Retrieval, Processing, Interpretation and Cataloging of Legacy Seismic Reflection Data, Gulf of Alaska

Project Award Number: # G12AP20078

Award Dates: May 2011 through December 2012

Submission date: August 8, 2013

Lee M. Liberty

Associate Research Professor

Megan Moeller

Undergraduate Assistant

Center for Geophysical Investigation of the Shallow Subsurface (CGISS)

Department of Geosciences

Boise State University

Boise, Idaho 83725-1536

Phone: 208-426-1419

Fax: 208-426-3888

lliberty@boisestate.edu

http://cgiss.boisestate.edu/~lml

Research supported by the U.S. Geological Survey (USGS), Department of the Interior, under USGS award number G12AP20078. 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.

Abstract

Using tsunami run up, seismic reflection and bathymetric data, we identify tsunamigenic sea floor ruptures that resulted from the 1964 Great Alaska earthquake. These sea floor lineaments are rooted in megathrust splay faults that appear across the 500-km wide Gulf of Alaska continental shelf. Based on estimated tsunami travel times, we identify two thrust faults that produced 5-10 m wave heights in the coastal town of Seward and remote settlements along the Kenai Peninsula. These faults splay from the megathrust along the trailing edge of the subducted Yakutat terrane that is sandwiched between the Pacific and North American plates. Duplexing along the megathrust likely transferred lateral motion along the decollement to vertical splay fault motion that resulted in multi-meter sea floor uplifts. We identify the Cape Cleare and Patton Bay faults as the source of the earliest tsunami arrival for Seward, Puget Bay and Whidbey Bay. Sparker seismic data, pre- and post-earthquake bathymetry and crustal seismic data characterize the along-strike Holocene motion on this 70-km long fault that parallels the Patton Bay fault that ruptured on nearby Montague Island. We define a strand of the Middleton Island fault system as the source of the second arrival in Puget and Whidbey Bays and the earliest tsunami source on Middleton Island and other sites in the eastern Gulf of Alaska. Sea floor displacements of more than 20 m suggest both of these faults have repeatedly ruptured during Holocene earthquakes. Additionally, we identify a series of active thrust faults along the length of the Gulf of Alaska to Kodiak Island that likely initiated tsunami waves from smaller sea floor displacements. We identify sea floor offsets and thrust faults across the length of the continental shelf to suggest Holocene coseismic rupture patterns are not reflected in interseismic GPS measurements along the Kenai Peninsula. Our observations are consistent with seismic, tsunami, and geodetic measurements from the 1964 earthquake, and provide a detailed distribution of Holocene slip across the Gulf of Alaska.

Key Points

Tsunami sources

1964 Great Alaska earthquake

Asperity recurrence, pattern, and slip distribution

Introduction

We have identified two key seismic reflection data sets that describe the tectonic setting for the Gulf of Alaska continental shelf between Middleton and Kodiak Islands (Figure 1). The Mineral Management Services (MMS) 75-02 data set contains a grid of 71 seismic profiles that were obtained in TIFF format. We converted the associated 150 seismic line segments to SEGY format for subsequent data processing. The USGS L-7-81-WG dataset contains a set of 7 digital profiles that overlap the MMS profiles on the continental shelf. The USGS profiles that are higher resolution than the MMS data and were obtained from the USGS marine seismic library in both stacked and unstacked form. This report provides a description of seismic datasets, steps taken to digitally process TIFF images, a comparison to other geophysical and tsunami data, and an interpretation for the Gulf of Alaska continental shelf region. We first describe the Great Alaska earthquake and related studies that describe the tectonic setting for southern Alaska. We then identify a number splay faults that show late Quaternary motion, and in some locations, offset the sea floor. In addition to highlighting a very complex tectonic setting, these two datasets show clear evidence for paleoseismic ruptures from both

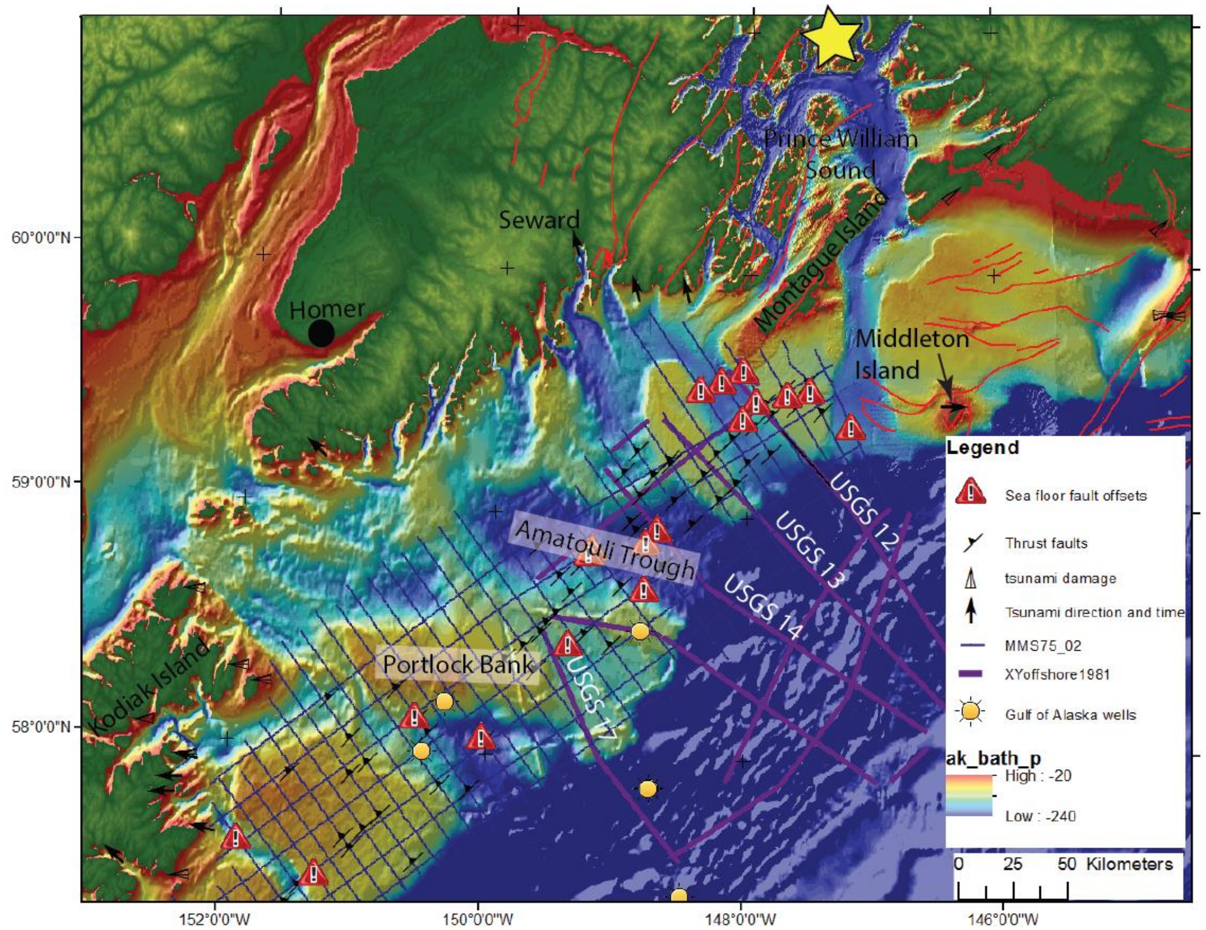


Figure 1. Study area showing bathymetry, seismic profile tracklines for the 1975 MMS survey and the 1981 USGS survey, previously mapped faults (red lines) by Plafker et al. [1978], and 1964 earthquake epicenter (star). Splay fault locations and related sea floor ruptures are derived from the MMS and USGS seismic data.

the 1964 M9.2 Great Alaska earthquake and previous large post-glacial (Holocene) earthquakes across the length of the continental shelf. The completed digital seismic data set will be available for download at the US Geological Survey archive for marine seismic surveys (walrus.wr.usgs.gov).

