shows a stress field from 0 to 25 km depth that is optimal for oblique normal and strike-slip faulting. In the upper 20 km minimum compressive stress is oriented WNW-ESE, with rotation to northeast-southwest between 20 and 25 km depth, a depth near the bottom of the inferred

Kula plate (Figure 3c). These stress directions are consistent with the orientation of P and T axes for focal mechanisms determined by *Ratchkovsky et al.* [1998] for this region.

In the lower plate (Figure 7b) western PWS is characterized by WNW-ESE oriented minimum compressive stress, similar to the results of *Lu et al.* [1997]. The stress field is optimal for normal to oblique normal faulting within western offshore PWS; however in the Columbia Bay and Port Fidalgo regions maximum compressive stress appears to rotate toward horizontal, a condition more favorable for strike-slip faulting. This is consistent with the observations by *Ratchkovsky et al.* [1998] *and Fisher et al.* [2005; 2006] that strike-slip faulting appears to be common within this region. The 1983 Columbia Bay earthquake sequence with normal faulting at 30 km depth (Figure 2c) is not consistent with this pattern. There are several explanations for this discrepancy. First, the smaller magnitude earthquakes may be reflecting a more localized stress field, since the state of stress both north and south of the Columbia Bay region appears optimal for normal faulting (Figure 7b). Second, the smaller magnitude events could be reflecting the state of stress in the upper part of the subducting plate (within the Yakutat block) closer to the plate interface, while the larger 1983 Columbia Bay earthquakes are reflecting stress within the Pacific plate. *Zweck et al*. [2002] have suggested that the locked zone extends to 30 km depth, with a maximum near 20 km, which also would be expected to influence the stress field with depth. Finally, the Columbia Bay region is both near the Contact fault zone and the region where the sediments on the Pacific plate are pinching out. Thus, there could be fluid and/or rheological changes influencing the shallower seismicity above the Pacific plate.

Deeper events (> 25 km) in the region northeast of College Fiord and in the Castle Mountain fault region (Figure 7b) show a stress field optimal for movement along low angle normal or high angle reverse faults. This orientation is not consistent with the focal mechanisms of larger events in these regions (Figures 2c and 2d), but is comparable to stress field patterns and the focal mechanisms of smaller earthquakes occurring at a similar depth within the subduction zone 150 km to the west beneath northern Cook Inlet [*Veilleux and Doser*, 2007] (Figure 8). The deepest events in the Tazlina region show a stress field optimal for normal faulting, similar to the focal mechanism observed for a larger magnitude event in 2004 (Figure 2d).

5. Discussion

Rheological contrasts between suture zones, slivers of the Kula plate (Tazlina glacier region) and Yakutat block (northern Knight Island), and ultramafic rocks (Knight Island) appear to concentrate seismicity in the upper plate and, in some instances, the lower plate of the PWS region. Suture zones and thrust faults that have emplaced slivers of mafic rocks also likely act as conduits for fluid migration from the subducted Yakutat block and Pacific plate, especially in the region where sediments on the Pacific plate are being pinched out in the subduction process. The close correspondence between trends observed in gravity and magnetic data (e.g. *Fisher et al.,* 2005; 2006) and seismicity reinforces the idea that rheological contrasts in composition and density of the upper crust serve to concentrate stress.

Plate coupling also plays a role in the location of upper and lower plate seismicity, especially of M_w>5.0 events (Figure 5). Larger upper plate events occur above an upwarp in the plate interface that is likely controlled by the subduction of the southwestern corner of the Yakutat block in southwestern PWS. Lower plate events concentrate near the edges of the zone of highest coupling (coupling coefficient ≥ 1.0) and most appear to be occurring within the Pacific plate (e.g. 1983 Columbia Bay sequence) at ~ 30 km depth where the amount of coupling decreases [Zweck et al., 2002]. An exception is the M_w=7.0 event off Montague Island in 1928 (Figure 3c) which may represent reverse faulting within the Yakutat block. Historical seismicity indicates that regions of the lower plate have been consistently active over the past 100 years (Figure 5) and that the maximum expected magnitude for these events is 7 to 7.5

Stress field analysis shows that thrust and reverse faulting is continuing in the upper plate in offshore PWS. Onshore we observe a mix of strike-slip and normal faulting, especially in the Tazlina region. In the lower plate(s) stress orientations are optimal for normal and normal-oblique faulting in western PWS, however in the Columbia Bay and Port Fidalgo regions the stress field is more favorable for strike-slip faulting. This could reflect a change in plate coupling, change in rheology associated with the Contact fault system and/or presence of fluids within these regions that alters the stress field. Normal faulting is occurring within the Pacific plate; however the differing rheology, fluid content and fracturing within the Yakutat block could lead to a different stress state, as suggested by the mechanism of the 1928 earthquake and our stress analysis of smaller earthquakes.

Determining the shape of the plate interface and the state of stress near the interface in westernmost PWS and the eastern Kenai Peninsula is key to understanding how structures control the southwestern portion of the asperity and the slip observed during the 1964 mainshock. However, this is hampered by a decrease in seismicity within this region, possibly due to decreased plate coupling. An M_w=6.7 event in 1949 (Figure 8) at 38 km depth with a normal-oblique focal mechanism [*Doser and Brown*, 2001] indicates earthquakes occasionally occur within this region. Lower plate seismicity in northeastern Cook Inlet suggests that the maximum compressive stress direction rotates as it crosses the southwestern boundary of the Yakutat block (bold dashed line, Figure 8). Clearly more data are needed to determine if this pattern continues southeastward to western PWS.

6. Conclusions

The inherited structure of previous episodes of suturing of terranes to North America plays an important role in concentrating seismicity within the PWS region and may control migration of fluids from the present subduction zone. Potential field data can aid in identifying these rheological controls in regions where active seismic studies are not available.

Most larger events in the upper plate of the PWS subduction zone have ranged between magnitude 5.5 and 6, occurred on reverse and thrust faults, and were concentrated above a region of maximum curvature in the plate interface and maximum coupling across the plate interface. Recent background seismicity reflects the same stress field as these larger events. In the lower plate background seismicity shows a mixture of normal, normal-oblique, and strike-slip faulting. Most larger magnitude events have occurred near the edge of the zone of maximum plate coupling and have ranged as high as magnitude 7 to 7.5. These events predominantly represent normal faulting within the Pacific plate, although infrequent events have occurred within the Yakutat block.

Acknowledgements. We thank M. Fisher, R. Bruhn, and N. Ruppert for discussions of our early results. G. Inchinose and D. Eberhart-Phillips generously provided us with preprints of their manuscripts. This research was supported by grant 05HQGR0101 from the U.S. Geological Survey's National Earthquake Hazards Reduction Program. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

References

Bradley, D.C., T. Kusky, P.J. Haeussler, R. J. Goldfarb, M.L. Miller, J.A. Dumoulin, S.W. Nelson and S.M. Karl (2003), Geologic signature of early Tertiary ridge subduction in Alaska, *Geol. Soc.Amer. Spec. Paper, 371*, 19-49.

Brocher, T.M., G.S. Fuis, M.A. Fisher, G. Plafker, M.J. Moses, J.J., Taber, and N.I. Christensen (1994), Mapping the megathrust beneath the northern Gulf of Alaska using wide-angle seismic data, *J. Geophys. Res., 99*, 11,663-11,685.

