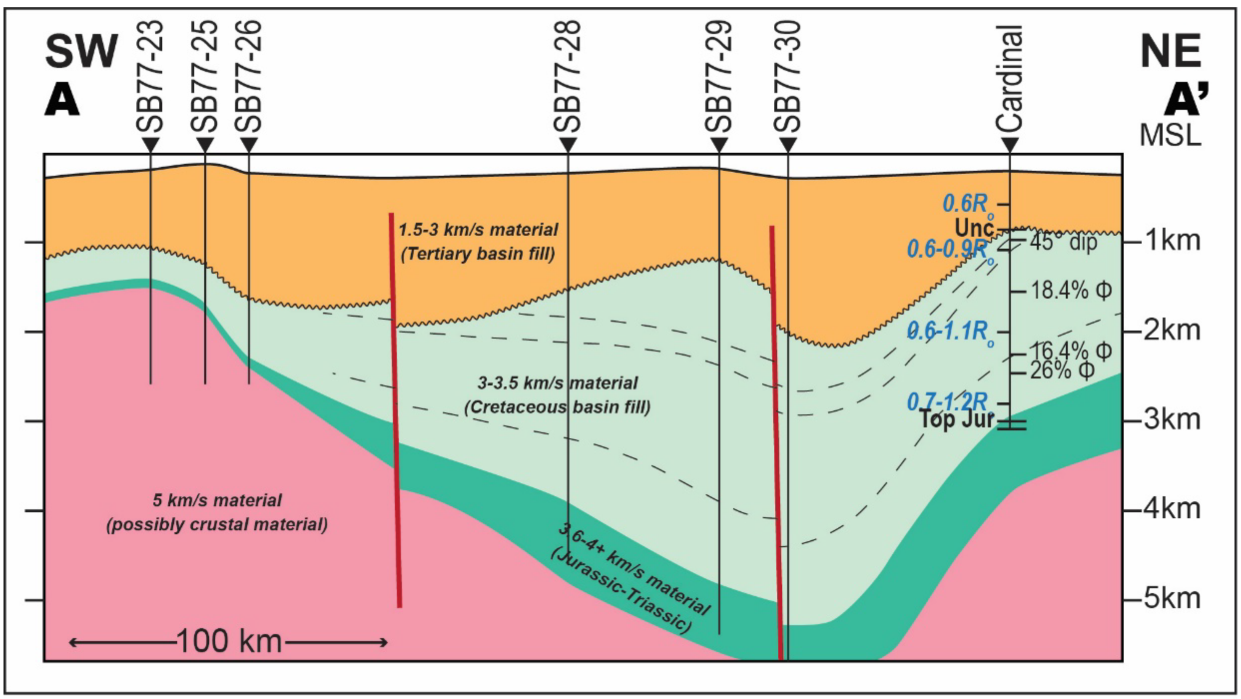
OCS Report
BOEM 2019-056

Integration of Multiple Data Types for Constraints on Basin Container and Fill in the Shelikof Strait Cook Inlet OCS, Alaska



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Bureau of Ocean Energy Management
Resource Evaluation
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Integration of Multiple Data Types for Constraints on Basin Container and Fill in the Shelikof Strait Cook Inlet OCS, Alaska

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ABOUT THE COVER

Cross section model, tending SW-NE along the Shelikof Strait, derived from integration of multiple data types. See rest of report, and Figure 6.

ACKNOWLEDGMENTS

This work is published under BOEM publication number 2019-056 and grew out of a presentation at the 2019 AAPG ACE meeting in San Antonio, TX. Discussions there greatly enhanced the integration of these data and provided the impetus to write this paper. This paper was greatly improved through discussion and reviews with Loren Zeigler and Caleb Jennings, with additional reviews by Heather Bedle, Laura Gregersen, and Jake Mongrain. The support of BOEM's Alaska Regional Office management and staff enabled the analysis and integration of these data into a compelling story.

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Abbreviations and Acronyms

1D	one dimensional
2D	two-dimensional
3D	three-dimensional
BBbls	billion barrels
BBO	billion barrels of oil
BOEM	Bureau of Ocean Energy Management
EOD	Environment of Depositional
ft	feet
GMC	Geologic Materials Center (State of Alaska Department of Natural Resources)
km	kilometers
m	meters
MD	measured depth
mD	millidarcy
MMS	Minerals Management Service
NMO	normal move out
NTG	net-to-gross
OCS	Outer Continental Shelf
OFR	Open File Report
RCA	routine core analysis
Ro	percent of vitrinite reflectance
SB	sonobuoys
SWC	side wall core
TCF	trillion cubic feet
TOC	total organic carbon
USGS	United States Geological Survey
VR	vitrinite reflectance
WC	whole core
wt%	weight percent

1 Abstract

The Cook Inlet Planning Area of the Alaska Outer Continental Shelf (OCS) was examined by integrating a variety of data to determine fundamental crustal structure, basin depths, regional structure, and basin filling sediment properties. Shelikof Strait, between Kodiak Island and the Alaska Peninsula, was investigated using seismic refraction, aeromagnetic, and well data. These data define a basin with a potential depth of more than 5 kilometers (km) (3.1 miles), with significant uplift at the well location. Integration of data from the single well drilled in the basin with a cross-section from potential field and seismic refraction interpretation suggests potential porosity trends deeper in the basin. These legacy geophysical data were integrated with more recent data to better constrain lateral extent and fill of an Alaska basin that may have been overlooked due to industry focus on Prudhoe Bay and other recent North Slope onshore plays. This work suggests that there may be unrecognized potential in the Shelikof Strait sub-basin of the Cook Inlet basin, a proven petroleum province that has already produced more than 1.3 billion barrels of oil (BBO) and 8.3 trillion cubic feet (TCF) of gas. The data used were collected more than 25 years ago, and as such, are available for public release immediately from the Bureau of Ocean Energy Management (BOEM) as proprietary restrictions have expired.

2 Introduction

Over the last 50 years, substantial amounts of geophysical data were collected on the Alaska Outer Continental Shelf (OCS). However, a significant fraction of these data have not been interpreted using modern technologies or integrated geologic and geophysical techniques. It is BOEM's mission to safeguard these data until they can become public, typically 25 years after collection. In addition, it is a goal of BOEM to analyze these datasets with current methodologies and integrate the information to form a more comprehensive understanding of basin evolution across the Alaska OCS.

This OCS Report demonstrates potential integration techniques for seismic refraction, aeromagnetic, and well data collected more than 25 years ago in the Cook Inlet Planning Area of southcentral Alaska (Figure 1). The Cook Inlet Basin is a forearc basin and has accumulated Mesozoic and Cenozoic strata in four packages separated by three major regional unconformities at mid-Jurassic, early Cretaceous, and early Cenozoic times (Fisher and Magoon, 1978). The northern portion of Cook Inlet is a proven petroleum basin, having produced 1.3 billion barrels (BBbls) of oil and 8.3 TCF of gas from more than 10 discovered fields (DNR, 2018).

