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Geology and Assessment of Undiscovered Oil and Gas Resources of the Chukchi Borderland Province, 2008

Chapter C of
The 2008 Circum-Arctic Resource Appraisal

Professional Paper 1824

U.S. Department of the Interior
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COVER

Northwestward view across the southern foothills of the Brooks Range along Akmagolik Creek, approximately 150 miles southwest of Prudhoe Bay, Alaska. Exposed rocks are part of the Mississippian–Pennsylvanian Lisburne Group and include a thrust-fault ramp at left. Photo includes two helicopters for scale, a blue-and-white one near the center and a red one at center-right at creek level. U.S. Geological Survey photograph by David Houseknecht.

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Chapter C

Geology and Assessment of Undiscovered Oil and Gas Resources of the Chukchi Borderland Province, 2008

By Kenneth J. Bird and David W. Houseknecht

Abstract

The Chukchi Borderland is both a stand-alone petroleum province and assessment unit (AU) that lies north of the Chukchi Sea. It is a bathymetrically high-standing block of continental crust that was probably rifted from the Canadian continental margin. The sum of our knowledge of this province is based upon geophysical data (seismic, gravity, and magnetic) and a limited number of seafloor core and dredge samples.

As expected from the limited data set, the basin's petroleum potential is poorly known. A single assessment unit, the Chukchi Borderland AU, was defined and assigned an overall probability of about a 5 percent chance of at least one petroleum accumulation >50 million barrels of oil equivalent (MMBOE). No quantitative assessment of sizes and numbers of petroleum accumulations was conducted for this AU.

Introduction

The Chukchi Borderland Province and AU is a prominent thumb-shaped bathymetric feature about 400 km east-west and 600 km north-south that protrudes into the deep Canada Basin north of the Chukchi Sea continental shelf (figs. 1–3). Regionally, the Chukchi Borderland is flanked on the north by the Alpha-Mendeleev Igneous Province, on the east by the extended continental and oceanic crust of Amerasia Basin Province (Canada Basin AU), and on the southeast and southwest by thick Mesozoic-Cenozoic sediment prisms of the Alaska Passive Margin AU and the North Chukchi-Wrangel Foreland Basin Province, respectively (fig. 2). The Chukchi Borderland lies in water depths ranging from 200 to 3,500 m and covers an area of approximately 246,000 km^2 (fig. 3). Physiographically, the Chukchi Borderland is characterized