DeMets, C., and T.H. Dixon (1999), New kinematic models for Pacific-North America motions from 3 Ma to present, 1: Evidence for steady motion and biases in the NUVEL-1A model, *Geophys. Res. Lett., 26*, 1921-1924.

Doser, D.I., (2006), Relocation of earthquakes (1899-1917) in south-central Alaska, *Pure and Appl. Geophys. 163*, 1461-1476.

Doser, D.I., and W.A. Brown, W.A., (2001), A study of historic earthquakes of the Prince William Sound, Alaska, region, *Bull. Seism. Soc. Amer., 91*, 842-857.

Doser, D.I., A.M. Veilleux, C. Flores and W.A. Brown (2006), Changes in seismic moment rates along the rupture zone of the 1964 great Alaska earthquake, *Bull. Seismol. Soc. Am.*, *96*, 1545-1550.

Doser, D. I., A. Veilleux, and M. Velasquez (1999), Seismicity of the Prince William Sound region for thirty two years following the 1964 great Alaskan earthquake, *Pure and Appl. Geophys.,154*, 593-632.

Eberhart-Phillips, D., D.H. Christensen, T.M. Brocher, R. Hansen, N.A. Ruppert, P.J. Haeussler and G.A. Abers (2006), Imaging the transition from Aleutian subduction to Yakutat collision in central Alaska, with local earthquakes and active source data, *J. Geophys. Res, 111,* B11303, doi:10.1029/2005JB004240.

Fisher, M.A., J.T. Freymueller, N.A. Ruppert, T. Parsons, D.M. Eberhart-Phillips, R.W. Sliter, and F.L. Wong (2006), The south boundary of the subducted Yakutat terrane seems to affect the distribution of forearc subsidence since the 1964 great Alaska earthquake (Mw=9.2), *Eos Trans. AGU, 87(52), Fall Meet. Suppl., Abstract T21D-0466.*

Fisher, M.A., N.A. Ratchkovski, R.E. Wells, D.M. Eberhart-Phillips, R.J. Blakely, R. Sliter, and E.L. Geist (2005), Seismotectonics of the rupture zone of the 1964 Mw=9.2 great Alaska earthquake, *Geol. Soc. Amer Abstr. With Prog., 37 (4),* 44.

Flores, C. and D.I. Doser (2005), Shallow seismicity of the Anchorage, Alaska region, *Bull. Seism. Soc. Am., 95*, 1865-1879.

Fogelman, K.A., J.C. Lahr, C.D. Stephens, and R.A. Page (1993), Earthquake locations determined by the southern Alaska network for Oct 1971- May 1989, *USGS Open File Report, 93-30.*

Fuis, G.S., and G Plafker (1991), Evolution of deep structure along the Trans-Alaska Crustal Transect, Chugach Mountains and Copper River Basin, southern Alaska, *J. Geophys. Res., 96*, 4229-4253.

Fuis, G.S., E.L. Ambos, W.D. Mooney, N.I Christensen, and E.L. Geist (1991), Crustal structure of accreted terranes in southern Alaska, Chugach Mountains and Copper River Basin, from seismic refraction results, *J. Geophys. Res. 96*, 4187-4227.

Fuis, G.S., E.L. Ambos, W.D. Mooney, R.A. Page, M.A. Fisher, T.M. Brocher, and J. J. Taber, (1987), Crustal structure beneath exposed accreted terranes of southern Alaska, *Geophys. J. R. Astron. Soc., 89,* 73-78.

Griscom, A. and P.E. Sauer (1990), Interpretation of magnetic maps of the northern Gulf of Alaska, with emphasis on the source of the Slope Anomaly, *USGS Open File Report, 90-0348*.

Ichinose, G., P. Somerville, H.K. Thio, R. Graves, and D. O'Connell (2007), Rupture process of the 1964 Prince William Sound, Alaska earthquake from the combined inversion of seismic, tsunami, and geodetic data, *J. Geophys. Res.,* in press, doi:10.102912006JB004728.

Johnson, J.M., K. Satake, S.R. Holdahl, and J. Sauber (1996), The 1964 Prince William Sound earthquake: Joint inversion of tsunami and geodetic data, *J. Geophys. Res., 101*, 523-532.

Lu, Z., M. Wyss, and H. Pulpan (1997), Details of stress directions in the Alaska subduction zone from fault plane solutions, *J. Geophys. Res., 102*, 5385-5402.

Page, R.A., C.D. Stephens and J.C. Lahr (1989), Seismicity of the Wrangell and Aleutian Wadati-Benioff zones and the North American plate along the Trans-Alaska crustal transect, Chugach Mountains and Copper River Basin, southern Alaska*, J. Geophys. Res.*, 94, 16,059-16,082.

Ratchkovsky, N.A., J. Pujol, and N.N. Biswas (1998), Relocation of shallow earthquakes in southern Alaska using Joint Hypocenter Determination method, *J. Seismology, 2*, 87-102.

Veilleux, A.M., and D.I. Doser, (2007), Studies of Wadati-Benioff zone seismicity of the Anchorage, Alaska region, *Bull. Seismol. Soc. Am., 97*, 52-62.

Waldhauser, F. and W.L. Ellsworth (2000), A double-difference earthquake location algorithm: Method and application to the northern Hayward fault, *Bull. Seism. Soc. Amer.*, *90*, 1353-1368.

Zweck, C., J.T. Freymueller, and S.C. Cohen (2002). Three dimensional elastic dislocation modeling of the postseismic response to the 1964 Alaska earthquake, *J. Geophys. Res.*, *107* (B4), 10.1029/2011JB000409.

Table 1. Stress Directions from Inversion of First Motion Data

Region	Latitude/Longitude	Number of first motions	σ_1 (azm,plng)	σ_3 (azm,plng)
Castle Mtn. (≥20 km)	61.7-62.25 N 146.75-148 W	2446	270,50	80,40
Columbia Bay (≥15 km)	60.6-61.05 N 146.5-147.9 W	7426	190,0	280,20
Copper River (< 15 km)	60.2-60.6 N 144.6-145.6 W	1533	320,10	120,80
E. of Montague Isl. (<15 km)	59.9-60.1 N 146.5-146.75 W	655	300,10	60,71
Hinchinbrook Isl. (< 15 km)	60.15-60.35 N 146.2-146.5 W	512	200,10	340,77
NE of College Fiord (20-25 km)	61.05-61.55 N 146.8-147.7 W	4441	0,80	110,3
NE of College Fiord (≥25 km)	61.2-61.7 N 147-148 W	3055	80,50	280,38
N. Knight Isl. (≥20 km)	60.3-60.55 N 147.5-148 W	1925	180,80	280,2
N. Montague Isl. (≥14 km)	60.25-60.5 N 147-147.5 W	909	40,80	290,3
Port Fidalgo (≥ 14 km)	60.6-60.9 N 146.6-147 W	727	0,50	90,0
S. Knight Isl. (≥14 km)	60-60.2 N 147.6-148 W	619	50,80	270,8
Tazlina (< 10 km)	61.1-61.65 N 146.25-146.8 W	771	200,70	100,4
Tazlina (10-15 km)	61.1-61.65 N 146.25-146.8 W	2056	190,70	280,3
Tazlina (15-20 km)	61.1-61.65 N 146.25-146.8 W	3217	100,70	280,20
Tazlina (20-25 km)	61.2-61.7 N 145.8-147 W	2471	30,50	250,33
Tazlina (≥40 km)	61.2-61.7 N 145.8-147 W	580	260,70	130,12
Valdez (< 20 km)	60.9-61.1 N 146.15 -146.8 W	3383	180,80	290,3
W. PWS (≥ 15 km)	60.5-60.85N 147-148 W	4727	160,80	290,7