The sedimentary infill of the Cook Inlet basin and Shelikof sub-basin ranges in age from late Triassic to modern, and was deposited in a basin bound by the Talkeetna island-arc, that was translated northward and northwestward through time. The oldest rocks (late Triassic to early Jurassic) were deposited in shallow- to deep-water, and range from limestone, shale, and volcanic-derived clastics to extrusive volcanic rocks from the adjacent oceanic Talkeetna Arc. In the middle to late Jurassic and early Cretaceous, the production of the Talkeetna Arc waned, and the arc was uplifted and eroded providing copious amounts of first-generation volcanic and batholithic sediment into the shallowing basin (Detterman and Hartsock, 1966). By mid-Cretaceous time, the basin had deepened again, and relatively deep-water sediments were deposited. Throughout the mid- and late Cretaceous, increasingly shallower water deposits were preserved, with numerous local and sub-regional unconformities within the section (LePain et al., 2013 and references therein). The Top Mesozoic Unconformity regionally eroded the late Cretaceous and older rocks (Gregersen and Shellenbaum, 2016). Following this, throughout the Cenozoic, deposition generally occurred at or just above sea level, as alluvial and fluvial processes eroded the surrounding highlands and dominated the depositional facies (see LePain et al. (2013) for a more detailed description of the Triassic to modern history of the Cook Inlet Basin).

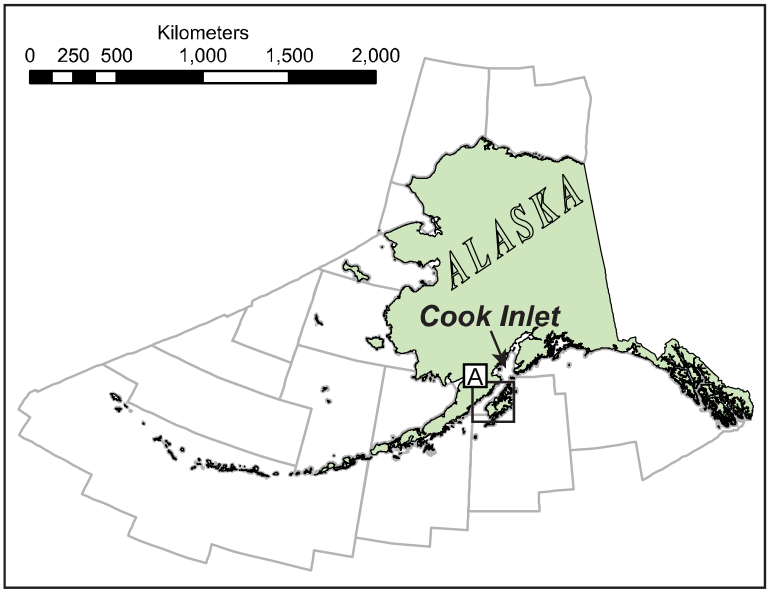

Figure 1. Map of Alaska
Figure 1 shows the planning areas administered by BOEM and the location of the Cook Inlet case study discussed in this paper, indicated by Box A. See Figure 2 for an expanded view of Box A.

Due to the complex depositional and deformational history of the Cook Inlet basin, combined with extreme tides and complex acquisition limitations, the available two-dimensional (2D) reflection seismic is of poor to very poor quality. The lateral variations of velocity in the Cenozoic fluvial deposits cause significant difficulty in 2D reflection seismic imaging due to scattering of energy both in- and out-of-plane. The deformational history includes significant erosion and inversion, further complicating velocity analysis for seismic imaging. Tides of up to 9 meters (m) (25 feet (ft)) and tidal currents of more than 8 knots create issues with both flow noise and statics corrections. In older 2D seismic acquisitions, streamer feathering was often significant further reducing the image quality. The narrowness of Cook Inlet, combined with the tides makes use of long streamers challenging, therefore reducing normal move out (NMO) velocity picking accuracy. Finally, relative shallow water (less than 250 m (800 ft); average 80 m (250 ft)) and relatively hard water bottom create significant multiple issues. Many of these imaging issues can be reduced with modern three-dimensional (3D) seismic, however, only two 3D seismic surveys have occurred in the OCS of Cook Inlet. Both of these suggest that careful acquisition and processing of 3D seismic can greatly enhance imaging and understanding of the subsurface.

There are two proven and one speculative petroleum systems in Cook Inlet. The proven Tertiary-reservoired gas system in the northern portion of the basin is composed of biogenic gas, derived from bacterial feeding on the widespread Tertiary coals, and reservoired in sandstones interbedded with the coals and associated shales in structural highs (Decker, 2006). The proven Tertiary-reservoired oil system hosts Mesozoic-sourced oils in non-marine Tertiary reservoirs, charged through the Top Mesozoic Unconformity, and trapped in structural culminations. For the oil charged reservoirs, the source rocks are the late Triassic Kamishak and middle to late Jurassic Tuxedni Group rocks (Decker, 2006). The Kamishak has average Total Organic Carbon (TOC) values in outcrop of 1.37 weight percent (wt%) (max 5.28 wt%) (Decker, 2006) along the southeastern margin of the Alaska Peninsula at Pule Bay (Figure 2). The average TOC of the middle Jurassic Kialagvik Formation member of the Tuxedni Group is 1.08 wt%, with a non-coal max TOC of 2.79 wt%. In northern Cook Inlet, oils from these source rocks are reservoired in the lower Tertiary non-marine alluvial-fluvial systems (Decker, 2006; LePain, et al., 2013). The unproven Mesozoic-reservoired oil and gas system is hypothesized to be sourced from the same Triassic-Jurassic source rocks, but reservoired in the mid- and late Cretaceous clastic deposits.

Exploration success for this system has been challenged by tightly cemented Cretaceous sandstones and challenging charging conditions in the wells that have targeted it so far (Decker, 2006). This report discusses a portion of the Cook Inlet Basin that potentially could prove the existence of the Mesozoic reservoired petroleum system.