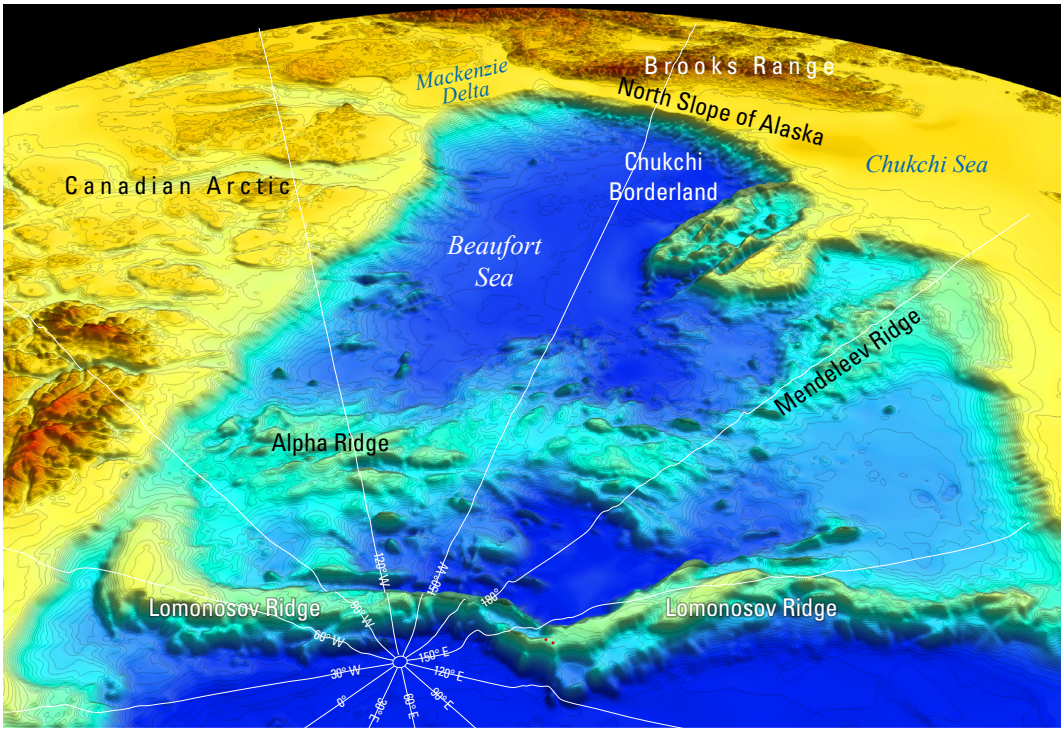


Figure 1. Perspective view from the North Pole southward across the Amerasia Basin toward the Canadian and northern Alaska margin. View shows the relatively high-standing character of the Chukchi Borderland and its dramatic projection in the deep Canada Basin. Figure created by C.P. Garrity (U.S. Geological Survey).

Figure by C.P. Garrity, U.S. Geological Survey.
Base from Esri, 2007, used herein under license.

Figure 2. Index map showing location of Chukchi Borderland Province in relation to adjacent provinces defined in the Circum-Arctic Resource Assessment. AU, assessment unit.

