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Late Neogene Uplift of the Fairweather Ground on the Basis of Bathymetric and Seismic Data from the Gulf of Alaska

A Thesis

Submitted to the Graduate Faculty of the
University of New Orleans
in partial fulfillment of the
requirements for the degree of

Masters of Science
in
The Department of Earth and Environmental Sciences

by

Peter David Guarisco, IV
B.A. Centenary College of Louisiana, 2001

May, 2008

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Dedication

I dedicate this work to the memory of my mother, Marion "Beth" Elizabeth Coleman (1953-2007). Without her love, uplifting spirit, and words of encouragement I do not know if this thesis would have been completed. She instilled in me the patience, determination and, most importantly, the sense of humor needed to meet all the challenges that this study has presented.

Acknowledgment

This thesis has been completed under the strangest of circumstances. The aftermath of Hurricane Katrina was a difficult time for everyone involved. I am thankful for the extraordinary efforts of the faculty and staff at the University of New Orleans to keep this research, and the department, above water.

The contributions of my thesis committee have been the building blocks of this study. I would like to thank my thesis advisor, Dr. Terry Pavlis, for encouraging me to study the unbelievably complex geology of southern Alaska. Dr. Pavlis was especially patient during a lengthy correspondence period, after Katrina, in order to complete this work. Dr. Laura Serpa helped lay the groundwork for the seismic interpretations and her positive attitude helped me get over more than one bump in the road. Dr. Mark Kulp made contributions to the technical writing and held my feet to the fire to finish this study.

I would like to acknowledge Dr. William Busch and Dr. Ron Stoessell for accepting me into the program so many years ago. Dr. Kraig Durstler fostered my enthusiasm for teaching during my time as Head Teaching Assistant. My course work with Dr. William “Skip” Simmons, Al Foster, and Dr. Mustofa Sarwar had a profound affect on the way I approach science, in general, and roused my interests in mineralogy and geophysics.

I must also recognize Dr. Martin T. O’Connell has been instrumental in his role as Graduate Coordinator. Dr. O’Connell has gone above and beyond his normal duties to assure that this study be completed.

I would like to extend my deepest gratitude to all my family and friends who have been by my side during this time in my life. My wife, Tricia, and my daughter, Myrtle, have been especially sweet.

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Abstract

Pliocene to Pleistocene glacial-marine deposits adjacent to the Fairweather Ground basement in the Gulf of Alaska are the focus for seismic interpretation using public domain seismic reflection data. The late Tertiary and early Quaternary sections of the Yakataga Formation record a glacial/ interglacial climate change sequence with increasing rates of sedimentation (175 meters per million years to 4000 meters per million years). The foreland basin sediment load is deposited onto the Yakutat block, a microplate that takes up the strike-slip to convergent movement with respect to North America and Pacific plates. Tectonic activity during the last 5 million years has resulted in Eocene rock exposed at the sea floor. High resolution bathymetry data adjacent to the Yakutat microplate is utilized to 1) observe the results of deformation from Pacific plate loading on the Yakutat microplate and 2) interpret the Transition fault as an active thrust to oblique thrust fault.

Keywords- Yakutat, microplate, Alaska, bathymetry, seismic, Fairweather Ground, uplift, Transition fault, Pacific Plate, basal ecsarpment

Introduction

The Gulf of Alaska provides an excellent location for studying the interplay of tectonic processes during oblique plate collision and the record of collision recorded by high rates of glaciomarine sedimentation. This region is one of the most seismically active sites in the world (Jacob, 1987) and also has some of the highest sedimentation rates in the world (Zellers, 1993) because of glacial contributions. Thus, the frequency of seismicity and high sedimentation rates suggests that the timing and geometry of complex deformation will be recorded by syntectonic deposition.

In the Gulf of Alaska region, the subduction of the Yakutat microplate (Figure 1) under the North American plate has produced the highest coastal mountain range on Earth and this highland lies directly adjacent to a major depositional basin (Jacob, 1987; Jaeger et al., 1998). This mountain building has affected local climate by increasing precipitation (Wilson and Overland, 1987) and, because of the latitude, temperate glaciation is a major process affecting the development of the Yakutat microplate's sedimentary sequences during the Cenozoic era.

There are several unresolved kinematic issues in the transition from strike-slip to convergent motion with respect to the North American and Pacific plates. The Yakutat microplate is wedged between the North American and Pacific plates at this transition and is being thrust northwest beneath the North American plate

at the subduction zone associated with the Aleutian Trench. This study focuses on the deformation and basement uplift of the Fairweather Ground area along the trailing edge of the Yakutat microplate. I consider two alternative hypotheses for the Fairweather ground: 1) uplift above an active thrust or oblique thrust or 2) a flexural bulge in advance of on-land thrust systems beneath the Yakutat foothills.

The objective of this study is to identify the relationship between the Yakutat microplate and the Pacific plate within the tectonic framework associated with the dextral oblique slip to convergent transition boundary with respect to North American and Pacific plate motion (Fig. 1). Reinterpretation of the Fairweather Ground uplift should provide understanding of the Transition Fault's role in the trailing edge deformation of the Yakutat microplate with respect to North America and Pacific plate motion.

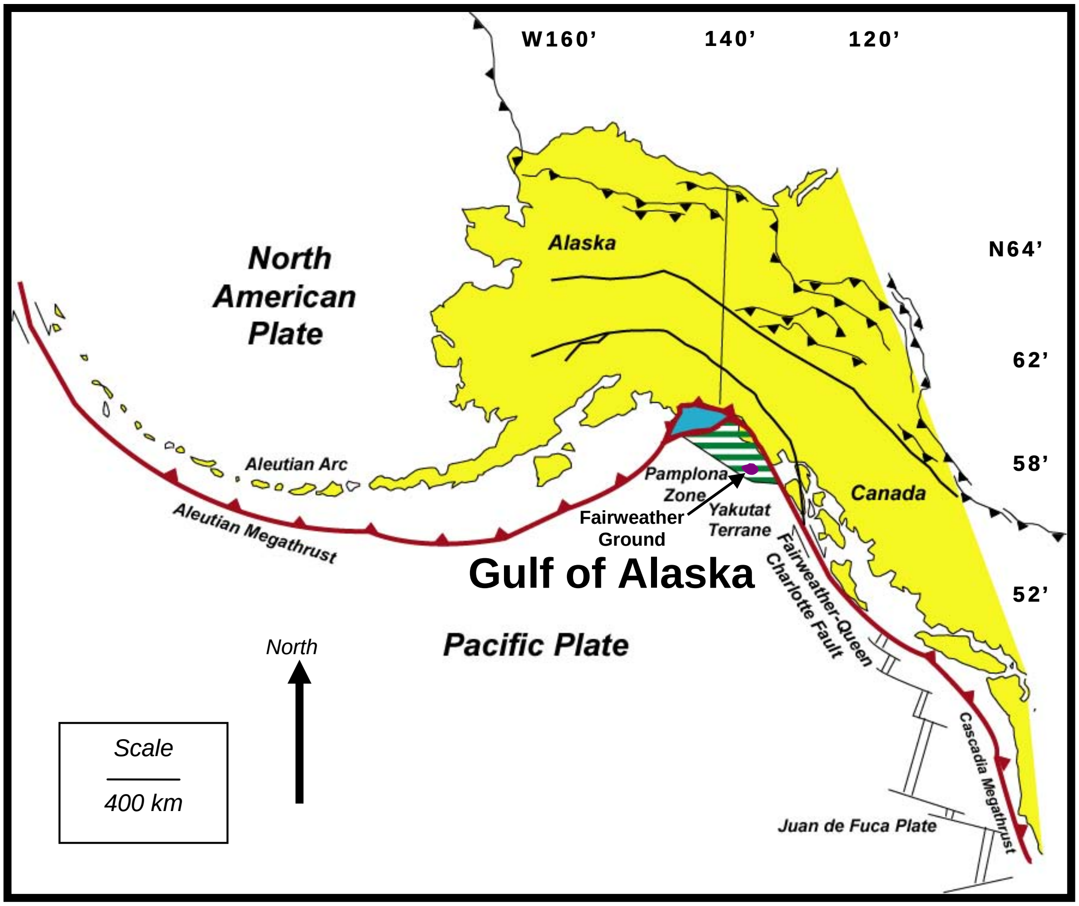


Figure 1. Tectonic framework and primary structural elements of the Gulf of Alaska. The Fairweather Ground is located in the southern portion of the Yakutat Terrane. (modified from Plafker et al., 1994)

Approach

High resolution bathymetry data (Gardner et al., 2005) from the Gulf of Alaska's continental slope to abyssal plane reveal the channel-fan complex associated with the Fairweather Ground uplift (Fig. 2). The Transition Fault, Fairweather Ground, and foreland basin assemblages are examined through the reinterpretation of 2-dimensional seismic data that were available from public domain United States Geologic Survey (Fig. 3). The understanding of Pliocene climate change and tectonics (Lagoe and Zellers, 1994) has improved significantly since these lines were first interpreted (Risley et al., 1992). Changes in paleoclimate and the continued growth and erosion of the coastal ranges effect Pliocene sediment accumulation rates (ranging from 4000m/ Myr to 175m/ Myr) which helps define the overlying seismic packages used to establish a timing relationship with the uplift of the Fairweather Ground.

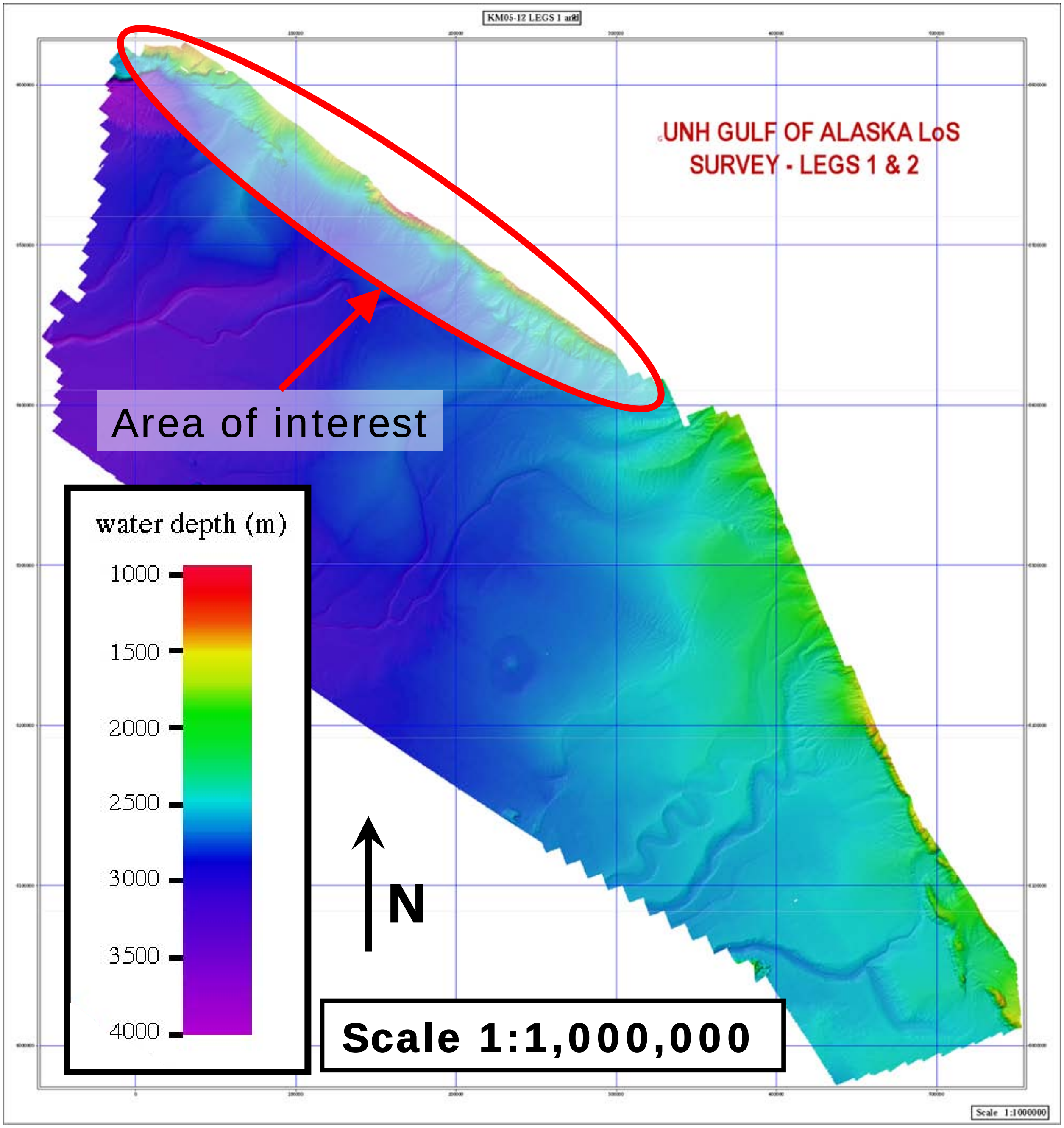


Figure 2. High resolution bathymetry data of the Gulf of Alaska's slope to abyssal plain. (modified from Gardner et al., 2005)

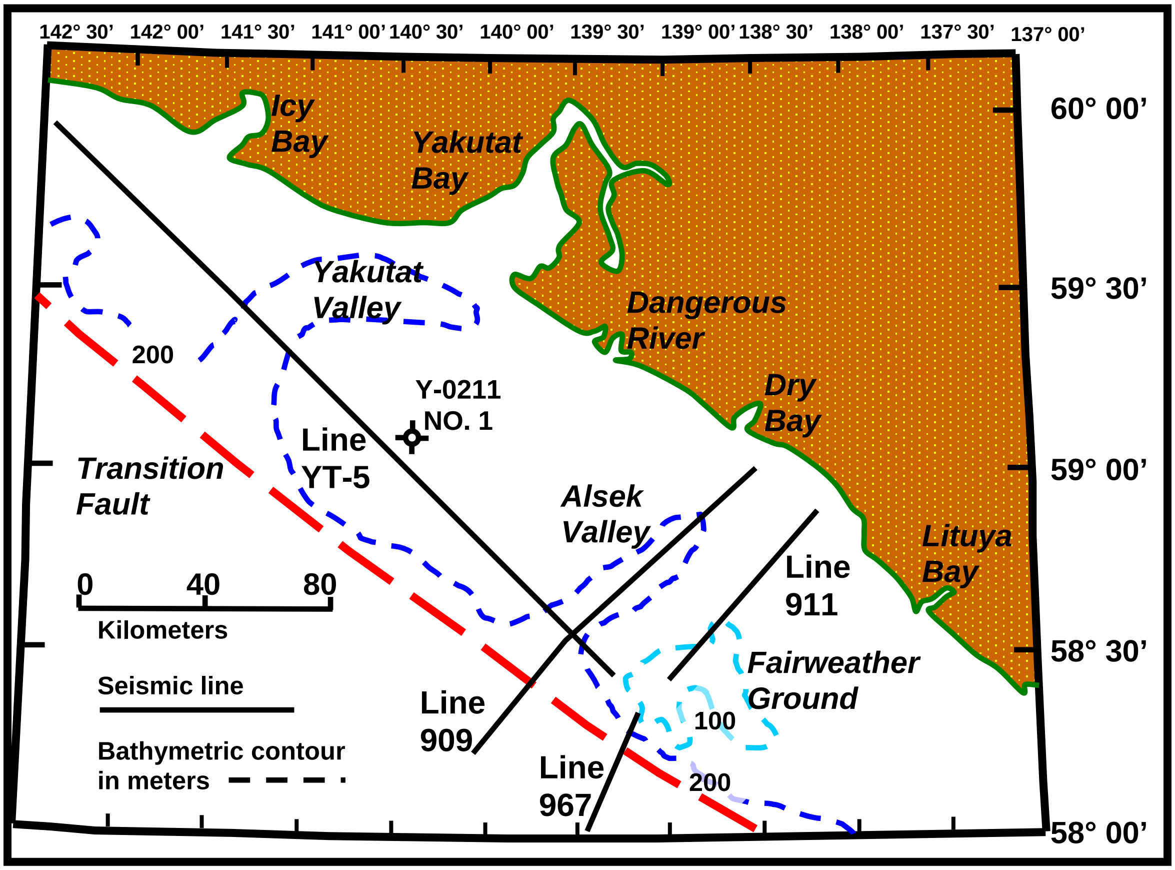


Figure 3. 2-D seismic reflectors and well site used in this study. Seismic lines 909, 911, and 967 run perpendicular to the Alaskan shoreline between Dry Bay and Lituya Bay. Line 909 trends from just south of Dry Bay in the East Yakutat Subbasin through the Alsek Valley and Fairweather Ground Basement Uplift, where it intersects the YT-5 line, and continues through the Transition Fault Zone onto the abyssal plain. Line 911 is just south of and parallel to line 909, recording the sedimentary assemblages of the East Yakutat Subbasin. Line 967 extends basinward of line 911 on the Fairweather Ground Basement Uplift through the Transition Fault Zone to the abyssal plain. (modified from Risley et al., 1992)

Geologic Background

The onshore portion of the Gulf of Alaska consists of a northern 'superterrane' and a southern accretionary wedge (Plafker et al., 1994). The Wrangellia, Alexander, Peninsular, and the Taku terranes were combined by late Jurassic time forming a larger terrane that collided with North America by mid-Cretaceous time (Hillhouse and Gromme, 1984; Plafker et al., 1989a, 1989b, 1994; Wallace et al., 1989). The Chugach and Prince Williams terranes were formed as a forearc accretionary complex that resulted in north-directed subduction and accretion beneath the margin since the Jurassic (Plafker, 1987; Pavlis et al., 1988; Plafker et al., 1994). This direction of convergence continues at modern rates of 40 to 55 mm/yr (Bruhn et al., 2004).