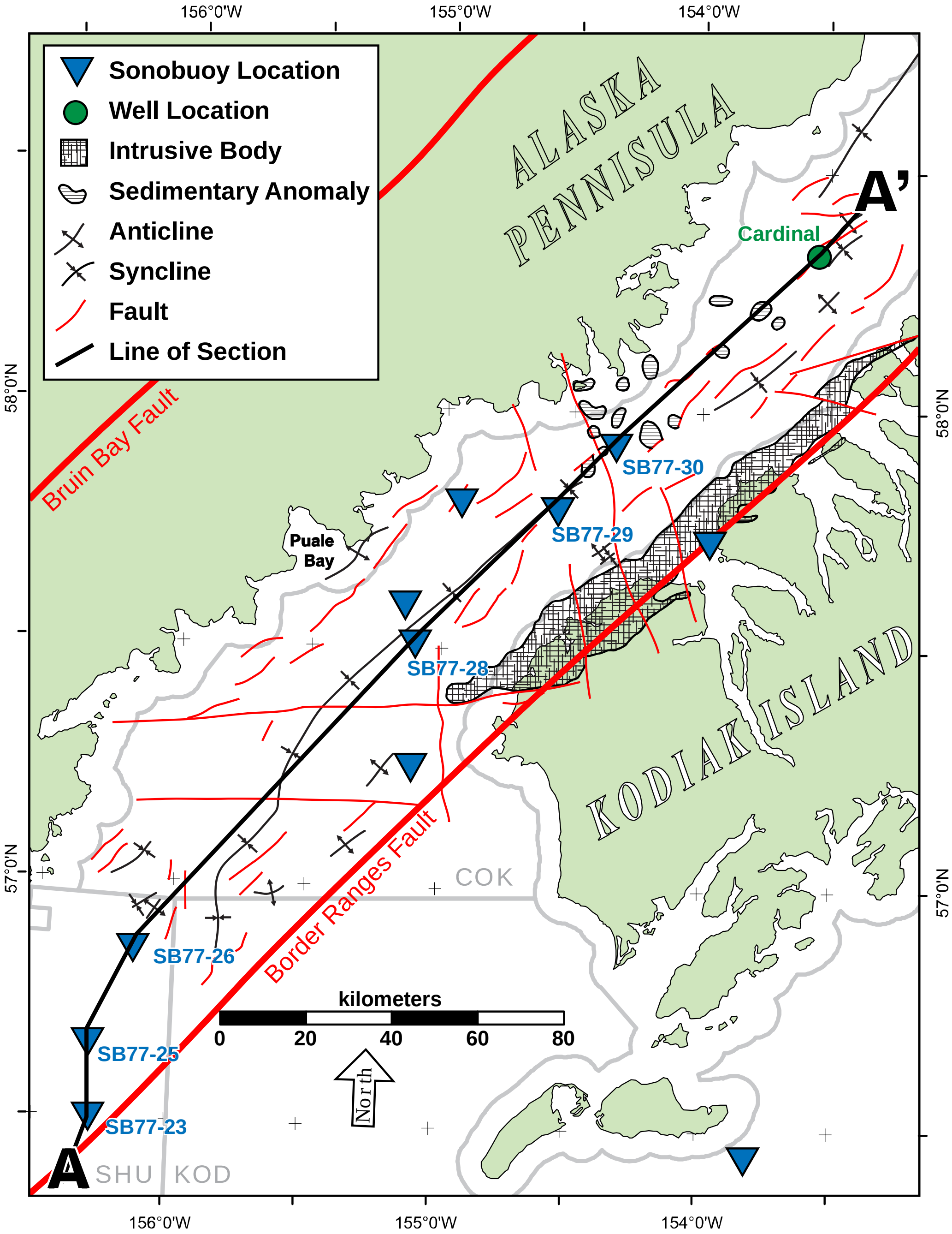

Figure 2. Map Showing Sonobuoy (SB) Profile and Well Locations in the Shelikof Strait Area of the Cook Inlet Planning Area

(see Figure 1 for location (Box (A)). Shelikof Strait lies between the Alaska Peninsula to the northwest, and Kodiak Island to the southeast. Both oil and gas production occur to the northeast in the Cook Inlet Basin. Structural interpretation is adapted from Aero Service (1980) aeromagnetic survey interpretation. Cross-section A-A' is shown in Figure 3 and Figure 6. The Shelikof sub-basin extends SW-NE between the Bruin Bay and Border Ranges faults.

The thermal maturity of the Cook Inlet Basin is complex, with varying uplift throughout the basin and multiple erosional events and is complicated by constant reworking of older material into newer deposits. Analysis by Johnsson and Howell (1996) suggests that the depth to the top of the oil window in the northern portion of Cook Inlet Basin is greater than 4,000 m (13,000 feet). However, data in the southern portion of Cook Inlet show values of 2.32 Ro for the Triassic at the surface on Kodiak Island and < 2.5 Ro for Upper Cretaceous rocks on the surface of the Alaska Peninsula north of Puale Bay (Johnsson et al., 1999), suggesting that these rocks have passed through and beyond the oil window before being uplifted.

In lower Cook Inlet, towards the southern edge of the planning area, is the Shelikof Strait sub-basin. This Jurassic- to modern-age basin lies approximately 400 kilometers southwest of Anchorage, between Kodiak Island and the Alaska Peninsula (Figure 1 and Figure 2). In this area, seismic refraction, aeromagnetic, and well data were acquired in the 1970s and 1980s, and 2D reflection seismic was collected from the 1970s through the mid-1990s. This sub-basin was selected as an integration case study because it is relatively under-explored despite being within a proven petroleum province with access to exploration and production infrastructure. The refraction, aeromagnetic, and well data were used to analyze the basin because the existing 2D seismic is poorly suited for understanding the basin depth, scale, and architecture.

2.1 Shelikof Strait

Following the initial discovery of oil in the Cook Inlet Basin onshore at Swanson River in 1957, interest in Cook Inlet encouraged a significant amount of data collection across the entire basin, including the OCS. Two-dimensional seismic reflection, marine gravity and magnetics, aeromagnetic, seismic refraction, side-scan sonar, dart cores, and bottom trawls were all collected in the Shelikof sub-basin portion of the Cook Inlet Planning Area of the OCS, culminating in a single exploration well (Cardinal OCS-Y-0248-1/1A - API# 55-249-00001/3) drilled on a structural high in the middle of the Strait (Figure 2). However, despite oil shows identified in the Cardinal core, the Shelikof sub-basin remains highly under-explored, with one well/20,000 km^2.

Given the scale of the resources already recovered in the northern portion of the Cook Inlet Basin, analysis of the Shelikof Strait sub-basin is prudent. This study defines the regional structure of the sub-basin, determines potential hydrocarbon kitchen locations, and predicts reservoir potential of the petroleum system. Integration of seismic refraction information (Holmes, et al., 1978) and proprietary aeromagnetic interpretation with previously released well data suggest that despite the Cardinal well having only shows, there is still exploration potential in the Strait.

3 Data Description

3.1 Refraction Seismic Data

The U.S. Geological Survey (USGS) collected long-offset seismic refraction data in 1975 and 1976 aboard the R/V Samuel P. Lee using 21.8 and 41 liter (1,326- and 2,501-$inch^3$) air gun arrays, and a 160-kilojoule sparker, recorded into fixed sonobuoys (SB) (Holmes et al, 1978). Maximum sub-bottom penetration was 5.1 km (3.1 miles). Data were recorded on magnetic tape. These data are publicly available in USGS OFR 78-368 (Holmes et al, 1978) in tabular form and in time-distance plots, and relevant data points are presented in Table 1.

Selected portions of these data were plotted from the Shelikof Strait along a cross-section (A-A’ in Figure 2 and Figure 3(A)), with velocity values determined from the refraction data plotted in depth. From these points, a series of isovelocity (constant velocity) surfaces, at 1.5 km/s (water bottom), 2.0 km/s, 2.5 km/s, 3.0 km/s, and 3.5 km/s, were interpreted. These surfaces of constant velocity represent the regional structure of the basin and basin filling materials [Figure 3(A)].

