Geology and Assessment of Undiscovered Oil and Gas Resources of the Northwest Laptev Sea Shelf Province, 2008

Chapter S 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 S

Geology and Assessment of Undiscovered Oil and Gas Resources of the Northwest Laptev Sea Shelf Province, 2008

By Timothy R. Klett and Janet K. Pitman

Abstract

The U.S. Geological Survey (USGS) has recently assessed the potential for undiscovered oil and gas resources in the Northwest Laptev Sea Shelf Province as part of the USGS Circum-Arctic Resource Appraisal. The province is in the Russian Arctic, east of Severnaya Zemlya and the Taimyr fold-and-thrust belt. The province is separated from the rest of the Laptev Sea Shelf by the Severnyi transform fault. One assessment unit (AU) was defined for this study: the Northwest Laptev Sea Shelf AU. The estimated mean volumes of undiscovered petroleum resources in the Northwest Laptev Sea Shelf Province are approximately 172 million barrels of crude oil, 4.5 trillion cubic feet of natural gas, and 119 million barrels of natural-gas liquids, north of the Arctic Circle.

Tectonostratigraphic Evolution

The Northwest Laptev Sea Shelf Province is interpreted as a rifted passive margin formed by the opening of the Eurasian Basin. The passive margin formed upon an extension of the Taimyr fold-and-thrust belt (fig. 2). To the south, the province is composed of extended continental crust and is a rift/sag-style rather than a rifted passive margin (Sekretov, 2002) because of its position relative to the Cenozoic spreading center of the Eurasia Basin and the Gakkel Ridge. The few interpreted geophysical profiles of the province (Sekretov, 2002; Franke and Hinz, 2005) provide some information on its geologic structure. Geologic cross sections modified from the profiles presented by Sekretov (2002) are shown in figure 3. The tectonostratigraphic evolution of the province was inferred from observations on the Taimyr Peninsula (Zonenshain and others, 1990; Vernikovsky, 1995, 1998; Sekretov, 2002).

Northwest Laptev Sea Shelf Province

Definition of Province Boundary

The Northwest Laptev Sea Shelf Province in the Russian Arctic, situated along the east coast of the Taimyr Peninsula and Severnaya Zemlya (figs. 1, 2), extends from the Taimyr fold-and-thrust belt in the west to the shelf edge in the east. An east-west trending transform fault, called the Severnyi Transform, separates the Northwest Laptev Sea Shelf Province from the rest of the Laptev Sea Shelf, forming its south boundary. The province is mostly offshore in approximately <100-m water depth.

Petroleum Occurrence

As of 2008, no wells have been drilled in the Northwest Laptev Sea Shelf Province, and so any petroleum occurrence there is speculative.
Figure 1. Map of the Arctic showing location of Northwest Laptev Shelf Province and Assessment Unit. Map from Persits and Ulmishek (2003); oil data from IHS Energy Group (2007).
Figure 2. Map of Northwest Laptev Sea Shelf Province showing major structural features and location of geologic cross sections used in assessment. Data from Sekretov (2002), Persits and Ulmishek (2003), and IHS Energy Group (2007).
Precambrian

The Taimyr Peninsula is divided into the North Taimyr, Central Taimyr, and South Taimyr terranes (Zonenshain and others, 1990). The North Taimyr terrane contains early Precambrian (2,400–2,200 Ma) crystalline rock and strongly deformed late Precambrian and possible Cambrian deep-marine sequences (Zonenshain and others, 1990). Riphean flyschoid rocks (sandstone and mudstone) are interpreted as continental-slope deposits (Zonenshain and others, 1990; Uflyand and others, 1991) that have been metamorphosed (Vernikovsky, 1995).

On the basis of isotopic-geochronologic data, Vernikovsky (1995) interpreted the Central Taimyr terrane as an accretionary prism formed by the collision of island arcs with continental blocks during the late Proterozoic. The Central Taimyr terrane most likely collided with and joined the accreted South Taimyr terrane and the Siberian craton during the late Proterozoic, becoming part of the Siberian passive margin until the late Carboniferous (late Riphean, 600–570 Ma; Bogdanov and others, 1998; Vernikovsky, 1998; Torsvik and Andersen, 2002). However, early and middle Paleozoic ophiolites and subduction complexes have not been observed between the Central and South Taimyr terranes, indicating that the collision might have been oblique (Vernikovsky, 1998).

