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Geology and Assessment of Undiscovered Oil and Gas Resources of the North Kara Basins and Platforms Province, 2008

Chapter P of
The 2008 Circum-Arctic Resource Appraisal

Professional Paper 1824

U.S. Department of the Interior
U.S. Geological Survey

Cover. Eocene strata along the north side of Van Keulenfjorden, Svalbard, include basin-floor fan, marine slope, and deltaic to fluvial depositional facies. The age and facies of these strata are similar to Tertiary strata beneath the continental shelves of Arctic Eurasia, thus providing an analog for evaluating elements of those petroleum systems. Relief from sea level to top of upper bluff is approximately 1,500 feet. Photograph by David Houseknecht.

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Chapter P

Geology and Assessment of Undiscovered Oil and Gas Resources of the North Kara Basins and Platforms Province, 2008

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Abstract

The U.S. Geological Survey (USGS) recently assessed the potential for undiscovered oil and gas resources of the North Kara Basins and Platforms Province as part of the its Circum-Arctic Resource Appraisal. This geologic province is north of western Siberia, Russian Federation, in the North Kara Sea between Novaya Zemlya to the west and Severnaya Zemlya to the east. One assessment unit (AU) was defined, the North Kara Basins and Platforms AU, which coincides with the geologic province. This AU was assessed for undiscovered, technically recoverable resources. The total estimated mean volumes of undiscovered petroleum resources in the province are ~1.8 billion barrels of crude oil, ~15.0 trillion cubic feet of natural gas, and ~0.4 billion barrels of natural-gas liquids, all north of the Arctic Circle.

North Kara Basins and Platforms Province

Province-Boundary Definitions

The North Kara Basins and Platforms Province (fig. 1) is on the North Kara Sea Shelf, between long 67°–100° E. and lat 75°–85° N., with the South Kara Sea to the south, the Barents Sea to the west, Severnaya Zemlya and the Taimyr Peninsula to the east, and the North Kara Sea Shelf margin to the north (fig. 2). The province covers an area of ~338,000 km^2 entirely north of the Arctic Circle, of which ~93 percent is offshore in water depths <500 m.

In this study, the North Kara Basins and Platforms Province contains smaller subbasins and local structural highs: the North Kara Basin (including the Uedineniya Trough), the North Kara Platform (consisting of the Vize High, the Ushakova High, and the Severnaya Zemlya High), the Schmidt Trough (also known as the Voronina Trough), and part of the Taimyr-Kara Platform (fig. 2). A fault system along the east edge of the St. Anna (Svyataya Anna) Trough separates the North Barents Basin from the province (fig. 2). An offshore structural high, which is related to early Cimmerian thrusting of the Novaya Zemlya fold and thrust belt, separates the province from the South Kara Sea Basin (Bogolepov and others, 1990; Otto and Bailey, 1995). The Paleozoic and Mesozoic history and stratigraphic succession indicate that the North Kara Basins and Platforms Province can be treated in this study as a single rift/sag basin. The deepest part of the province (Uedineniya Trough) is filled with 10 km of primarily Paleozoic rocks and 4 km of presumably Neoproterozoic rocks (fig. 3). A thin (<1 km thick) section of Mesozoic and Cenozoic rocks overlies the older rocks.

Petroleum Occurrence

No wells have been drilled in the North Kara Basins and Platforms Province as of this study (2008), and so any petroleum occurrence is speculative.

Tectonostratigraphic Evolution

The North Kara Basins and Platforms Province occupies part of a continental block, including the northern part of the Taimyr Peninsula (North Taimyr platform and Taimyr fold and thrust belt) and Severnaya Zemlya, that is considered one of the largest Arctic massifs (Zonenshain and Natapov, 1990). The tectonostratigraphic evolution of the province is inferred from observations on small islands within the North Kara Sea, on Severnaya Zemlya, and on the Taimyr Peninsula. Geologic cross sections (fig. 3) show the characteristics of the basin fill; structure and tectonostratigraphic events are shown in figure 4. Although only a few interpreted geophysical profiles have been published (for example, Bogolepov and others, 1992, fig. 3), they provide some information on the geologic structure of the province.