Table 1. Selected Refraction Velocities in the Shelikof Strait Area from OFR 78-368

	Velocity (km/sec)						**Thickness (km)**					**Depth to Event (ΣHn)**				
Sono-buoy	**V1**	**V2**	**V3**	**V4**	**V5**	**6**	**WD H1**	**H2**	**H3**	**H4**	**H5**	**D1**	**D2**	**D3**	**D4**	**D5**
77-23	1.49	1.89	2.18	5.21			0.21	0.12	0.58			0.21	0.33	0.91		
77-25	1.49	1.93	2.16	3.11			0.14	0.11	0.43			0.14	0.26	0.68		
77-26	1.49	2.07	2.22	2.89			0.24	0.25	0.4			0.24	0.49	0.89		
77-28	1.49	1.95	3.06	3.57			0.23	0.4	1.05			0.23	0.64	1.68		
77-29	1.49	1.68	2.24	3.25	3.47	5.33	0.2	0.17	0.58	0.46	3.19	0.20	0.37	0.95	1.41	4.60
77-30	1.49	1.60	2.47	2.92	3.86	5.72	0.28	0.06	0.45	1.23	3.26	0.28	0.34	0.79	2.02	5.29

Source: Holmes, et al., 1978

Notes: See Figure 2 for locations of these data.
Vn = refraction-derived layer velocities Hn = layer thicknesses Dn = depths to the tops of each layer

Analyses of the refraction data shows that material with lower velocity thin onto a shallow high-velocity structure to the southwest. These lower velocity materials are interpreted to be sediments on-lapping onto a basement high and deepening to the northeast (Figure 3(A)).

3.2 Aeromagnetic Data

Aero Service collected approximately 15,300 line km (9,500 line miles) of then proprietary aeromagnetic data in between July 17 and November 18, 1979, on a line spacing of approximately 2.4 km (1.5 miles) by 9.6 km (6 miles), under OCS Permit 79-17[1]. Their sensor was a Varian cesium vapor magnetometer flown on a Cessna Titan, generally at 450 m (1,500 ft) above sea level. Magnetometer, navigation, altimeter, and time data were digitally recorded (Aero Service, 1980). These data are part of a larger region-wide series of aeromagnetic surveys collected Alaska-wide during the late 1960s through the early 1980s by Aero Service and other permittees.

Following de-noising and reduction to pole, Aero Service staff interpreted the profiles using Werner deconvolution techniques (Aero Service, 1980). At the time of collection, the USGS-Conservation Division selected the analog profiles on rolled paper, gridded data and interpreted maps on sepia, and the interpretation report. Digital data were recorded, but not selected for retention. The interpreted maps highlight depth to basement (presumed Triassic at the time of interpretation), depth to magnetic sources deeper and shallower than interpreted basement, areas of intrusive rocks, depth to sedimentary anomalies, and a qualitative analysis of the magnetic character of the sedimentary deposits. These interpretations were contoured where possible, and structural features (folds and faults) were identified (Aero Service, 1980). The interpreted structural trends were adapted and magnetic anomalies identified from the Aero Service interpretation products for integration in this study (Figure 2).

[1] Scanned copies of these data (scanned analog line profiles) are available for viewing in person at the BOEM Alaska Regional Office, with an advanced appointment.

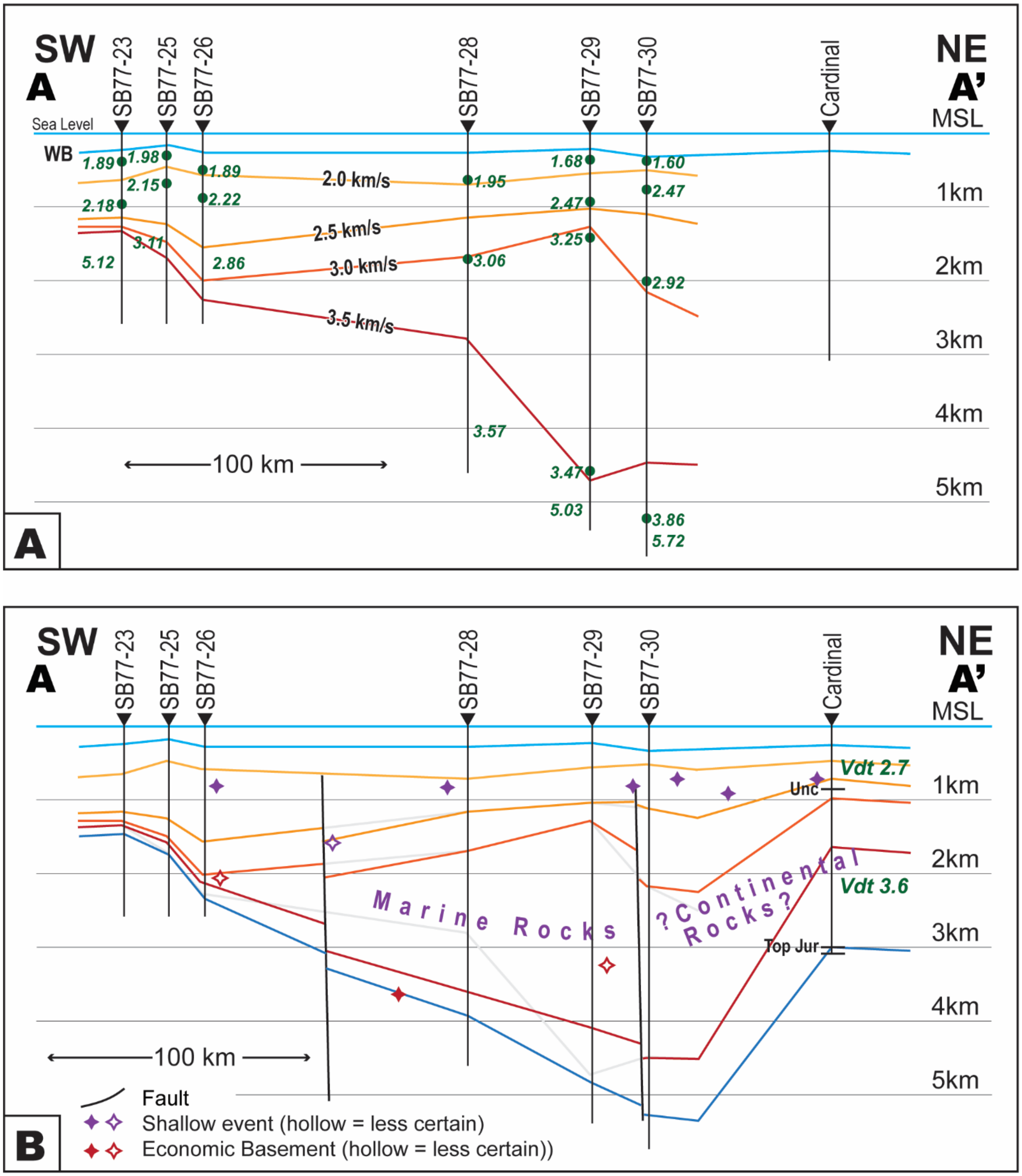

Figure 3. Cross-Section along the Axis of the Shelikof Strait Sub-Basin
See Figure 2 for location. In (A), refraction velocities from Holmes, et al (1978) are posted and isovelocity surfaces are interpreted from these velocities. In (B), information from the aeromagnetic survey and the blocked well sonic velocities are integrated, and the isovelocity surfaces are modified to fit both data sets. In addition, (B) includes interpretation of qualitative depositional environment interpretation derived from the Aero Service's interpretation of the aeromagnetic data (Aero Service, 1980).