Figure Captions

Figure 1. General location map of the Prince William Sound region. Inset in upper right shows locations of Pacific and North American plates, Yakutat block (shaded gray) and Alaska-Aleutian megathrust (bold line). Thin dashed lines indicate seismic refraction/reflection lines of *Fuis et al.* [1991] and *Brocher et al.* [1994]. Bold dashed line is Slope Magnetic Anomaly [*Griscom and Sauer*, 1990]. Bold arrow indicates plate motion for Pacific-North America plate [*DeMets and Dixon*, 1999]. Smaller arrows labeled a-d indicate locations of cross sections shown in Figure 4. Star is location of 1964 mainshock. Locations are CB, Columbia Bay; CF, College Fiord; CRD, Copper River delta; NI, Naked Island; PF, Port Fidalgo.

Figure 2. Relocations of Prince William Sound earthquakes (1971-2001). SMA is slope magnetic anomaly, CF is Contact fault zone, BRF is Border Ranges fault zone. Diamonds are $M_w \geq 5.0$ earthquakes occurring between 1964 and 2004, circles are $M_w \geq 5.0$ events occurring prior to 1964. Black focal mechanisms are from *Doser et al.* [1999] and *Doser and Brown* [2001] and were obtained from body waveform modeling. Gray focal mechanisms are from the *Alaska Earthquake Information Center* [www.giseis.alaska.edu/Seis/html_docs/ moment_tensors.html] or the *Harvard Centroid Moment Tensor Catalog* [www.seismology.harvard.edu/CMTsearch .html]. Numbers in brackets are focal depths. a) 0-15 km depth, b) 15-25 km depth, c) 25-35 km depth, and d) $\geq$ 35 km depth

Figure 3. Seismicity projected on to structure obtained from the seismic refraction/reflection studies of *Brocher et al.* [1994] and *Fuis et al.* [1991]. See Figure 1 for profile locations. Small numbers indicate seismic velocities in km/sec. Earthquakes

located within ± 15 km of the profiles are shown in a) and b). In c) seismicity located 35 to 65 km to the west is projected on to the profile. Gray shading indicates Pacific plate; diagonal lines, Yakutat block; vertical lines, Kula plate; stippled pattern, sediments between Pacific plate and Yakutat block. Arrows indicate northern and/or southern extent of zone of high seismic coupling (coupling coefficient ≥ 0.5) from *Zweck et al.* [2002]. Open diamonds indicate location of $M_w \geq 5.0$ events located within ± 15 km of the profiles. Solid diamond indicates a bend in the TACT line (see Figure 1). BRF, Border Ranges fault zone; CF, Contact fault zone; TG, Tazlina Glacier region; V, Valdez.

Figure 4. North-south (a, b) and east-west (c, d) cross sections of seismicity across PWS region (location of cross sections is shown in Figure 1). Earthquakes located within ± 5 km of the cross sections are shown. Dashed lines indicate interpreted position of the plate interface. Open diamonds show $M_w \geq 5.0$ events located within ± 15 km of the cross sections. Triangles show depth to the plate interface from contours of *Brocher et al.* [1994]. Arrows indicate northern and/or southern extent of zone of high seismic coupling (as in Figure 3). CB, Columbia Bay; CRD, Copper River delta; MI, Montague Island; NI, Naked Island; SMA, Slope Magnetic Anomaly; TG, Tazlina Glacier region; V, Valdez region.

Figure 5. Contour map of depth to the plate interface (bold lines, this study; gray dashed lines, *Brocher et al.* [1994]). Plusses are data points used to create this study's map. Gray star is epicenter of 1964 mainshock. Earthquakes of $M_w \geq 5.0$ are indicated by symbols (diamonds events from 1964-2004; squares from 1928-1964; black stars from 1906-1916). Open symbols are upper plate events and solid symbols are lower plate events. Black dashed line indicates zone where interface coupling coefficient is ≥ 1.0

[*Zweck et al*., 2002]. Bold “X” indicates site of maximum slip on the PWS asperity during the 1964 mainshock [*Ichinose et al*., 2007].

Figure 6. Bouguer gravity of PWS region. a) Upper plate seismicity (depth < 15 km), compared with depth to plate interface (bold dashed lines). White star is 1964 mainshock epicenter. b) Lower plate seismicity (depth ≥ 15 km) compared to low pass filtered gravity data. Dashed ellipse is approximate location of 35 km depth contour to the 7.5 km/sec isovelocity surface of *Eberhart-Phillips et al*. [2006].

Figure 7. Stress orientations from inversion of first motion data for regions indicated by boxes. Bold black lines denote direction of maximum principal stress, dashed gray lines direction of minimum principal stress. Length of line is proportional to plunge, with horizontal plunge indicated at top right. Details of regions and stress orientations are given in Table 1. a) Upper plate orientations. Bold arrow denotes direction of motion between the Pacific and North American plates [*DeMets and Dixon*, 1999]. Results for the Tazlina region are shown by depth range. b) Lower plate orientations. The region northeast of College Fiord (NE) shows results for two depth range. The results for the Tazlina region (T) are for depths > 40 km. The individual regions are: CB, Columbia Bay; CM, Castle Mountain; NE, northeast of College Fiord; NK, north Knight Island; NM, north of Montague Island; PF, Port Fidalgo; SK, south of Knight Island; T, Tazlina region; V, Valdez; WP, western Prince William Sound.

Figure 8. Orientation of maximum principal stress in the lower plate, northern PWS and northern Cook Inlet. Small lines show orientations of P-axes obtained from first motion studies by *Veilleux and Doser* [2007] and *Flores and Doser* [2005]. The lines are keyed to focal mechanism as indicated at right with N, normal; ON, oblique-normal; OR,

oblique-reverse; R, reverse; SS strike-slip. Diamonds are the orientations of maximum principal stress obtained from inversion of first motion data by *Veilleux and Doser* [2007], *Flores and Doser* [2005], and this study. Black symbols indicate conditions are optimal for reverse faulting; gray, normal faulting; open, strike-slip faulting; half-gray, oblique-normal faulting. Bold gray double arrow labeled 1949 is P-axis orientation for an M_w=6.7 earthquake in 1949 [*Doser and Brown*, 2001]. Bold dashed line is inferred southwestern edge of Yakutat block [*Eberhart-Phillips et al.,* 2006]. Dashed gray curve indicates region where interface coupling coefficient is ≥ 1.0 [*Zweck et al*., 2002]