The M w 9.2 1964 earthquake and related tsunamis

The 1964 Mw 9.2 Great Alaska earthquake was the second-largest earthquake ever recorded instrumentally. The earthquake rupture extended over an area approximately 800 km long by 250 km wide, and generated tsunamis that devastated local communities across southern Alaska and damaged distant communities along the North American coast (Figure 1) [Plafker, 1969]. The earthquake initiated beneath the area immediately north of Prince William Sound (PWS) at a depth of about 25 km, and had two high moment release areas with about 21 m of slip beneath PWS and 15 m of slip near Kodiak Island [e.g., Plafker, 1969; Christensen and Beck, 1994; Johnson et al., 1996; Zweck et al., 2003; Suito and Freymueller, 2009]. The earthquake initiated at the boundary between the downgoing Yakutat plate and North American plate, but rupture propagated along splay faults through the subducted Yakutat terrane and overlying accretionary complex (Plafker, 1969; Brocher et al., 1994; Eberhart Phillips et al., 2006; Fuis et al., 2008). The earthquake shifted PWS southeast about 21 m and lifted portions of the region more than 12 m (Plafker, 1969; Figure 2). A surface uplift as great as 7 m was documented across the Patton Bay fault on southwestern Montague Island, with additional surface uplifts of 5 m documented in Hanning Bay on Montague Island and 3.5 m on Middleton Island (Figures 1 and 2).

Tsunami run up from tectonic sources were documented from numerous sites on Kodiak Island, Kenai Peninsula, PWS, Middleton Island, and the Alaska panhandle [Plafker, 1969] (Figure 1). Tsunami travel times ranged from minutes to hours and point to numerous near-shore continental shelf sources. Splay faults that extend across the western Gulf of Alaska are consistent with the Suleimani et al. (2011) tsunami model, which showed that a source on the continental shelf is needed to produce the tsunami that arrived at Seward about 30 minutes after the earthquake. Additionally, Plafker [1969] recognized that faults must have ruptured in the Gulf of Alaska during the 1964 earthquake to produce the footwall uplift along the south shore of Montague Island.

For this report, we estimated the location of tectonic sources from run up travel times for sites along the eastern Kenai Peninsula and Middleton Island (Figure 2). Additionally, we rely on the tsunami, geodetic and seismic models from Ichonese et al. [2008] to identify asperity regions across the length of the western Gulf of Alaska shelf. We estimated the tsunami sources from near the eastern Kenai Peninsula by calculating tsunami speed and distance for water depths provided from digital bathymetric data. Eye witness accounts from remote settlements in Puget and Whidbey Bays suggest two tectonic sources for wave run ups that arrived approximately 20 and 30 minutes after initial earthquake ground motion [Plafker, 1969]. Plafker [1969] also estimated the wave direction for both Puget and Whidbey bays traveled north-northeast while the tsunami source on Middleton Island originated from west of the island (Figure 2). We show travel time contours for the faster arrival time from the Kenai Peninsula locations are consistent with the Liberty et al. (in press) observation for significant 1964 uplift along the Cape Cleare and Patton Bay faults immediately west of Montague Island (Figure 2). The initial tsunami source that arrived on Middleton Island and the second wave run up recorded in Whidbey and Puget

Bays are consistent with a sea floor lineament and underlying splay fault along what we term the Middleton Island fault. In this report, we will show the tectonic character for the faults that we have identified, in addition to other likely tsunami tectonic sources from the 1964 earthquake.

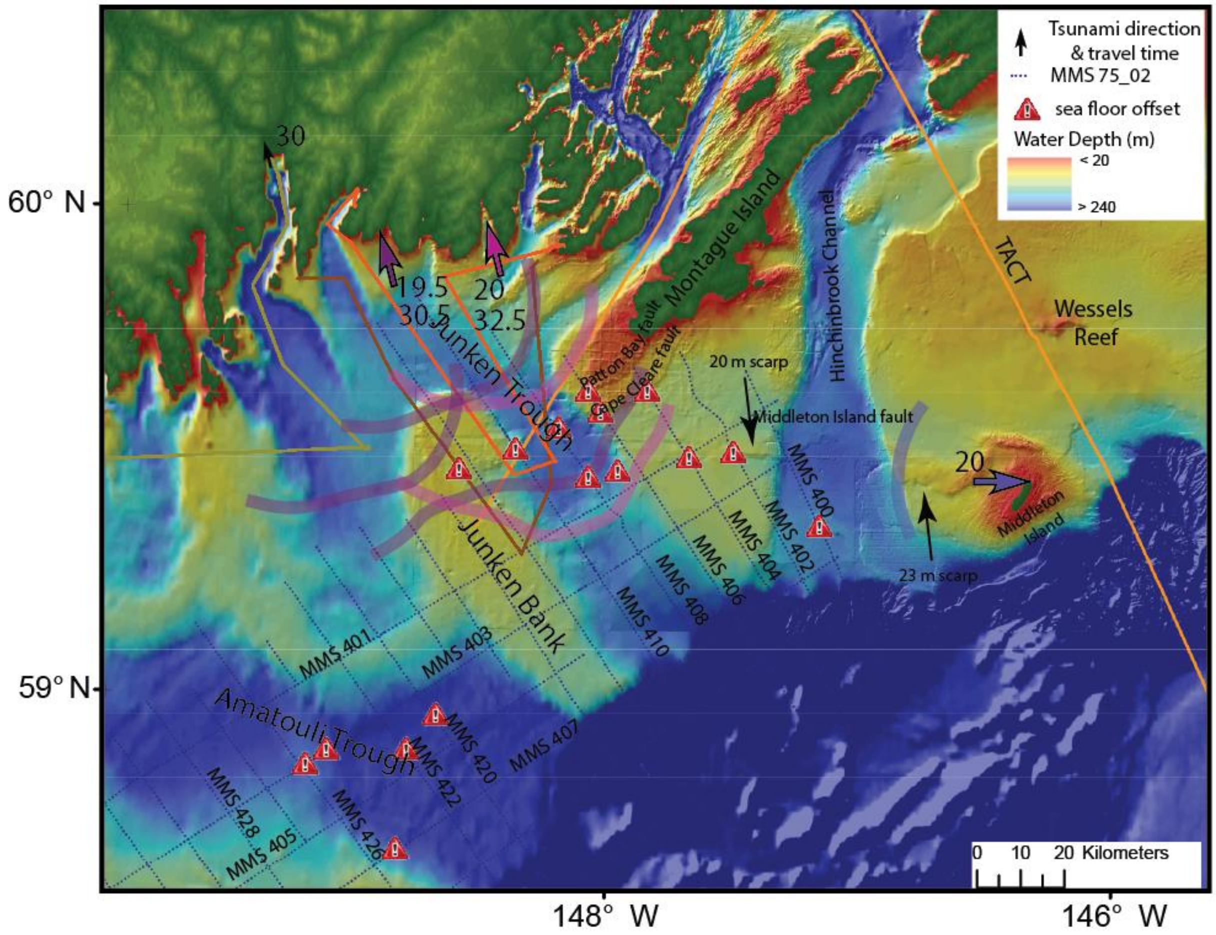


Figure 2. Bathymetric map for a portion of the Gulf of Alaska. Tsunami travel times and locations point to tectonic sources both west and south of Montague Island. Seismic profiles and bathymetric maps point to sea floor offsets that are rooted in splay faults.