Aero Service interpretations of depth to events derived from Werner deconvolution were hand-transferred from the interpretation maps to the cross-section in depth [Figure 3(B)], in particular the events interpreted as shallow anomalies and basement features. These aeromagnetically-derived crustal structure points were integrated with the refraction data points to improve upon the initial interpretation from the refraction velocities (Figure 3(A)) to better define the shape of the basin (Figure 3(B)). In addition, interpretation of sedimentary facies by Aero Service (1980) suggest the rocks to the northeast of the basin are more likely to be sub-aerially deposited sediments (continental deposits), due to their higher frequency magnetic response, while those on the southwest end are more likely to be marine (Figure 3(B)).

The redefined cross-section seen in Figure 3(B) displays similar features as seen in Figure 3(A), but with refinement and increased depth of the isovelocity surfaces between SB77-26 and SB77-28, driven by the depth-to-basement interpretation from the aeromagnetic interpretation.

3.3 Well Data

With the basin shape and basic parameters defined via integration of seismic refraction and aeromagnetic interpretation, data were incorporated from the Cardinal well (OCS Y-0248-1A)[2] drilled by Chevron in 1984 in the northeastern portion of the Shelikof Strait sub-basin (Figure 2). A reasonable set of data were acquired on this well; most importantly, sonic and dipmeter logs as well as both continuous and sidewall core were collected. These data were released to the public by the Minerals Management Service (MMS) in 1986 (MMS, 1989).

Routine core analysis (RCA) from the cores provided porosity, and micropaleontology was analyzed from cuttings while vitrinite reflectance (VR) and Rock-Eval pyrolysis (also from cuttings) provided age and thermal maturity (Figure 4).

The dip log shows a marked change in dip at 670 m (2,220 ft) measured depth (MD), with the rocks changing from dipping 10° to the southwest to dipping more than 45° to the northwest. The interface separating the change in dip is interpreted to be the Top Mesozoic Unconformity surface that is present throughout the Cook Inlet basin (Magoon, 1994; Shellenbaum et al., 2010).

The biostratigraphic data for the well supports this interpretation, with the overlying sediments dated to the Oligocene and the underlying sediments dated to the early Maastrichtian (Bujak Davies, 1987). Unfortunately, the abundance charts and interpreted environment of deposition for the biostratigraphic data are missing from the currently available reports in BOEM’s files, limiting their use for determining paleo water depth and environment of deposition.

However, the VR data for the well are conflicting. Three different data sets for the well exist: one of unknown provenance (Unknown, 1990) available from the Alaska Geologic Materials Center (GMC) (identified as Unknwn90 in Figure 5), one by Bujak Davies Group done in 1987 (identified as 87BJ in Figure 5), and another also completed by Bujak-Davies in 1988 (BJ88 in Figure 5). The first, from the GMC, has the lowest Ro values (0.3–0.6) of the three analyses and is thought to be the least reliable. This is because currently there are no additional metadata associated with the analysis and the dates in the file are from 1980, before the well was spud in 1985. The 1987 Bujak-Davis report suggests that there is a slight increase in VR with increasing depth; from 0.9 Ro in the Eocene and Maastrichtian to 1.2 Ro in the Jurassic at the bottom of the well (Bujak Davies, 1987). The 1988 Bujak-Davies report records composited sample-averaged Ro values ranging from 0.58 to 0.69, with unexpectedly variable values with

[2] Data from the Cardinal well are available for viewing in person at the BOEM Alaska Regional Office, with an advanced appointment.

depth (for instance, 0.6 Ro in the Eocene-Maastrichtian, but 0.5 Ro in the Albian) (Bujak Davies, 1988). Values from both of the Bujak-Davies reports are included on Figure 5 and Figure 6.

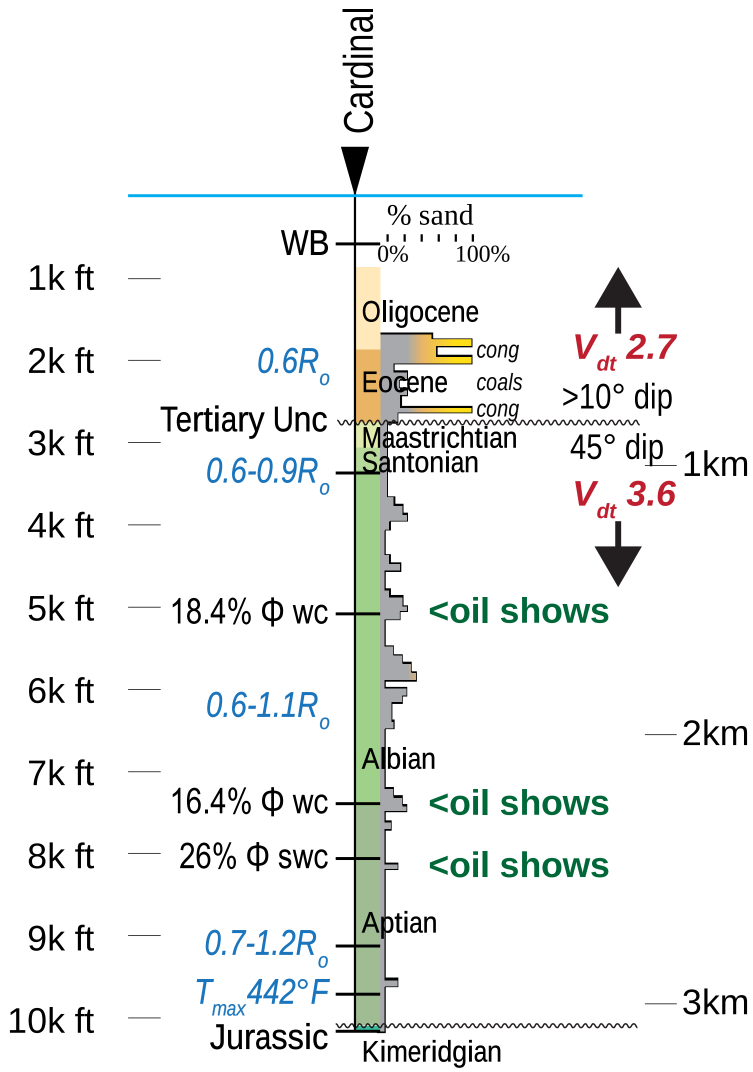

Figure 4. The Cardinal well with selected data derived from logs, VR analysis, biostratigraphy, shows, and RCA posted
Blocked velocities from sonic log are in red, VR data in blue, oil shows in green.