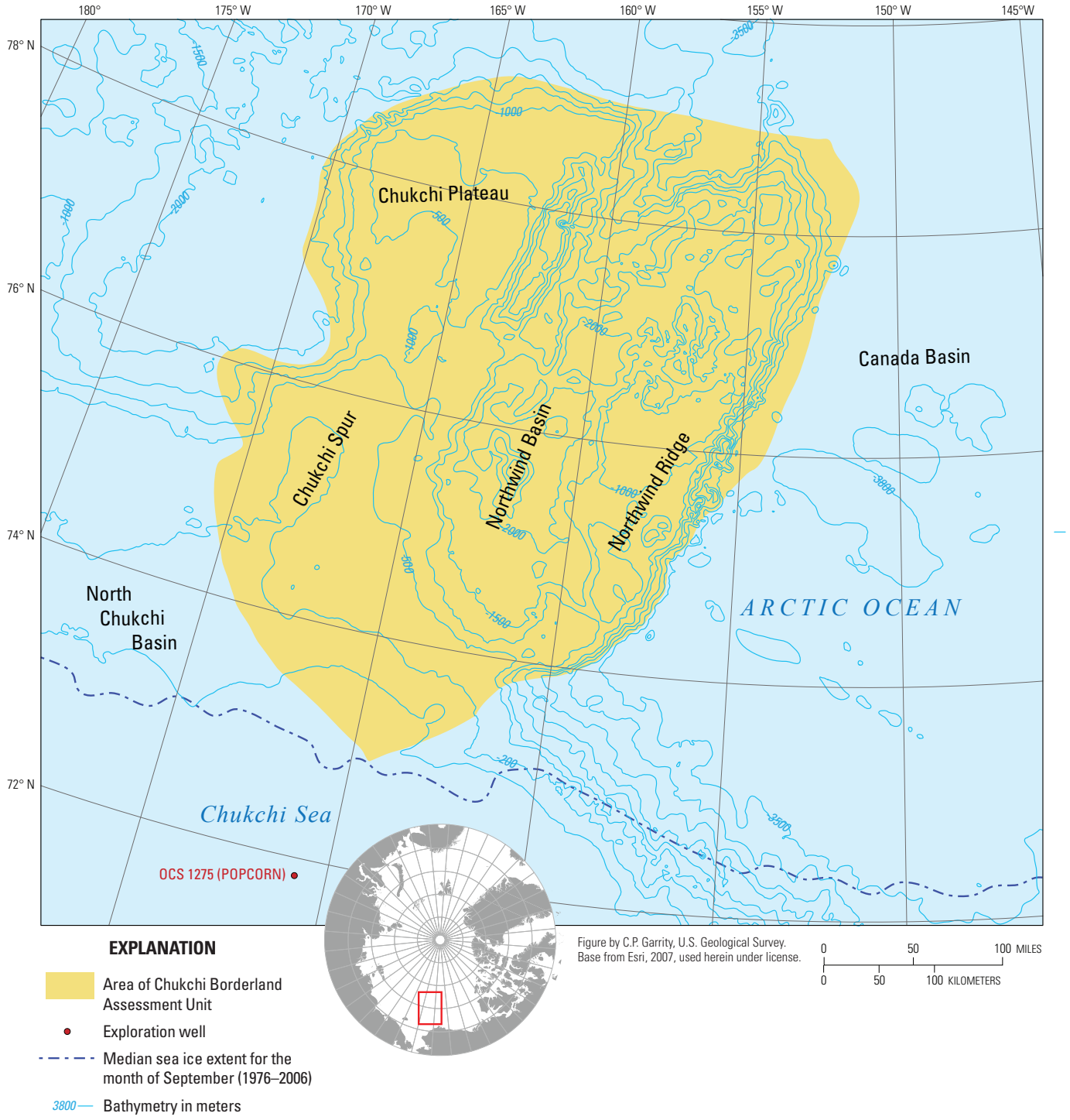


Figure 3. Index map showing location, bathymetry, and main physiographic features of the Chukchi Borderland Province. Exploratory well OCS 1275 (Popcorn), located on the Chukchi Sea continental shelf, is the nearest well control.

by a central north-trending trough (Northwind Basin) that displays basin and range-like topography. The floor of the trough lies more than 1000 m below the bordering Chukchi Spur–Chukchi Plateau on the west and Northwind Ridge on the east.

Geologic Setting and Stratigraphy

The Chukchi Borderland is interpreted as a fragment of continental crust based on its high-standing character and distinct gravity and magnetic signatures. Core data show that it is composed of Paleozoic to recent sedimentary strata with similarities to rocks in Sverdrup Basin and northern Alaska. Extensional deformation is a characteristic feature on seismic records. Widely scattered seismic lines with confirming seafloor cores and dredge samples show that the Chukchi Borderland AU is mantled by Cretaceous and Cenozoic pelagic sediments and air-fall volcanic ash deposits above a prominent unconformity (Grantz and others, 1998). The unconformity may represent the regional Lower Cretaceous break-up unconformity of northern Alaska. On seismic records, these mantling deposits display thicknesses of less than 1,000 m over the ridges and plateaus and as much as 3,500 m in grabens and half-grabens of Northwind Basin (fig. 4). Cores on the east flank of Northwind Ridge from a position beneath the unconformity reveal the presence of carbonate and clastic sedimentary strata of Cambrian, Ordovician, Carboniferous, Permian, Triassic, and Jurassic ages. Some of these strata display lithologic and (or) paleontologic affinities to strata in Sverdrup Basin and northern Alaska. On seismic records, these rocks are generally designated as acoustic basement, but in some areas discontinuous reflections are observed and show a moderate angular relationship to the unconformity.

The geologic evolution of Chukchi Borderland is a matter of debate with many different hypotheses (for example, Lawver and Scotese, 1990), but rifting is common to all. Most interpretations of the origin of the Chukchi Borderland were made early on, without benefit of the results of coring and dredging on Northwind Ridge by Grantz and others (1998). Lithologic and paleontologic details from the Northwind Ridge cores tend to support the so-called rotational hypothesis. The most recent version of the rotational hypothesis (Grantz and others, 2011) was followed here and is summarized in a set of schematic cross sections (fig. 5). In this interpretation, the Chukchi Borderland was originally a part of the Arctic Alaska-Chukotka Microplate located adjacent to the Canadian continental margin (Sverdrup Rim) that rifted and rotated counterclockwise about a pivot in the Mackenzie Delta in Jurassic and early Cretaceous time forming the Canada Basin. At about the same time, the Borderland itself, as a separate block, rifted and rotated in a relatively clockwise direction away from the Arctic Alaska-Chukotka microplate leaving the North Chukchi Basin in its wake. As there seems to be little evidence of compression along the boundary between the Chukchi Borderland and the Canada Basin, the Chukchi Borderland may have been fixed relative to Canada Basin while