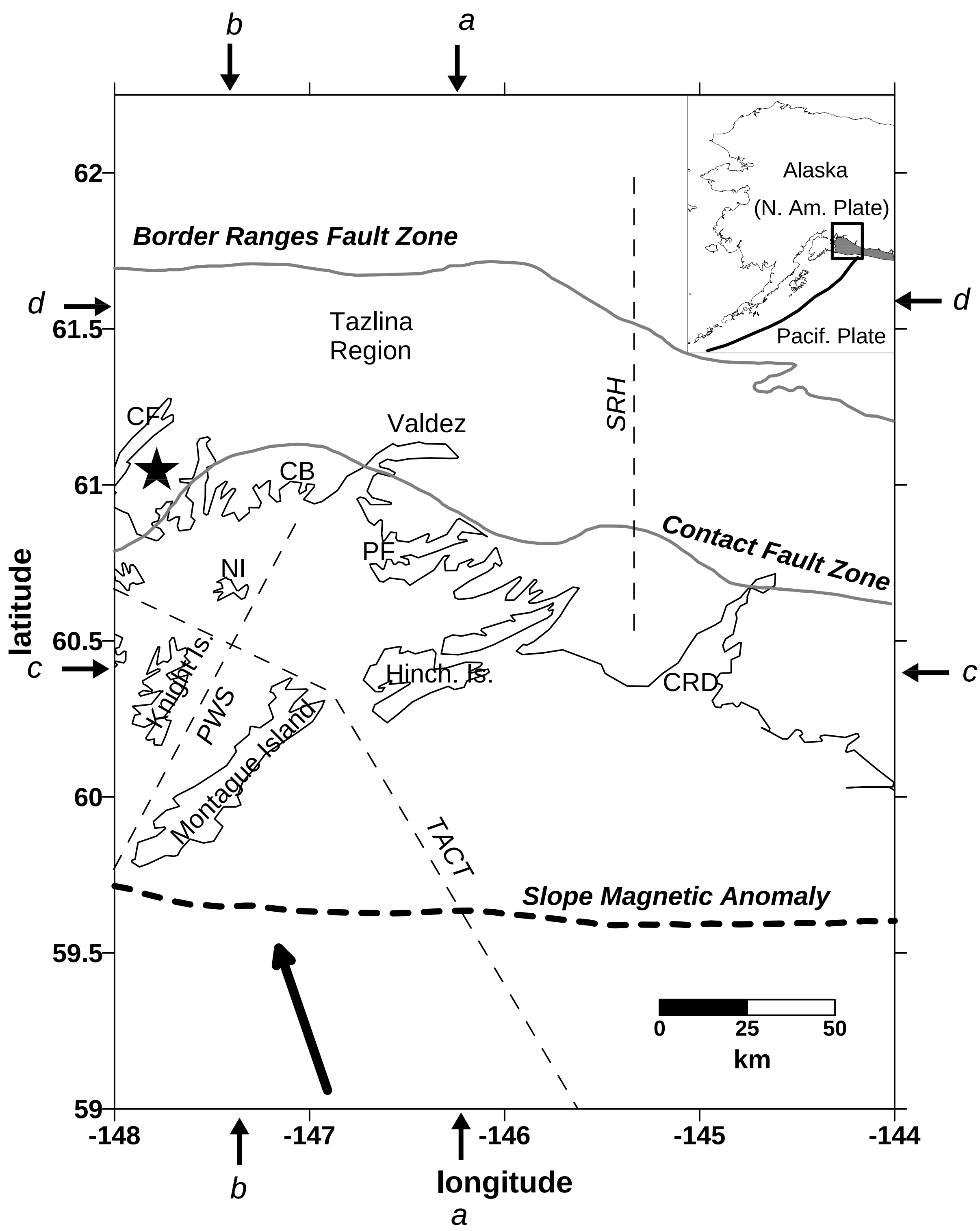

Figure 1. General location map of the Prince William Sound region. Inset in upper right shows locations of Pacific and North American plates, Yakutat block (shaded gray) and Alaska-Aleutian megathrust (bold line). Thin dashed lines indicate seismic refraction/reflection lines of Fuis et al. [1991] and Brocher et al. [1994]. Bold dashed line is Slope Magnetic Anomaly [Griscom and Sauer, 1990]. Bold arrow indicates plate motion for Pacific-North America plate [DeMets and Dixon, 1999]. Smaller arrows labeled a-d indicate locations of cross sections shown in Figure 4. Star is l ocation of 1964 mainshock. Locations are CB, Columbia Bay; CF, College Fiord; CRD, Copper River delta; NI, Naked Island; PF, Port Fidalgo.