Tectonic Setting

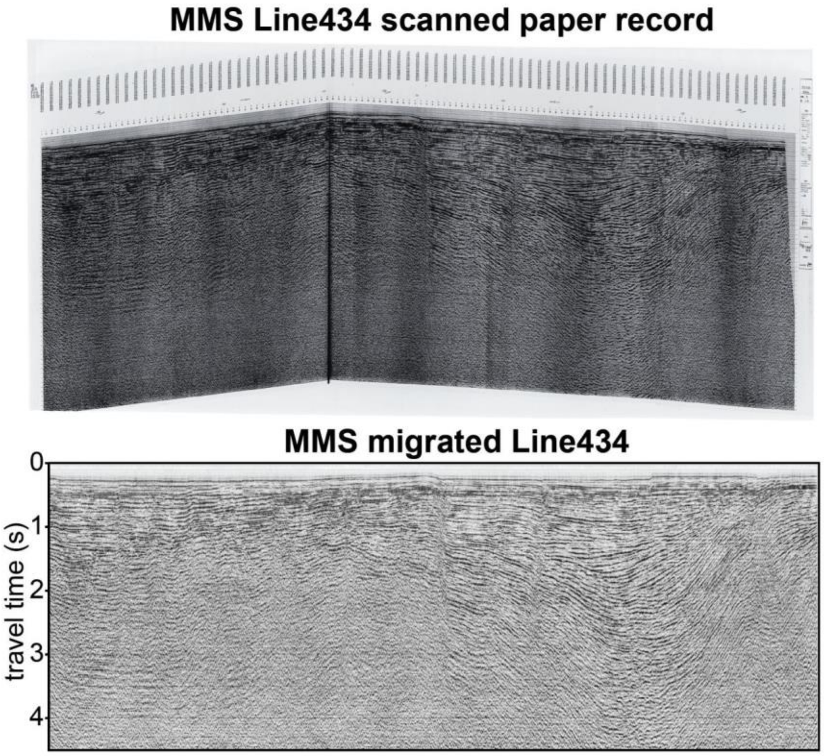
The PWS seismic asperity, defined as a region of high moment release [e.g. Lay et al., 1982; Scholz and Campos, 2012], was centered beneath the southwest end of Montague Island near a prominent magnetic high that defines the western boundary of the subducted Yakutat terrane (Figure 1) [Bruns, 1985; Giscom and Sauer, 1990; Brocher et al; 1994; Johnson et al., 1996; Zweck et al., 2002; Eberhart-Phillips et al., 2006]. The megathrust beneath PWS is the contact between the accreted Yakutat terrane and the overlying Prince William terrane [Brocher et al., 1994]. West of Montague Island, the Yakutat plate is absent and the Pacific Plate subducts directly beneath the North American plate [e.g., Brocher et al., 1994; Eberhart-Phillips et al., 2006]. The relatively buoyant Yakutat terrane is moving north-northwest approximately 50 mm/year relative to North America while the Pacific plate is subducting in a slightly more northerly direction at 51 mm/year (Figure 1) [Elliot et al., 2010]. The buoyancy of the Yakutat plate results in a subduction angle of approximately 3° beneath PWS compared to the steeper 8° dip along the Kodiak segment [e.g., Brocher et al., 1994; Eberhart-Phillips et al., 2006; Doser and Veilleux, 2009]. The maximum slip from the 1964 earthquake was largely coincident with the southwestern edge of the subducted Yakutat terrane, which appears to be largely coupled to the underlying Pacific plate [Zweck et al., 2002; Doser et al., 2004; Eberhart-Phillips et al., 2006; Ichinose et al., 2007]. Sea floor ruptures identified on MMS and USGS profiles are consistent with this asperity region, where at least three faults ruptured the sea floor (Figures 1 and 2).

Geodetic measurements in the PWS area show movement at the Pacific-North America plate rate, which indicates a locked asperity [Zweck et al., 2002] with repeat times for large megathrust earthquakes of 330-900 years [summary in Carver and Plafker, 2008]. This locked asperity lies adjacent to a region of presumed very low seismic coupling along the Kenai Peninsula and western Gulf of Alaska that is may accommodate plate convergence mostly by aseismic slip [e.g., Zweck et al., 2002]. However, the seismic reflection results presented in this report suggest that the Kenai Peninsula offshore area contains abundant thrust faulting, many that offset the sea floor. Although the rate of uplift on the splay faults along the Kenai Peninsula appear to have lower Quaternary slip rates than areas near Montague Island, Holocene coseismic ruptures appear across the entire region from Kodiak to Middleton Islands. Our results are consistent with asperity models from seismic, tsunami, and geodetic measurements (Ichonese et al., 2007), but the distribution of faulting is more widespread than previously documented.

Seismic Datasets

MMS 75-02

A grid of 71 seismic profiles was acquired in the Gulf of Alaska in 1975 for Mineral Management Services (MMS) for the purposes of oil/gas lease assessment (Figure 1). These data were acquired at a grid spacing of 10 km with a 20 airgun array totaling 1080 cu in. A 96 channel hydrophone array was used during acquisition with near channel group spacing of 50 m, far channel group spacing of 25 m and a maximum source-receiver distance of 3,800 m. The data were acquired with an 8-62 Hz recording filter with a recording length of 6 sec. Processing included a detailed velocity analysis, a time-varying deconvolution operator, and post-stack time-varying band pass filter. We received the variable area/wiggle trace data in TIFF format from MMS (http://maps.ngdc.noaa.gov/viewers/geophysics) and we converted the images to SEGY format using Seismic Unix and netPBM software packages (summarized on Figure 3). Our process converts the 8-bit gray scale value (0-255) to seismic amplitude. Although this conversion process loses phase and amplitude information from the original stacked sections, reflectors can be traced on the digital data and geologic structure can be identified and cataloged in a georeferenced framework. Once we converted to a standard SEGY format, we corrected for any image scan warping by picking and leveling to the travel time 0 grid line (Figure 3). We then spatially (station position) and temporally (travel time) rectified each image, and applied a Kirchoff time migration algorithm to place each reflector in the proper spatial position.