Gamma ray and mud logs show the interval below the unconformity to be low net-to-gross (NTG), suggesting the uppermost Cretaceous interval, which is potential reservoir elsewhere in the basin, is eroded at this location. Porosity and permeability values from lower quality sands in two whole cores (WC) show porosities are good, with 18% porosity at approximately 1,524 m (5,000 ft) MD, and 16% porosity at nearly 2,286 m (7,500 ft) MD. Permeability from WC sample at 1,676 m (5,500 ft) are low, maxing at 2 mD. Analysis of more than 100 sidewall cores (SWC) suggests even higher porosity than the WC data near 2,438 m (8,000 ft) MD, however these may be unreliable since they are derived from percussion SWC. Porosity information is generalized on Figure 4.

Cuttings and SWC analysis and SWC description show fair to good shows in the well near 5,000 ft (1,5 m), 7,500 ft (2,300 m) and 8,000 ft (2,500 m) MD. These shows comprise dry sample, streaming cut, and residual cut yellow fluorescence. Dean Stark extractions show low but positive oil saturations (Petroleum Testing Service, 1985).

In order to connect the well data to the other information, the sonic logs were blocked into five domains, each 450–820 m (1,500–2,700 ft) thick, to tie the well into the refraction-derived cross-section. The analysis shows material of 2.7 km/s velocity is present above and 3.6 km/s velocity material exists below the top Mesozoic unconformity (Figure 4).

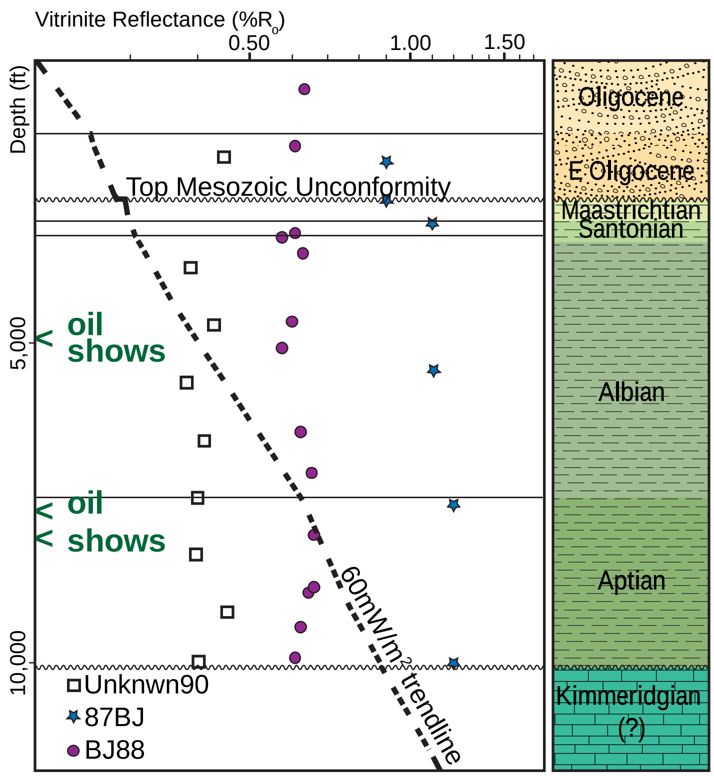

Figure 5. Preliminary 1D Thermal Model at the Cardinal Well Location, Using a 60 mW/m^2 Geothermal Gradient

R_o values from VR are plotted as: closed stars = data from the 1988 Bujak-Davies report (BJ88); closed circles = data from the 1897 Bujak-Davies report (87BJ); and open squares = data of unknown provenance provided by the Alaska GMC (Unknwn90). The age of the intervals is derived from the biostratigraphic interpretation.

4 Interpretation, Integration, and Extrapolation

Integration of the three different data sets suggests that the Shelikof sub-basin extends NE–SW between Kodiak Island and the Alaska Peninsula, and reaches depths of at least 5 km (16,400 ft) (Figure 3(A) and (B)). The velocities for the refraction data suggest that the basin is underlain by 'hard,' 'basement' rock with velocities >5 km/s (16,000 ft/s) at sonobuoy locations SB77-23, SB77-29, and SB77-30; depths to basement at SB77-25, SB77-26 and SB77-28 are not indicated (Table 1), suggesting that sedimentary material might extend deeper in the section. This would potentially allow for a deeper and thicker petroleum kitchen.

Blocking the well log sonic velocities enabled projection of the isovelocity surfaces to the well. Analysis of the isovelocity cross-section seen in Figure 3(B) suggests that there is uplift and erosion of the upper Mesozoic basin fill at the well location. This is supported by the dipmeter data, and interpretation of the well logs and micropaleontology. As late Cretaceous sands are often of reasonable quality elsewhere in the Cook Inlet basin, this suggests failure at the Mesozoic-targeted Cardinal well was at least in part due to erosion of the prospective late Cretaceous sandy interval.