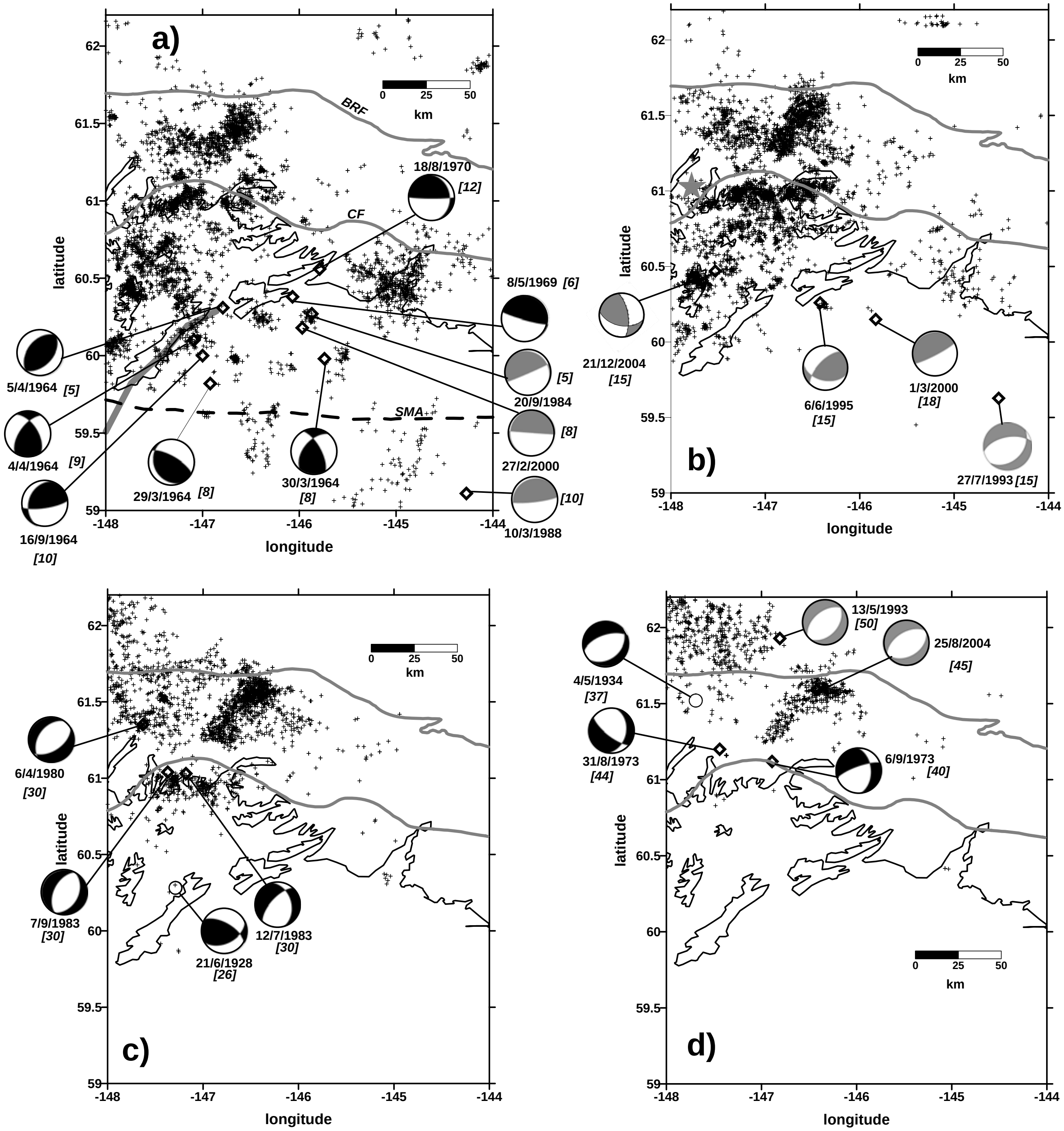

Figure 2. Relocations of Prince William Sound earthquakes (1971-2001). SMA is slope magnetic anomaly, CF is Contact fault zone, BRF is Border Ranges fault zone. Diamonds are Mw?5.0 earthquakes occurring between 1964 and 2004, circles are Mw?5.0 events occurring prior to 1964. Black focal mechanisms are from Doser et al. [1999] and Doser and Brown [2001] and were obtained from body waveform modeling. Gray focal mechanisms are from the Alaska Earthquake Information Center [www.giseis.alaska.edu/Seis/html_docs/ moment_tensors.html] or the Harvard Centroid Moment Tensor Catalog [www.seismology.harvard.edu/CMTsearch .html]. Numbers in brackets are focal depths. a) 0-15 km depth, b) 15-25 km depth, c) 25-35 km depth, and d) >= 35 km depth

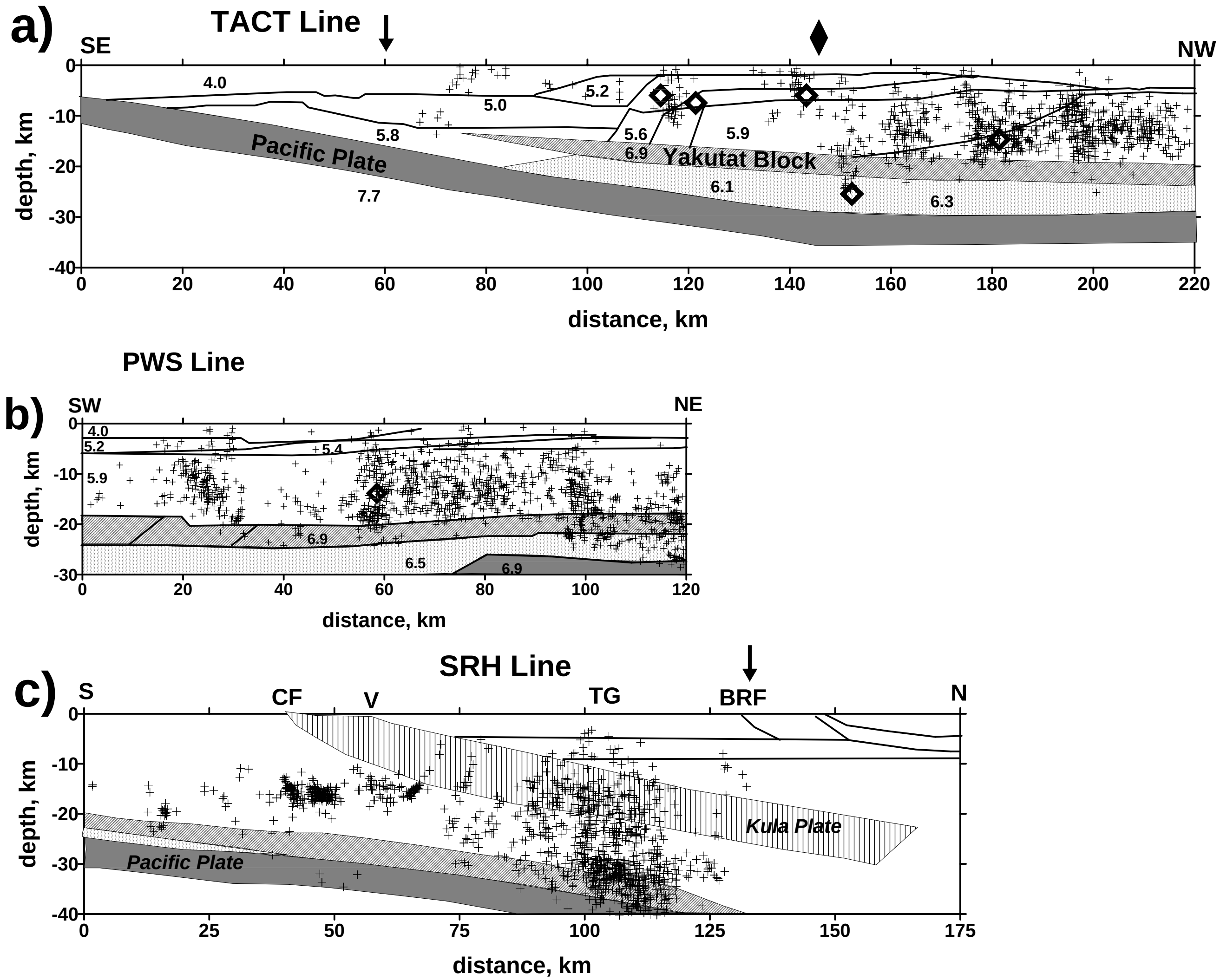

Figure 3. Seismicity projected on to structure obtained from the seismic refraction/reflection studies of Brocher et al. [1994] and Fuis et al. [1991]. See Figure 1 for profile locations. Small numbers indicate seismic velocities in km/sec. Earthquakes located within ± 15 km of the profiles are shown in a) and b). In c) seismicity located 35 to 65 km to the west is projected on to the profile. Gray shading indicates Pacific plate; diagonal lines, Yakutat block; vertical lines, Kula plate; stippled pattern, sediments between Pacific plate and Yakutat block. Arrows indicate northern and/or southern extent of zone of high seismic coupling (coupling coefficient >= 0.5) from Zweck et al. [2002]. Open diamonds indicate location of Mw>=5.0 events located within ± 15 km of the profiles. Solid diamond indicates a bend in the TACT line (see Figure 1). BRF, Border Ranges fault zone; CF, Contact fault zone; TG, Tazlina Glacier region; V, Valdez.