Paleozoic

Riphean and Paleozoic rocks of the North Taimyr terrane (part of the Kara block) were deposited along a passive margin (Uflyand and others, 1991). The Kara block (Metelkin and
Geology and Assessment of Undiscovered Oil and Gas Resources of the Northwest Laptev Sea Shelf Province, 2008

The South Taimyr terrane became a passive margin on which as much as 4 km of shelf carbonates and mudstones were deposited during the Ediacaran through Vendian to middle Carboniferous (Kontorovich and others, 1994). The area was a northward-dipping (present day) monocline until the end of the late Paleozoic (Stepanenko, 1988). During the Devonian, however, the Siberian craton passed over a mantle plume (hot spot), causing magmatism and forming rift grabens between the South Taimyr terrane and the Siberian craton, beneath the present-day Yenisey-Khatanga Basin (fig. 2).

The Siberian craton collided with the Kara block in the Taimyr area beginning in the late Carboniferous (Vernikovsky, 1995, 1998; Bogdanov and others, 1998; Golonka and others, 2003). Although some researchers have suggested that this event was an extension of the Uralian collision (Zonenshain and Natapov, 1990; Vernikovsky, 1995; Inger and others, 1999; Gee and others, 2006), no Paleozoic oceanic rocks and Uralian collisional assemblages have been observed in the Taimyr fold-and-thrust belt (Gee and others, 2006; Lorenz and others, 2007). According to Vernikovsky (1995), late Carboniferous collision is responsible for the regional metamorphism, granitic intrusions, and transformation of the Siberian continental margin. The Kara block was uplifted and eroded at that time, shedding clastic sediment into the Sverdrup and Barents Basins and onto the South Taimyr passive margin (Zonenshain and Natapov, 1990).

From the Devonian through Triassic, the Siberian craton drifted northward, moving from warmer, dry climate in low to middle latitudes to cooler, humid climate in higher latitudes (Zonenshain and others, 1990). In the middle Carboniferous, carbonate deposition was replaced by deposition of terrigenous clastic sediment (Stepanenko, 1988; Kontorovich and others, 1994; Girshgorn, 1996).

Another extensional event that occurred during the late Permian and Early Triassic between the South Taimyr terrane and the Siberian craton might also have affected the southern part of the Northwest Laptev Sea Shelf Province. This event resulted in magmatism and volcanism in part of the South Taimyr terrane and the formation of the Yenisey-Khatanga Basin (fig. 2; Kontorovich and others, 1994; Girshgorn, 1996).

### Petroleum-System Elements

Because the stratigraphic section in the Northwest Laptev Sea Shelf Province is thin (<4 km), any potential petroleum would have been generated off the shelf edge under a thicker sedimentary succession, migrating updip into marine shelf sedimentary deposits. A single Mesozoic and Cenozoic composite Total Petroleum System (TPS) was identified for the province, and lithostratigraphic column and a TPS events chart with petroleum-system elements is shown in figure 4.

### Source Rocks

Source rocks in the Northwest Laptev Sea Shelf Province are presumed to be Paleogene mudstone deposited during periods of restricted marine and anoxic conditions (Grantz and others, 2001), on the basis of the geochemical composition of organic matter in samples recovered from steep slopes of the Northwind and Lomonosov Ridges. Other potential source rocks include Lower and Upper Cretaceous and Paleogene gas-prone coaly and carbonaceous strata. Cretaceous coaly and carbonaceous clastic rocks are observed on Bol’shoy Begichev Island (fig. 2). Organic-rich and oil-prone Upper Jurassic marine mudstone crops out on Bol’shoy Begichev Island and the nearby Pakhsa Peninsula (fig. 2). The presence of these Mesozoic source rocks in the province, however, is unknown. Cretaceous and Paleogene source rocks, deposited along the east edge of the province and on the continental slope outside the province, probably began to generate petroleum during the Paleogene and presently are still in the petroleum-generation stage of maturity. Some petroleum may have migrated laterally updip into marine shelf sediment.

### Mesozoic and Cenozoic

A major tectonic event (the early Kimmerian orogeny) 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). This event resulted in deformation of the Taimyr fold-and-thrust belt (Torsvik and Andersen, 2002).

Localized Late Cretaceous inversion and folding occurred before the opening of the Eurasian Basin (Scott and others, 2003). Rifting might have begun as early as 64 Ma, with initial spreading at 56–58 Ma, younging southward (Sekretov, 2002). Oceanic spreading has continued until the present, though at progressively slower rates (Sekretov, 2002).