Study Area

Truncated late Cenozoic sediment records the Fairweather Ground uplift in the southern portion of the Yakutat microplate. The Plio-Piestocene Yakataga Formation sedimentation rates are substantial, locally exceeding 10 mm/yr (Hallet et al., 1996, Jaeger et al., 1998, Sheaf et al., 2004), because the Yakutat microplate deposition center is located less than 50km from coastal mountains that exceed 4500 m in elevation. Sediment accumulation rates during the initiation of regional North Pacific glaciation (3.5Ma to 2.5Ma) are ~ 2000m/my, whereas younger (<1Ma) offshore accumulation rates range from 2000 m to >6000m/my (Zellers, 1993). The Fairweather Ground uplift exposes pre-Tertiary

rock (acoustic basement) to the seafloor near the continental shelf margin (Risley et al., 1992).

The Yakutat microplate (Fig. 4) is bounded by the Fairweather-Queen Charlotte transform system to the northeast (Campbell and Dodds, 1982). Total movement along the Fairweather-Queen Charlotte system during the Cenozoic has an estimated range between 5° and 30° (~550 km to ~3200 km) in an overall northward direction (Plafker, 1983; Bruns, 1983). Along the northern boundary of the Yakutat microplate is a fold and thrust belt. The suture of this fold and thrust belt is the Chugach-St. Elias fault which places variably metamorphosed Mesozoic to Eocene rocks atop unmetamorphosed Tertiary sedimentary rocks of the Yakutat terrane (Plafker, 1987). The Yakutat microplate’s western extent is the highly deformed Kayak Island zone. It is unclear how deformation is distributed within the orogen. Evidence of offshore active deformation along both the Kayak Island zone and the Pamplona zone to the east suggests regional scale shortening. Nonetheless, it appears most of the deformation must be accommodated along the Kayak Island zone, or westward, because convergence rates in the Pamplona zone account for only a small fraction of the total convergence (Picornell, 2001).

The southern boundary of the Yakutat microplate, the Transition Fault, is not fully understood. The translational motion from the Fairweather- Queen Charlotte system and the stalling subduction of Yakutat basement constrain Transition fault movement (Gulick et al.,2007), which is consistent with recent studies (Doser and Lomas, 2000; Gardner, 2006) that suggest that the southeastern portion of the

Transition fault is active. Previously, Transition Fault interpretations have ranged from dextral oblique slip (Plafker et al., 1987; Perez and Jacob, 1980; Plafker, 1987) to inactive (Bruns, 1985) during the last 5 million years.

The Fairweather Ground bathymetric high (Fig. 4), which structurally defines the Fairweather Ground uplift, is located near the continental shelf margin south of Dry Bay and west of Cross Sound (Risley et al., 1992). The magnitude of late Cenozoic uplift along the Fairweather Ground has been estimated to be more than 2km (Bruns, 1982b). Southwest of the Fairweather Ground Uplift, the Transition fault is located at the base of the shelf margin slope. Along the northern margin of the Fairweather Ground uplift lies an elongated, block-faulted subbasin, the Fairweather Ground rift zone (Risley et al., 1992).

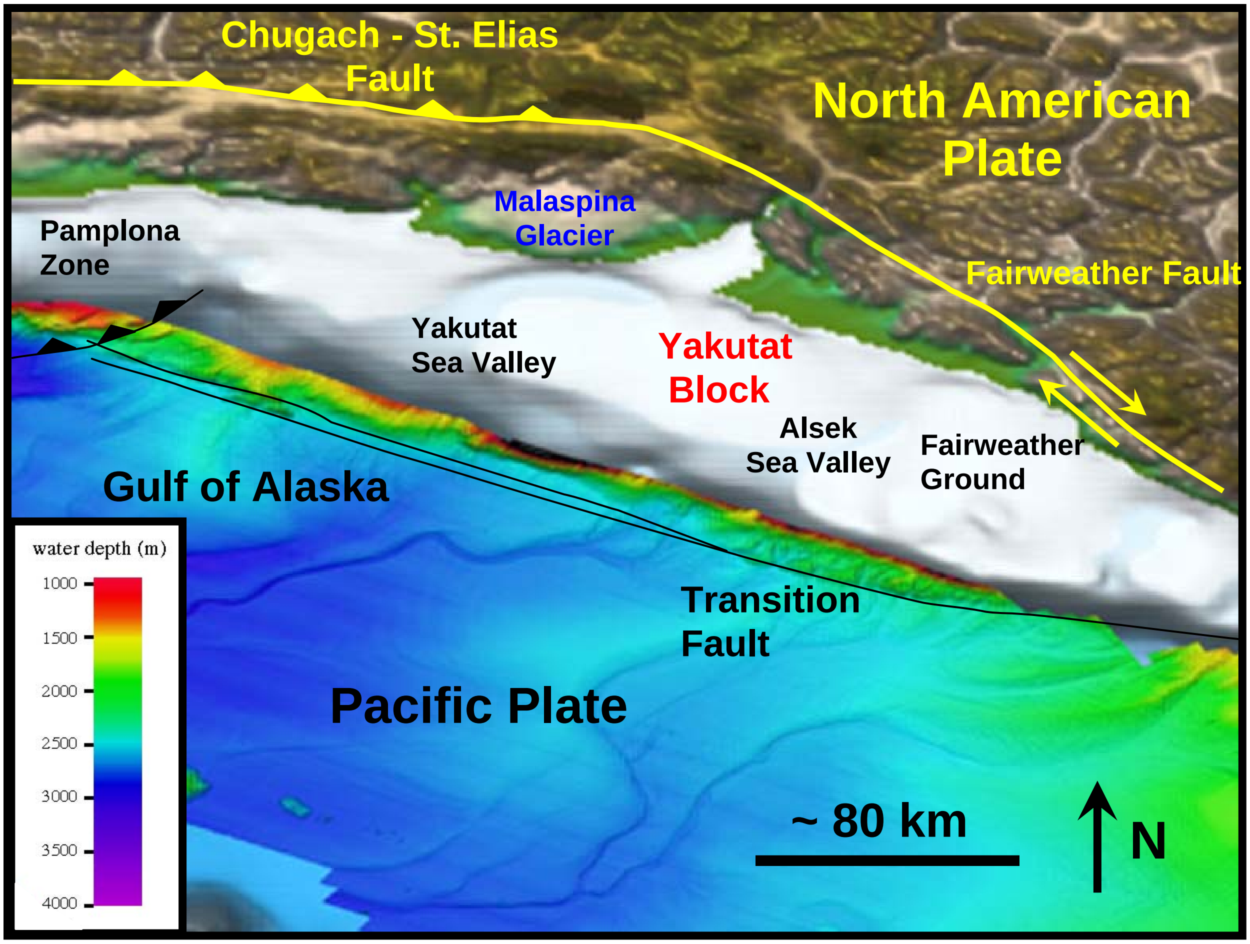


Figure 4. Digital elevation model with Gulf of Alaska high resolution bathymetry and onshore topography. (modified from Gulick et al.,2007)

Late Mesozoic to Cenozoic

Late Mesozoic through Cenozoic dextral faulting dismembered the outer Cordilleran terranes after accretion of the ‘superterrane’ to North America (Plafker et al., 1994). The Denali and Tintina faults merge along at least 1000 km of slip (Plafker et al., 1994). During the early Cenozoic, as much as, 650 km of slip can be attributed to Castle Mountain and Border Range fault systems that form the Gulf of Alaska’s coastal mountain range (Pavlis et al., 1988; Pavlis and Roeske, 2007; Smart, 1995). A belt of Eocene forearc plutonism and metamorphism is a result of Paleogene deformation and the Alaskan orocline (Bradley et al., 1997; Hillhouse and Gromme, 1984; Pavlis and Sisson, 1995, 2003). The Eocene magmatic event is generally considered a product of Pacific spreading ridge subducting beneath the Cordilleran subduction zone. Neogene mountain building has exposed high-grade metamorphic assemblages generated by this event in the St. Elias Mountains (Hudson and Plafker, 1983; Sisson et al., 1989; Pavlis and Sisson, 1995).

Eocene to Oligocene

The direction of convergence between the oceanic lithosphere and adjacent onshore terranes shifted from northeast to northwest following the abandonment or subduction of the Pacific-Kula spreading center (Engerbertson et al., 1985; Lonsdale, 1988). The Transition fault may have developed as a ridge-trench transform system due to the change in plate motion from oblique convergent to almost parallel to the shelf margin in the eastern Gulf of Alaska (Plafker, 1987).

Volcanism in the Alaskan Peninsula and Aleutian arc (Wallace and Engerbertson, 1984; Wilson, 1985; Scholl et al., 1987) increased from middle Eocene to early Oligocene probably a result of the subduction of the Pacific plate beneath the western portion of the Gulf of Alaska and conversion of the eastern limb of the Alaskan orocline to an obliquely convergent margin (Wilson, 1985; Plafker, 1987; Plafker et al., 1989b).

By Late Oligocene (~25 Ma) the Fairweather-Queen Charlotte transform system separated the Yakutat Microplate from the Pacific continental margin of North America (Plafker, 1983; Bruns, 1985; Richter et al., 1990). On the basis of petrography studies of Paleogene sandstones and paleomagnetic data from the Yakutat terrane, the Yakutat microplate may have initially been located adjacent to British Columbia (Hollister, 1979; Plafker et al., 1980; Chisholm, 1985; Van Alstine et al., 1985). An alternative model suggests the location as far south as the Pacific Northwest (Bruns, 1983). Regardless, each model specifies that following separation, the Yakutat block moved northward along the North American plate margin.

Miocene, Pliocene, Pleistocene

Throughout the Miocene the Yakutat microplate continued to move northwest relative to North America while some of the Yakutat movement with respect to the Pacific plate was apparently taken up by dextral offset and oblique subduction along the Transition fault (Plafker, 1987). During the Miocene-Pliocene boundary (~5 Ma) the continued underthrusting of the Yakutat microplate beneath

the North American plate initiated uplift of the Chugach and St. Elias mountain ranges in southeast Alaska. This mountain building event caused local climatic cooling by increasing regional precipitation and alpine glaciation (Lagoe et al., 1993; Marincovich, 1990). Rapid uplift and erosion produced a complete record of Cenozoic glaciation, the Yakataga Formation, on the continental margin basins in the northern Gulf of Alaska (Risley et al., 1992).

The Transition fault apparently remained active as an oblique subduction margin until early Pliocene (~5 Ma) (Bruns, 1985b). Lack of deformed Pliocene and Quaternary sediments above the Transition fault or the lack of an accretionary wedge (Risley et al., 1992) confirms Bruns' (1985b) view that the fault has been inactive or a site of only minor displacement since early Pliocene (~5 Ma). Pavlis et al. (2004) noted however that ages of the overlapping sediments are not well constrained and it is possible the overlapping sediments are Pleistocene sediments that do not yet record recognizable shortening. This hypothesis is consistent with seismicity in the area (Page, 1975; Perez and Jacob, 1980) and geodetic data (Fletcher and Freymueller, 1999, 2000), which suggest dextral oblique slip and aseismic convergence on the Transition fault. The Yakutat block is currently moving northwest with respect to the North American plate at nearly full North American-Pacific plate velocity. Along the Yakutat's northern boundary the block is undergoing crustal shortening where it is underthrusting beneath the North American plate.

Paleoclimate

Foraminifera have been studied by Lagoe and Zellers (1996) to gain an understanding of the paleoclimate and associated glacial-marine accumulation rates during Pliocene time (table 1). The climate events are labeled as intervals P1 (5.35 to 4.2 Ma), P2 (4.2 to 3.0-3.5 Ma), and P3 (3.0-3.5 to 1.8 Ma) based on biostratigraphy and paleoclimatic indicators (Lagoe and Zellers, 1996). Interval P1 is interpreted as a glacial period based on the development of tidewater glaciation. Uplift of the Alaskan coastal ranges and regional cooling influence the thickness of the sedimentary package between the Yakutaga/Poul Creek unconformity and the mid-Pliocene unconformity (Lagoe et al., 1993). Interval P2 is a mid-Pliocene warm interval (Zellers, 1995). P2 is interpreted as a period of reduced glaciomarine activity and consistent with this interpretation contains evidence for eustatic sea-level change (Lagoe and Zellers, 1996). Interval P3 records development of tidewater glaciers coincident with the onset of major northern hemisphere glaciation recognized on the basis of cold water benthic forminifera and increased diamictites and ice-rafted debris (Lagoe et al., 1993; Krissek, 1994).

Glacial Sequence Stratigraphy

Powell and Cooper (2002) have produced a glacial sequence stratigraphic model for the Yakutat block (table 1). Their 3-dimensional conceptual model contains one Type II AK sequence (similar to Lagoe and Zellers' P2 interval) between two Type I AK sequences (P1 and P3). Each of their Type I AK (P1 and

P3) sequences has four glacial system tracts: glacial advance (GAST), glacial maximum (GMaST), glacial retreat (GRST), and glacial minimum system tracts (GMiST). The Type II AK (P2) sequence is dominated by a progradational system that represents a partial glacial advance (Powell and Cooper, 2002). They used the term ‘glacial sequence stratigraphy’ to suggest that sea level is not necessarily the only control on base level. Glaciers have the ability to erode regional unconformities well below sea level and the glacier bed is also a primary source of sediment introduced below sea level (Powell and Cooper, 2002). This distinction, ‘glacial sequence stratigraphy’ vs. the original ‘sequence stratigraphy’, also takes into consideration the effects of glacial isostasy and glacial advance and retreat signatures as controlling factors along with isostatic forces (water and sediment loading), tectonism, and local water-depth controls of local erosion and sediment accumulation rates (Powell and Cooper, 2002).

poch	Ma	terval*	Sequence**	l Sequence Stratigraphy**	aleoclimate*
iocene	)-3.5 to 1.8	P3	Type I AK	advance, glacial max., retreat, and glacial min.	er glaciers due to n hemisphere on
liocene	to 3.0-3.5	P2	Type II AK	dational system with partial advance	nterval with c sea-level
liocene	.35 to 4.2	P1	Type I AK	advance, glacial max., retreat, and glacial min.	er glaciation due of coastal ranges gional cooling

Table 1. *From Lagoe and Zellers, 1996. ** From Powell and Cooper, 2002

Yakutat Microplate Origin

There is debate about the origin of the Yakutat microplate. Bruns (1983) proposed a model, formulated from paleoclimate indicators, that requires 30° (~ 3200 km) of northward movement of the Yakutat microplate during the Cenozoic. Plafker (1983) claimed, however, that all of the first-order geologic features can be explained with 5° (~550 km) of northward movement. The underlying purpose of this study is to provide additional geologic background for the origin of the Yakutat microplate.