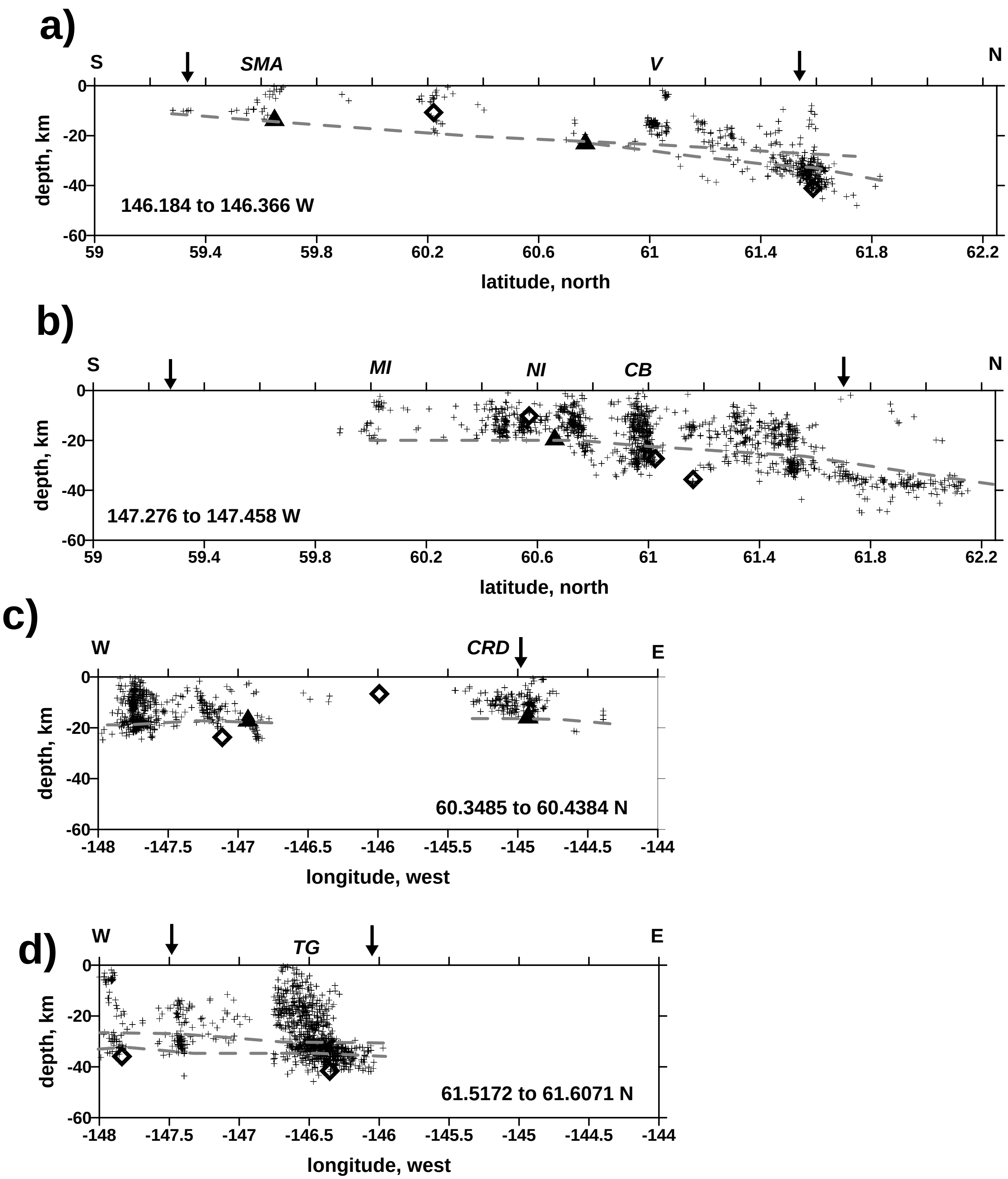

Figure 4. North-south (a, b) and east-west (c, d) cross sections of seismicity across PWS region (location of cross sections is shown in Figure 1). Earthquakes located within ± 5 km of the cross sections are shown. Dashed lines indicate interpreted position of the plate interface. Open diamonds show Mw>=5.0 events located within ± 15 km of the cross sections. Triangles show depth to the plate interface from contours of Brocher et al. [1994]. Arrows indicate northern and/or southern extent of zone of high seismic coupling (as in Figure 3). CB, Columbia Bay; CRD, Copper River delta; MI, Montague Island; NI, Naked Island; SMA, Slope Magnetic Anomaly; TG, Tazlina Glacier region; V, Valdez region.

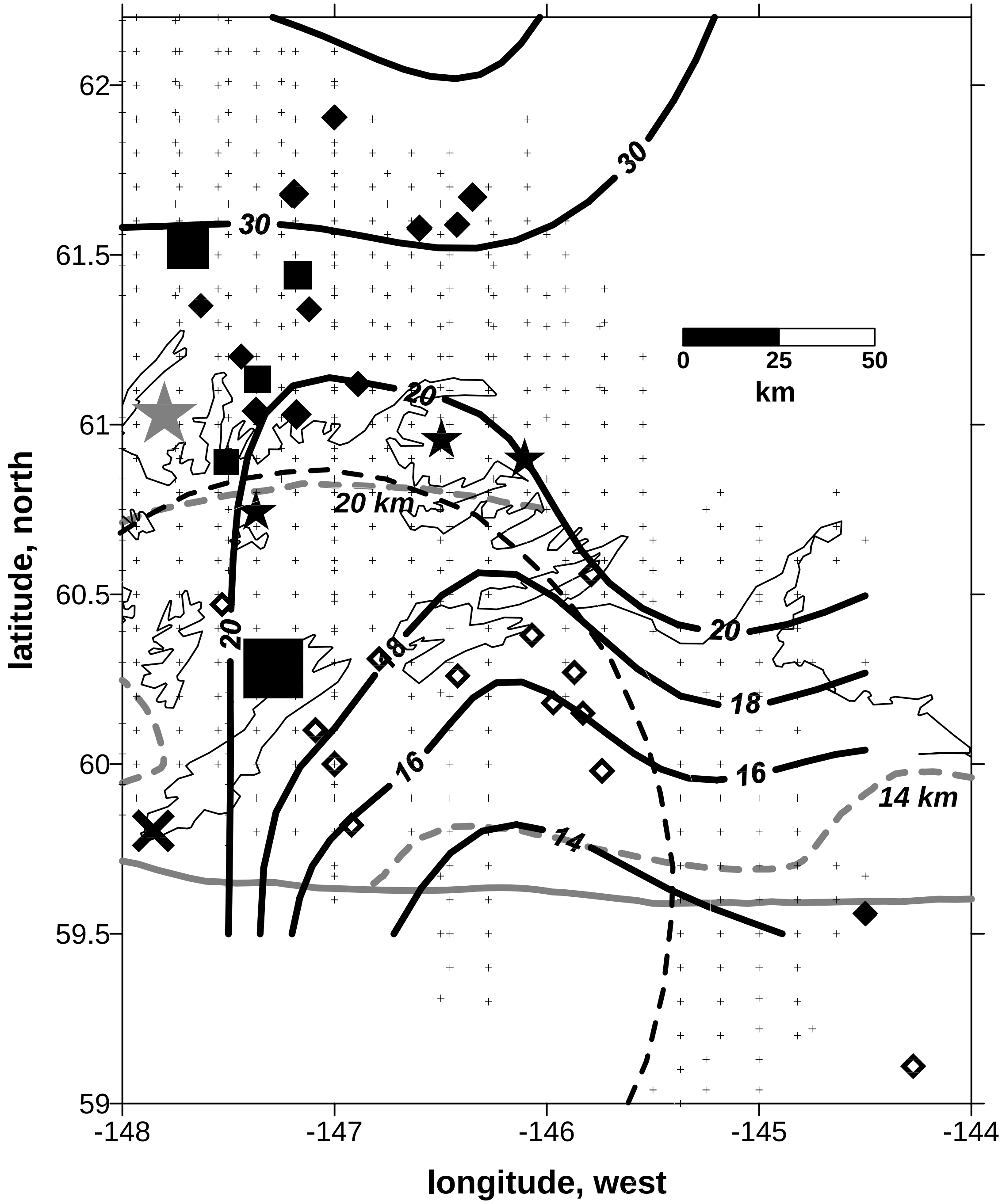

Figure 5. Contour map of depth to the plate interface (bold lines, this study; gray dashed lines, Brocher et al. [1994]). Plusses are data points used to create this study's map. Gray star is epicenter of 1964 mainshock. Earthquakes of Mw=5.0 are indicated by symbols (diamonds events from 1964-2004; squares from 1928-1964; black stars from 1906-1916). Open symbols are upper plate events and solid symbols are lower plate events. Black dashed line indicates zone where interface coupling coefficient is >=1.0 [Zweck et al., 2002]. Bold "X" indicates site of maximum slip on the PWS asperity during the 1964 mainshock [Ichinose et al., 2007].