MMS Line434 scanned paper record

MMS migrated Line434

Step 1 --> scan the paper record to 8-bit gray scale tiff image

6 second records at 12″
300 dpi, 0.5 s per inch
sample rate = 1.67 ms

1 km = 1″ length
1000 m @ 300 dpi
3.33 m/trace

Step 2 --> convert tiff image to SEGY file

skew correction --> Pick and adjust t0 line to correct for any scan skew

calculate/adjust temporal sampling and (optionally) resample

calculate spatial sampling and (optionally) resample by summing adjacent traces

convert 8-bit image (0-255) to seismic amplitude via trace dc shift

Step 3 --> post-stack processing

Change aspect ratio
Migrate image
Trace summing/averaging
Display wiggles/gray scale/color

Georeference data
Pick horizons
Interpret profile

Figure 3. Paper record seismic processing steps for the MMS dataset.

USGS L-81-WG

USGS L-7-81-WG seismic data set consisted of 33 track lines in the vicinity of Kodiak Island (http://walrus.wr.usgs.gov/infobank/l/l781wg/html/l-7-81-wg.seis.html). The portions of these data seaward of the continental shelf were published by Fruen et al (1999), but the continental shelf portions of these data remain unpublished. For this report, we analyzed seven unpublished profiles located in the Gulf of Alaska between Kodiak and Middleton Islands. These 24-channel airgun seismic data contain higher frequencies compared to the MMS dataset due to the smaller airgun array, but signal penetration was limited to the upper few km. Geologic structures and sea floor offsets are clearly observed on many of these profiles.

Active faults

Patton Bay fault

The primary surface expression from the megathrust related to the 1964 earthquake is the Patton Bay fault, which was identified on Montague Island as an en echelon, 45 km long, 50-70° dipping reverse fault (Plafker, 1969). Integrating onshore mapping results with offshore bathymetry results, Liberty et al. (in press) observed the greatest displacement for the 1964 rupture of the Patton Bay fault immediately southwest of Montague Island on the Cape Cleare Bank (Figure 2). The bathymetry shows a 40-m-high marine terrace that decreases in height to the southwest. A 12 m offset related to the 1964 earthquake was documented where the scarp measures 35 m tall, and a decreasing scarp height to the southwest. The Patton Bay fault is defined as a >75 km long megathrust splay fault with displacements as great as 12 m during the 1964 earthquake on the Cape Cleare Bank. Offsets on the last glacial maxima (LGM) reflector suggest a 2 to 3.5 m average uplift per 700 year earthquake within the Junken Trough (Figure 1).

We image the Patton Bay fault on USGS Line 12 and MMS profile 406 (Figures 2 4, and 5). Both profiles show clear sea floor offsets and compelling evidence for growth faulting. However, these profiles do not provide the same resolution as sparker seismic data (Liberty et al. in press) in an area with shallow depth to bedrock. These seismic profiles are best used to track the spatial position of the Patton Bay fault.

Cape Cleare fault

There is no evidence for the Cape Cleare fault on Montague Island from observations following the 1964 earthquake (Plafker, 1969). However, Liberty et al (in press) measured a 50-m scarp across the Cape Cleare fault at a location that is coincident with 7 m of bathymetric uplift during the 1964 earthquake. These sparker seismic profiles shows truncated reflectors and an unconformity 80 m below the seafloor in the footwall block that likely represents the LGM (~15 ka) time. Offset from the hanging wall surface to the interpreted LGM unconformity on the footwall block measures 131 m. If the 7 m 1964 earthquake uplift measured along this profile is an average uplift per megathrust earthquake, 19 Holocene earthquakes on this fault are needed to account for the total post-glacial fault offset. Assuming the post-LGM unconformity represents a 15 kya marker and that this fault ruptured with each megathrust earthquake, a vertical slip rate upwards of 9 mm/year is needed and a recurrence interval for large subduction zone earthquakes of 789 years. This recurrence interval is remarkably consistent with other paleoseismic and seismological studies in the region (see summary in Carver and Plafker, 2008), which implies this megathrust splay fault ruptured during most Holocene earthquakes. These estimates assume no sea floor erosion and a flat topography immediately following the last glaciation, and an uncertain age estimate on the LGM reflector. Regardless of these assumptions, there is compelling evidence that the Cape Cleare fault is the active fault with the greatest uplift along this profile during the Holocene, and thus is the likely tsunami first arrival for Whidbey and Puget Bays.

Along USGS Line 12 and MMS 404/406, we document sea floor offsets across the Cape Cleare fault (Figures 2, 4, and 5). Because of the shallow nature of bedrock across the Cape Cleare fault, the airgun profiles do not provide additional insight into long-term slip rates. However, we identify an additional fault approximately 9 km south of the Cape Clear fault that does not offset shallow (late Quaternary?) layers and was not documented by Liberty et al (in press). It is possible that this dormant fault reflects a previous position for the trailing edge of the Yakutat plate.

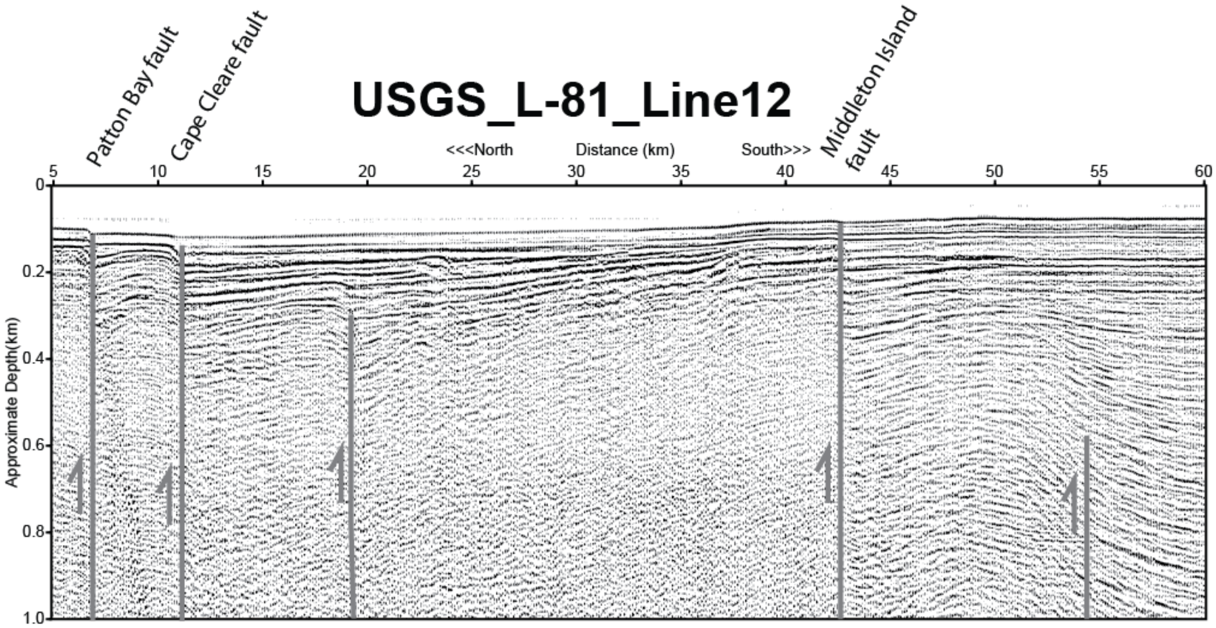


Figure 4. USGS L-81 Line 12 migrated profile showing both active and dormant faults related to the trailing edge of the Yakutat terrane.