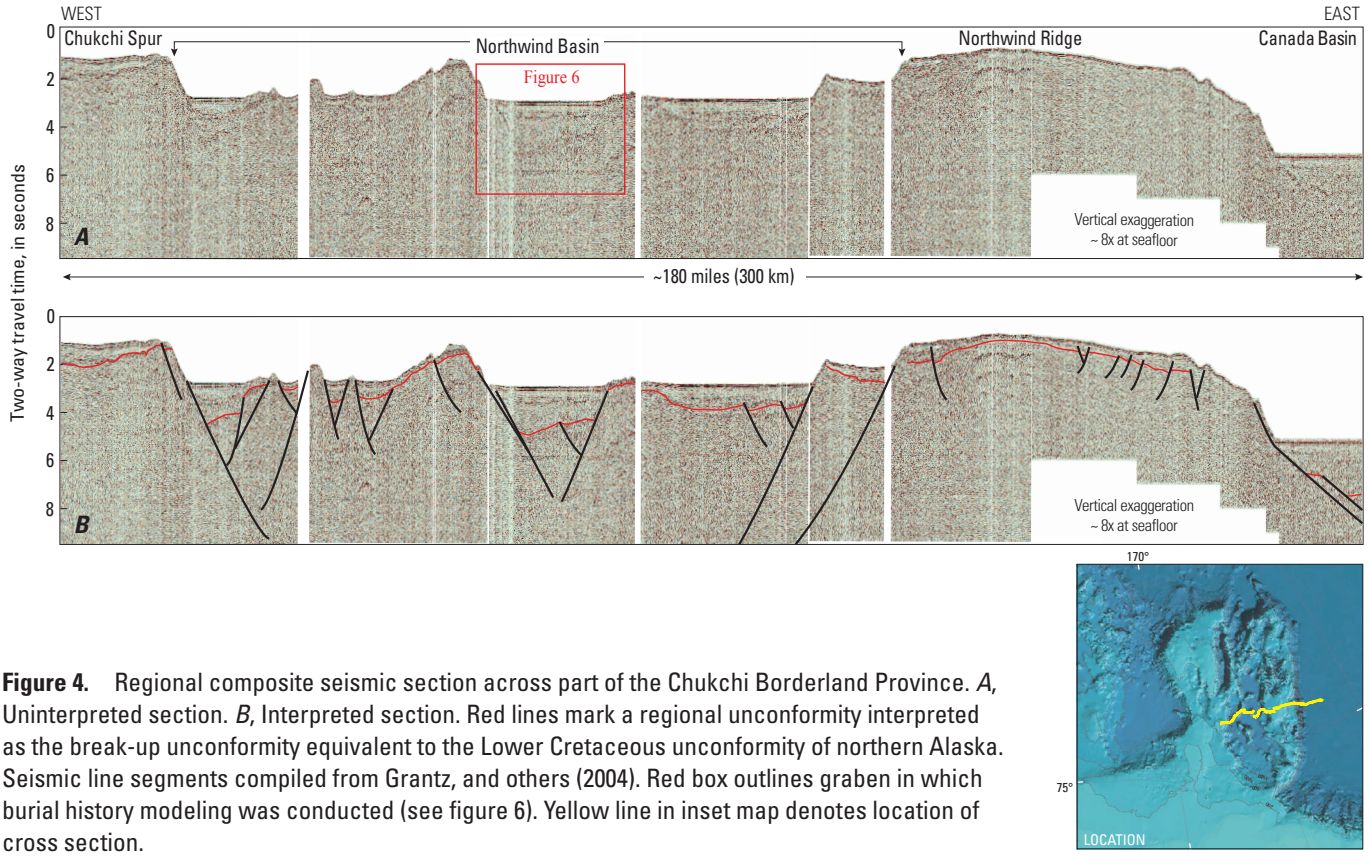


Figure 4. Regional composite seismic section across part of the Chukchi Borderland Province. *A*, Uninterpreted section. *B*, Interpreted section. Red lines mark a regional unconformity interpreted as the break-up unconformity equivalent to the Lower Cretaceous unconformity of northern Alaska. Seismic line segments compiled from Grantz, and others (2004). Red box outlines graben in which burial history modeling was conducted (see figure 6). Yellow line in inset map denotes location of cross section.