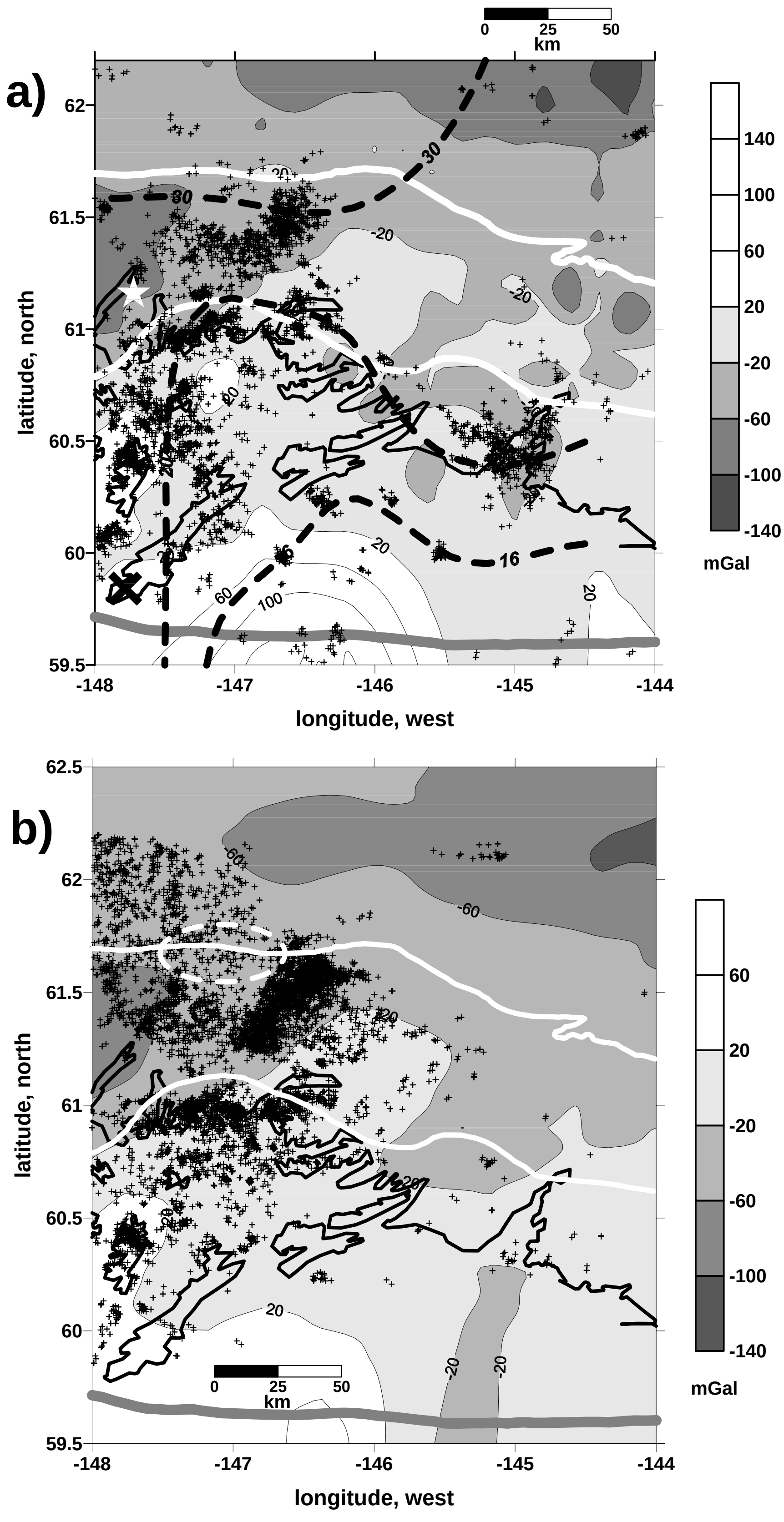

Figure 6. Bouguer gravity of PWS region. a) Upper plate seismicity (depth < 15 km), compared with depth to plate interface (bold dashed lines). White star is 1964 mainshock epicenter. b) Lower plate seismicity (depth >= 15 km) compared to low pass filtered gravity data. Dashed ellipse is approximate location of 35 km depth contour to the 7.5 km/sec isovelocity surface of Eberhart-Phillips et al. [2006].