Bruns Model

Bruns' (1983) model accounts for the large displacement required by microfaunal assemblages from the Yakutat microplate, as well as indicated by interpretations of marine seismic-reflection data. Cool water species include *Globorotalia psuedoscitula, Globigerina primitive and linaperta* and warm water *Globorotalia soldadoenis, bullbrooki, aragonesis* and *broedermanni* which indicates a latitude of 30±5° north (Keller et al., 1984). The reflection data along the southern margin of the Yakutat microplate (Transition fault) show no evidence for major deformation, accretion, or subduction, indicating little pre-Pliocene Pacific-Yakutat convergence and no convergence since the Pliocene (Bruns, 1983).

Arguments against Bruns' model for the origin of the Yakutat microplate include the location of sedimentary source data, Eocene climate, and inconsistencies in the interpretation of seismic-reflection records. Hollister (1979) has identified the Coast Crystalline Complex of British Columbia and southern

Alaska as a potential source terrane with the proper lithology, uplift history, and volume for the Paleogene sediments. During the Eocene, low latitude planktic assemblages in the Atlantic expanded to 50-55°N (Wolfe and Poole, 1982). This early Eocene climate change allows for low latitude paleoclimate indicators on the Yakutat microplate without requiring large latitudinal shifts indicated by Keller et al. (1984). Bruns' seismic interpretation found no deformation or accretionary wedge. Plafker (1984) noted that many known circum-Pacific convergent margins lack deformation or an accretionary wedge on seismic-reflection records.

Plafker Model

Plafker's model (1983) is based on petrographic and sedimentologic data. The proximity of the possible sedimentary source area requires only 5° (~550 km) of northward movement. Bruns (1983) indicated that this model requires substantial subduction of the Pacific plate beneath the Yakutat microplate and about 45° of rotation during emplacement. Both models exist with a degree of ambiguity. No suitable igneous rocks for age dating or remnant magnetization in the sampled sedimentary rocks on the Yakutat microplate paleomagnetic studies have been identified to constrain the displacement history (Plafker, 1984).

Methodology

A 2005 University of New Hampshire Law of the Sea mapping project resulted in bathymetric data for between 1 and 4.5 km's of water depth in the Gulf of Alaska (Fig. 3). This location images the continental shelf/slope margin and abyssal plane. A 12-kHz multibeam echosounder used in this study pinged more than 162,000 km^2 of the Gulf of Alaska with 100 m spatial resolution (Myer et al., 2005). This data set is used to investigate the Transition fault based on the identification of fault scarps (fault scarps would suggest movement along the Transition fault). The multibeam data set is also used to identify major depositional channel fan complexes located 400 km off the continental slope.

This study also utilizes public domain seismic lines originally shot and processed for the United States Geological Survey (USGS) from 1977 to 1978 (Bruns and Bayer, 1977). An Outer Continental Shelf (OCS) well log was obtained from Minerals Management Service. Bruns (1983), Plafker (1987), and Risley (1992) incorporated the seismic reflection data and offshore well logs for regional resource assessment studies of petroleum potential in the OCS and geologic assessment for stratigraphic analysis. This study reviews those data along with new interpretations to identify the timing relationship and dominant tectonic mechanisms of the Yakutat microplate's Fairweather Ground uplift.

Bathymetry Data

The bathymetry data set (Fig. 5) is made available to the public through the CCOM/JHC in several forms (ASCII, ESRI, and IVS3D SD). This study uses the ESRI formatted data to create shade relief and contour maps with the ESRI ArcGIS 9.0 software package. The IVS3D SD data is used to interpret bathymetric features for structural interpretation of the Transition fault and the adjacent Pamplona zone.

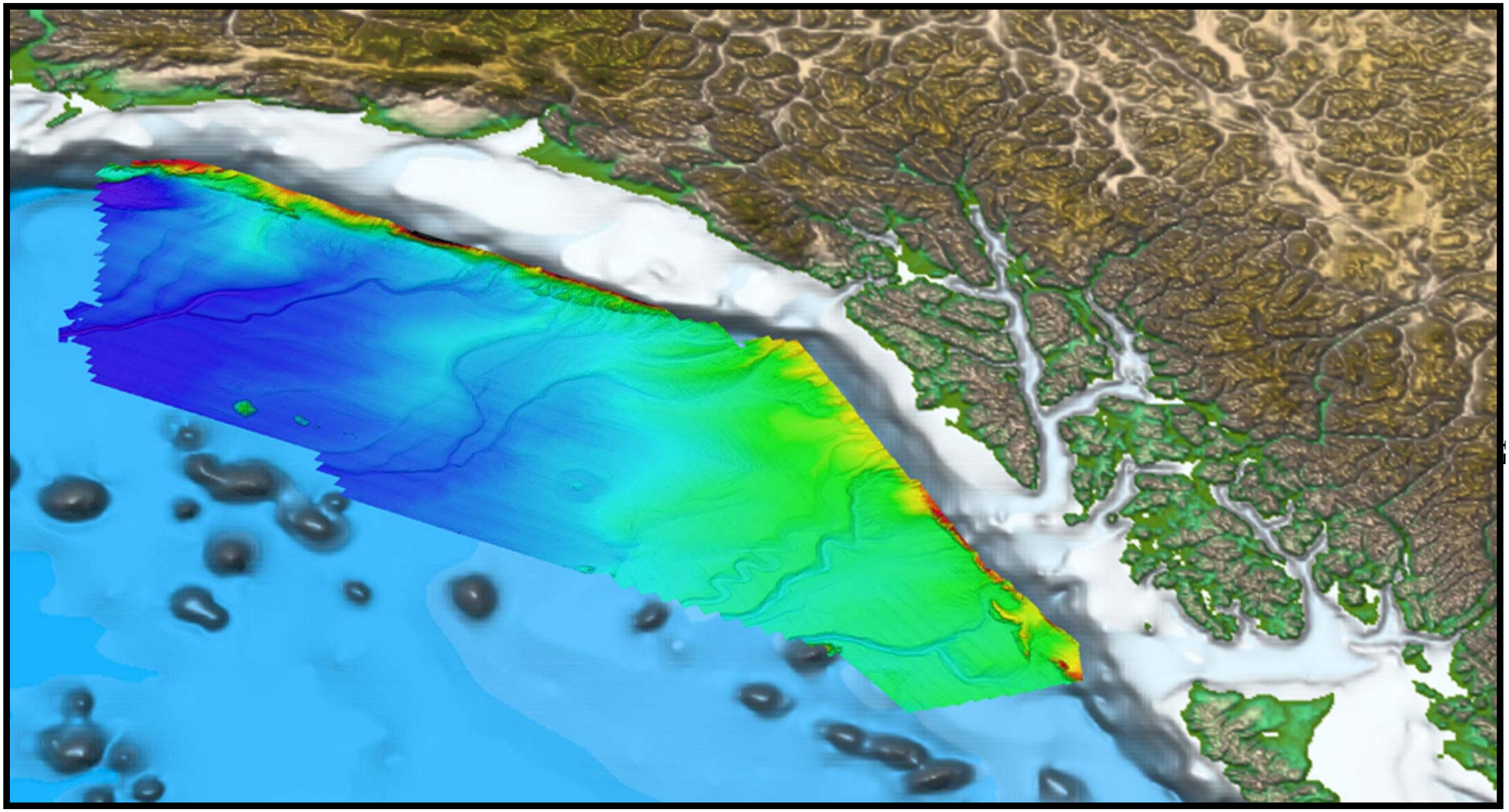


Figure 5. Digital elevation model with Gulf of Alaska high resolution bathymetry and onshore topography. (modified from Gardner, et al., 2005)

2D Seismic Reflection Lines

Four seismic lines are used to make new interpretations on the Fairweather Ground uplift and are made available for this study via public domain USGS. Paper copies from the archives at the National Oceanic and Atmospheric Administration were scanned and converted to portable document format. Three lines (909, 911, and 967) run NE to SW and image the Gulf of Alaska shelf and Fairweather Ground, through the slope, and abyssal plain (Fig. 6-8).

The fourth seismic line, YT-5, is used as the regional view, connecting the deformation of the Pamplona Zone in the northern section of the Yakutat microplate through the large depositional basin to the trailing edge of the microplate, the Fairweather Ground. The YT-5 seismic profile runs NW to SE along the Gulf of Alaska's continental shelf transecting both the Yakutat Valley and the Alsek Valley (Fig. 10). The proximity of this line to the OSC Y-0211 No. 1 Well in the West Yakutat Subbasin provides the only well tie in this study.

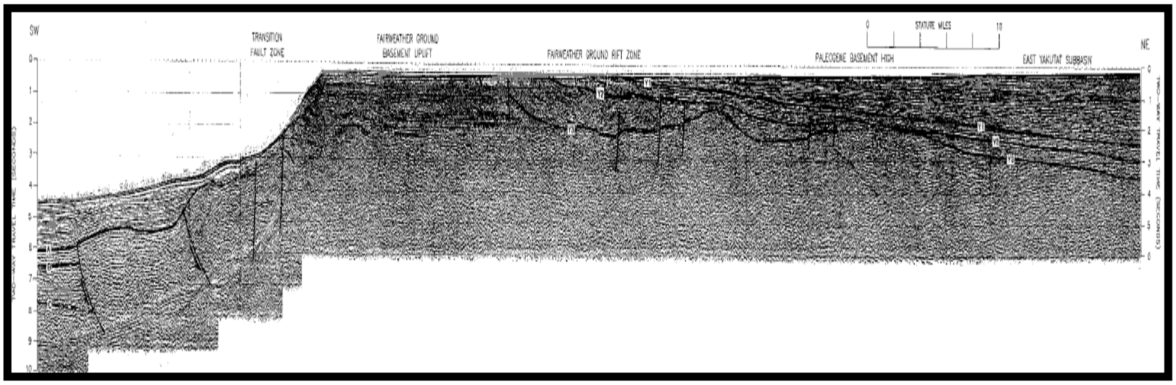


Figure 6. Seismic line 909, with original interpretations from Risley et. al, 1992

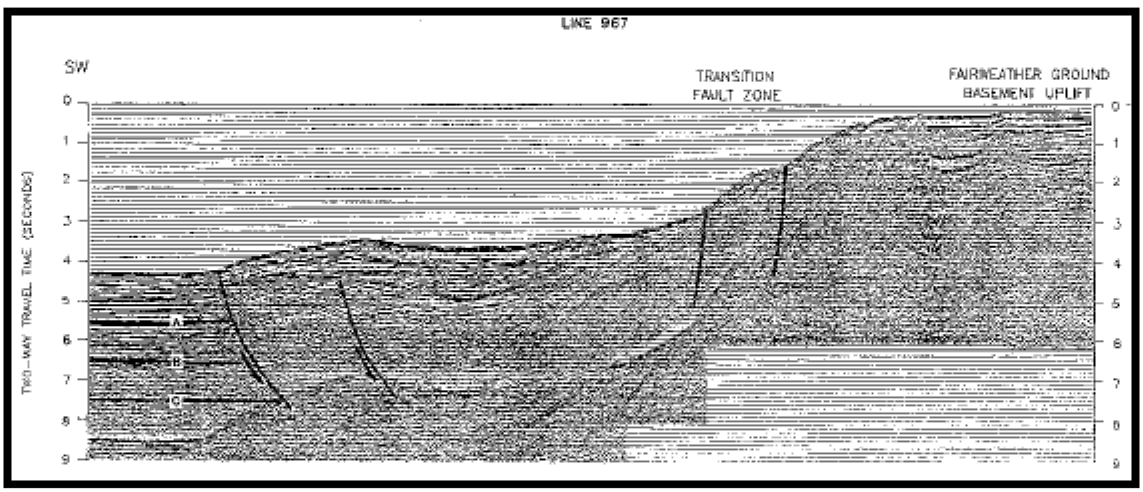


Figure 7. Seismic line 967, with original interpretations from Risley et. al, 1992

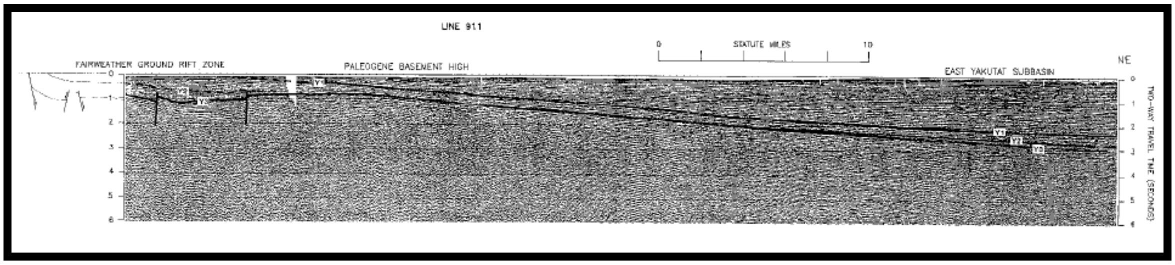


Figure 8. Seismic line 911, with original interpretations from Risley et. al, 1992

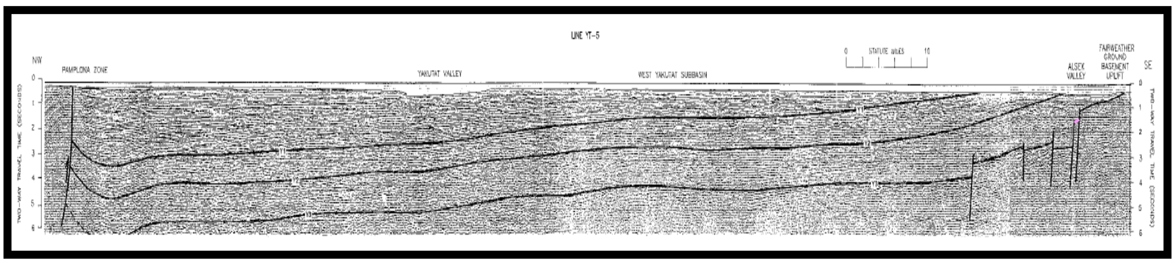


Figure 9. Seismic line YT-5, with original interpretations from Risley et. al, 1992

Well Data

The Arco OCS Y-0221 No. 1 was used along with a synthetic seismogram by Risley (Risley et al., 1992) for correlation with the seismic data on the continental slope of the Gulf of Alaska (Fig. 10). The OCS Y-0221 has a total depth of 5,428m and penetrates the six strata boundaries used in this study uses for interpreting seismic horizons.

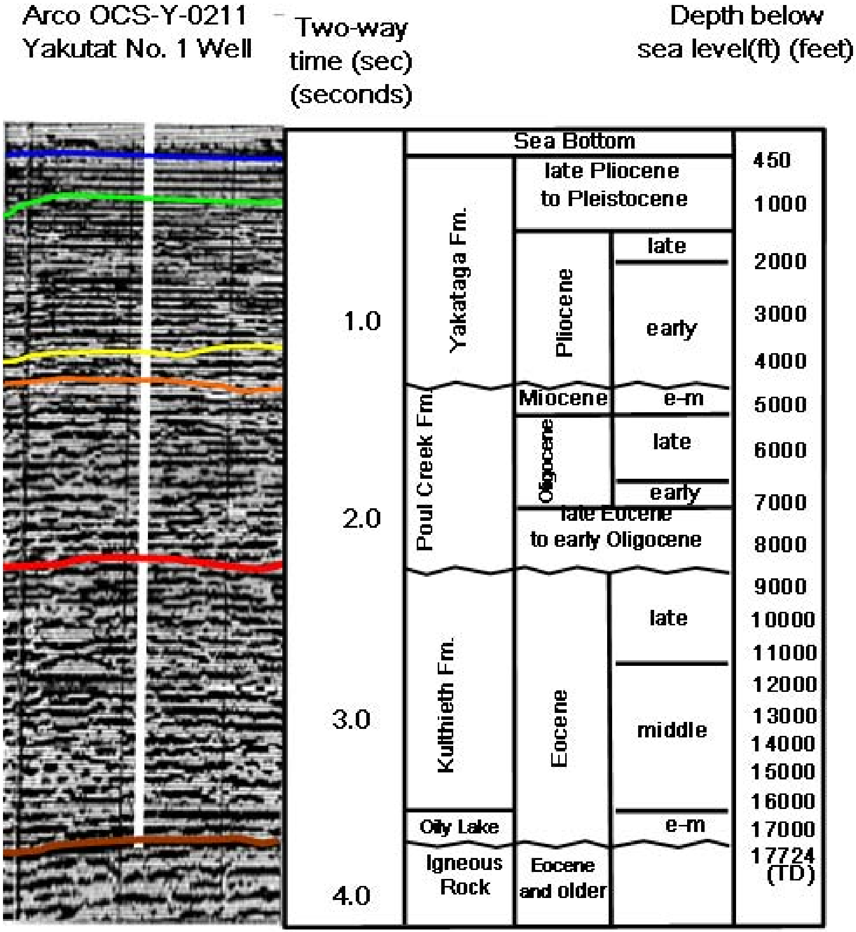


Figure 10. Synthetic seismogram with interpreted seismic horizons (modified from Risley et. al, 1992). The seismic profile is courtesy of Arco Alaska, Inc.