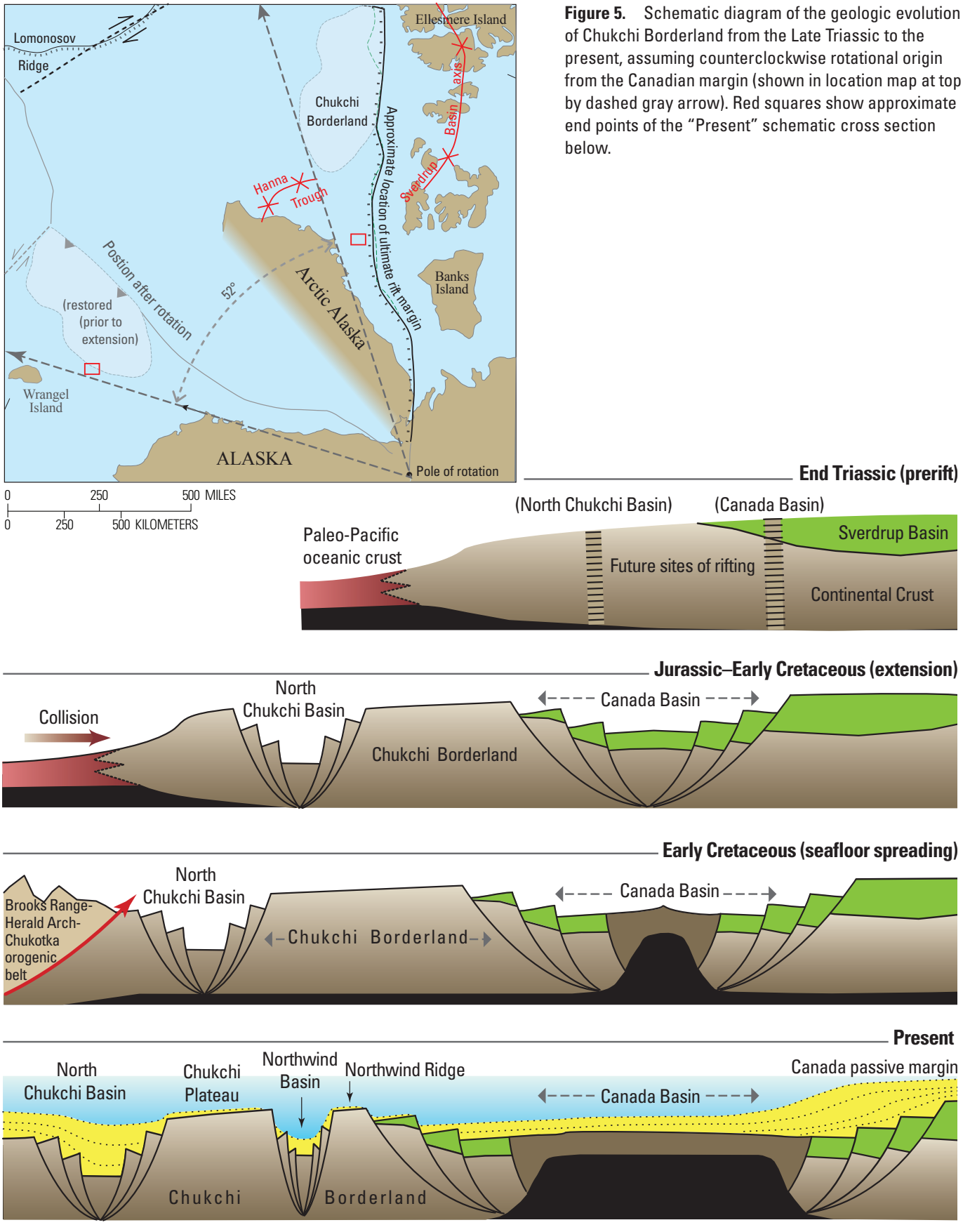


Figure 5. Schematic diagram of the geologic evolution of Chukchi Borderland from the Late Triassic to the present, assuming counterclockwise rotational origin from the Canadian margin (shown in location map at top by dashed gray arrow). Red squares show approximate end points of the "Present" schematic cross section below.