Middleton Island fault

Plafker et al [1978] mapped a series of faults and folds from seismic reflection data for the eastern Gulf of Alaska region (Figure 1). They identified two faults to the north and south of Middleton Island that are the likely source of island exhumation and interseismic island tilt [Plafker and Rueben, 1978]. West of Middleton Island, USGS Line 12 and MMS profiles 400, 402 and 404 all show two east-striking thrust faults that approach Middleton Island (Figure 2). The northern fault displaces the sea floor, shows

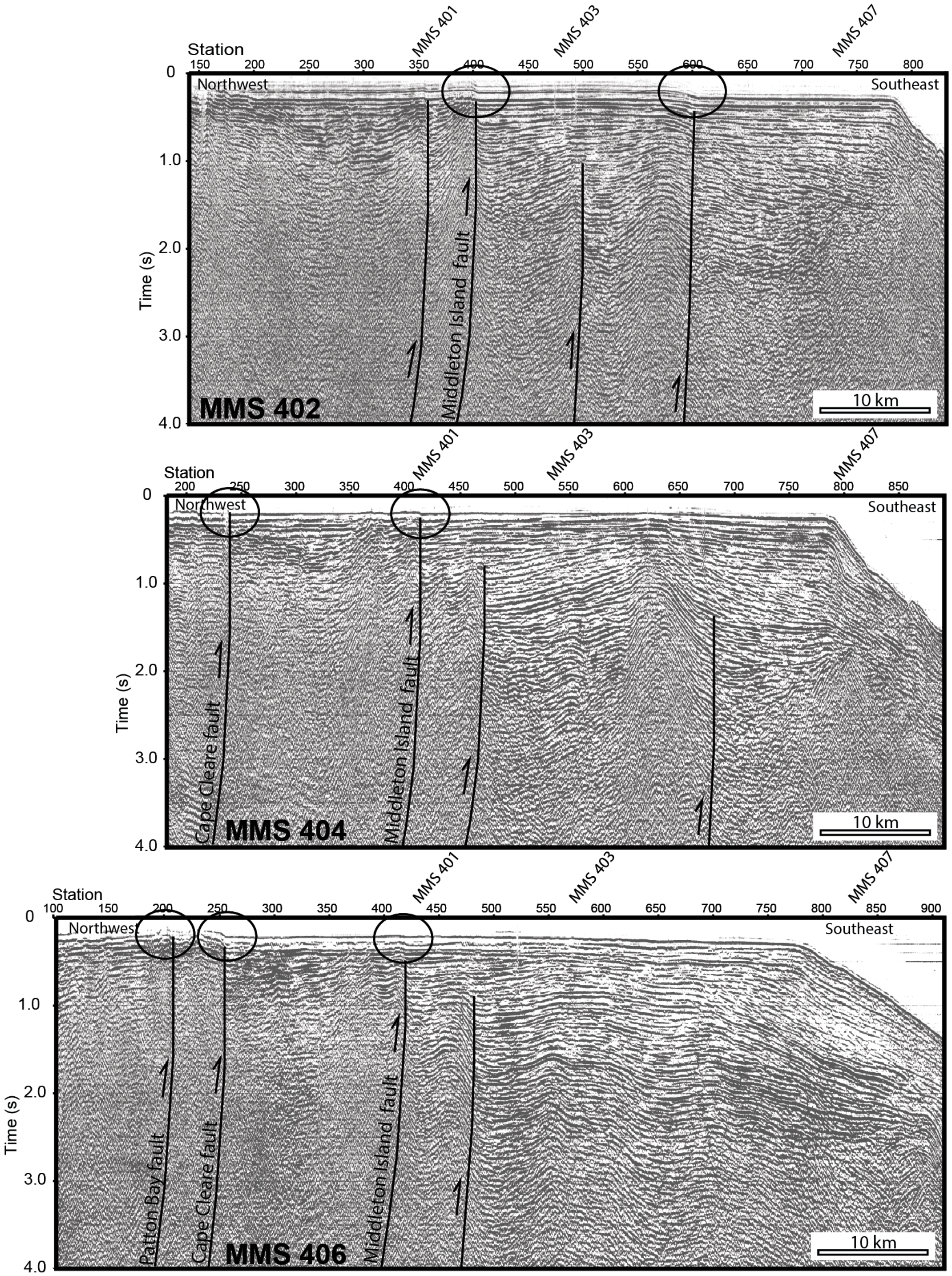


Figure 5. MMS profiles 402, 404 and 406 that parallel the western margin of Montague and Middleton Islands (Figure 2). Circles represent sea floor offsets that are rooted in thrust faults. These profiles are spaced 10 km apart.

compelling evidence for growth faulting, and is consistent with the second tsunami source that reached Whidbey/Puget Bays approximately 30 minutes after the earthquake and the initial run up that reached Middleton Island. We term this fault the Middleton Island fault because the sea floor lineament merges with the northwestern margin of Middleton Island.

The thrust fault that appears 5-15 km south of the Middleton Island fault does not surface on USGS 12 or MMS 402, 404 or 406, but does offset Neogene? strata at of approximately 1 km depth (equivalent travel time). Similar to the inactive fault located south of the Cape Cleare and Patton Bay faults, this dormant fault may reflect changing mid-crustal conditions where active faults have migrated northward.

Amatouli Trough faults

Based on seismic, geodetic, and tsunami data, Ichonese et al. [2007] identified three seismic asperities related to the 1964 earthquake. The central asperity was located on the continental shelf approximately 150 km east of Kodiak Island and 150 km south of the central Kenai Peninsula on the Portlock Bank (Figure 1). The Amatouli Trough is located approximately 40 km east of the asperity center and contains convincing evidence that splay faults ruptured the sea floor in 1964. The USGS Line 14 shows two sea floor scarps with offsets from1-3 m. The shalllowest strata are offset across both thrust faults (Figure 6). Figure 7 shows 3 MMS profiles in the vicinity of the Amatouli Trough that show a sea floor rupture that is rooted in a splay fault that extends more than 60 km. This sea floor uplift was the likely source for tsunami run ups along the Kodiak Island coast