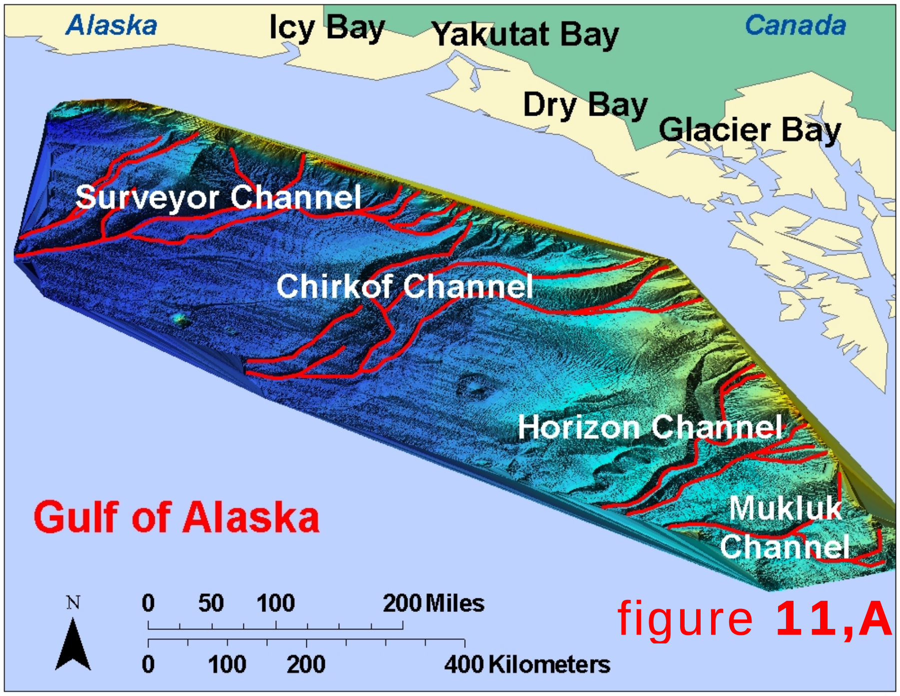
Results

Analysis of Bathymetry Data

The Gulf of Alaska bathymetry is shown in shaded relief, contour maps, and stereo pairs. The four submarine channel systems of the Gulf of Alaska (Surveyor, Chirkof, Horizon, and Mukluk Channel) are readily identified in the data (Fig. 11A). Deformation that has affected the surface deposition is resolvable and is used here to aid interpretation of the available seismic data.

The northernmost section of the bathymetry data shows an area of high relief (> 300 m). There are several stair-step changes in ocean bottom depth that generally trend west to east and display a degree of curvature (Fig. 11). There are five slightly curving ridges that are interpreted here as the product of deformation associated with shortening in the Pamplona Zone.

The Pamplona Zone (Fig. 12-13) is thought to be a secondary effect of late Neogene fault morphology (Bruhn and Pavlis, 2001). The Pamplona Zone records only a small fraction of shortening (~1 to 2 km) while most of the North American/Pacific plate contraction takes place on land or westward in the Kayak Island zone (Picornell, 2001). The timing of the offshore fold and thrust belt of the Pamplona Zone, as well as, the deformation due to shortening must be considered when evaluating the relationship between the Transition Fault and the Fairweather Ground Uplift.



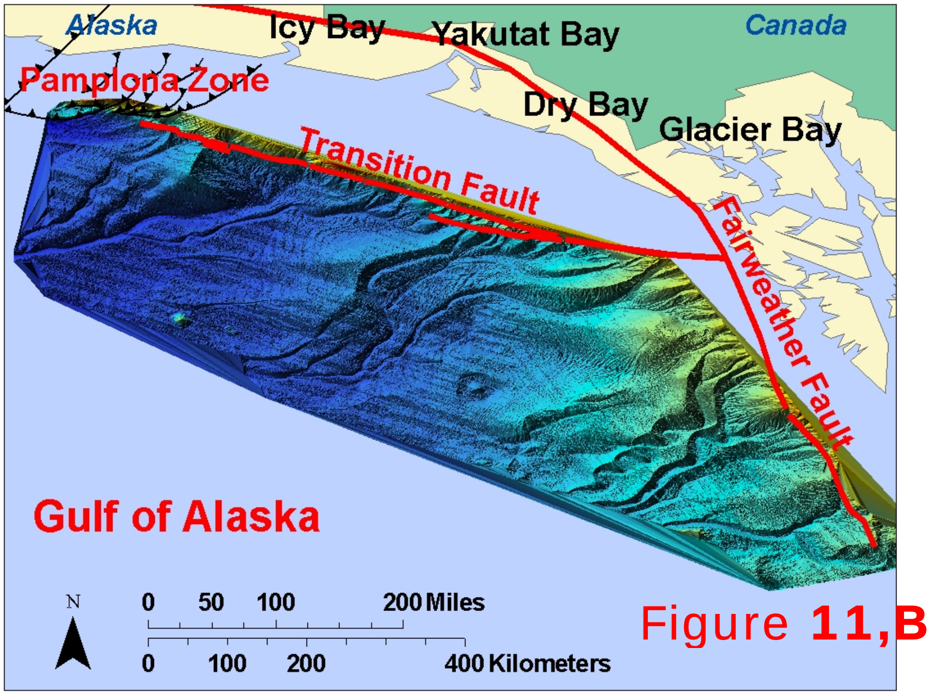
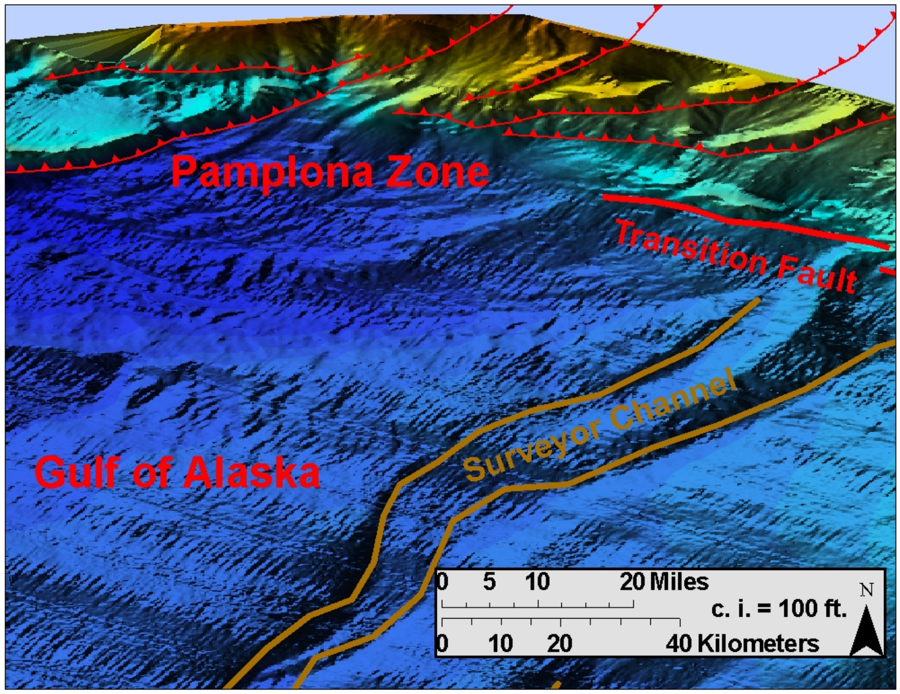


Figure 11. A. Shade relief bathymetry and regional scale channel systems of the Gulf of Alaska. B. Shade relief bathymetry and regional scale faults, Gulf of Alaska. As the Fairweather Fault continues offshore to the southeast the fault changes names to the Queen Charlotte fault.

Figure 12, A



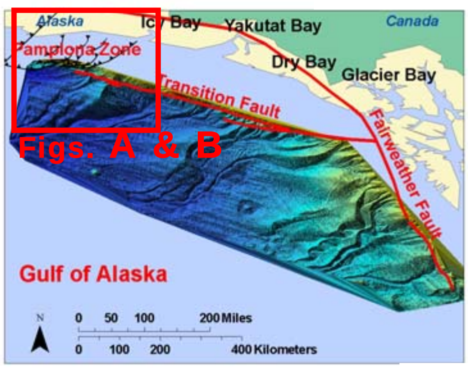
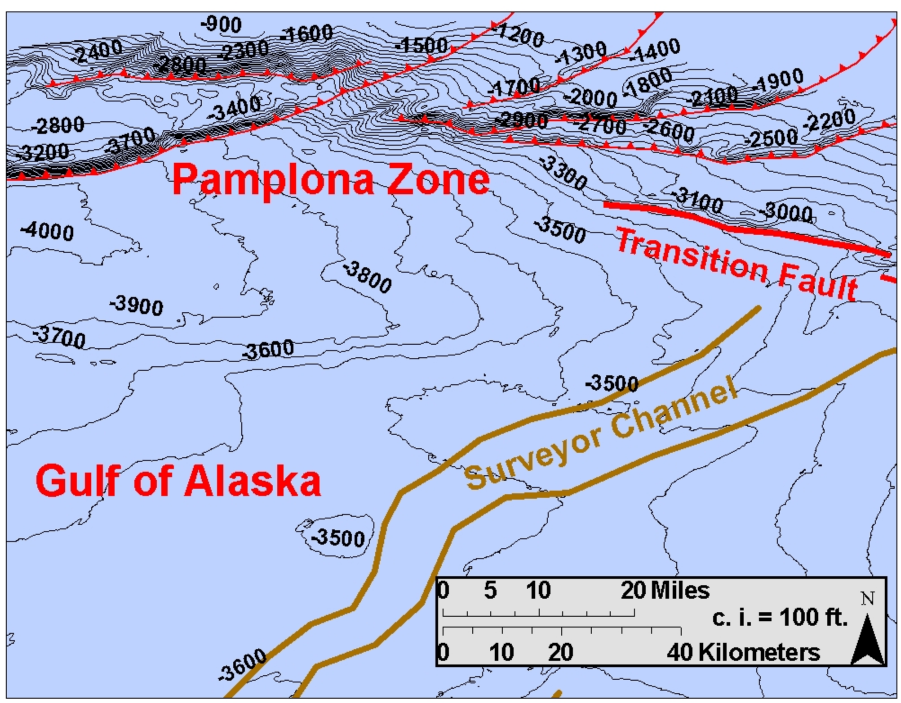


Figure 12. A. Shaded relief map of the northern section of the Transition Fault near the Pamplona Zone, Gulf of Alaska
B. Contour map of the northern section of the Transition fault near the Pamplona Zone, Gulf of Alaska

Figure 12, B



The southeast to northwest trending bathymetric ridges are identified along the previously mapped trace of the Transition Fault. These bathymetric ridges extend much farther in relatively straight segments with smaller changes in depth (10's of meters) than the Pamplona ridges. These topographic steps are interpreted as fault scarps along a southeast to northwest trend and are consistent with the oblique to strike-slip movement on the Transition fault with respect to the Yakutat microplate and the Pacific plate (Gulick et al., 2007).

The section of the Transition fault adjacent to the Fairweather Ground (Fig. 14-17) provides insight into the tectonic mechanism responsible for the Fairweather Ground basement uplift. Here, I consider two alternative hypotheses for the Fairweather ground: uplift above an active thrust or oblique thrust vs. a flexural bulge in advance of on-land thrust systems to the east beneath the Yakutat foothills.

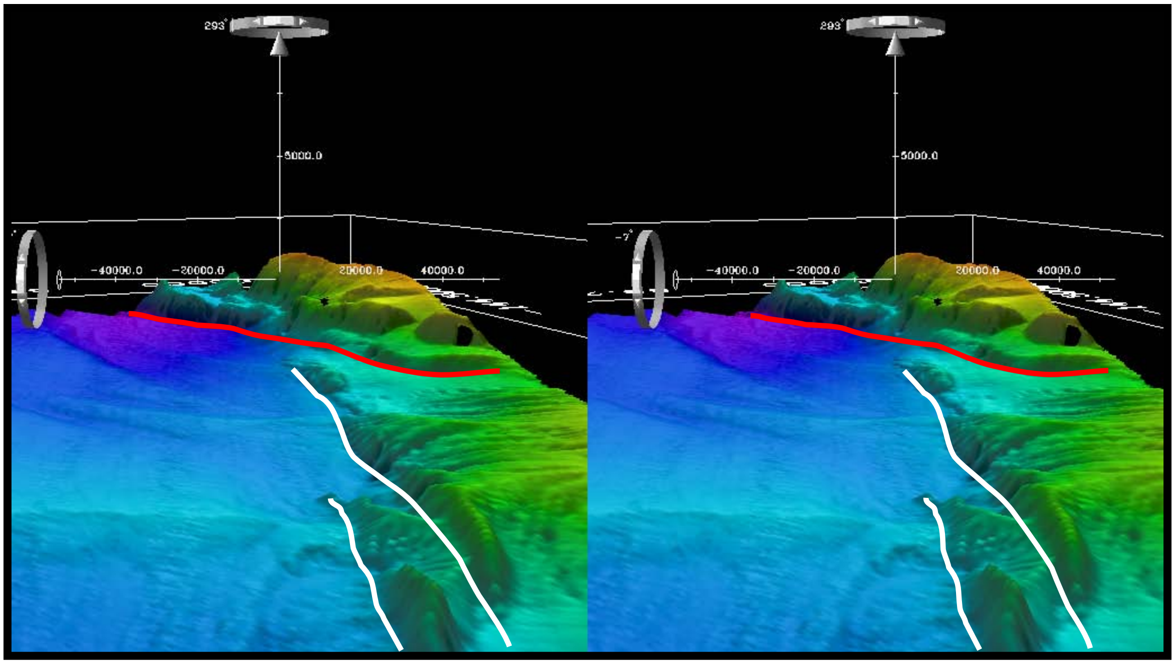


Figure 13. Stereo pair, oblique view of the northern section of the Transition Fault (solid white lines, foreground) and Pamplona Fold and Thrust Zone (red line, background), Gulf of Alaska. The point of view is outboard the shelf/slope break looking northwest along the strike of the Transition Fault. VE=6x

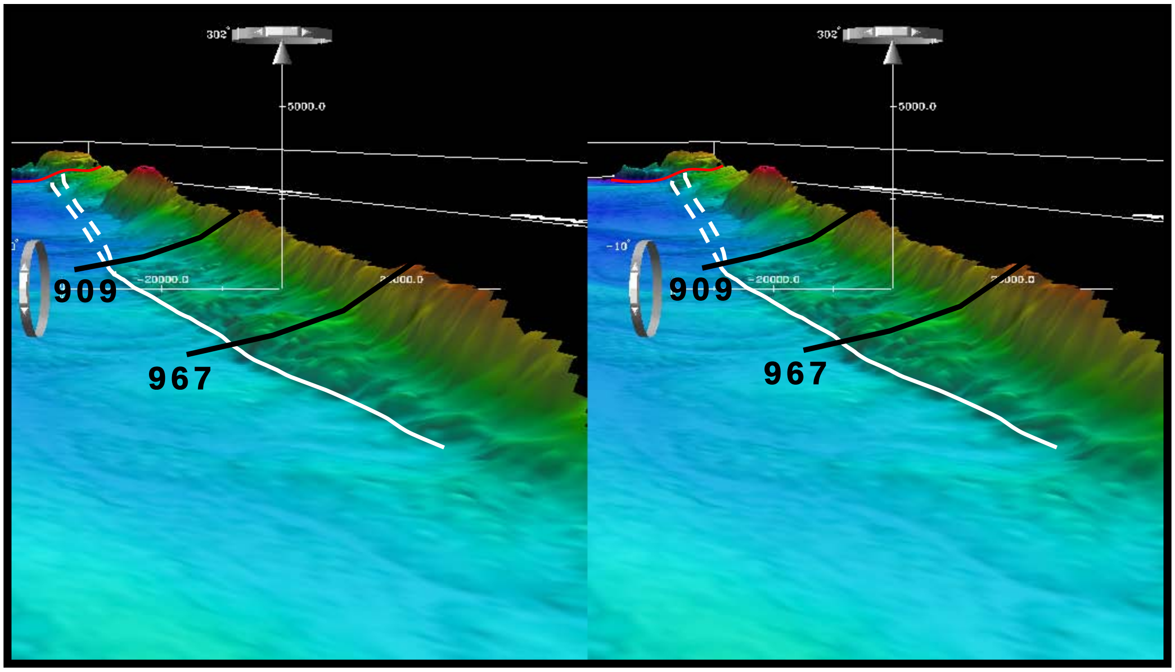


Figure 14. Stereo pair, oblique view of the Transition Fault (solid white line) near Fairweather Ground Uplift (foreground), seismic lines used in this study (solid black lines) and Pamplona Fold and Thrust Zone (red line, background). The point of view is outboard the shelf/slope break looking northwest along the strike of the Transition Fault. VE=6x