the Arctic Alaska-Chukotka microplate continued to rotate. A later episode of extension of postulated Paleogene age, and perhaps related to the Hanna Wrench-Fault Zone on the Chukchi shelf (Lothamer, 1994), extended the Chukchi Borderland crust producing the basin-and-range-like Northwind Basin (fig. 4).

Petroleum Systems

There is no direct evidence of an active petroleum system in the Chukchi Borderland. Source rocks may occur above or below the regional Lower Cretaceous unconformity. Triassic and Jurassic mudstones are present in cores taken on Northwind Ridge from a position beneath the regional unconformity and similar age strata are known source rocks in the Sverdrup Basin and northern Alaska. But their general character and areal extent in the Borderland are unknown. Maturity measurements in pre-Cretaceous rocks from Northwind Ridge show a range of values from immature to post-mature with highest values in Triassic rocks and lower values in Paleozoic rocks (Grantz and others, 1998). As these rocks are currently outcropping on the seafloor, the observed maturity pattern suggests different pre-Cretaceous burial histories for different parts of Northwind Ridge.

Source rocks above the regional unconformity may include Early Cretaceous (pebble shale unit, Hue Shale gamma-ray zone, and lower Torok Formation equivalents), mid-Cretaceous (Seabee Formation equivalents), and Eocene (*Azolla*) intervals (see Houseknecht and Bird, 2006). Burial history modeling in the deepest graben identified on the seismic section (fig. 6) shows that these rocks may be buried to depths adequate for early maturity (vitrinite reflectance values of 0.5–0.7 percent Ro). Based on this modeling, post-unconformity sediment thicknesses are deemed insufficient to mature any source rocks except within Northwind Basin beneath local grabens and half-grabens. Preservation of oil generated from Triassic and Jurassic source rocks in pre-Cretaceous time is considered unlikely given the inferred history of Mesozoic rifting, uplift and erosion, and later Cenozoic extension and burial.