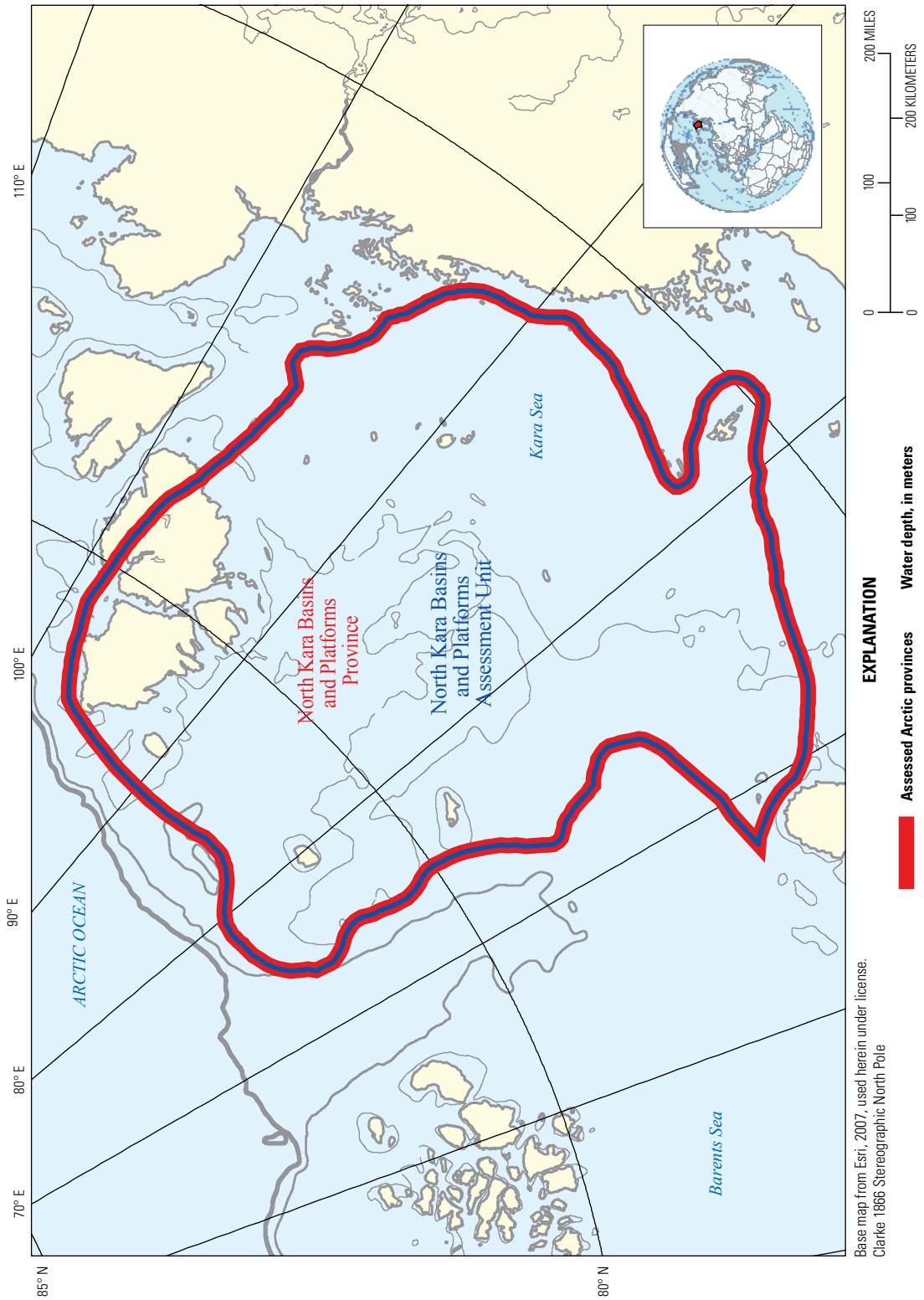

Figure 1. Map showing location of the North Kara Basins and Platforms Province and Assessment Unit.

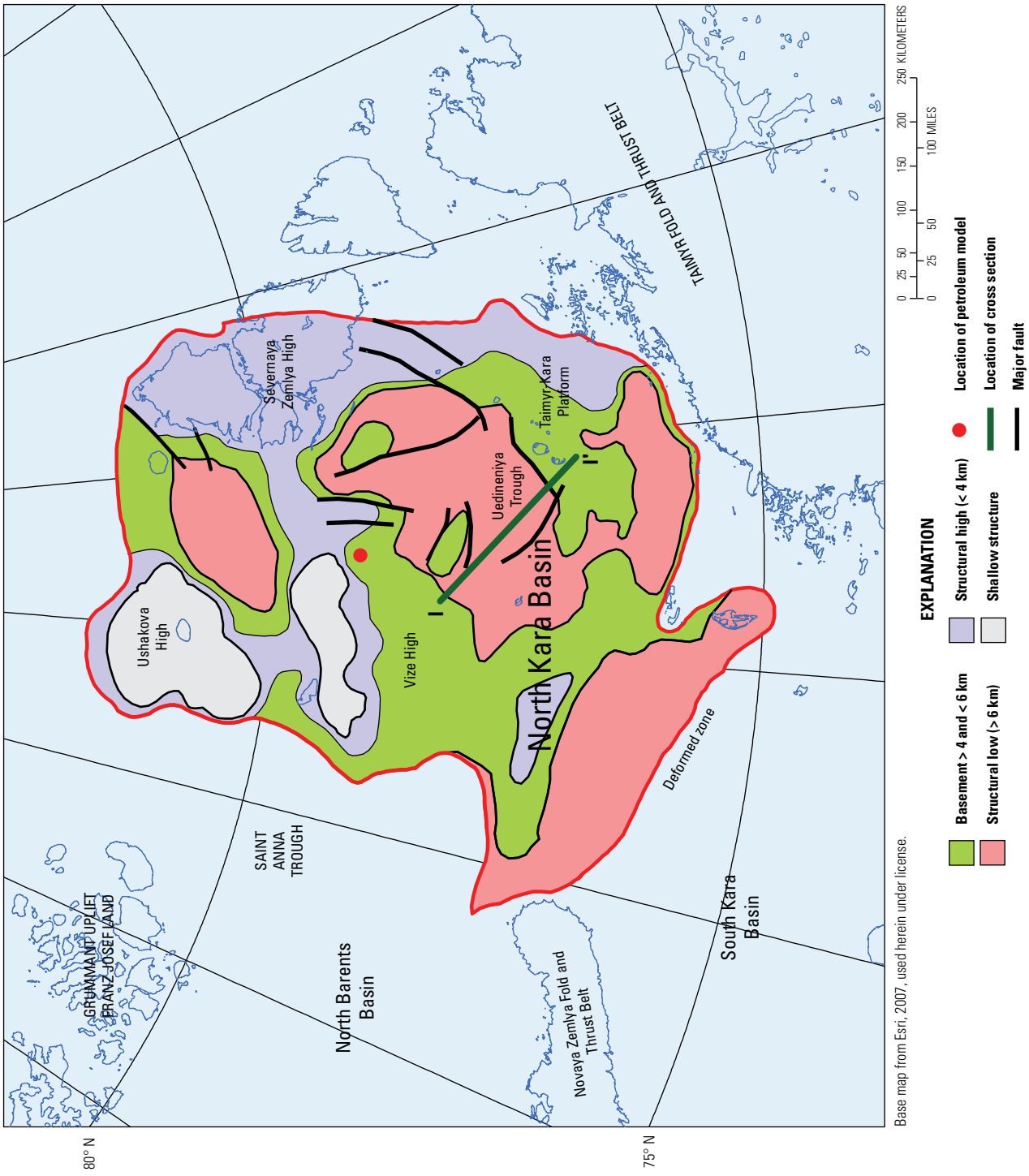

Figure 2. Map of North Kara Basins and Platforms Province, showing major structural features and locations of geologic cross sections (see fig. 3) and total petroleum system models used in assessment. Data from Persits and Ulmishek (2003) and Bezrukov and Vinokurov (2005).