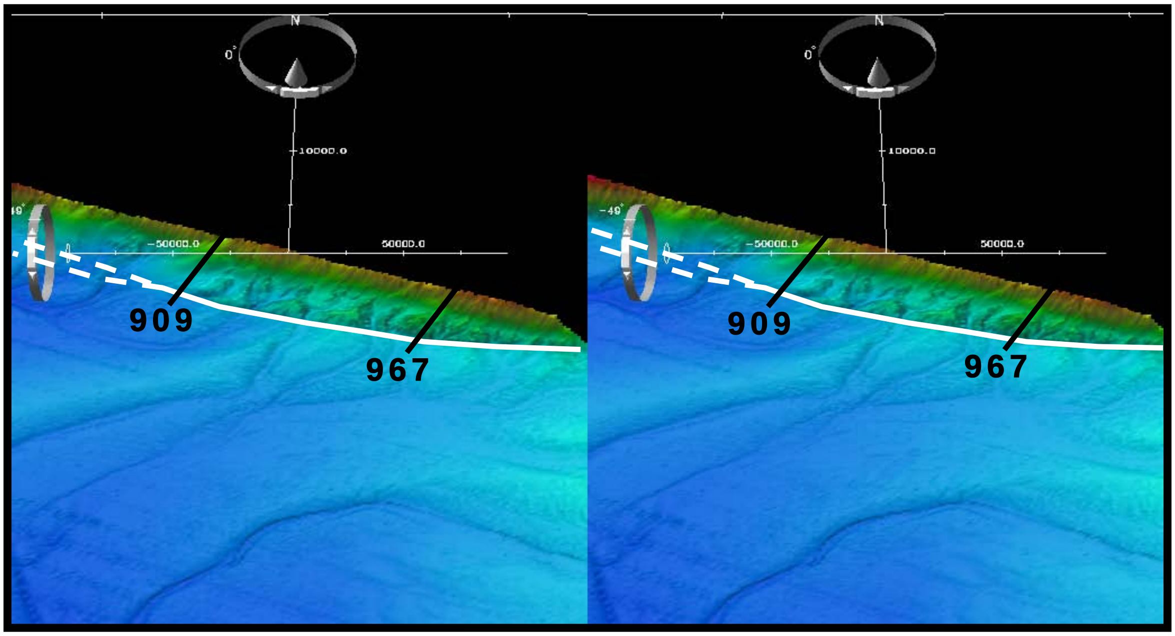
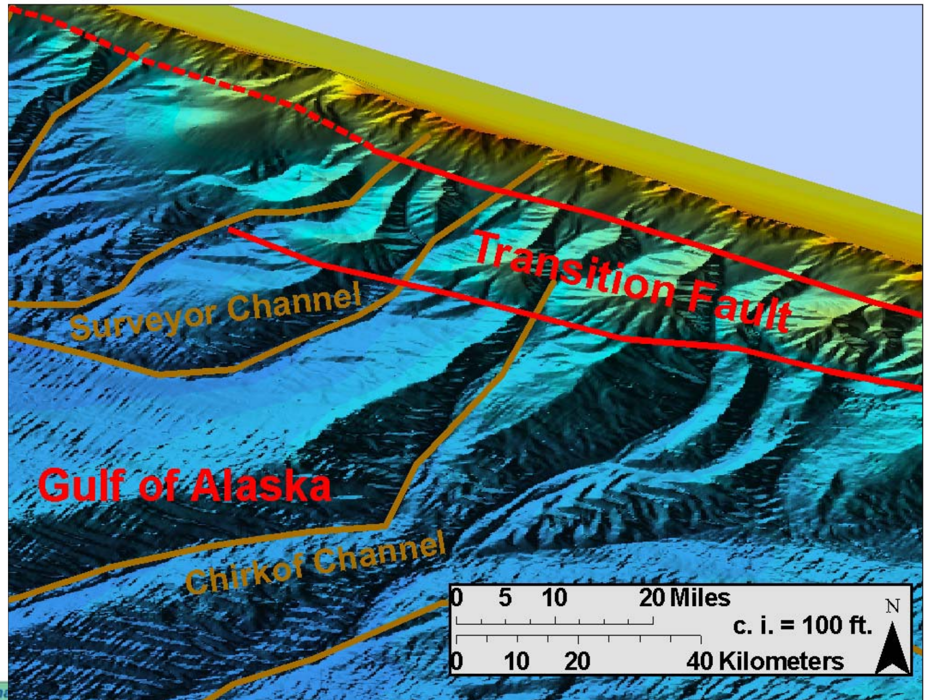


Figure 15. Stereo pair, oblique view of the Transition Fault (solid white line) near Fairweather Ground Uplift and seismic lines used in this study (solid black lines). The point of view is from the Gulf of Alaska, south of the Fairweather Ground Uplift, looking north. VE=6x

Figure 16, A



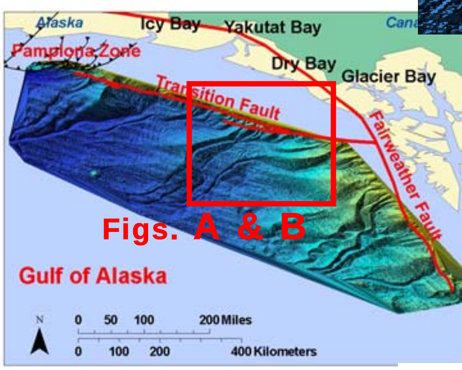


Figure 16. A. Shaded relief map of the section of the Transition Fault near the Fairweather Ground uplift, Gulf of Alaska
B. Contour map of the section of the Transition Fault near the Fairweather Ground uplift, Gulf of Alaska

Figure 16, B

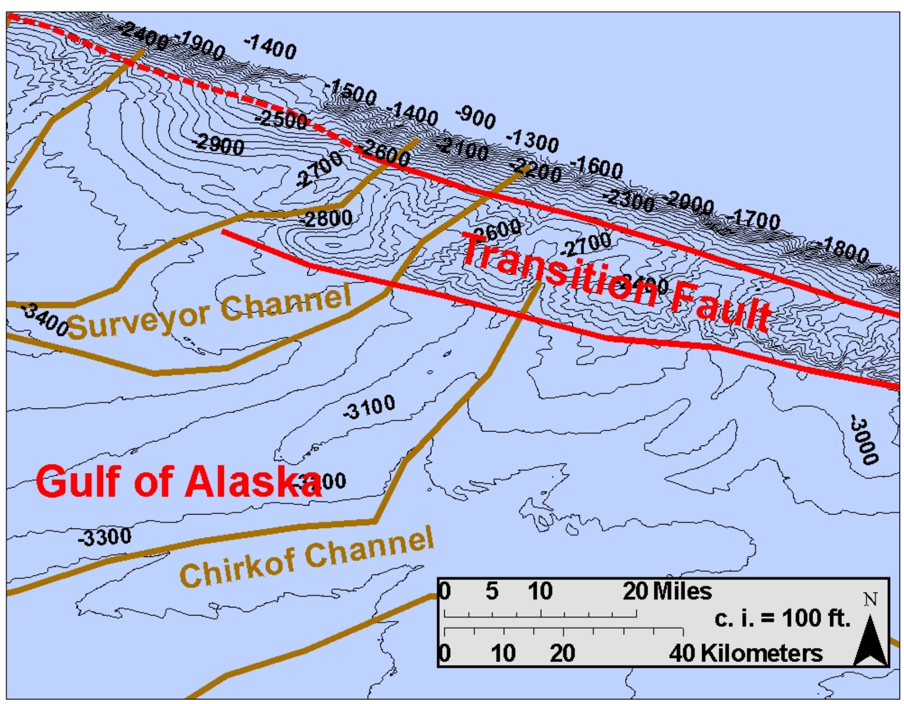
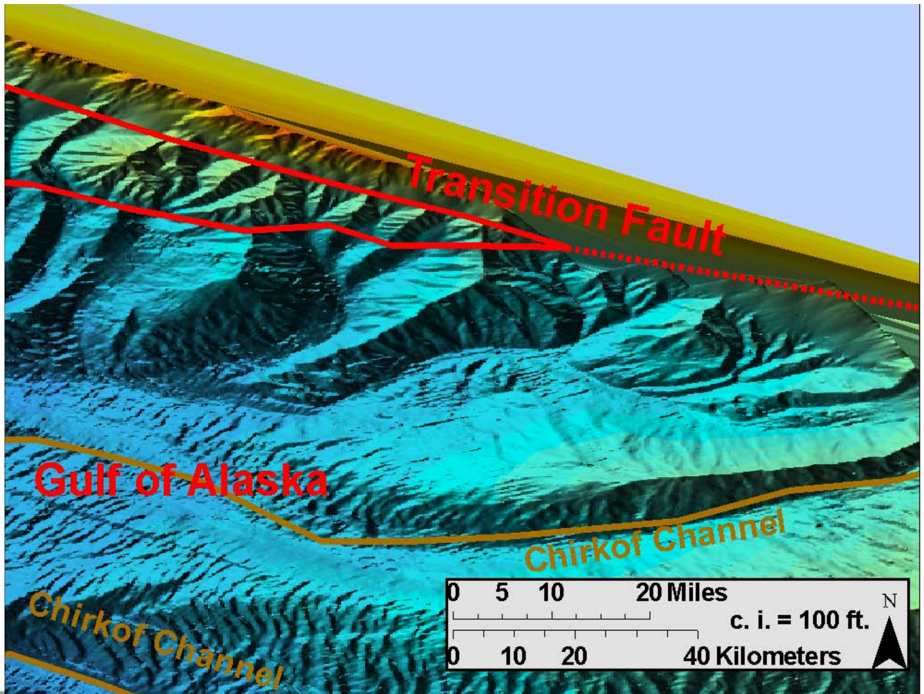


Figure 17, A



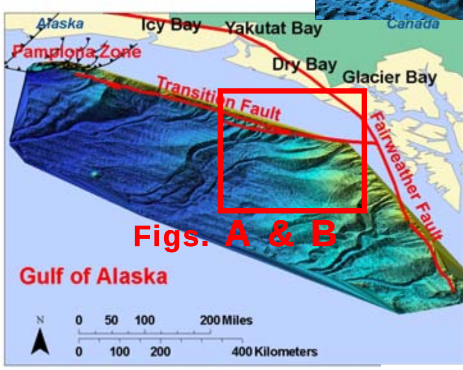
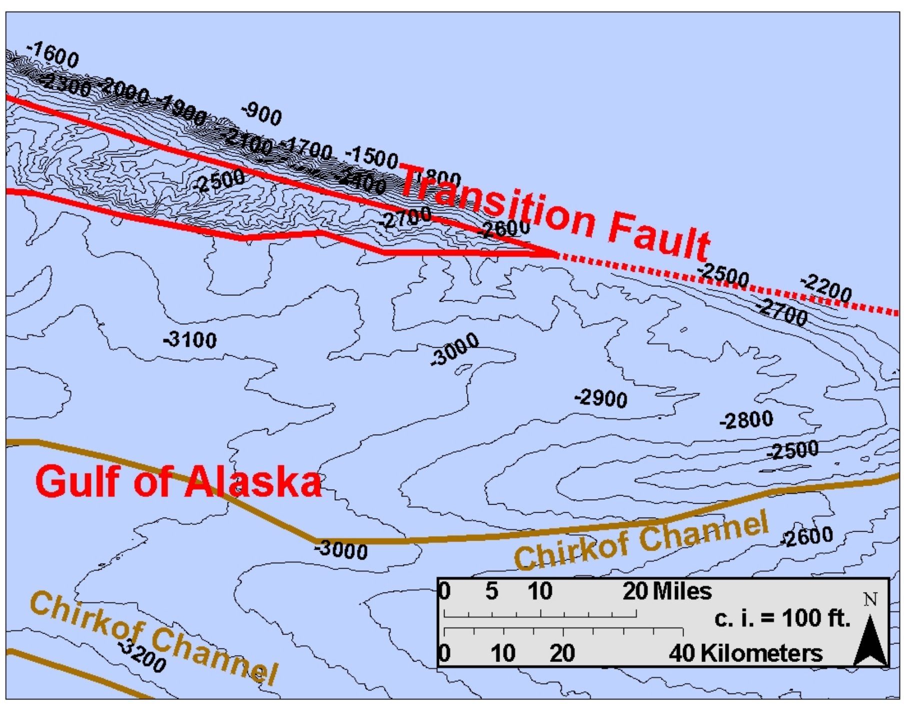


Figure 17. A. Shaded relief map of the section of the Transition Fault near the Fairweather Ground uplift, Gulf of Alaska
B. Contour map of the section of the Transition Fault near the Fairweather Ground uplift, Gulf of Alaska

Figure 17, B



Analysis of Seismic Data

With the use of seismic stratigraphy, the reinterpretation of 2D seismic lines in the Gulf of Alaska establishes the history of uplift for the Fairweather Ground. By identifying those seismic reflectors that pinch out (onlap or downlap) at the acoustic basement and overlying unconformities, the relationship between tectonic uplift and sediment discharge can be placed inside the larger framework of Yakutat microplate movement with respect to the Pacific plate.

Three seismic horizons have been interpreted as regional unconformities by Risley (Risley et al., 1992), Y3, Y2, and Y1; which have been color coded Brown, Red, and Orange respectively for this study. The Brown horizon separates the acoustic basement (Eocene and older sediments and igneous rock) from the overlying glacio-marine sediment. The Red horizon is a regional unconformity interpreted by Risley et al. (1992) as the Kulthieth/Poul Creek boundary. The Orange horizon is interpreted as the Poul Creek/ Yakataga boundary (Risley et al., 1992). The reinterpretation of seismic reflectors above the regional unconformities records the history of uplift in the study area.

The focus for the seismic sequence stratigraphic approach, with respect to the initiation of the Fairweather Ground uplift, is the Pliocene-Pleistocene glacial/interglacial cycle recorded in the Yakataga Formation adjacent to the Fairweather Ground uplift. This study will adhere to the nomenclature put forth by Lagoe and Zellers (1994) when discussing the glacial/interglacial/glacial sequence as P1, P2, and P3, respectively. However, the color code used for this study does

not match the color code for the works by Lagoe and Zellers (1994) or Zellers (1995). The seismic reflectors of the Yakataga formation overlay an erosional unconformity interpreted as the Poul Creek/ Yakataga boundary, the Orange horizon. Two unconformities, designated as the Yellow horizon and the Green horizon, separate episodes of glacial (P1 and P3) and interglacial (P2) deposition on the Yakutat block (Lagoe and Zellers, 1994, Zellers, 1995)

For this study the seismic window (0 to 3 seconds, two-way travel time) overlies the Orange horizon. Due to the lack of seismic resolution on the regional seismic lines only three horizons can be identified consistently throughout the data set. The horizons are Pliocene to Pleistocene unconformities associated with a regional glacial/ interglacial cycle. The Orange horizon is interpreted as the Yakataga/ Poul Creek boundary, which marks the onset of a Pliocene glacial period near 5.5 Ma. The Yellow horizon is interpreted as the glacial retreat of the mid-Pliocene warming event (~4.2Ma) as an unconformity, indicated by the onlap of overlying seismic reflectors (Lagoe and Zellers, 1994). The Green horizon typically conforms to the seismic reflector geometry but in some areas is identified as an unconformity. This is to be expected as the Green horizon is interpreted as a late Neogene (3 to 3.5 Ma) glacial advance. The Blue Horizon is interpreted as the present water bottom. Water bottom multiples prevent a more accurate picking of the last major glacial retreat (~20,000 years ago) in the offshore Gulf of Alaska. The seismic package between the Green horizon and the Blue horizon is interpreted as late Pliocene to Pleistocene glacio-marine sediment.