Thin strata of Upper Triassic through Cretaceous clastic rocks, Paleogene clastic rocks (mainly sandstone), and unconsolidated Pleistocene and Holocene clastic sediment are exposed on Severnaya Zemlya and the Taimyr Peninsula (Churkin and others, 1981). Upper Jurassic mudstone; unconsolidated Lower Cretaceous clastic sediment including Albian coal; and Pleistocene sand and gravel crop out on Bol’shoy Begichev Island, along the western province margin (fig. 2; Churkin and others, 1981). Mesozoic and Cenozoic strata thicken offshore, to ~2.5 km on the Northwest Laptev Sea Shelf and ~8 km on the continental slope (fig. 3).

The Northwest Laptev Sea Shelf Province has probably undergone periodic glaciation from the late Pliocene onward, but the thickness, duration, and extent of ice sheets are poorly constrained.
Reservoir and Seal Rocks

If present, Jurassic and Lower Cretaceous sandstones constitute potential reservoirs in the Northwest Laptev Sea Shelf Province, similar to those in the neighboring Yenisey-Khatanga Basin (Kontorovich and others, 1994). Younger strata are shallow and thin but might provide adequate reservoirs. Interbedded mudstone would provide seals. Potential reservoirs that could be present in the prerift section include Proterozoic and Paleozoic clastic and carbonate rocks in the folded basement.

Charging Mesozoic and older reservoir rocks with petroleum from younger source rocks can be problematic. Reservoir rocks must be juxtaposed with source rocks sometime during the structural formation of the area, unless petroleum migration occurred vertically through faults and fractures.

Traps and Timing

Traps for petroleum accumulation include extensional structures, such as normal faults and rollover anticlines and onlapped marine-shelf strata (pinchouts), that probably formed before and during petroleum generation.

Assessment Units

One assessment unit (AU), the Northwest Laptev Sea Shelf AU, was defined for the Northwest Laptev Sea Shelf Province. In this study, an AU is defined as a volume of rock within the TPS that has similar geologic characteristics. The estimated numbers and sizes of undiscovered petroleum accumulations in the AU are listed in the appendix, and the geologic analog data used to evaluate the AUs are summarized in tables 1 and 2.

Northwest Laptev Sea Shelf Assessment Unit

The Northwest Laptev Sea Shelf AU coincides with the Northwest Laptev Sea Shelf Province and is the only AU in the province. The AU area is approximately 114,000 km², 91 percent of which is offshore in the Laptev Sea. The AU is entirely north of the Arctic Circle. The stratigraphic section includes sedimentary rocks in the prerift, synrift, and postrift successions.

Geological Analysis of Assessment Unit Probability

No petroleum accumulations have been discovered, nor have any wells been drilled, in the Northwest Laptev Sea Shelf AU as of 2008. The probability that the AU contains at least one petroleum accumulation equal to or greater than the minimum field size of 50 million barrels of oil equivalent (MMBOE) is estimated at 40 percent (0.40). The input data are reported in the appendix and summarized below.

Charge Probability.—A charge probability of 0.50 was estimated because the presence of thermally mature source rocks in and adjacent to the AU has not been proved and petroleum migration into older Mesozoic reservoir rocks is problematic.

Rock Probability.—A rock probability of 0.80 was estimated. The existence of reservoir rocks and traps is inferred but has not been proved.

Timing and Preservation Probability.—A timing-and-preservation probability of 1.00 was estimated. Potential Mesozoic and Paleogene source rocks would have been mature by the end of the Paleogene, and traps associated with rifting and marine-shelf deposition were present before petroleum generation.

Geologic Analogs for Assessment

We used data for passive rift margins (table 1) from the U.S. Geological Survey (USGS) Analog Database (Charpentier and others, 2008) to estimate the number and size distributions of undiscovered petroleum accumulations in the Northwest Laptev Sea Shelf AU. The analog dataset contains 23 AUs representing extensional, rifted passive margins, with both clastic and carbonate rocks and no salt structures (table 1). Some AUs had early preextension compressional events. The analog AUs have discovered oil and gas fields larger than the minimum size defined for this assessment (50 MMBOE; table 1).