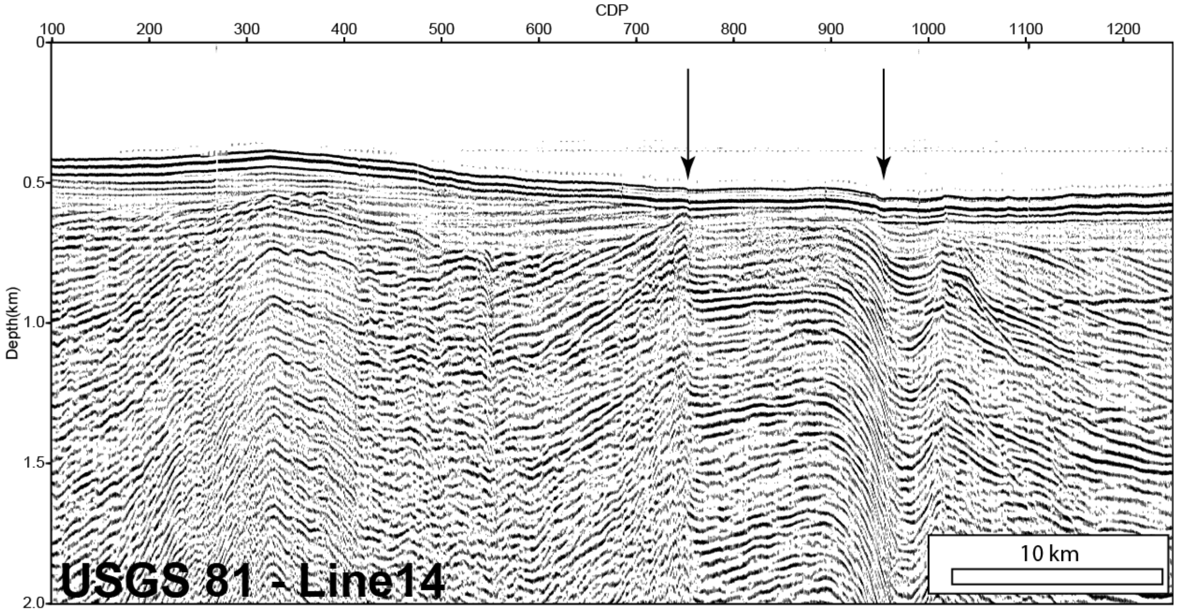


Figure 6. **USGS L81 Line 14 migrated profile showing two sea floor ruptures rooted in thrust faults. Profile location is shown on Figure 1.**

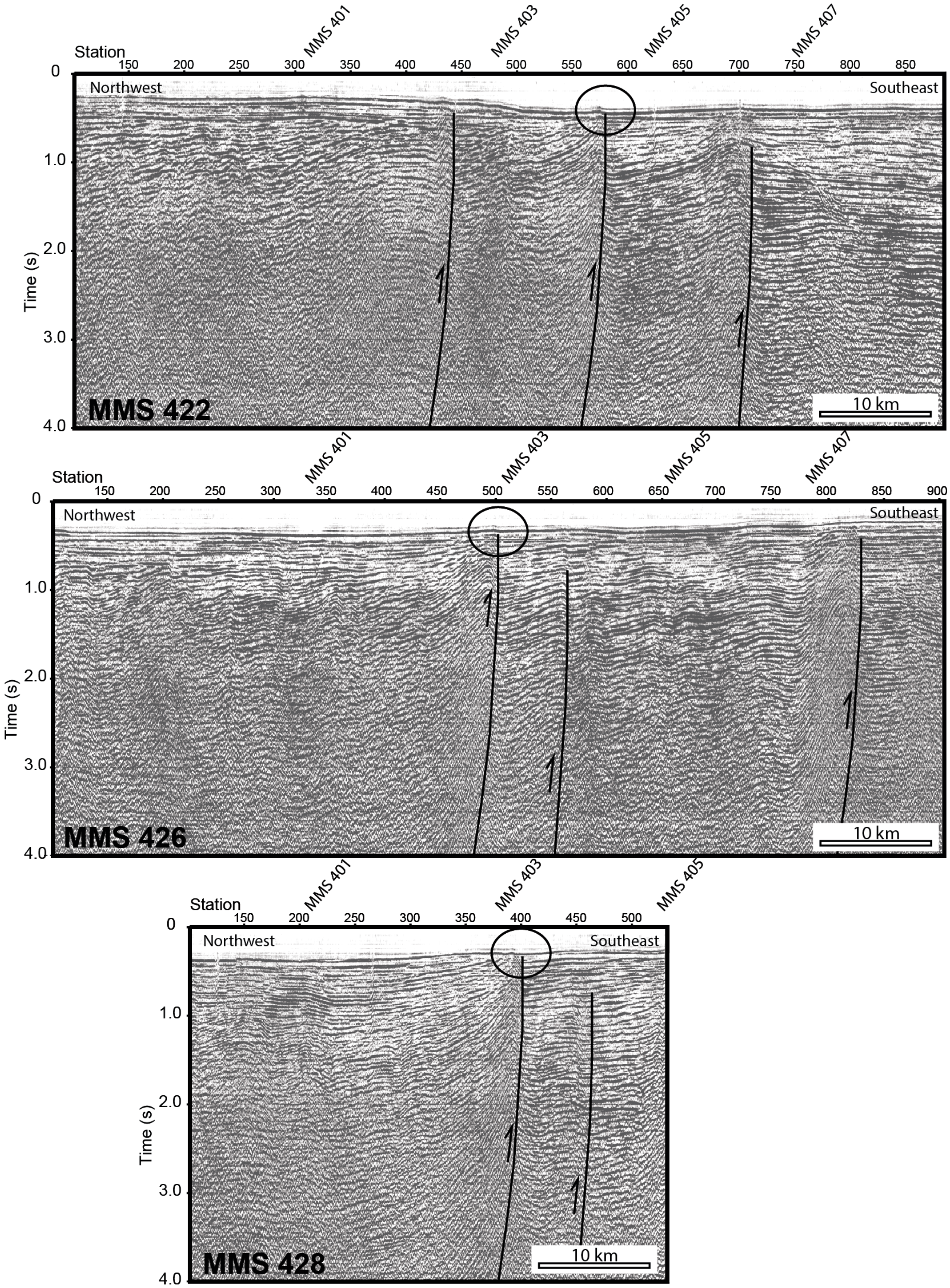


Figure 7. MMS profiles 422, 426 and 428 that are located in the Amatouli Trough (Figures 1 and 2). Circles represent sea floor offsets that are rooted in thrust faults. These profiles are spaced 20 and 10 km apart respectively.

Portlock Bank Area

The Portlock Bank area, east of Kodiak Island and west of the Amatouli Trough (Figure 1), contains the Portlock Anticline and the Stevenson Basin (Fisher and vonHuene, 1982) and is located between near a recognized asperity (Ichonese et al., 2007). The Stevenson Basin contains more than 7 km of deformed Eocene and younger sediments, and age control and velocity depth information is available via MMS exploration wells [Turner et al., 1987]. Sea floor scarps rooted in thrust faults bisect the Stevenson Basin and suggest this basin that likely formed via extension is now actively shortening (Figures 8 and 9). USGS Line 17 shows two sea floor scarps (Figure 8). The northern 6 m scarp shows little offset across deeper reflectors and is down to the north. The southern 18 m scarp shows a pattern of growth faulting near the continental slope and is down to the south. MMS profile 444 shows that the Stevenson basin is cut by an active thrust fault and parallel profiles MMS448 and MMS 452 show that this fault extends more than 40 km. Additional thrust faults appear near the northwest portion of each profile on the Portlock Anticline. These faults offset shallow strata, and exploration well KSST #4A suggests late Pleistocene strata are offset. If these faults were active during the 1964 earthquake, slip models did not capture the associated motion (e.g. Johnson et al., 1996; Ichonese et al., 2007).