Chukchi Borderland Assessment Unit

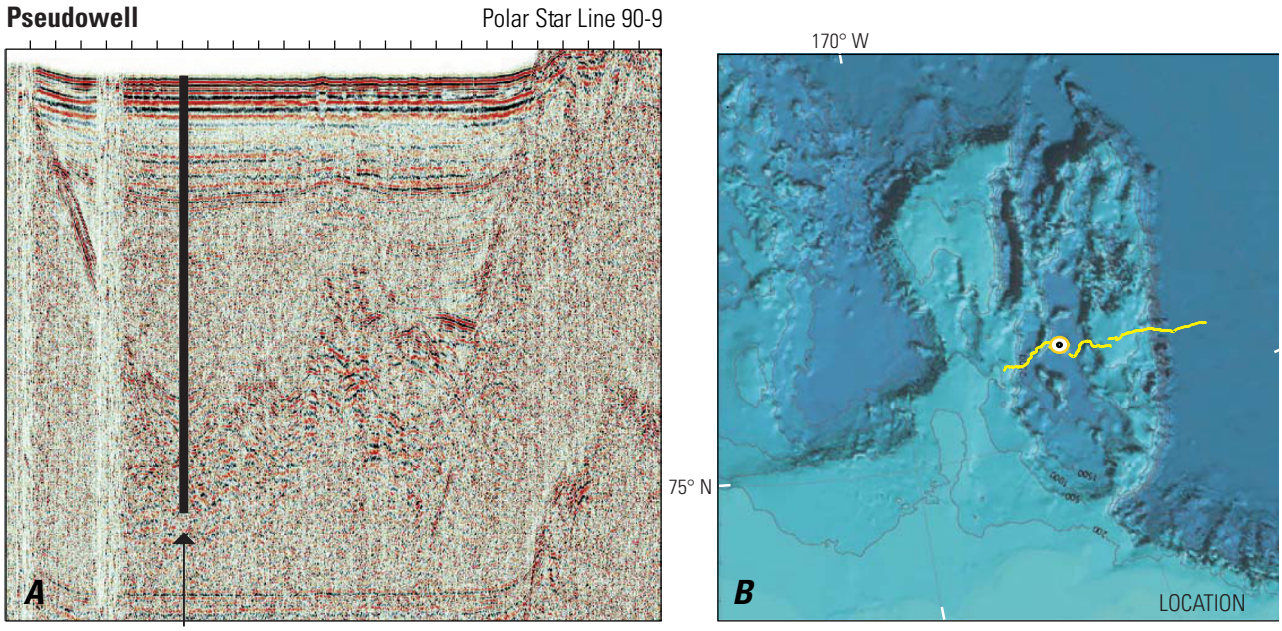
AU Description.—The Chukchi Borderland AU includes the entire province covering an area of approximately 246,000 km^2 located in water depths ranging from 200 to 3,500 m. The AU is flanked east and west by relatively high-standing ridges or plateaus mantled by less than 1000 m of seismically reflective strata above acoustic basement. Cores indicate the mantling strata are Cretaceous and Cenozoic pelagic and airfall tuff deposits while the acoustic basement includes carbonate and clastic sedimentary strata of Cambrian, Ordovician, Carboniferous, Permian, Triassic, and Jurassic ages. A north-trending trough that displays basin and range topography bisects the Chukchi Borderland AU opening northward into the deep Canada basin and grading southward into the Chukchi continental shelf. Seismic reflection records shows as much as 3,500 m of inferred Cretaceous and Cenozoic strata in some grabens.

Geological Analysis of Assessment Unit Probability.— The likelihood that the Chukchi Borderland AU contains at least one undiscovered accumulation >50 million barrels of oil equivalent (MMBOE) is considered to be about 5 percent on the basis of its postulated tectonic history and limited petroleum geologic information. This probability falls below the 10-percent minimum necessary for a full quantitative assessment of the AU, and so no assessment of sizes and numbers of petroleum accumulations was conducted. Petroleum system characteristics that led to the low probability estimate are summarized below.

Charge.— Although there is no direct evidence of an active petroleum system in the Chukchi Borderland AU, source rocks of Cretaceous and Paleogene age are postulated to occur throughout the province above the observed regional unconformity. Potential source rocks of Jurassic and Triassic age are known to occur below the unconformity, but their distribution is unknown. Burial history modeling shows that these source rocks may be buried to depths adequate for early maturity (vitrinite reflectance values of 0.5–0.7 percent Ro) only in grabens with >2,300 m of sediment fill. Uncertainty about the presence, character, and distribution of potential source rocks resulted in a probability value of 0.3 assigned to charge in the AU.

Rocks.— Reservoir rocks in the Chukchi Borderland AU may consist of Paleozoic carbonate rocks and Mesozoic sandstones beneath the regional unconformity but the character, distribution and thickness of these rocks, as well as possible seals, are unknown. Above the regional unconformity, Cretaceous and Tertiary rocks are likely to be mostly pelagic deposits with the possibility of a transgressive marine sandstone directly above the unconformity and perhaps talus and rubble associated with graben-bounding faults. The adjacent North Chukchi Basin and Alaska passive margin are inferred to have acted as traps for northward prograding sediments shed from the highlands of the Brooks Range-Herald Arch orogenic belt, thus reducing the potential for Cretaceous and Cenozoic sandstone reservoirs in the Borderland. Reservoir presence is considered the greatest risk in this AU and was assigned a probability value of 0.2.

Timing and Preservation.— Preservation of oil generated from pre-Cretaceous source rocks prior to rifting is considered unlikely. Oil generation by Cretaceous or Paleogene source rocks could occur only in the deeper grabens of Northwind Basin at the time of maximum burial (Neogene). For this latter scenario, timing and preservation were judged to be relatively favorable resulting in assignment of a probability value of 0.9.