Number of Undiscovered Accumulations.—The number of undiscovered petroleum accumulations was estimated from field densities (estimated number of undiscovered accumulations plus number of discovered accumulations exceeding 50 MMBOE per 1,000 km²) contained in the analog dataset, which are as follows: (1) the median and maximum densities of discovered accumulations are 0.03 and 0.2 fields per 1,000 km², respectively; and (2) the median and maximum densities of discovered plus undiscovered accumulations are 0.2 and 0.5 fields per 1,000 km², respectively. Densities of 0.1 and 0.50 (median and maximum, respectively) were used in this assessment, approximating those of the analogs. The total minimum, median, and maximum number of undiscovered petroleum accumulations are 1, 10, and 60, respectively (see appendix). The minimum of one field was chosen as a default parameter. A gas-rich oil/gas mixture of 0.2 (from 0 to 0.5) was assumed because potential Cretaceous and Paleogene source rocks are most likely gas prone. The estimated number of undiscovered oil accumulations is 0 (minimum), 2 (median), and 30 (maximum) and the estimated number of undiscovered gas accumulations is 1 (minimum), 8 (median), and 60 (maximum) (appendix 1).

Sizes of Undiscovered Accumulations.—The minimum, median, and maximum sizes of undiscovered petroleum accumulations are reported in the appendix. The minimum sizes of undiscovered accumulations are 50 million barrels...
Figure 4. Lithostratigraphic column and Total Petroleum System events chart for the Northwest Laptev Sea Shelf Province. Source rocks column at far left 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).
### Table 1. Rifted passive margins used as geologic analogs for the Northwest Laptev Sea Shelf Assessment Unit.

[Analog data from Charpentier and others (2008)]

<table>
<thead>
<tr>
<th>Province (Assessment Unit)</th>
<th>Structural setting</th>
<th>Trap system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Volga-Ural Region (10150102)</td>
<td>Compressional</td>
<td>Basement-involved block structures</td>
</tr>
<tr>
<td>Ma’Rib-Al Jawf/Masila Basin (20040101)</td>
<td>Extensional</td>
<td>Extensional grabens and other structures related to normal faulting</td>
</tr>
<tr>
<td>Widyan Basin-Interior Platform (20230101)</td>
<td>Extensional</td>
<td>Basement-involved block structures</td>
</tr>
<tr>
<td>Widyan Basin-Interior Platform (20230201)</td>
<td>Extensional</td>
<td>Basement-involved block structures</td>
</tr>
<tr>
<td>Pelagian Basin (20480101)</td>
<td>Compressional, Extensional</td>
<td>Extensional grabens and other structures related to normal faulting; Transtensional and transpressional</td>
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<tr>
<td>Pelagian Basin (20480201)</td>
<td>Compressional, Extensional</td>
<td>Extensional grabens and other structures related to normal faulting; Transtensional and transpressional</td>
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<td>Red Sea Basin (20710101)</td>
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<td>Extensional grabens and other structures related to normal faulting</td>
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<td>Red Sea Basin (20710201)</td>
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<td>Bonaparte Gulf Basin (39100201)</td>
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<tr>
<td>Bonaparte Gulf Basin (39100301)</td>
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<td>Browse Basin (39130101)</td>
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<td>Northwest Shelf (39480101)</td>
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<td>Extensional grabens and other structures related to normal faulting</td>
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<td>Vestford-Helgeland (40170101)</td>
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<td>Bombay (80430101)</td>
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<td>Basement-involved block structures; stratigraphic undeformed</td>
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Table 2. Field densities, median oil- and gas-field sizes, and exploration maturities of geologic analogs used for the Northwest Laptev Sea Shelf Assessment Unit.

[Analog data from Charpentier and others (2008). Rift-sag basin analogs are listed in table 1. Asterisk (*), not reported in analog database; BCF, billion cubic feet; MMB, millions of barrels; MMBOE, million barrels of oil equivalent; gas volumes are nonassociated].

<table>
<thead>
<tr>
<th>Province (Assessment Unit)</th>
<th>*Field density: number of discovered fields &gt;50 MMBOE per 1,000 km²</th>
<th>Field density: number of discovered and undiscovered fields &gt;50 MMBOE per 1,000 km²</th>
<th>Field size distribution median field size &gt;50 MMBOE</th>
<th>Exploration maturity, in percent by volume in fields &gt;50 MMBOE</th>
<th>Maximum field size (MMBOE)</th>
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<td>0.03</td>
<td>0.21</td>
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<td>0.51</td>
<td>111</td>
<td>35</td>
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(MMB) of crude oil and 300 billion cubic feet (BCF) of natural gas (6 BCF equals 1 MMBOE). The median sizes of undiscovered accumulations are 110 MMB of crude oil and 660 BCF of natural gas. The median size of undiscovered oil fields (100 MMBOE) is slightly less than that of the analog dataset (110 MMBOE). The low-probability maximum field size (2,000 MMBOE) is less than the median of the maximum field sizes in the analog dataset (2,800 MMBOE; see appendix). The median and maximum sizes (660 BCF and 18,000 BCF, respectively) of undiscovered gas fields are greater than those of undiscovered oil fields because Cretaceous and Paleogene potential source rocks most likely are gas prone (see appendix).