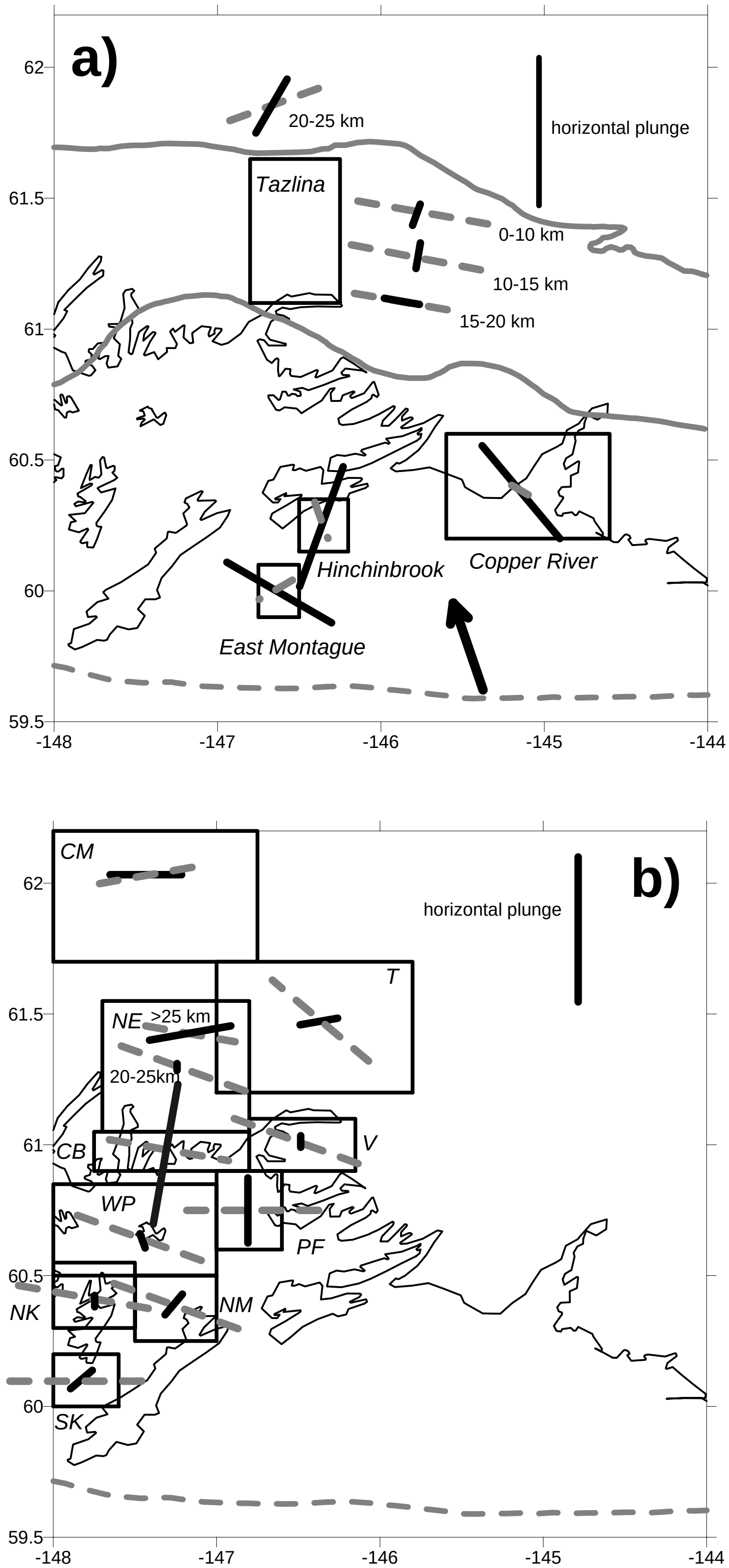

Figure 7. Stress orientations from inversion of first motion data for regions indicated by boxes. Bold black lines denote direction of maximum principal stress, dashed gray lines direction of minimum principal stress. Length of line is proportional to plunge, with horizontal plunge indicated at top right. Details of regions and stress orientations are given in Table 1. a) Upper plate orientations. Bold arrow denotes direction of motion between the Pacific and North American plates [DeMets and Dixon, 1999]. Results for the Tazlina region are shown by depth range. b) Lower plate orientations. The region northeast of College Fiord (NE) shows results for two depth range. The results for the Tazlina region (T) are for depths > 40 km. The individual regions are: CB, Columbia Bay; CM, Castle Mountain; NE, northeast of College Fiord; NK, north Knight Island; NM, north of Montague Island; PF, Port Fidalgo; SK, south of Knight Island; T, Tazlina region; V, Valdez; WP, western Prince William Sound.

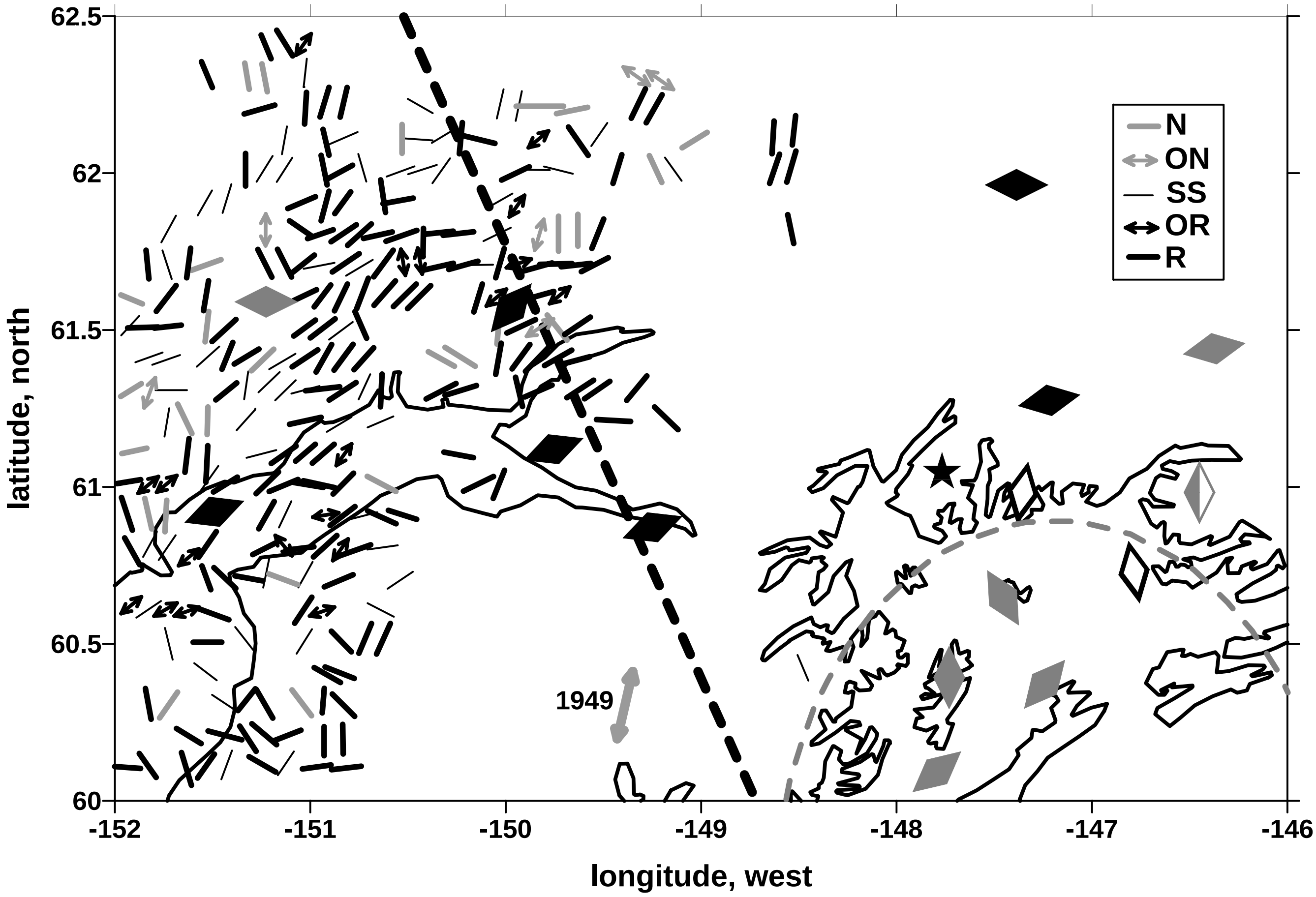

Figure 8. Orientation of maximum principal stress in the lower plate, northern PWS and northern Cook Inlet. Small lines show orientations of P-axes obtained from first motion studies by Veilleux and Doser [2007] and Flores and Doser [2005]. The lines are keyed to focal mechanism as indicated at right with N, normal; ON, oblique-normal; OR, oblique-reverse; R, reverse; SS strike-slip. Diamonds are the orientations of maximum principal stress obtained from inversion of first motion data by Veilleux and Doser [2007], Flores and Doser [2005], and this study. Black symbols indicate conditions are optimal for reverse faulting; gray, normal faulting; open, strike-slip faulting; half-gray, oblique-normal faulting. Bold gray double arrow labeled 1949 is P-axis orientation for an Mw=6.7 earthquake in 1949 [Doser and Brown, 2001]. Bold dashed line is inferred southwestern edge of Yakutat block [Eberhart-Phillips et al., 2006]. Dashed gray curve indicates region where interface coupling coefficient is >= 1.0 [Zweck et al., 2002].