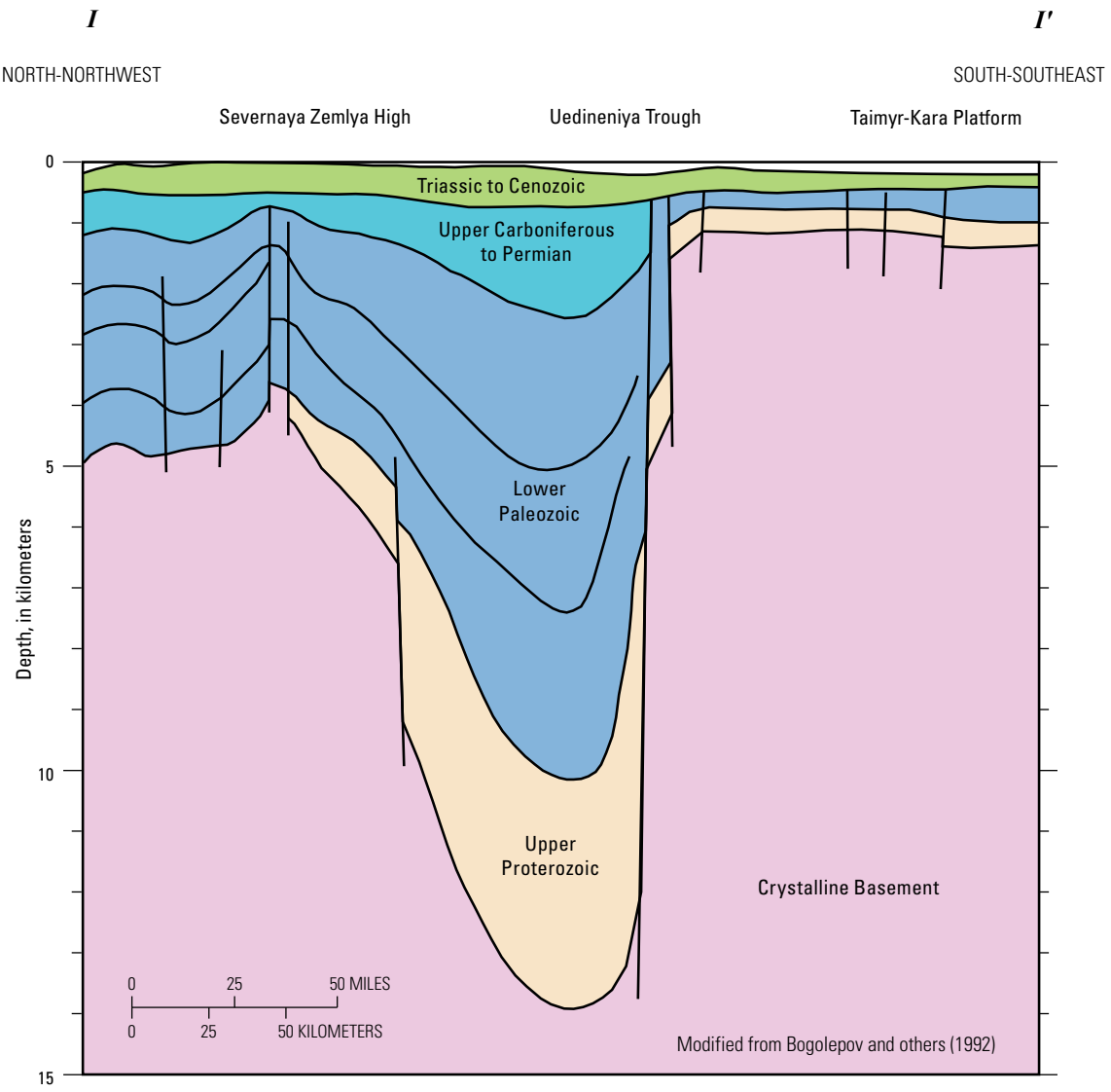

Figure 3. Regional geologic cross section of the North Kara Basins and Platform Province (see fig. 2 for location). Modified from Bogolepov and others (1992).

The North Kara Basins are rift/sag basins that formed on the Arctida or Baltica continent, the same basement that underlies the Barents basins. The sedimentary section is presumed to be composed mainly of Proterozoic through Paleozoic rocks, on the basis of outcrops on Severnaya Zemlya. The Mesozoic stratigraphy is similar to that of the East Barents Basins Province but thins and becomes unimportant east of the west province boundary.

Vinogradov (1991) described two major deep basins that are observed in seismic-reflection profiles (fig. 2). One basin, the Uedineniya Trough, is in the east, and the other (unnamed) in the west; both contain 14 to 16 km of sedimentary deposits. A northwest-southeast-trending high separates the two basins. The sedimentary section consists of four sequences separated by regional unconformities (Vinogradov, 1991). The timing and style of deformation throughout the Taimyr fold and thrust belt have been much debated, and even the dates of major continental-collision events are controversial (Scott and others, 2003).

Precambrian

The Kara block has been interpreted as either an independent microcontinent (Cocks and Torsvik, 2005; Metelkin and others, 2005) or part of a larger continent, such as Arctida or Baltica before or during the Timanide (Neoproterozoic [Vendian]) orogenesis (Zonenshain and others, 1990; Gee and others, 2006; Lorenz and others, 2007). Basin formation may have begun with intracontinental rifting during the Neoproterozoic, resulting in as much as 4 km of Riphean and Vendian strata filling the rifts (Vinogradov, 1991).