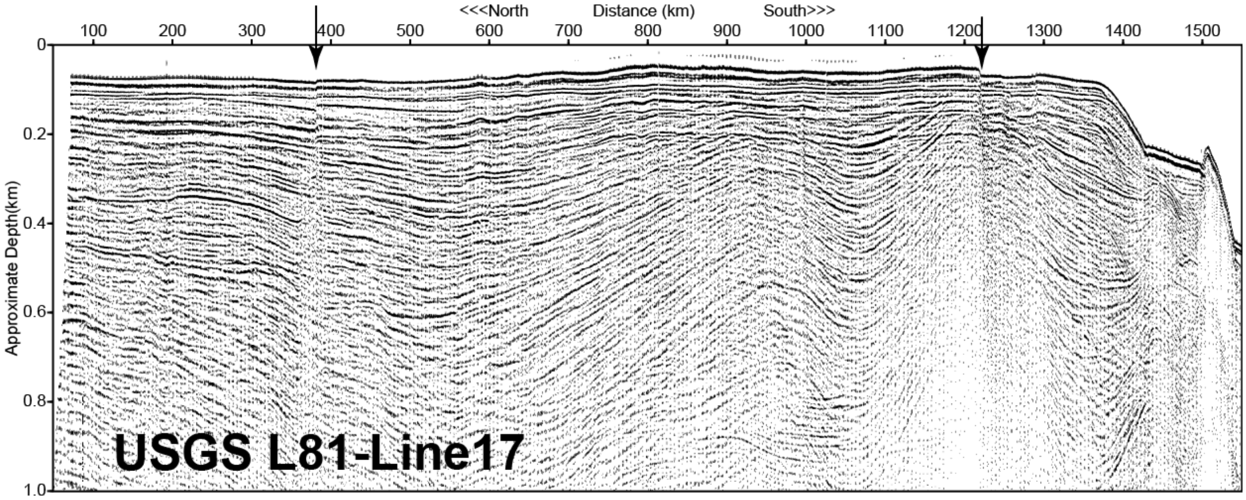


Figure 8. **USGS L81 Line 14 migrated profile showing two sea floor ruptures rooted in thrust faults. Profile location is shown on Figure 1.**

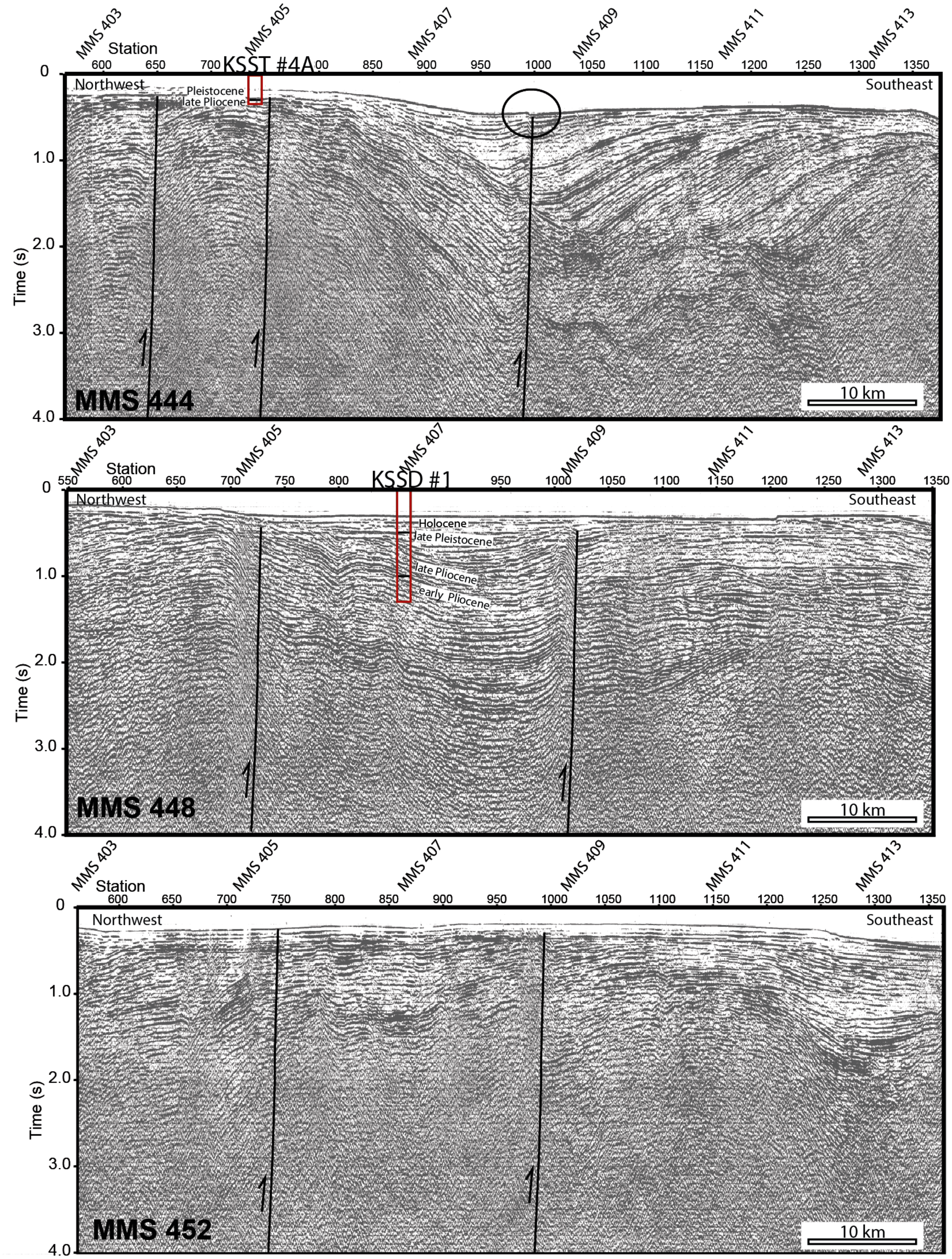


Figure 9. MMS profiles 444, 448 and 452 are located near the Portlock Bank (Figure 1). Circles represent sea floor offsets that are rooted in thrust faults. These profiles are spaced 20 km apart and show regionally extensive faulting.

Conclusions

From two unpublished, legacy datasets, we identify active thrust faults related to subduction across the length of the western Gulf of Alaska shelf. Active faults extend across the region and show evidence for repeated tectonic uplift. However, the documented uplift from the 1964 earthquake from both land and sea measurements, large sea floor scarps, and steep dipping hanging wall reflectors indicates that uplift is greatest (and scarps more abundant) near Middleton and Montague Islands along the Patton Bay, Cape Cleare, and Middleton Island faults. This region is coincident with the prominent magnetic anomaly at the trailing boundary of Yakutat slab subduction (e.g. Liberty et al., in press). The geometry and uplift of faults that extend across the Gulf of Alaska appear in an en echelon pattern with variable rates of growth along strike. Broad scale folding appears in the central study area with shorter wavelength folding and faulting near Kodiak and Montague Islands. These data are available to the scientific community through the USGS marine seismic database.

Acknowledgments

We thank Peter Haeussler and Ray Sliter, US Geological Survey, for their assistance and support during the grant period. Use of ProMAX seismic processing software was provided by Landmark Graphics Corporation Strategic University Alliance Grant Agreement No. 2013-UGP-009000. This work was funded from the U.S. Geological Survey National Earthquake Hazards Reduction Program

References

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 (B6), 11,663–11,685, doi:10.1029/94JB00111.

Bruns, T. R. (1983a), Model for the origin of the Yakutat block, an accreting terrane in the northern Gulf of Alaska, Geology, 11, 718–721, doi:10.1130/0091-7613.

Carver, G. and Plafker, G. (2008), Paloseismicity and neotectonics of the Aleutian subduction zone – an overview, in: Active tectonics and seismic potential of Alaska, edited by: Freymueller, J., Haeussler, P., Wesson, R., and Ekstrom, G., Washington, DC, AGU, Geophysical Monograph Series 179 43–63.