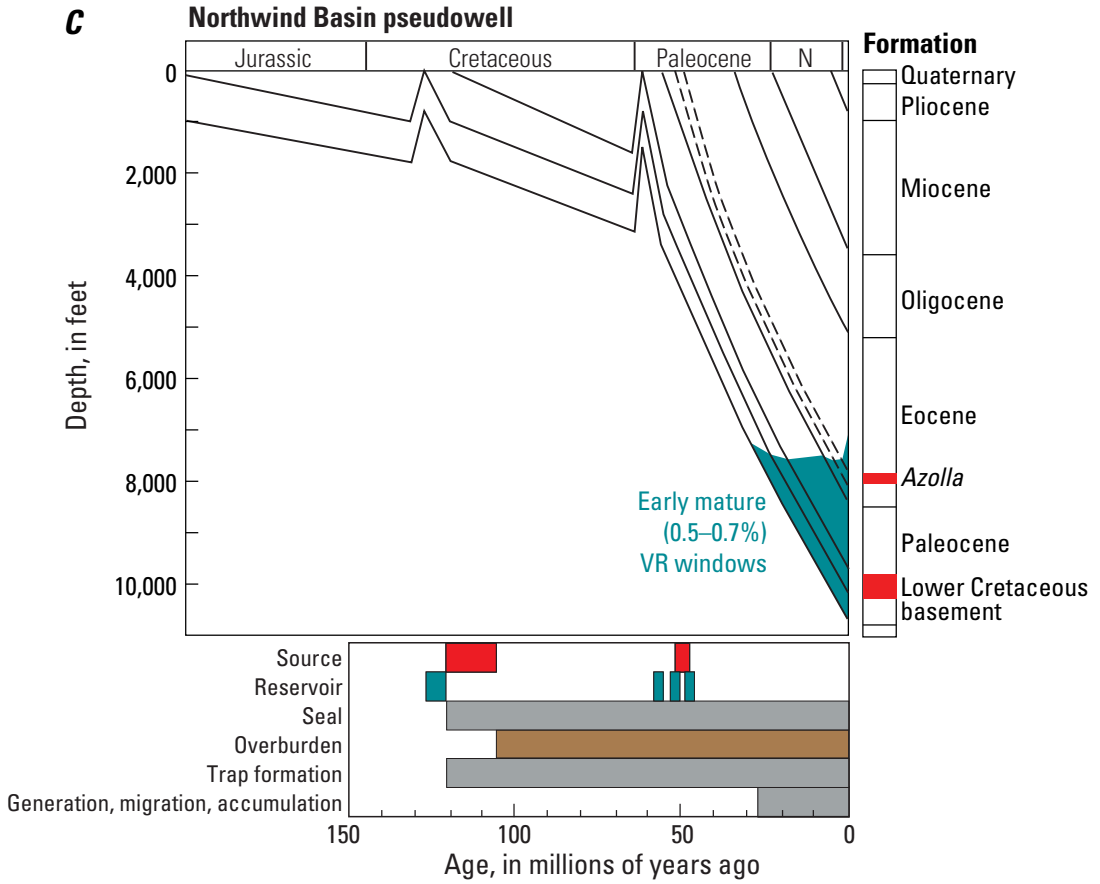


Figure 6. Burial history model of a pseudowell located in the deepest graben identified on seismic line crossing the Northwind Basin (fig. 4). A, Location of pseudowell (black line) shown in an expanded view of seismic profile (see fig. 4). B, Location of pseudowell and composite seismic profile (segmented yellow line; fig. 4) shown on shaded-relief bathymetric map. C, Model shows the onset of petroleum generation at burial depths below 2,300 meters at 30–25 million years ago. A constant heat flow of 55 milliwatts per square meter was used, similar to that calculated for the OCS 1275 (Popcorn) well on the Chukchi Shelf located 500 kilometers to the south (fig. 3). N, Neogene; VR, vitrinite reflectance, in percent (%).

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Appendix

Appendixes are available online only, and may be accessed at https://doi.org/10.3133/pp1824C

Appendix 1. Input data for the Chukchi Borderland Assessment Unit.

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