As stated earlier, the North Kara Basins and Platforms Province includes the northern part of the Taimyr Peninsula (North Taimyr platform and Taimyr fold and thrust belt) and Severnaya Zemlya. According to Zonenshain and others (1990), the North Taimyr terrane was probably a continental fragment that collided with another continental margin, possibly Arctida or Baltica, resulting in flysch deposition and the initial formation of the Kara block. The North Taimyr terrane contains Paleoproterozoic (2.2–2.4 Ga) crystalline basement and strongly deformed Neoproterozoic and possible Cambrian deep-marine sequences, mainly flysch (Zonenshain and others, 1990). The Riphean flyschoid deposits (sandstone and mudstone) are interpreted as metamorphosed continental-slope sedimentary rocks (Zonenshain and others, 1990; Uflyand and others, 1991; Vernikovsky, 1995).

Paleozoic

Riphean and Paleozoic rocks of the Kara block were deposited along a passive margin, on the basis of rocks on Severnaya Zemlya and in the North Taimyr terrane (Zonenshain and others, 1990; Uflyand and others, 1991). The Kara block contains 2 to 5 km of Ordovician through Devonian sedimentary strata (Bogdanov and others, 1998). The block was covered by a shallow sea in a platform setting during the Ordovician and Silurian (Zonenshain and others, 1990). The Lower and Middle Ordovician rocks are primarily clastic, whereas the Upper Ordovician and Silurian rocks are primarily shallow-water, probably shelf, carbonates containing fauna with Siberian affinities (Zonenshain and others, 1990).

Silurian and Devonian rocks on Severnaya Zemlya indicate lagoonal and continental deposition, including Old Red Sandstone facies, red-beds, and fossil fish with European affinities. The Old Red continent formed by the beginning of the Devonian during the Caledonian orogenesis, depositing clastic sediment from the deformation front to Severnaya Zemlya (Zonenshain and Natapov, 1990). Lorenz and others (2007) suggested eastward migration of Caledonian deformation across the Old Red Sandstone foreland basin to Severnaya Zemlya. Devonian clastic rocks exposed on Severnaya Zemlya are similar to those exposed on Svalbard and in other parts of the northern Caledonides (Churkin and others, 1981). On the basis of the orientation of folds and thrusts and the presence of Old Red Sandstone facies on Severnaya Zemlya, the Kara block was probably part of the Caledonides (Churkin and others, 1981). The sedimentary section was moderately deformed at the end of the Devonian and the beginning of the Carboniferous (Zonenshain and others, 1990).

Subsidence continued throughout the Paleozoic and Mesozoic, except for short periods of uplift and erosion. Subsidence rates differed within each of the two deep basins of the province (Vinogradov, 1991).

Siberia collided with the Kara block in the Taimyr area beginning during the late Carboniferous (Vernikovsky, 1995, 1998; Bogdanov and others, 1998; Golonka and others, 2003). Some studies suggest that the collision might have been an extension of the Uralian collision (Zonenshain and Natapov, 1990; Vernikovsky, 1995; Inger and others, 1999), although no Uralian suture rocks have been observed in the Taimyr fold and thrust belt (Lorenz and others, 2007). Moreover, no Paleozoic oceanic rocks and Uralian collisional assemblages have been observed in this belt (Gee and others, 2006). Late Carboniferous collision is responsible for the regional metamorphism, granitic intrusions, and transformation of the Siberian continental margin (Vernikovsky, 1995). The Kara block was uplifted and eroded at that time, shedding clastic sediment to the Sverdrup and Barents Basins and the South Taimyr passive margin (Zonenshain and Natapov, 1990). No upper Paleozoic rocks have been observed on Severnaya Zemlya, which was part of the Kara block (Churkin and others, 1981).

Mesozoic and Cenozoic

Only thin Mesozoic rocks (Upper Triassic through Cretaceous), Paleogene clastic rocks (mainly sandstone), and unconsolidated Pleistocene and Holocene sediment are exposed on Severnaya Zemlya and in the North Taimyr terrane (Churkin and others, 1981). Outcrops on the North Kara Sea islands are of mostly unconsolidated Cretaceous clastic sediment, ranging from Aptian through Cenomanian and Santonian (Churkin and others, 1981).

Another (early Cimmerian) major tectonic event associated with dextral transpression is assumed to have occurred during the Late Triassic and possibly into the Early Jurassic (Inger and others, 1999; Torsvik and Andersen, 2002). The event resulted in deformation of the Taimyr fold and thrust belt (Torsvik and Andersen, 2002).

The North Kara Basins and Platforms Province most likely underwent periodic glaciation from the late Pliocene onward. However, the thickness, duration, and extent of ice sheets in the province and, in turn, the severity of glacial exhumation are poorly constrained. According to Vågnes and others (1992), glacial erosion on the North Kara Sea Shelf ranges from 600 m along Severnaya Zemlya and the Taimyr Peninsula to 1,200 m in the Schmidt Trough but generally from 800 to 1,000 m.

Total Petroleum System

A Paleozoic composite total petroleum system (TPS) was defined for the North Kara Basins and Platforms Province. The name implies that potential source and reservoir rocks occur in the Paleozoic stratigraphic succession. Seal rocks, as well as trap rocks and timing, are also elements of the TPS. Neoproterozoic rocks probably entered thermal maturity during the Paleozoic and became overmature by Mesozoic time. A lithostratigraphic column and TPS events chart for the province is shown in figure 4.