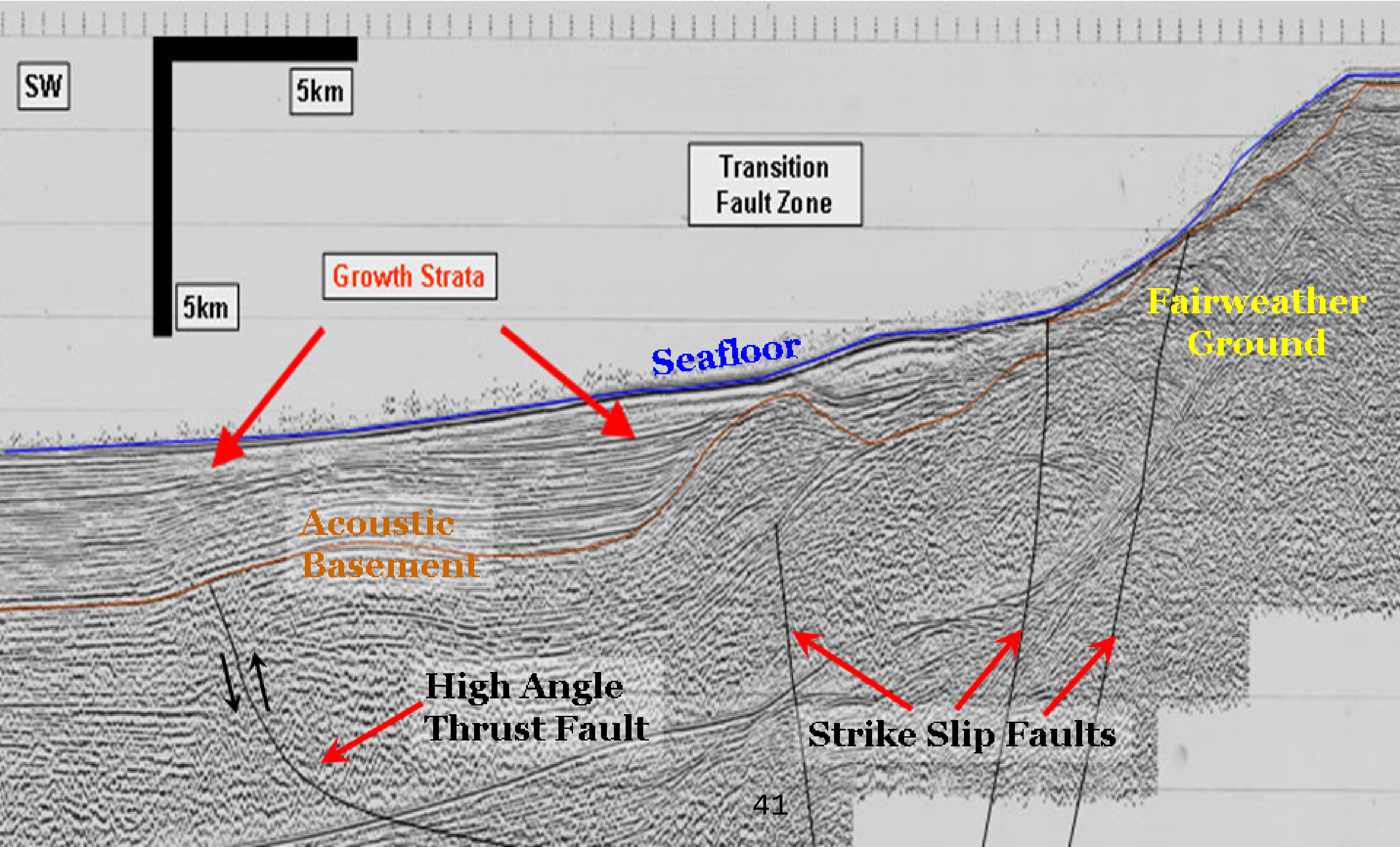
The reinterpretation of syntectonic deposition of glacio-marine sediment above the Orange horizon helps to understand the timing of the Fairweather Ground uplift and the creation of accommodation space for subsequent deposition (Fig. 19-21d). The seismic package below the Orange horizon (between the Brown horizon and the Orange horizon) has a uniform thickness and does not pinch out against the underlying reflectors, suggesting the Fairweather Ground basement rock must have been flat lying at the time of the Poul Creek formation deposition, late Eocene to early Miocene. The seismic reflectors above the Orange horizon onlap, or pinch out, against the Orange horizon in the direction of the acoustic basement, the Brown horizon, indicating the initiation of the Fairweather Ground basement uplift near 5.5 Ma, early Pliocene. Alternatively, these truncations indicate the onset of subsidence to the east and signifying thrust loading near the Fairweather foothills and resultant depression of the basin.

Line 909

Seismic line 909 (Fig. 19), just south of Dry Bay, records the depositional history landward and seaward of the Fairweather Ground uplift. The Transition fault zone is interpreted at the base of slope. The seaward reflectors could not be correlated due to the lack of well control across the slope of the Gulf of Alaska. The key observation with respect to the seaward reflectors is the definite growth strata on the leading edge of the anticline and the back side of the system (Fig. 19b). The appearance of growth strata in the Transition fault zone support a thrust model with relatively low deformation rates. The seaward reflectors also onlap the underlying unconformity which has been interpreted as the acoustic basement (Risley et al., 1992). This reflector corresponds to the top of the Eocene igneous rock exposed at the shelf edge. The deposition landward of the Fairweather Ground records reflectors onlaping southwest in the direction of the Fairweather Ground basement. The Dangerous River zone and the Paleogene basement high overlap adjacent to the Fairweather Ground. Accommodation has been created in the northwest portion of the seismic line and the sediment growth thickens away from the Fairweather Ground uplift.

Figure 19. Seismic Line 909, Regional scale 2D line in the Gulf of Alaska

Southwest Section of Seismic Line 909



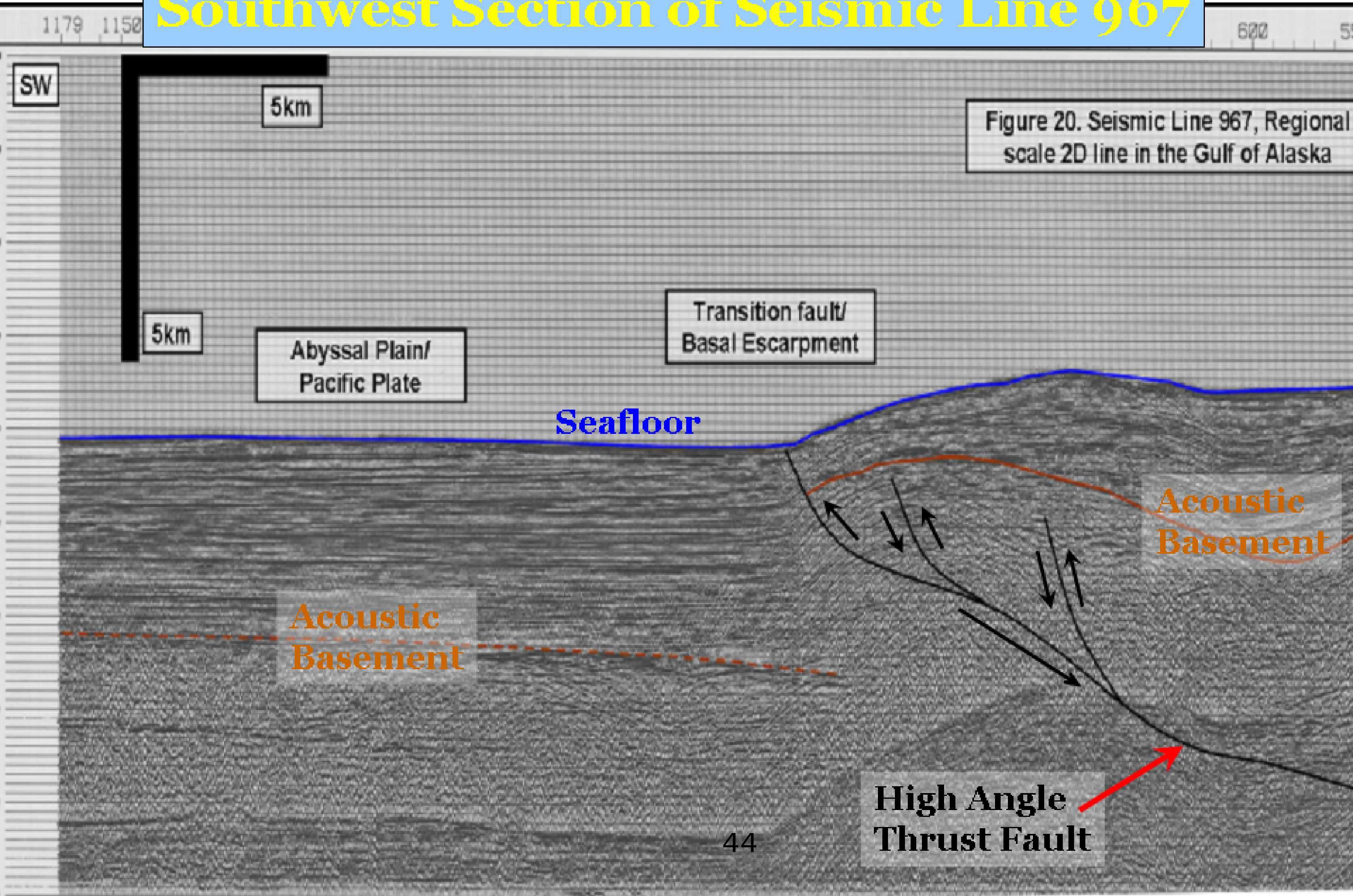
Line 967

Seismic line 967 (Fig. 20) is the shortest line in this study at 40 kilometers in length. The seismic line runs from the seafloor exposed Fairweather Ground acoustic basement through the Transition fault zone. The seismic reflectors overlying the interpreted acoustic basement could not be correlated due to lack of well control at the shelf break. Line 967 illuminates the seafloor exposed Eocene igneous basement rock of the Fairweather Ground (Wilson et al., 2005).

In the southwest section of seismic line 967, the reflectors are relatively flat lying and have uniform thickness above the Brown horizon, suggesting undeformed rocks deposited in a deep marine depositional environment. The Transition Fault zone is interpreted at the base of the slope as a high angle thrust fault (Fig. 20b). Interpreted vertical to near vertical faults on the slope take up the oblique slip motion of the Transition fault. The Fairweather Ground uplift, in the northeast section of the seismic line, places Eocene age igneous rock on the seafloor (Risley et al., 1992). The Brown horizon is exposed to the seafloor at the shelf break while the water bottom is shown by the Blue horizon. Depth conversion of line 967 reveals the flat lying sedimentary package above the Brown horizon to have a thickness of 1700m to 2000m.

Figure 20. Seismic Line 967, Regional scale 2D line in the Gulf of Alaska

Southwest Section of Seismic Line 967

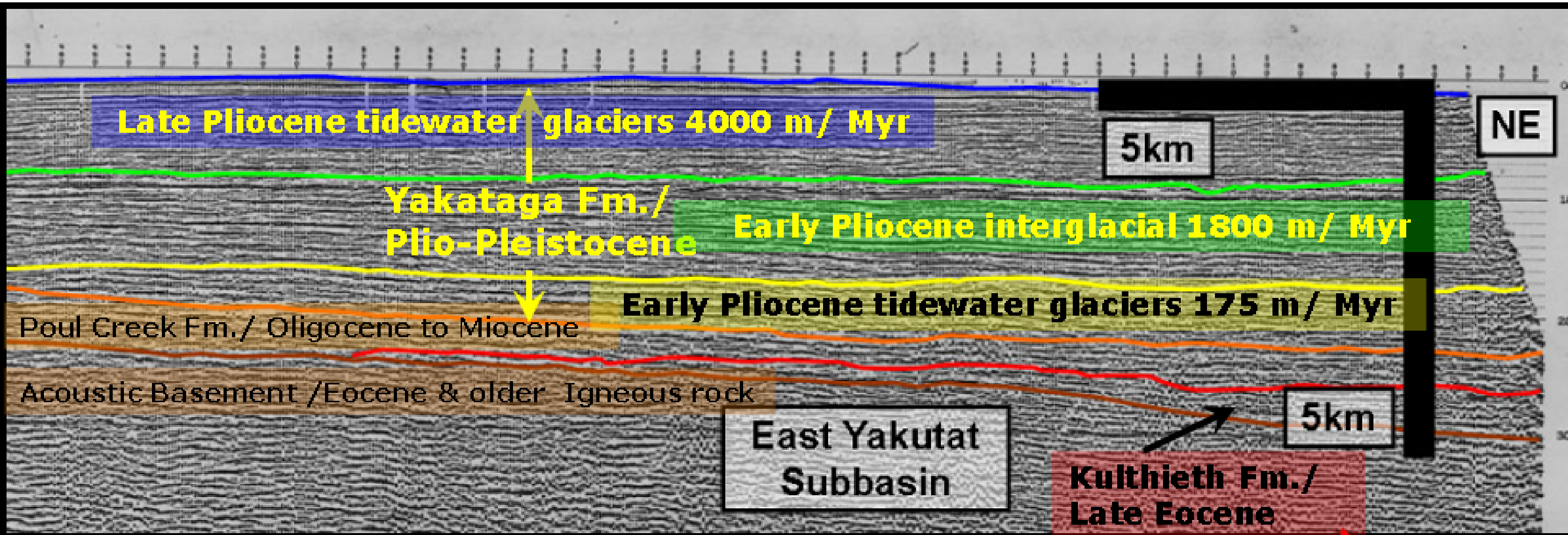


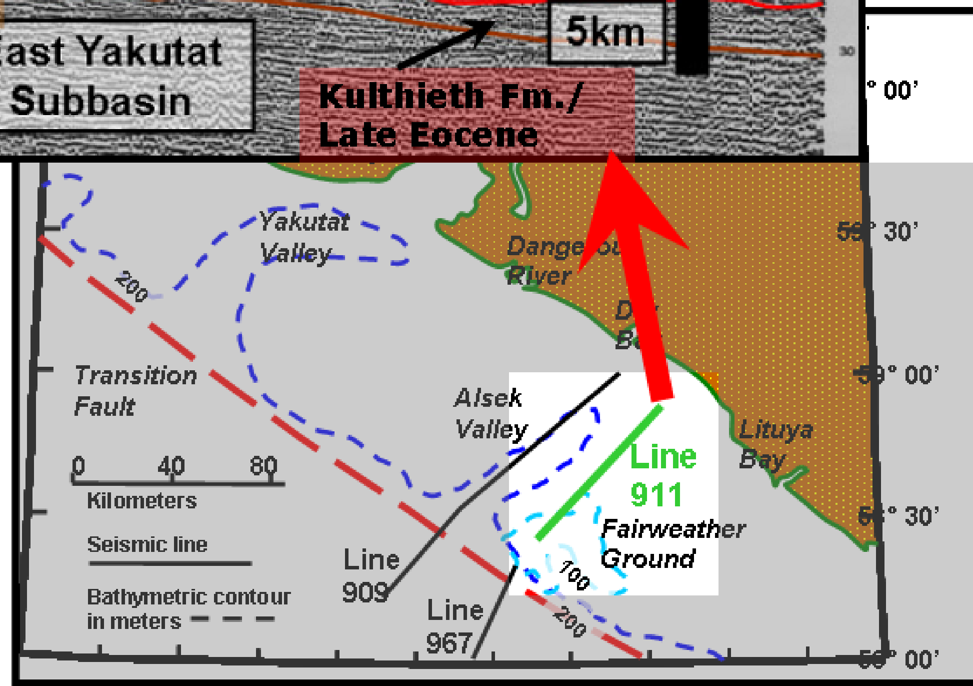
Line 911

Seismic line 911 (Fig. 21) does not image the seafloor exposed Fairweather Ground basement uplift or the Transition fault zone, but rather the deposition of overlying sediments which indicate the timing of tectonic uplift and the effects this movement has on creating accommodation space for the glacio-marine sediment. Of the seismic lines used for this study, line 911 has the most continuous reflectors. All seismic reflectors above the Orange horizon onlap in the direction of the Fairweather Ground uplift. Similarly, the interpreted horizons above the Orange horizon show a general thickening of sedimentary packages landward. This landward thickening trend (Fig. 21b-21d) is a result of the uplift of the Fairweather Ground and depression of the surrounding basement. The Fairweather Ground basement high gets uplifted after the deposition of the Poul Creek Formation and as a result accommodation is created on the landward side of the uplifted area for subsequent depositional packages. Sediment deposited in this area is trapped by the relative low adjacent to the Fairweather Ground and are allowed to build up against the uplifted Fairweather Ground.