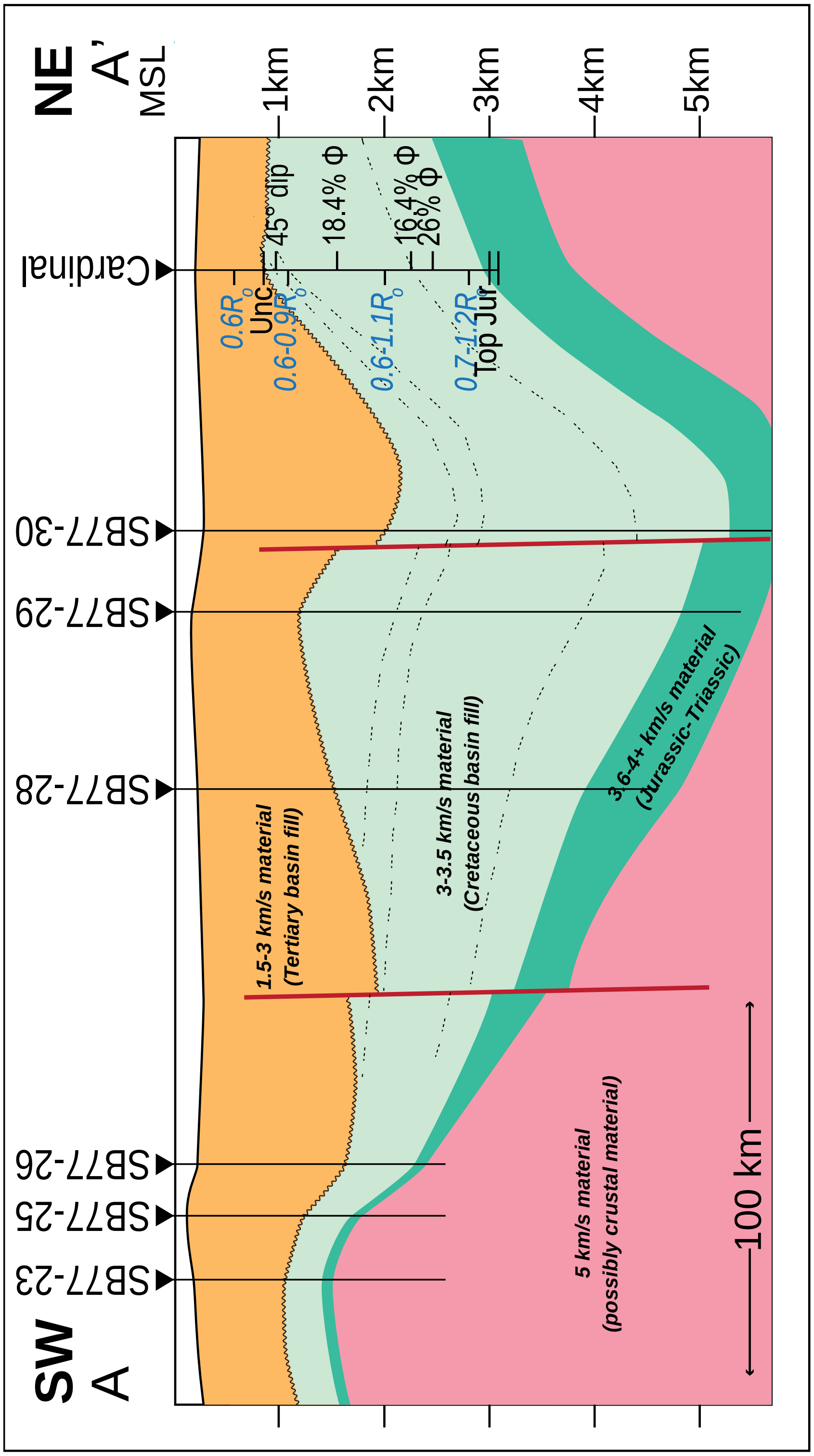

Figure 6. Schematic Geologic Cross-Section Showing Integration of Seismic Refraction
(see Figure 3(A), aeromagnetic (Figure 3(B)), and well data (Figure 3(B), Figure 5 and Figure 6) along the axis of the Shelikof Strait sub-basin (see Figure 2 for location). The isovelocities from Figure 3(A) define the basin container, the

aeromagnetic data from Figure 3(B) define the structural segmentation and basin-fill facies, and the well data (Figure 3(B), Figure 5 and Figure 6) provide temperature, age, stratigraphic information and properties that can be projected along the section to predict sub-surface parameters.

In addition to postulating the cause of missing reservoir section, by integrating the well data with the other data, the properties from the well (Figure 4) can be projected onto the cross-section. There are two ways to project the information from the well – either horizontally (parallel to the seafloor) or stratigraphically along the isovelocity surfaces. Each of these applies different assumptions about the thermal history of the rocks – horizontal projection assumes the thermal alteration occurred in the Cenozoic and follows a direct porosity-depth relationship, while stratigraphic projection assumes the thermal history of the sediments is dominated by Mesozoic events.

Since the primary information available is the refraction velocities, and that velocity is directly related to rock properties, the well data were projected along the isovelocity surfaces. The projection of these rock properties along isovelocity surfaces is suggested by dashed lines extending into the basin southwest of the well (Figure 6).

This interpretation suggests that there is potential for reasonable porosity in the upper Cretaceous extending deeper into the basin, especially given that the porosity values are from the poor quality, low NTG portion of the middle Cretaceous in the well (Figure 6).

In addition, interpretation of the aeromagnetic data by Aero Service suggests that the Cretaceous interval near the Cardinal well is likely to be composed of more continentally deposited facies, while deposits in the more distal portion of the basin to the southwest are interpreted to be marine facies, based on intensity and frequency of anomalies on the Total Magnetic Intensity maps (Aero Service, 1980). Such a facies change suggests that there is potential for a more marine-dominated source facies, as well as more appealing marginal-marine sandstone deposits. However, without details from the biostratigraphic studies, validation of this interpretation is difficult. Such an environment of depositional (EOD) could set up a number of sedimentary sequences and bodies attractive to exploration.

Thermal maturity data and preliminary modeling at the well location are conflicting. Figure 5 presents the available Ro data points plotted from each VR study. However, the data from the VR studies are anomalous – both in Ro values and the depth trend of those values. All of the values categorized by study (Unknwn90, 87BJ, BJ88) show a nearly vertical trend (i.e. no heat flow, which is geologically unlikely). This may indicate there was contamination of samples from uphole intervals. The range in Ro values between the different studies (0.4–1.2) suggests additional concerns with the data. Given that the available information is contradictory and confusing, a preliminary one dimensional (1D) Ro model (Figure 5) was generated, using a 60 mW/m^2 heat flow curve. The 60 mW/m^2 heat flow value was selected by using the heat flow map from Batir et al. (2013). In addition, a 609 m (2,000 ft) erosion event was modeled along the Top Mesozoic Unconformity surface. This preliminary model suggests the Cretaceous interval could potentially be well within the peak oil window (Figure 5).

Finally, the erosion of the prospective upper Cretaceous interval at the Cardinal well location suggests the possibility that stratigraphic truncation traps exist downdip of the well. In addition, structural culminations deeper in the basin may preserve the upper Mesozoic in four-way dip or three-way + fault closures. Unfortunately, the integrated data are too low resolution to define such traps.

5 Suggestions for Further Study

This work was initiated as a “quick look” analysis of an underexplored sub-basin in a Planning Area with a lease sale scheduled in 2021. This “quick look” has generated more questions to be answered, such as:

- How can the VR data be checked? Analysis of chips from whole core might enable validation or repudiation of the available Ro data by removing the potential for shallow caving contamination.
- How much burial occurred before uplift at the well location? Further analysis of porosity and sonic logs might enable calculation of pre-uplift max burial depth.
- What is the porosity and permeability potential in the upper Cretaceous rocks not penetrated at the well location?
- What is the subsidence and uplift history of the basin southwest of the well location?
- Can the reflection seismic data be reprocessed to find indications of stratigraphic sequences to further define EODs and truncation traps?
- Are there source intervals in the potentially more marine rocks interpreted in the southwestern end of the Shelikof Straits?
- Are there syn-sedimentary tectonic structures in the basin that might generate lateral facies changes?
- Is projection of the well data along isovelocity surfaces appropriate? Or, should there be a depth related hybrid projection method to account for potential depth related porosity reduction?

6 Conclusions

Analysis and integration of three different data types demonstrates that there may be previously unrecognized hydrocarbon potential in the Shelikof Strait area of Alaska. General basin shape along strike was defined by building a cross-section and using isovelocity surfaces from seismic refraction data. Aeromagnetic data further refined the basin shape and structure between velocity data points. Well data were used to define stratigraphy and identify missing section. Integration of the well data with the cross-section permitted the projection of the well properties along the isovelocity surfaces into the basin. Analysis of VR data identified potential issues with those data yet provided a framework to generate a 1D thermal maturity model, potentially indicating that the hypothesized distally deposited source section is well within the peak oil generation window.