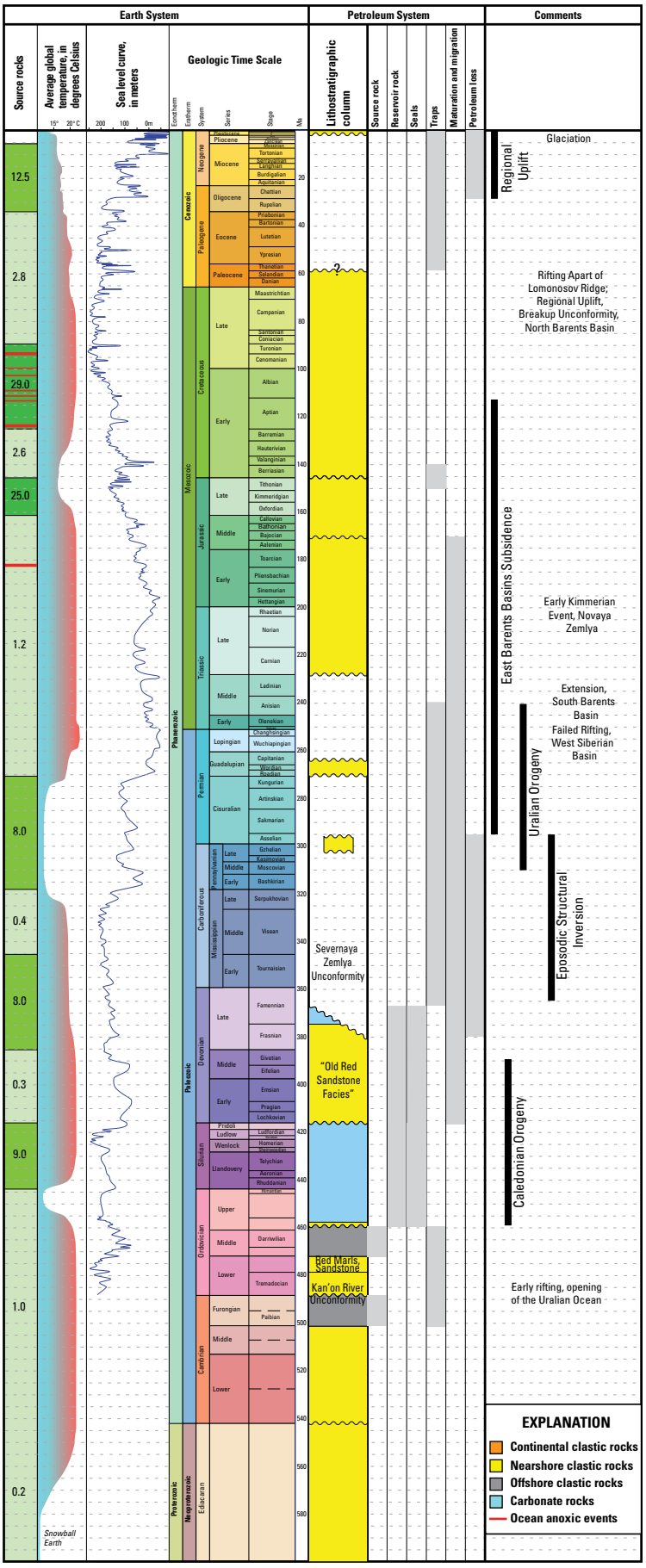

Figure 4. Lithostratigraphic column and total petroleum system (TPS) events chart, showing TPS elements and major tectonic events in the North Kara Basins and Platform Province. Source rocks column shows the percent of the world's total petroleum reserves generated by source (modified from Ulmishek and Klemme, 1990). Average global temperature data is from Frakes and others (1992) and Barrett (2003). Sea level curve is from Golonka and Kiessling (2002) and Hardenbol and others (1998). Geologic time scale is that of Gradstein and others (2004). Petroleum system data are from Gee and others (2006) and Lorenz and others (2007).

Source Rocks

Potential source rocks in the North Kara Basins and Platforms Province are interpreted to be similar to the black mudstones observed within the Upper Cambrian through Middle Ordovician sections on Severnaya Zemlya (Gee and others, 2006).

Burial-history modeling (fig. 5) indicates that Upper Cambrian through Middle Ordovician source rocks reached sufficient thermal maturity to generate petroleum during the late Paleozoic as a result of burial by thick Silurian and Devonian sections, and reached overmaturity by the end of the Mesozoic. Modern heat flow is zoned east to west, ranging from 30 mW/m^2 in the western part of the North Kara Basins and Platforms Province to 60 mW/m^2 west of Severnaya Zemlya, returning to 40 mW/m^2 on the Severnaya Zemlya islands (Khutorskoi and others, 2003). For most of geologic history, however, heat flows of 65 to 70 mW/m^2, which are normal for