Christensen, D. H., and S. L. Beck (1994), The rupture process and tectonic implications of the great 1964 Prince William Sound earthquake, Pure Appl Geophys., 142, 29–53.

Doser, D. I. and Veilleux, A. M. (2009), Seismicity of the Prince William Sound Region and Its Relation to Plate Structure and the 1964 Great Alaska Earthquake. Active Tectonics and Seismic Potential of Alaska. AGU Book. Page 201-214. Washington, DC.

Doser, D. I., N. A. Ratchkovski, P. J. Haeussler, and R. Saltus (2004), Changes in crustal seismic deformation rates associated with the 1964 great Alaska earthquake, Bull. Seismol. Soc. Am., 94, 320 – 325, doi:10.1785/0120030096.

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

Elliott, J. L., C. F. Larsen, J. T. Freymueller, and R. J. Motyka (2010), Tectonic block motion and glacial isostatic adjustment in southeast Alaska and adjacent Canada constrained by GPS measurements, J. Geophys. Res., 115, B09407, doi:10.1029/2009JB007139.

Evans, K. R., Carlson, P. R., Hampton, M. A., Marlow, M. S., Barnes, P. W. (2000), Map of Distribution of Bottom Sediments on the Continental Shelf, Gulf of Alaska, USGS Miscellaneous Field Studies Map: 2335

Fisher, M.A. and Von Huene, Roland, 1982, Map showing the geological structure of the continental shelf southeast and southwest of Kodiak Island, Alaska: U.S. Geological Survey Miscellaneous Field Studies Map 1457, 1 sheet, scale 1:500,000.

Freymueller, J.T., Woodard, H., Cohen, H.S., Cross, R., Elliott, J., Larsen, C., Hreinsdottir, S., Zweck, C. (2008), Active deformation processes in Alaska, based on 15 years of GPS measurements, in Active Tectonics and Seismic Potential of Alaska, AGU Geophysical Monograph, 179, J.T. Freymueller, P.J. Haeussler, R. Wesson, and G. Ekstrom, eds., pp. 1-42, AGU, Washington, D.C., doi: 10.129/179GM02

Fruehn, J., R. von Huene, and M. A. Fisher (1999), Accretion in the wake of terrane collision: The Neogene accretionary wedge off Kenai Peninsula, Alaska, Tectonics, 18, 263– 277.

Fuis, G. S., Moore, T. E., Plafker, G., Brocher, T.M., Fisher, M.A., Mooney, W.D., Nokleberg, W.J., Page, R.A., Beaudoin, B.C., Christensen, N.I., Levander, A.R., Lutter, W.J., Saltus, R.W., Ruppert, N.A. (2008), Trans-Alaska Crustal Transect and continental evolution involving subduction underplating and synchronous foreland thrusting, Geology, v. 36, no. 3, p. 267-270.

Griscom, A., and Sauer, P.E. (1990), Interpretation of magnetic maps of the northern Gulf of Alaska, with emphasis on the source of the Slope anomaly: U.S. Geological Survey Open-File Report 90–348, 18 p.

Hamilton, T.D. (1994), Late Cenozoic glaciation of Alaska, in Plafker, G., and Berg, H.C. editors, The Geology of Alaska, The Geology of North America, vol. G-1, Boulder, Colorado, Geological Society of America, p. 813-844.

Holdahl, S.R., and Sauber, J. (1994), Coseismic slip in the 1964 Prince William Sound earthquake: A new geodetic inversion: Pure and Applied Geophysics, v. 142, p 55-82, 1994.

Ichinose, G., Somerville, P., Thio, H.K., Graves R., O'Connell, D. (2007), Rupture process of the 1964 Prince William sound, Alaska, earthquake from the combined inversion of seismic, tsunami, and geodetic data: J. Geophys. Res., v. 112, B07306, doi:10.1029/2006JB004728.

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

Lay, T., H. Kanamori, and L. J. Ruff (1982), The asperity model and the nature of large subduction zone earthquakes, Earthquake Predict. Res., 1, 3–71.Liberty, L.M. Finn, S.P., Haeussler, P.J. Pratt, T.L. and Peterson, A., in press, Megathrust splay faults at the focus of the Prince William Sound asperity, Alaska, Journal of Geophysical Research.

Plafker, G. (1969), Tectonics of the March 27, 1964 Alaska earthquake: U.S. Geological Survey Professional Paper 543-I, 74 p.

Plafker, G. (1972), The Alaskan earthquake of 1964 and Chilean earthquake of 1960; Implications for arc tectonics: *Journal of Geophysical Research*, v. 77, no. 5, p. 901–925

Plafker, G., Bruns, T.R., Carlson, P.R., Molnia, B.F., Scott, E.W., Kahler, Rodger, and Wilson, Charles, (1978), Petroleum potential, geologic hazards, and technology for exploration in the outer continental shelf of the Gulf of Alaska Tertiary province: U.S. Geological Survey Open-File Report 78-490, 33 p

Plafker, G., and Rubin, M., (1978), Uplift history and earthquake recurrence as deduced from marine terraces on Middleton Island, Alaska, in Proceedings of Conference VI, Methodology for identifying seismic gaps and soon-to-break gaps: U.S. Geological Survey Open-File Report 78-943, p. 687-721.

Plafker, G. and Savage,J.C. (2010), Near-Field Tsunami Characteristics of Giant Earthquakes in Chile (1960), Alaska (1964), and Sumatra (2004), USGS Open File report 2010-1152.

Scholz, C. H., and J. Campos (2012), The seismic coupling of subduction zones revisited, J. Geophys. Res., 117, B05310, doi:10.1029/2011JB009003.

Suito, H., and J. T. Freymueller (2009), A viscoelastic and afterslip postseismic deformation model for the 1964 Alaska earthquake, J. Geophys. Res., 114, B11404, doi:10.1029/2008JB005954.

Suleiman E., Hansen R., Haeussler P. (2011), Combined effects of tectonic and landslide-generated tsunami runup at Seward, Alaska during the MW 9.2 1964 earthquake. Pure Appl. Geophys., 168, 1053–1074, doi 10.1007/s00024-010-0228-4.

Turner, R. F. (1988). Geological and operational summary, Kodiak Shelf stratigraphic test wells, Western Gulf of Alaska (Vol. 87). US Dept. of the Interior, Minerals Management Service, Alaska OCS Region.

von Huene, R., Fisher, M.A. and Bruns, T.R. (1987), Geology and evolution of the Kodiak Margin, Gulf of Alaska, in Geology and Resource Potential of the Continental Margin of Western North America and Adjacent Ocean Basins -- Beaufort Sea to Baja California, Earth Sci. Ser., vol. 6, edited by D.W. Scholl, A. Grantz, and J.G. Vedder, pp. 191-212, Circum-Pacific Counc. for the Energy and Miner. Resour., Houston, Tex.

Wells, R. E., Blakely, R. J. Sugiyama, Y. Scholl, D. W. and Dinterman, P. A. (2003), Basin-centered asperities in great subduction zone earthquakes: A link between slip, subsidence, and subduction erosion?, J. Geophys. Res., 108(B10), 2507, doi:10.1029/2002JB002072.

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), 2064, doi:10.1029/ 2001JB000409.