Integration of all the data show the potential for a deeper basin perhaps persevering the uppermost Cretaceous potential reservoir interval not found at the well. Projection of well data into the basin along isovelocity surfaces suggests the possibility of porosities greater than 16% are possible in the thicker portions of the basin. Combined with the thermal model generated at the well, it seems that much of the basin may currently be in the peak oil generation window, and reasonable reservoir quality may be present.

This work suggests that there may be unrecognized potential in the Shelikof Strait sub-basin of the Cook Inlet basin, a proven petroleum province that has already produced more than 1.3 BBO and 8.3 TCF gas.

7 Additional Information

The BOEM Alaska Regional Office in Anchorage is responsible for managing the OCS for petroleum, renewable energy, and mineral resources. As part of that management, BOEM issues permits for data collected in the exploration of these OCS resources. After the data are collected, scientists from BOEM (and its predecessor agencies) inspect the acquired data to determine if it is useful for resource evaluation and select data that are suitable. Between 1964 and 2019, 716 permits were issued for data collection in the Alaska OCS, and 906 data sets of specific types were acquired. These data types range from classic 2D marine seismic data (449 permits) to an experimental pulsed airborne electromagnetic survey (1 permit). Specific data types were frequently acquired together, in particular marine 2D seismic, marine gravity, and marine magnetics. Other data types are less commonly associated under a single permit, though multiple data sets may have been collected under a specifically designed ‘exploration program’ of multiple permits.

Detailed examination of databases, data stores, permit and contract files, and archived records show that 137 permits collected non-seismic-reflection data – marine gravity or magnetics, aeromagnetic, hard-water (ice-based stations) gravity, or seismic refraction data in the Alaska OCS. Of these 137 acquired permits, BOEM selected data from 68. Of the selected data, multiple formats were received and stored including digital and analog data and interpretation of various types. These data ranged from preliminary field values to final processed grids, and from acquisition reports to interpretation maps (Unger, 2019).

Much of the data and information discussed in this paper is available to the public via Freedom of Information request and is viewable in person with an appointment. Please contact the Resource Evaluation Supervisor in the BOEM Alaska Regional Office, 3801 Centerpoint Drive, Suite 500, Anchorage, AK 99503-5820, or via boem.gov for a catalog of data and more information on how to request such data.

8 References

Aero Service, 1980. Interpretation Report and Aeromagnetic Survey, Shelikof Strait, Alaska, for United States Geological Survey, unpublished report, Aero Service Division, Western Geophysical Company of America.

Batir, J., D.D. Blackwell, and M.C. Richards, 2013. Updated Heat Flow of Alaska: New Insights into the Thermal Regime, http://acep.uaf.edu/media/57321/HFMAK_final-report.pdf, accessed 31 July 2019.

Bujak Davies, 1987. Palynological Analysis of the Interval 1710-10,110ft: Cardinal #1A, North Alaska, Report Number 86-0075, unpublished report dated February 1987.

Bujak Davies, 1988. Vitrinite Reflectance of the Interval 1980-10,110ft, Well 0248-1a, Alaska, Report Number 87-0124, unpublished report dated February 1988.

Decker, P.L., 2008, Mesozoic and Cenozoic source rock-characteristics, Puale Bay outcrops and north Aleutian Shelf COST #1 Well, in Reifenstuhl, R.R., and Decker, P.L., eds., Bristol Bay-Alaska Peninsula region, overview of 2004-2007 geologic research: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2008-1B, p. 11-33. http://doi.org/10.14509/17942.

Decker, P.L., and DGGS Staff, 2006, Alaska GeoSurvey News - A brief overview of Alaska petroleum systems: Alaska Division of Geological & Geophysical Surveys Newsletter 2006-2, 10 p. http://doi.org/10.14509/15750.

DNR (Alaska Department of Natural Resources) 2018. Cook Inlet areawide oil and gas lease sale: Written Finding of the Director. November 2, 2018.

Detterman, R.L, and J.K Hartsock, 1966. Geology of the Iniskin-Tuxedni Region, Alaska, USGS Prof Paper 512, 76 p.

Fisher, M.A. and L.B. Magoon, 1978. Geologic Framework of Lower Cook Inlet, Alaska, AAPG Bulletin, 62, 373-402.

Gregersen, L.S., and D.P. Shellenbaum, 2016, Top Mesozoic unconformity subcrop map, Cook Inlet basin, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2016-4, 1 sheet, scale 1:500,000. http://doi.org/10.14509/29658

Holmes, M.L., C.A. Meeder, and K.C. Creager, 1978. Sonobuoy Refraction Data near Kodiak, Alaska, USGS Open File Report 78-368.

Johnsson, M.J., and D.G. Howell, 1996. Generalized thermal maturity map of Alaska, USGS Miscellaneous Investigations Series Map I-2494, scale 1:2,500,000

Johnsson, M.J, K.R. Evans, and H.A. Marshall, 1999. Thermal Maturity of Sedimentary Rocks in Alaska: Digital Resources, USGS Digital Data Series DDS-54, V 1.0

LePain, D.L., R.G. Stanley, K.P. Helmold, and D.P. Shellenbaum, 2013. Geologic Framework and Petroleum Systems of the Cook Inlet Basin, South-Central Alaska, in D.M. Stone, and D.M. Hite ed, Oil and gas fields of the Cook Inlet Basin, Alaska: AAPG Memoir 104, p. 37-116.

Magoon, L.B., 1994. Tuxedni–Hemlock(!) petroleum system in Cook Inlet, Alaska, U.S.A., in Magoon, L.B., and Dow, W.G., eds., The Petroleum System - From source to trap: American Association of Petroleum Geologists Memoir 60, p. 359–370.

Petroleum Testing Service, 1985. Core Analysis, OCS Y-248 1A, unpublished report.

MMS (Minerals Management Service), 1989. Digital Well Log Data Gulf of Alaska, National Geophysical Data Center, Data Announcement 89-MGG-07, https://www.ngdc.noaa.gov/mgg/fliers/89mgg07.html, accessed 22 October, 2019.

Shellenbaum, D.P., L.S. Gregersen, and P.R. Delaney, 2010. Top Mesozoic unconformity depth map of the Cook Inlet basin, Alaska: Alaska Division of Geological & Geophysical Surveys Report of Investigation 2010-2, 1 sheet, scale 1:500,000. http://doi.org/10.14509/21961.

Unknown, 1990. Vitrinite reflectance data of cuttings (2,130-10,130' T.D.) from the Chevron USA Inc. OCS Y-0248-1A (Cardinal) well: Alaska Division of Geological & Geophysical Surveys Geologic Materials Center Data Report 153.

Unger, M. R., 2019. New-Old Potential Field Data in the Alaska OCS: Presented at the AAPG Annual Convention and Exposition, San Antonio, Texas, 19-22 May, 2019.

Department of the Interior (DOI)

The Department of the Interior protects and manages the Nation's natural resources and cultural heritage; provides scientific and other information about those resources; and honors the Nation’s trust responsibilities or special commitments to American Indians, Alaska Natives, and affiliated island communities.

Bureau of Ocean Energy Management (BOEM)

The mission of the Bureau of Ocean Energy Management is to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way.