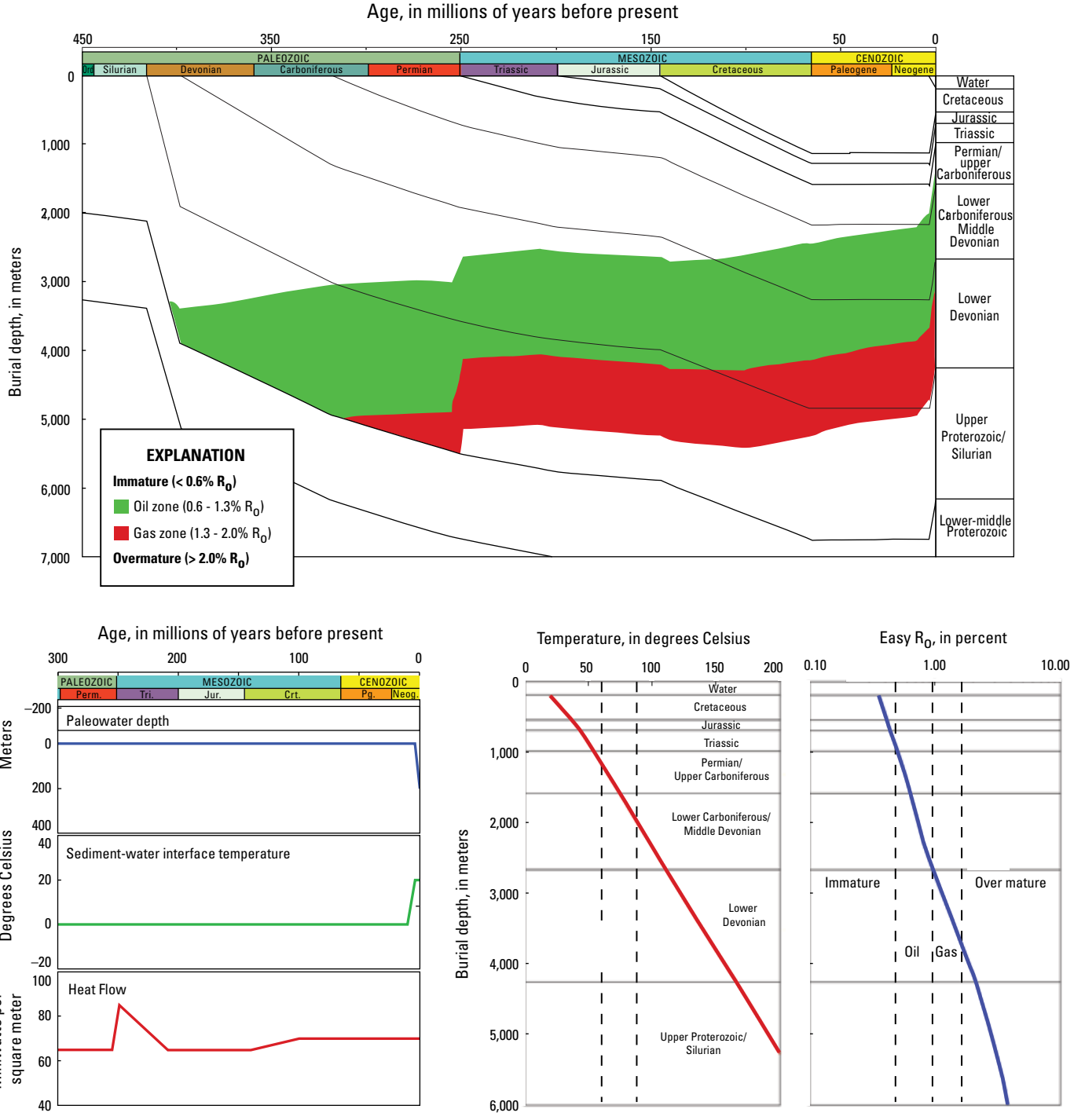

Figure 5. Burial-history model for a pseudowell depicting thermal maturity (see figs. 2 and 3 for location). Ro, vitrinite reflectance, in percent (%). Data from Levashkevich and others (1992), Vågnes and others (1992), Verzhbitskii (2000, 2002), Khutorskoi and Podgornykh (2001), and Khutorskoi and others (2003, 2008). PetroMod references: Wygrala (1989), Sweeney and Burnham (1990), and Integrated Exploration Systems (2008).

rift/sag basins, were assumed for the burial-history model. A spike in regional heat flow to 90 mW/m^2 was assumed for the late Permian and Early Triassic in accordance with regional extension and magmatism in the adjacent East Barents Basin and northern West Siberia.

Reservoir and Seal Rocks

Potential reservoir and seal rocks include Lower Ordovician nearshore-marine, passive-margin sandstone and conglomerate, Upper Ordovician basal sandstone, and Upper Ordovician and Silurian carbonate platform and associated reef rocks.

Traps and Timing

Potential traps are associated with folds and faults that formed during Neoproterozoic rifting, early Paleozoic extension (sag phase associated with thermal subsidence), and late Paleozoic compression and inversion. The traps formed before and during petroleum generation. However, late Paleozoic through Cenozoic erosion might have caused some of the previously accumulated petroleum to remigrate or be destroyed. Other potential traps include stratigraphic onlaps and pinchouts along structural highs, drapes over structures, carbonate shelf- and reef-associated deposits, submarine-fan deposits, and submarine-channel sandstones.

Assessment Units

A single assessment unit (AU), the North Kara Basins and Platforms AU, was defined for the North Kara Basins and Platforms Province. In this study, an AU is defined as a volume of rock within the TPS that has consistent geologic characteristics. The estimated numbers and sizes of undiscovered oil and gas accumulations in each AU are listed in the appendix, and the geologic analog data used to evaluate the AUs are summarized in tables 1 and 2.

North Kara Basins and Platforms Assessment Unit

The North Kara Basins and Platforms AU follows the outline of the North Kara Basins and Platforms Province (figs. 1, 2). The AU is bounded on the west by the North Barents Basin and the St. Anna Trough, on the east by the east edge of the Severnaya Zemlya High, on the south by the Taimyr Peninsula, and on the north by the North Kara Sea shelf margin. The AU area is 338,084 km^2, 93 percent of which is offshore in the North Kara Sea. The AU is completely north of the Arctic Circle. The stratigraphic interval includes the entire sedimentary section from Neoproterozoic through Mesozoic.

Most likely source rocks are mature Ordovician and Silurian mudstone. Potential reservoir rocks and seals are lower Paleozoic carbonates and reefs, similar to those in the Timan-Pechora Basin, and upper Paleozoic clastic rocks. No wells have been drilled within the AU as of this study (2008); only seismic surveys have been conducted.

Geological Analysis of Petroleum Probability

The probability that the North Kara Basins and Platforms AU contains at least one accumulation greater than or equal to the minimum field size of 50 million barrels of oil equivalent (MMBOE) is estimated to be >50 percent (0.504). Because no petroleum accumulations have been discovered in this geologic province as of 2008, source, reservoir, seal rocks, and trap configurations can only be inferred. The assessment input data are listed in the appendix and summarized below.

Charge Probability.—A charge probability of 0.70 was estimated because the presence of thermally mature source rocks has not been proved. Ordovician and Silurian source rocks probably occur in the two deeper basins of the AU.

Rock Probability.—A rock probability of 0.80 was estimated. The presence of reservoir rocks and traps consisting of lower Paleozoic carbonates and reefs and upper Paleozoic clastic rocks is inferred but has not been proved. Coarse clastic sediment similar to the Devonian Old Red Sandstone was deposited over the area as a result of erosion of the Caledonian deformation front; these deposits might provide reservoirs should adequate seals exist.

Timing and Preservation Probability.—A timing and preservation probability of 0.90 was estimated. Petroleum generation models indicate Paleozoic source rocks would have been mature by the end of the Mesozoic and that traps associated with rift/sag formation were present before petroleum generation. Inverted fault blocks, anticlines, and other compressional traps could have formed as a result of late Carboniferous through Triassic deformation, although some previously trapped petroleum accumulations might have been modified and destroyed.