Figure 21. Seismic Line 911, Regional
scale 2D line in the Gulf of Alaska

Northeast Section of Seismic Line 911





Central Section of Seismic Line 911

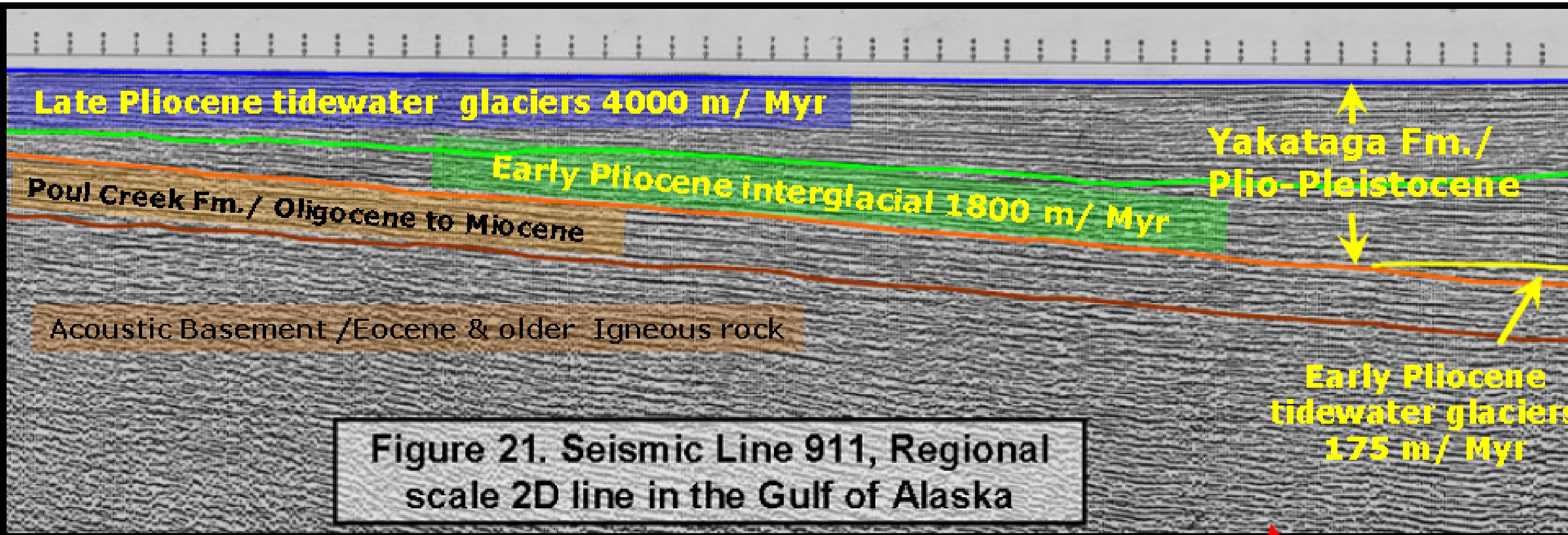
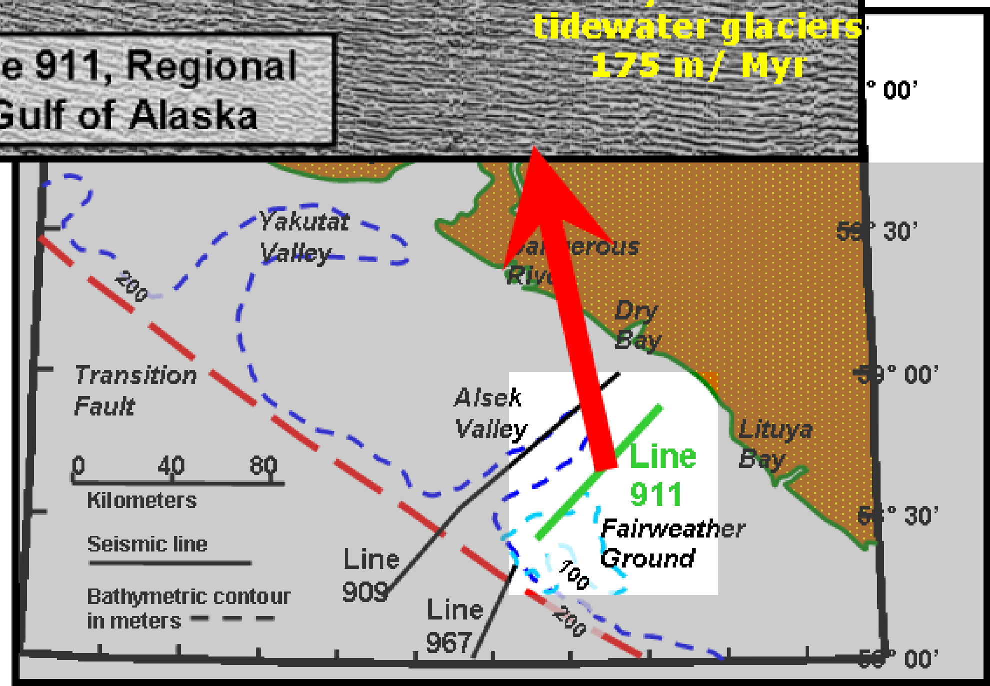
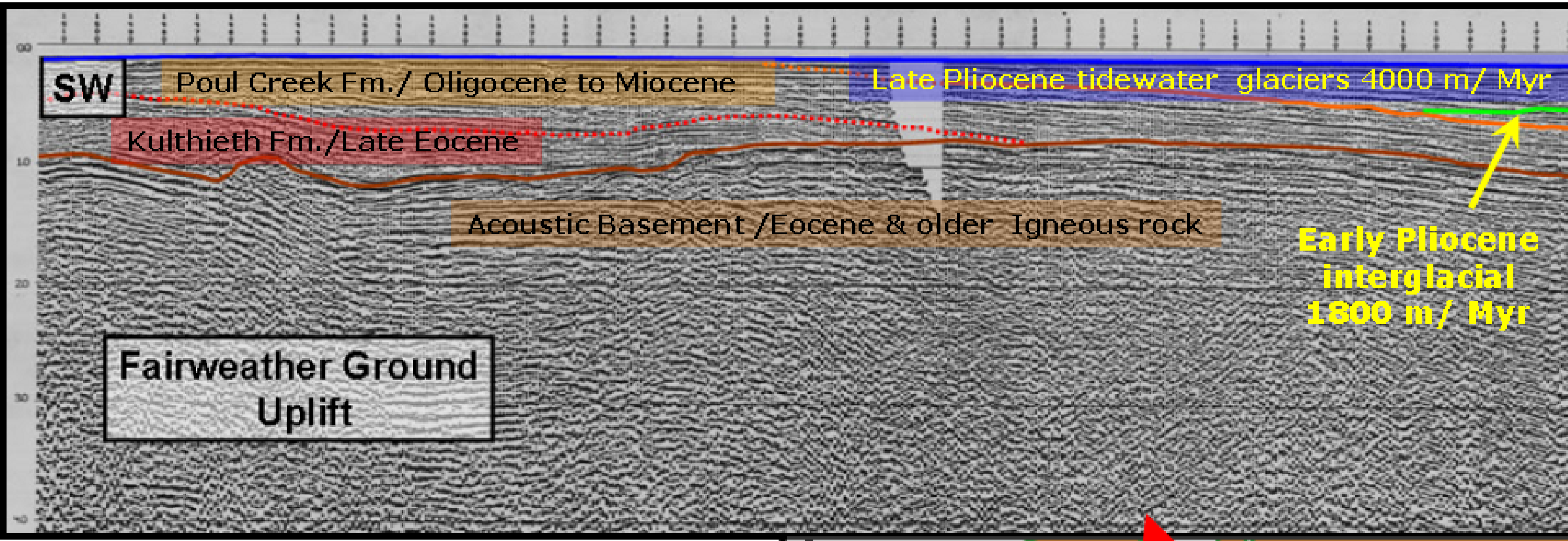
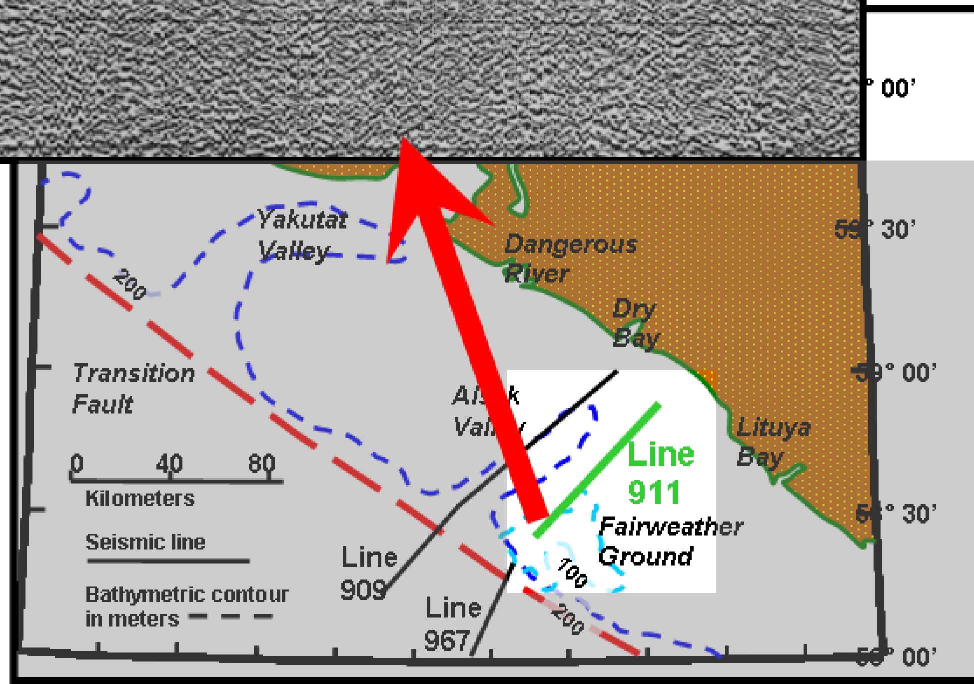


Figure 21. Seismic Line 911, Regional scale 2D line in the Gulf of Alaska



Southwest Section of Seismic Line 911





Line YT-5

Seismic line YT-5 is the longest line used for this study at nearly 242 kilometers. The primary function of the YT-5 line, in this study, was to correlate the synthetic seismogram (Risley et al. 1992) horizons across the Yakutat block to the seismic lines of the Fairweather Ground. YT-5 runs from west of Icy Bay to the basement uplift at Fairweather Ground. The seismic reflectors above the Orange horizon onlap to the southeast toward the Fairweather uplift and generally thicken away from the Fairweather Ground uplift. The northwestward sediment growth ends abruptly with deformation at a thrust fault in the Pamplona zone. The geometry of the seismic reflectors from the acoustic basement up to the sea floor indicate the Fairweather Ground uplift is not a localized event but rather indicative of Yakutat microplate motion.

Analysis of Well Data

The OCS Y-0211 No. 1 well log along with a synthetic seismogram was used by Risley (Risley et al., 1992) to correlate the interpreted unconformities with the correct seismic response. The synthetic seismogram was used to join the depth scale with the seismic profile to establish seismic sequences and horizons, stratigraphic divisions, and chronostratigraphy, for the multichannel seismic-reflection profile of the OCS-Y-0211 Yakutat No. 1 well in the Yakutat segment of the Gulf of Alaska (Risley et al., 1992). The seismic profile amplitude was correlated with the YT-5 seismic line amplitude to resolve Plio-Pleistocene unconformities.

Discussion

Bathymetric data suggest the height of the Pamplona zone fault scarp system is ten times that of the Transition fault scarp (Fig. 11-13). The strike-slip to oblique-slip movement along the Transition fault must be considered when comparing the vertical components of motion. The Pamplona zone exhibits more than 300m of relief for 1km of shortening while the Transition Fault displays only 30m of relief (Picornell, 2001). The height of the fault scarps depend on the vertical component of uplift relative to the rate of burial. Burial is probably comparable in both sites when considering the height of the scarps at the base of the slope so the difference in vertical relief may be attributed to a difference in kinematics (Pavlis et al., 2004).

Where the seismic lines 909 and 967 (Fig. 22) overlap the bathymetry data there is a perched basin in the hanging wall of the thrust fault associated with the Transition fault. The bathymetry data shows that the overlapping sediments above the thrust system in seismic line 909 are being eroded today by numerous channels. Seismic line 909 was recorded along the Alsek Valley, a submarine valley that cuts into the perched basin. The bathymetry data shows that seismic line 967 is imaging a ridge associated with the Transition fault zone. The interpretation of the Transition fault at

the base of slope on line 967 coupled with the ridge system observations from the bathymetry indicate that the Transition fault zone is located at the basal escarpment and represents a high angle fault (Fig. 20 & 20b).

The interpretation of seismic line 909 is an important insight in understanding the deformation in the Transition fault zone. The existence of a frontal ridge required a high level of initial deformation. Growth strata in younger sediments record the continued motion of an entrenched ridge. The growth strata are present in line 909 and not line 967 because this later motion is only recorded by the growth strata in the intervening valleys.

The difficulties in interpreting the seismic data may be explained by the differences in bathymetric signature between seismic line 909 and seismic line 967. The three dimensional irregularities from the shelf edge to the base of slope produce acoustic scatter in the critical seismic section that cross the entrenched perched basin. The Transition fault zone is interpreted to lie at the base of the slope and the thrust loading model extends the Transition fault below the shelf edge. Imaging in this area, where the seafloor irregularities result in acoustic scatter, allows for alternative Pacific Plate/Yakutat block models.

An active thrust to oblique thrust Transition fault model with respect to the Fairweather Ground uplift can resolve bathymetry observations and seismic interpretations. The synthesis of bathymetry with seismic line 967 shows an active basal escarpment. The interpretation of seismic line 909 reveals growth strata on the leading edge of the anticline and the back side of the system.

Presently, at this linear boundary adjacent to the Fairweather Ground, the Pacific Plate is subducting beneath the Yakutat microplate with relatively low deformation rates. The Fairweather Ground basement uplift is the result of Pacific Plate thrust loading on the Yakutat microplate.

The Fairweather Ground basement uplift has a two-fold effect on regional glacio-marine sedimentation (Fig. 23-24). Uplift at the shelf/ slope margin creates sediment accommodation landward associated with the relative bathymetric low. The seismic interpretations of lines 909 and 911 show sedimentary packages that thicken landward. 2) Uplift of the Fairweather Ground obstructs the course of sediment deposition beyond the shelf/slope margin. As the Fairweather Ground rises the overlying sedimentary packages thin westward and eventually pinchout against the Fairweather Ground. The timing relationship between the Fairweather Ground uplift and the adjacent onlapping sedimentary packages is established by foraminiferal studies (Lagoe and Zellers, 1994 and Zellers, 1995) and glacial sequence stratigraphy (Powell and Cooper, 2002).