**Expected Maximum Undiscovered Accumulation Size.**—The expected maximum size of undiscovered gas accumulations (not reported in appendix) is based on the analog dataset: 3,000 BCF, or 18,000 MMBOE (table 2). The expected maximum size of undiscovered oil accumulations is 200 MMB.

**Petroleum Composition and Properties of Undiscovered Accumulations.**—Coproducts and petroleum-quality properties are derived from global statistics (table 3).

### Assessment Results

The assessment results for the Northwest Laptev Sea Shelf Province and AU are summarized in table 4. Estimates represent undiscovered, technically recoverable, conventional petroleum resources.

The risked mean of undiscovered crude oil is 172 MMB, with a 95-percent chance (F95) of 0 MMB, a 50-percent chance (F50) of 0 MMB, and a five-percent chance (F5) of 894 MMB. The risked mean volume of undiscovered non-associated natural gas is 4,488 BCF, with an F95 of 0 BCF, an F50 of 0 BCF, and an F5 of 20,427 BCF. The largest expected size of an undiscovered oil field is ~232 MMB, and the largest expected size of an undiscovered gas field is ~3,242 BCF (not listed in table 4).

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

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

[Data from Charpentier and others (2008)]

<table>
<thead>
<tr>
<th>Variable</th>
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<tr>
<td>Coproduct ratios</td>
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<tr>
<td>Natural gas-to-crude oil ratio in oil accumulations (cubic feet per barrel)</td>
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<tr>
<td>Natural gas liquids-to-natural gas ratio in oil accumulations (barrels per thousand cubic feet)</td>
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<tr>
<td>Natural gas liquids-to-natural gas ratio in gas accumulations (barrels per thousand cubic feet)</td>
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<tr>
<td>Ancillary data for oil accumulations</td>
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<tr>
<td>API gravity (degrees)</td>
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<td>Viscosity (centipoise)</td>
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<td>Sulfur content of oil (percent)</td>
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<tr>
<td>Ancillary data for gas accumulations</td>
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<tr>
<td>Inert gas content (percent)</td>
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<tr>
<td>Carbon dioxide content (percent)</td>
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<td>Hydrogen sulfide content (percent)</td>
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<td>Depths</td>
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<td>Depth (meters) of water (if applicable)</td>
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<td>Drilling depth (meters)</td>
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Acknowledgments

We are extremely grateful to the USGS Library staff for their help in obtaining rare, hard-to-find geologic articles from the Russian scientific literature. We also thank Feliks Persits for GIS support, and Donald L. Gautier and Gregory F. Ulmishek for their reviews of the manuscript.

References Cited


Table 4. Assessment results for the Northwest Laptev Sea Shelf Province (conventional undiscovered resources).

<table>
<thead>
<tr>
<th>Total petroleum systems and assessment units</th>
<th>AU probability</th>
<th>Field type</th>
<th>Oil (MMB) F95</th>
<th>F50</th>
<th>F5</th>
<th>Mean</th>
<th>Gas (BCF) F95</th>
<th>F50</th>
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<th>NGL (MMB) F95</th>
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<td>Northwest Laptev Sea Shelf AU</td>
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<td>Gas N/A N/A N/A 0 0 18,992 4,221 0 0 513 112</td>
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</table>

[MMB, million barrels; BCF, billion cubic feet. Results shown are fully risked estimates. For gas fields, all liquids are included under the natural gas liquids (NGL) category. F95 denotes a 95-percent chance of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. TPS, total petroleum system; AU, assessment unit. Gray shading indicates not applicable. Numbers do not exactly add to the totals because totals were calculated by statistical aggregation.]


Appendix. Input Data for the Northwest Laptev Sea Shelf Assessment Unit

The appendix is available online only, and may be accessed at https://doi.org/10.3133/pp1824S