Geologic Analogs for Assessment

Data for rift/sag basins (tables 1, 2) from the USGS Analog Database (Charpentier and others, 2008) were used as analogs to estimate the number and size distributions of undiscovered petroleum accumulations in the North Kara Basins and Platforms AU. The resulting analog dataset contains 20 AUs representing rift/sag basins that underwent extension and compression, with both clastic and carbonate rocks (table 1). These AUs have discovered oil and gas fields greater than the minimum size defined for this assessment (50 MMBOE) (table 2).

Number of Undiscovered Petroleum Accumulations.—The number of undiscovered petroleum accumulations in the North Kara Basins and Platforms AU (see appendix) was estimated by comparing field densities (estimated number of undiscovered accumulations plus number of discovered accumulations >50 MMBOE per 1,000 km^2) in the analog dataset

(table 2). The density of discovered petroleum accumulations, which generally is smaller than the density of both discovered and undiscovered accumulations, was used to calibrate the densities of undiscovered petroleum accumulations for this AU. Median and maximum densities of ~0.1 and 0.3, respectively, were used. The median density, 0.1, is lower than that (~0.25) in the analog dataset (table 2) because some potential petroleum accumulations trapped in rift/sag traps might have been destroyed during late Paleozoic and Mesozoic compression. The maximum density of undiscovered petroleum accumulations estimated for this AU (0.3) is less than that of the analog set (1.12, density of discovered accumulations and 1.78, density of both discovered and undiscovered accumulations; table 2) because the maximum density in the analog dataset is 0.4 to 0.6 (table 2) when the values for analogs that do not represent this AU are removed. Because of the geologic risk associated with this AU, the minimum number of undiscovered fields is 1, and the total, median, and maximum numbers of undiscovered petroleum accumulations are 1, 35, and 100, respectively (see appendix). The estimated numbers of undiscovered oil accumulations is 0 (minimum), 16 (median), and 90 (maximum), and the estimated numbers of undiscovered gas accumulations are 1 (minimum), 18 (median), and 95 (maximum).

Size of Undiscovered Petroleum Accumulations.—The minimum, median, and maximum sizes of undiscovered oil and gas fields in the North Kara Basins and Platforms AU are listed in the appendix. The minimum sizes of undiscovered fields defined for the AU are 50 million barrels (MMB) of crude oil and 300 billion cubic feet (BCF) of natural gas (6 BCF=1 MMBOE). The median sizes of undiscovered oil and gas fields in the AU, 100 MMB of crude oil and 600 BCF of natural gas, are approximately equal to those (110 MMB of crude oil and 590 BCF of natural gas) in the analog dataset (table 1). The low-probability, maximum sizes of undiscovered fields in the AU, 5,000 MMB of crude oil and 30,000 BCF of natural gas, are larger than the largest median and mean sizes of oil and gas fields (1,060 and 3,156 MMBOE, respectively) in the analog dataset. The expected maximum sizes of undiscovered fields in the AU (not reported in appendix) are estimated at 1,000 MMB of crude oil and 6,000 BCF of natural gas, much smaller than the estimated maximum sizes of undiscovered fields and equivalent to the median size of the largest accumulation in the analog dataset.

Table 1. Rift/sag basins used as geologic analogs in the North Kara Basins and Platforms Assessment Unit assessment.

[Analog data from Charpentier and others (2008)]

Province Name (Assessment Unit #)	Structural Setting	Trap System
Bohaiwan Basin (31270101)	Extensional	Extensional grabens and other structures
Bohaiwan Basin (31270102)	Extensional	Extensional grabens and other structures
Dnieper-Donets Basin (10090102)	Extensional	Basement blocks
Malay Basin (37030101)	Compressional	Basement-involved blocks
Malay Basin (37030102)	Compressional	Basement-involved blocks
Malay Basin (37030201)	Compressional	Basement-involved blocks
North Sea Graben (40250101)	Extensional	Extensional grabens and other structures
North Sea Graben (40250102)	Extensional	Extensional grabens and other structures
North Sea Graben (40250103)	Extensional	Stratigraphically undeformed, salt-induced structures, extensional grabens, and other structures related to normal faulting
North Ustyurt Basin (11500201)	Compressional	Local uplifts, origin uncertain
North Ustyurt Basin (11500301)	Compressional	Local uplifts, origin uncertain
Pannonian Basin (40480101)	Extensional	Stratigraphically undefined, growth faults, basement blocks
Pannonian Basin (40480201)	Extensional	Stratigraphically undefined, growth faults, basement blocks
Sirte Basin (20430101)	Extensional	Extensional grabens and other structures
Sirte Basin (20430102)	Extensional	Extensional grabens and other structures
Songliao Basin (31440101)	Unknown	Extensional grabens and other structures
Songliao Basin (31440102)	Compressional/extensional	Extensional grabens and other structures
Songliao Basin (31440201)	Compressional/extensional	Extensional grabens and other structures
West Siberian Basin (11740101)	Compressional	Basement-involved blocks, stratigraphically undefined
West Siberian Basin (11740201)	Passive	Basement-involved blocks, stratigraphically undefined

Table 2. Field densities, median sizes of oil and gas fields, and exploration maturities of geologic analogs used in the North Kara Basins and Platforms Province Assessment Unit assessment.