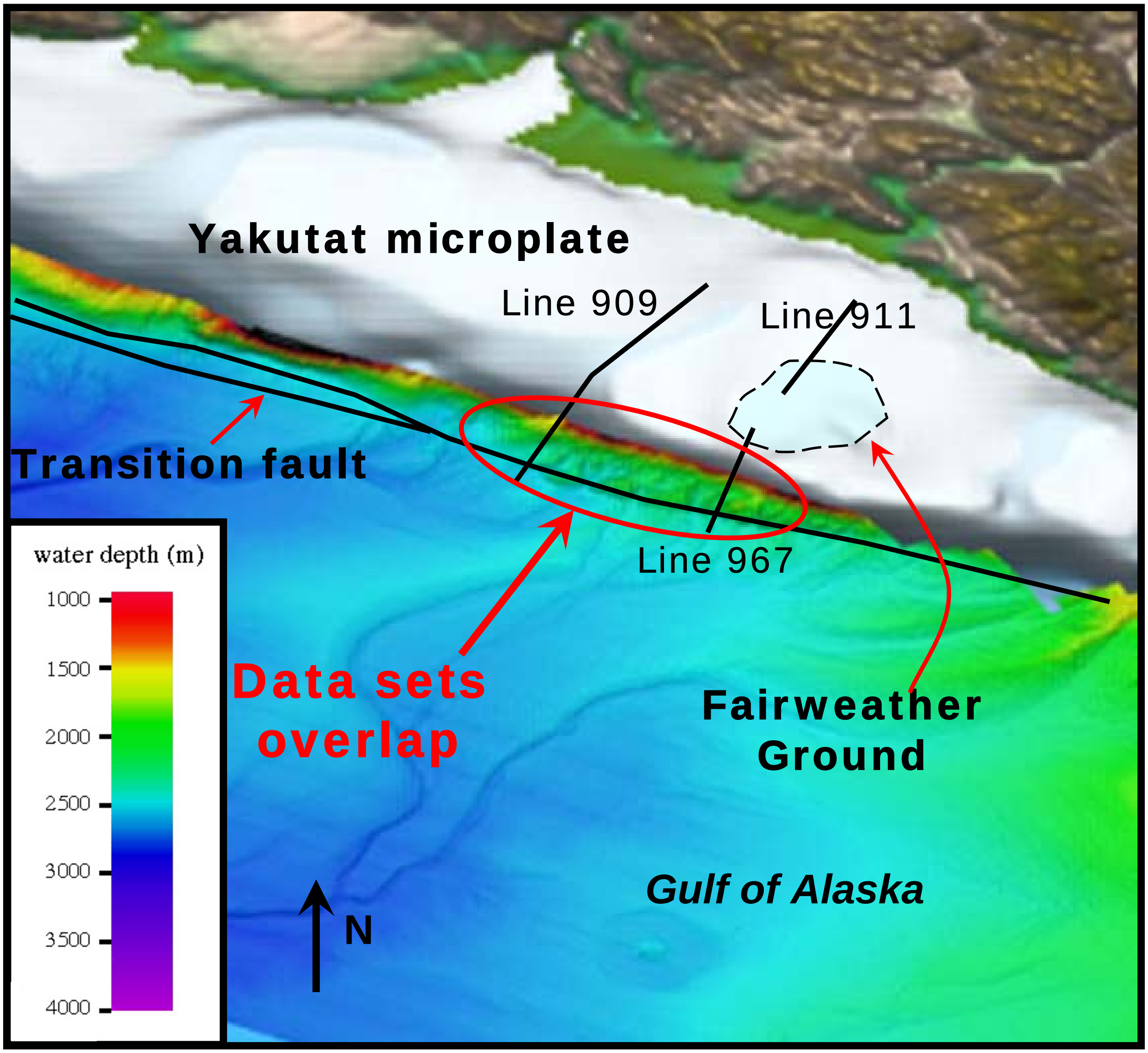


Figure 22. Digital elevation model with Gulf of Alaska high resolution bathymetry and onshore topography with 2D seismic lines used for this study. (modified from Gulick et al.,2007)

The sedimentary package between the interpreted Red horizon and the Orange horizon is interpreted to be the late Eocene to Oligocene Poul Creek formation. The uniform thickness of the interpreted Poul Creek formation records a depositional basin unaffected by uplift of the underlying basement rock, which implies the Fairweather Ground had not yet begun to uplift. The sedimentary package between the interpreted Orange horizon and the Yellow horizon is the lowermost package that appears to pinch out against the underlying Poul Creek Formation. This lowermost pinchout marks the initial uplift of the Fairweather Ground from late Miocene to earliest Pliocene (5.35 to 4.2 Ma). Although the younger packages are more difficult to correlate and characterize, the continued rise of the Fairweather Ground gets recorded by the pinchouts of the adjacent sedimentary packages. The sedimentary package between the Yellow horizon and the Green horizon (4.2 to 3~3.5 Ma) and the package between the Green horizon and the Blue horizon (3~3.5 to 1.8 Ma) both pinchout against the uplifting Fairweather Ground.

These observations make a strong argument for active Pacific Plate thrust loading on the Yakutat microplate along the Transition fault. The seismic interpretations coupled with the bathymetry indicate thrust faulting at the base of the slope along the trend of the Transition fault, but can not be considered the major driver of the adjacent Fairweather Ground uplift without considering the alternative model. The Fairweather Ground uplift may be controlled by North America Plate / Yakutat microplate interaction.

Seismicity in the Yakutat foothills (Page et al., 1991), along the Fairweather-Queen Charlotte fault, could imply that the Fairweather Ground uplift is a flexural bulge in advance of a foreland basin driven by this thrust system. The uplift and associated relative bathymetric low are the result of the initiation of a large scale “piggyback” basin development. The overall geometry of the interpreted seismic packages, onlaping the Fairweather Ground uplift and thickening landward, conforms to the “piggyback” basin model. Gulick and others (2007) introduce an anomalously thick Yakutat block into the model that results in strike-slip motion along the eastern segment of the Transition fault. The interpreted basal escarpment of the thrust model can be explained by periodic, localized strike-slip to oblique movement of the Transition fault.

The “piggyback” basin model can not explain the entrenched frontal ridge. The presence of growth strata indicates the continued deformation of an active Pacific Plate thrust loading on the Yakutat microplate along the Transition fault. The interpretation of uplift above an active thrust or oblique thrust is based on the interpretations and observations of bathymetry data, the synthesis of bathymetry data with seismic data, and new interpretations of public domain regional scale seismic lines.

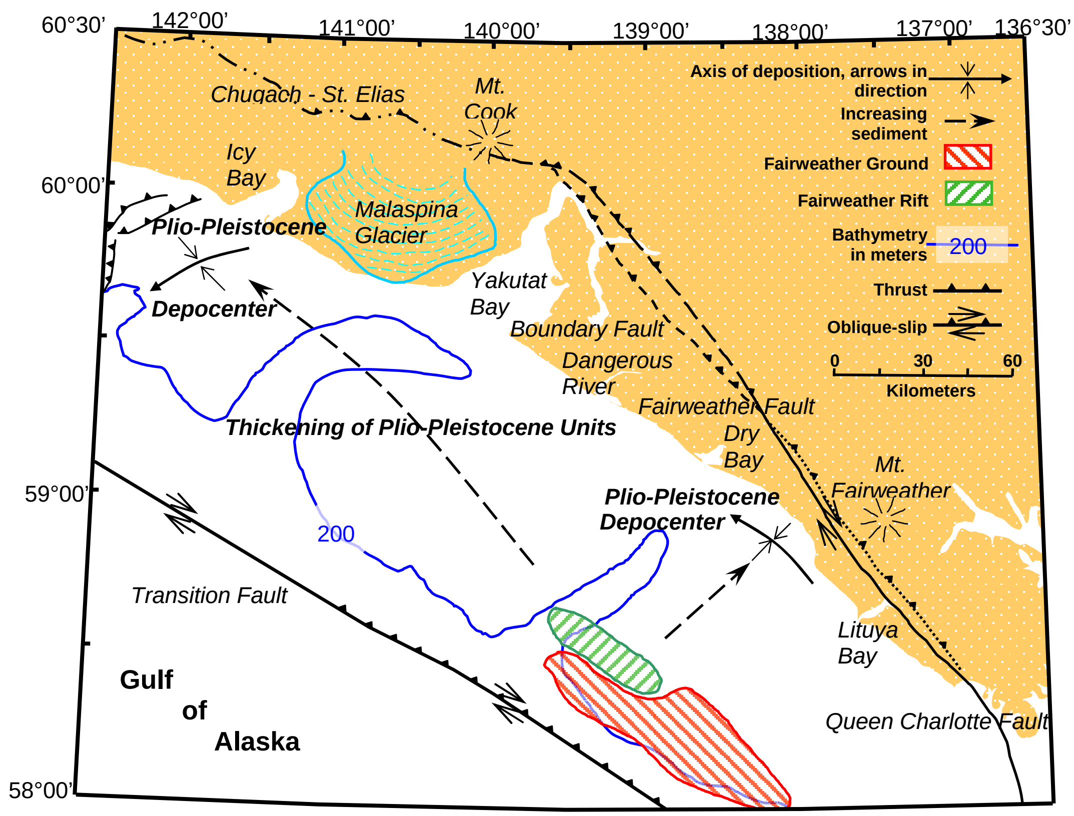


Figure 23. Yakutat microplate is bounded by the Transition fault to the south and the Fairweather fault to the north. The Fairweather Ground, indicated with red strips, located on the continental shelf margin between the Transition fault to the south and the Fairweather Ground rift zone, green stripes, to the north. Plio-Pleistocene sedimentation on the Yakutat microplate as a result of ongoing uplift of Fairweather Ground basement rock, indicated with increasing sedimentation arrows and deposition center markers. Modified from Risley et al., 1992

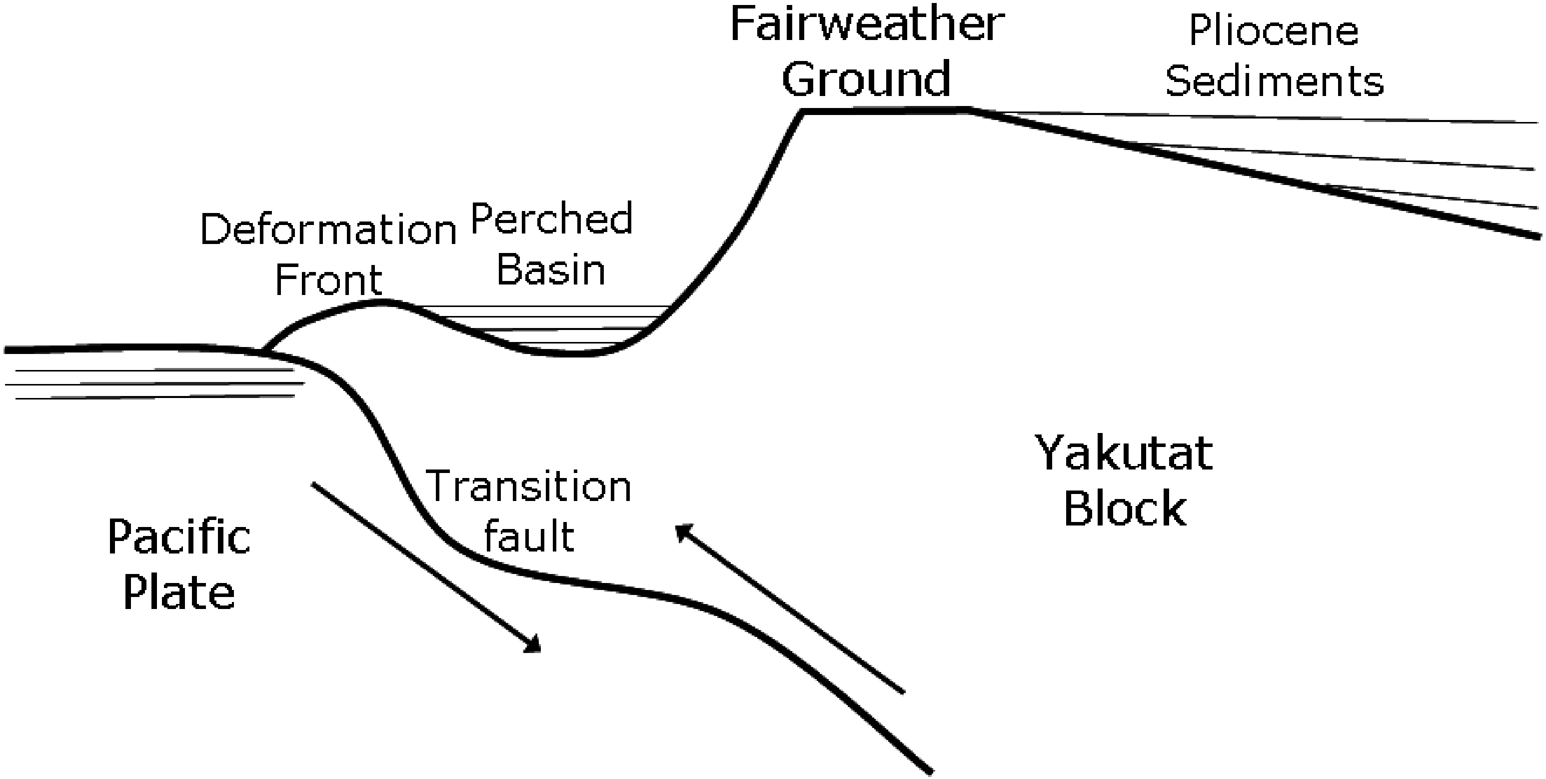


Figure 24. Regional scale conceptual model of the Fairweather Ground uplift and Transition fault in the Gulf of Alaska (not to scale).

Conclusion

Since the initiation of the basement uplift at the beginning of the Pliocene, glacial-marine sediment has been deposited in the accommodation space created north and east of the Fairweather Ground. This uplift continued while the Gulf of Alaska experienced massive sedimentation associated with glacial and interglacial cycles. These glacial advances and retreats are recorded as unconformities in the subsurface and identified in the seismic data. This research suggests that the Fairweather Ground uplift is a structural ‘container’ or ‘backstop’ that blocks sediment from being deposited seaward of the shelf break. Furthermore, this barrier concentrates the massive Plio-Pleistocene sediment on the Yakutat microplate.

Observations from the bathymetric data advance the thesis that Pacific Plate thrust loading on the Transition fault explains the Fairweather Ground Uplift. The Pacific plate/Yakutat plate basal escarpment is identified in the bathymetry data and there is agreement where the seismic data overlaps. This study proposes a Yakutat model (Fig. 24) that includes thrust loading on the Yakutat/Pacific plate boundary along the eastern section of the Transition fault. This flexural model accounts for the Fairweather Ground basement uplift and includes the Plio-Pleistocene depositional center.

The interpretation of Plio-Pleistocene sediment also provides a timing constraint for Yakutat block movement. The Fairweather Ground uplift records thrust loading on the Yakutat plate with respect to the Pacific plate at the Transition fault while the thickening seismic packages are, in part, the result of increased accommodation on the Yakutat block. The thickened packages of sediment can also be attributed to increased sedimentation rates associated with glacial cycles and the increased sediment supply from mountain building of southern Alaska.

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Vita

Peter David Guarisco, IV was born on April 23, 1978 in Baton Rouge, Louisiana to P. David Guarisco, III and Marion “Beth” Elizabeth Coleman. He is the oldest of four children, having a brother and two sisters. The family moved to Lafayette, Louisiana where Peter began school. While in Lafayette, Peter took an interest in science and excelled in sports. During his senior year in high school, Peter was the President of the Science Club and was honored as a first team All-State selection in soccer. He graduated from Lafayette High School in 1996.

In the fall of 1996, Peter moved to Shreveport, Louisiana to attend Centenary College of Louisiana. Peter played soccer for the ‘Gents’ and was drawn to the natural sciences. He decided to major in geology during his second year of study and received the Woolf Geology Summer Research Award. Peter’s studies brought him to the Snake River Valley in central Idaho for field work and to the University of South Carolina, Columbia for petrological analysis. Peter received his bachelor’s degree from Centenary in 2001.

After a short time visiting with family and volunteering with USGS in Miami, Florida, Peter began graduate school at the University of New Orleans. In 2002, he was awarded a Teaching Assistantship position. Peter maintained a 3.6 GPA in his coursework while improving his approach and style as a teacher. In 2003, Peter married Tricia Lavin in a small gathering of family and friends in Washington, Louisiana. Also in 2003, Peter was promoted to Head Teaching Assistant and was later awarded the William Craig Memorial Geoscience Education Award.

In May of 2004, Peter started working full time as a geologist for Minerals Management Service. The progress of Peter’s thesis work slowed considerably and was almost abandoned in the aftermath of Hurricane Katrina. With the birth of his daughter, Myrtle, in 2006 and the loss of his mother to breast cancer in 2007, Peter resolved to complete his graduate work.

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