[Analog data from Charpentier and others (2008). Rift/sag basin analogs listed in table 1. Asterisk (*), not reported in U.S. Geological Survey Analog Database. BCF, billion cubic feet; MMB, millions of barrels; MMBOE, million barrels of oil equivalent. Gas volumes are nonassociated]

Province (assessment unit)	*Density of discovered fields >50 MMBOE per 1,000 km^2	Density of discovered and undiscovered fields >50 MMBOE per 1,000 km^2	Field size distribution of median oil-field size >50 MMB	Field size distribution of median gas-field size >300 BCF	Exploration maturity in percent age of oil by volume in oil fields >50 MMB	Exploration maturity in percent age of gas by volume in gas fields >300 BCF	Maximum field size (MMBOE)
Bohaiwan Basin (31270101)	0.31	0.43	110	594	90	65	
Bohaiwan Basin (31270102)	0.08	0.13	113	544	66	0	
Dnieper-Donets Basin (10090102)	–	0.12	92	555	0	0	
Malay Basin (37030101)	0.39	0.64	104	677	88	52	
Malay Basin (37030102)	–	0.16	70	375	0	0	
Malay Basin (37030201)	0.36	0.51	212	1045	100	93	
North Sea Graben (40250101)	1.12	1.78	125	851	84	88	
North Sea Graben (40250102)	0.64	0.83	111	380	92	98	
North Sea Graben (40250103)	0.77	1.05	116	572	82	69	
North Ustyurt Basin (11500201)	0.01	0.04	58	752	53	87	
North Ustyurt Basin (11500301)	–	0.04	–	610	–	0	
Pannonian Basin (40480101)	0.11	0.09	106	585	100	96	
Pannonian Basin (40480201)	0.15	0.13	85	1097	100	96	
Sirte Basin (20430101)	0.35	0.41	164	342	93	100	
Sirte Basin (20430102)	0.23	0.36	122	614	89	75	
Songliao Basin (31440101)	0.10	0.17	108	343	92	0	
Songliao Basin (31440102)	0.55	0.71	264	574	100	100	
Songliao Basin (31440201)	–	0.02	–	370	–	0	
West Siberian Basin (11740101)	0.15	0.32	130	1171	78	99	
West Siberian Basin (11740201)	0.01	0.13	100	778	68	90	
Median	**0.27**	**0.25**	**110**	**590**	**89**	**81**	**1,060**
Mean	**0.33**	**0.40**	**122**	**641**	**76**	**60**	**3,156**

Composition and Properties of Undiscovered Petroleum Accumulations.—Oil/gas mixture, coproducts, and petroleum-quality properties for the North Kara Basins and Platforms AU were derived from data gathered from discovered petroleum accumulations on Kolguyev Island and in the Timan-Pechora Basin, as well as from world statistics (table 3). Minimum, modal, and maximum oil/gas-field ratios of 0.05, 0.5, and 0.9, respectively, were estimated because the petroleum composition within the basin is unknown (see appendix). Drilling depths for undiscovered fields (see appendix) were estimated from interpreted seismic profiles in the AU (fig. 2) and petroleum-generation models (fig. 5). Minimum, median, and maximum depths for undiscovered oil and gas fields were estimated at 1.0, 3.0, and 5.0 km, respectively.

Summary of Assessment Results

The assessment results for the North Kara Basins and Platforms AU and Province are summarized in tables 3 and 4. Estimates represent undiscovered, technically recoverable, conventional petroleum resources.

The North Kara Basins and Platforms AU has an overall probability of 0.504. The risked mean amount of undiscovered crude oil is 1,807 MMB, with a 95-percent probability (F_{95}) of 0 MMB, a 50-percent probability (F_{50}) of 488 MMB, and a 5-percent probability (F_5) of 6,810 MMB. The risked mean volume of undiscovered nonassociated natural gas is 12,129 BCF, with an F_{95} of 0 BCF, an F_{50} of 4,115 BCF, and an F_5 of 44,522 BCF. The largest expected size of an undiscovered oil field is ~968 MMB, and the largest expected size of an undiscovered gas field is ~6,148 BCF.

The geologic probabilities for the AUs in this study were determined on the basis of a consideration of the geology of each province and on the geologic probabilities assigned to the AUs in all Arctic basins. Using this approach, the probabilities were consistently applied throughout the Arctic region.

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Table 3. World statistics for oil and gas coproduct ratios, ancillary data, and depths.

[Data from Charpentier and others (2008)]

Variable	Minimum	Median	Maximum
Coproduct ratios			
Natural gas-to-crude oil ratio in oil accumulations (cubic feet per barrel)	100	1,000	20,000
Natural-gas-liquids-to-natural-gas ratio in oil accumulations (barrels per thousand cubic feet)	5	25	85
Natural-gas liquids-to-natural-gas ratio in gas accumulations (barrels per thousand cubic feet)	5	25	75
Ancillary data for oil accumulations			
API gravity (degrees)	20	38	55
Viscosity (centipoise)	0.01	3	30
Sulfur content of oil (weight percent)	0	0.3	1.5
Ancillary data for gas accumulations			
Inert gas content (percent)	0	2	10
Carbon dioxide content (percent)	0	1.5	10
Hydrogen sulfide content (weight percent)	0	0.5	3.5
Depths			
Depth (meters) of water (if applicable)	0	50	2,700
Drilling depth (meters)	350	2,000	7,000

Table 4. Assessment results (conventional undiscovered resources) for the North Kara Basins and Platforms Province.

[AU, assessment unit; BCF; billion cubic feet; MMB, million barrels; TPS, total petroleum system. Results shown are fully risked estimates. For gas fields, all liquids are included under the natural gas liquids (NGL) category. F95, 95-percent probability of at least the amount tabulated, and so on for F50 and F5. Fractiles are additive under the assumption of perfect positive ocrrelation. N/A, not applicable. Numbers do not exactly add to totals because totals were added by statistical aggregation]

Total petroleum systems and assessment units	AU probability	Field type	Oil (MMB)				Gas (BCF)				NGL (MMB)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
Assessment results—entire province; Paleozoic composite total petroleum system														
North Kara Basins and Platforms AU	0.504	Oil	0	488	6,810	1,807	0	519	11,246	2,845	0	12	272	68
		Gas	N/A	N/A	N/A	N/A	0	4,115	44,522	12,129	0	105	1,198	322
Total undiscovered petroleum resources			0	488	6,810	1,807	0	4,634	55,768	14,974	0	117	1,470	390

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Appendix. Input Data for the North Kara Basins and Platforms Assessment Unit

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