Geology and Assessment of Undiscovered Oil and Gas Resources of the Yenisey-Khatanga Basin Province, 2008

Chapter R of
The 2008 Circum-Arctic Resource Appraisal

Professional Paper 1824

U.S. Department of the Interior
U.S. Geological Survey
Eocene strata along the north side of Van Keulenfjorden, Svalbard, include basinfloor 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.
The 2008 Circum-Arctic Resource Appraisal

Chapters

A. Introduction to the 2008 Circum-Arctic Resource Appraisal (CARA) Professional Paper
   By Donald L. Gautier and Thomas E. Moore

B. Methodology for Assessment of Undiscovered Oil and Gas Resources for the 2008
   Circum-Arctic Resource Appraisal
   By Ronald R. Charpentier

North America

C. Geology and Assessment of Undiscovered Oil and Gas Resources of the Chukchi
   Borderland Province, 2008
   By Kenneth J. Bird and David W. Houseknecht

D. Geology and Assessment of Undiscovered Oil and Gas Resources of the Hope Basin
   Province, 2008
   By Kenneth J. Bird, David W. Houseknecht, and Janet K. Pitman

E. Geology and Assessment of Undiscovered Oil and Gas Resources of the Arctic Alaska
   Petroleum Province, 2008
   By David W. Houseknecht, Kenneth J. Bird, and Christopher P. Garrity

F. Geology and Assessment of Undiscovered Oil and Gas Resources of the Yukon Flats Basin
   Province, 2008
   By Kenneth J. Bird and Richard G. Stanley

G. Geology and Assessment of Undiscovered Oil and Gas Resources of the Northwest Canada
   Interior Basins Province, Arctic Canada, 2008
   By Marilyn E. Tennyson and Janet K. Pitman

H. Geology and Assessment of Undiscovered Oil and Gas Resources of the Franklinian Shelf
   Province, Arctic Canada and North Greenland, 2008
   By Marilyn E. Tennyson and Janet K. Pitman

I. Geology and Assessment of Undiscovered Oil and Gas Resources of the Sverdrup Basin
   Province, Arctic Canada, 2008
   By Marilyn E. Tennyson and Janet K. Pitman

Greenland

J. Geology and Assessment of Undiscovered Oil and Gas Resources of the West Greenland-
   East Canada Province, 2008
   By Christopher J. Schenk
K. Geology and Assessment of Undiscovered Oil and Gas Resources of the East Greenland Rift Basins Province, 2008
   By Donald L. Gautier

North Atlantic Ocean

L. Geology and Assessment of Undiscovered Oil and Gas Resources of the Jan Mayen Microcontinent Province, 2008
   By Thomas E. Moore and Janet K. Pitman

Eurasia

M. Geology and Assessment of Undiscovered Oil and Gas Resources of the Mezen’ Basin Province, 2008
   By Timothy R. Klett and Janet K. Pitman

N. Geology and Assessment of Undiscovered Oil and Gas Resources of the Timan-Pechora Basin Province, Russia, 2008
   By Christopher J. Schenk

O. Geology and Assessment of Undiscovered Oil and Gas Resources of the East Barents Basins Province and the Novaya Zemlya Basins and Admiralty Arch Province
   By Timothy R. Klett

P. Geology and Assessment of Undiscovered Oil and Gas Resources of the North Kara Basins and Platforms Province, 2008
   By Timothy R. Klett and Janet K. Pitman

Q. Geology and Assessment of Undiscovered Oil and Gas Resources of the Northern West Siberian Mesozoic Composite Total Petroleum System of the West Siberian Basin Province, Russia, 2008
   By Christopher J. Schenk

R. Geology and Assessment of Undiscovered Oil and Gas Resources of the Yenisey-Khatanga Basin Province, 2008
   By Timothy R. Klett and Janet K. Pitman

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

T. Geology and Assessment of Undiscovered Oil and Gas Resources of the Lena-Anabar Basin Province, 2008
   By Timothy R. Klett and Janet K. Pitman
U. Geology and Assessment of Undiscovered Oil and Gas Resources of the Tunguska Basin Province, 2008
   By Craig J. Wandrey and Timothy R. Klett

V. Geology and Assessment of Undiscovered Oil and Gas Resources of the Lena-Vilyui Basin Province, 2008
   By Timothy R. Klett and Janet K. Pitman

W. Geology and Assessment of Undiscovered Oil and Gas Resources of the Laptev Sea Shelf Province, 2008
   By Timothy R. Klett and Janet K. Pitman

X. Geology and Assessment of Undiscovered Oil and Gas Resources of the Zyryanka Basin Province, 2008
   By Timothy R. Klett and Janet K. Pitman

Y. Geology and Assessment of Undiscovered Oil and Gas Resources of the East Siberian Sea Basin Province, 2008
   By Kenneth J. Bird, David W. Houseknecht, and Janet K. Pitman

Z. Geology and Assessment of Undiscovered Oil and Gas Resources of the Vilkitskii Basin Province, 2008
   By Kenneth J. Bird, David W. Houseknecht, and Janet K. Pitman

AA. Geology and Assessment of Undiscovered Oil and Gas Resources of the Long Strait Province, Russian High Arctic, 2008
    By Kenneth J. Bird, David W. Houseknecht, and Janet K. Pitman

Arctic Ocean

BB. Geology and Assessment of Undiscovered Oil and Gas Resources of the Amerasia Basin Petroleum Province, 2008
    By David W. Houseknecht, Kenneth J. Bird, and Christopher P. Garrity

CC. Geology and Assessment of Undiscovered Oil and Gas Resources of the Lomonosov-Makarov Province, Central Arctic Ocean, 2008
    By Thomas E. Moore, Kenneth J. Bird, and Janet K. Pitman

DD. Geology and Assessment of Undiscovered Oil and Gas Resources of the Eurasia Basin Province, Eastern Arctic Ocean, 2008
    By Thomas E. Moore and Janet K. Pitman
Contents

Abstract ........................................................................................................................................................... 1
Yenisey-Khatanga Basin Province .................................................................................................................. 1
  Province Boundary Definition ......................................................................................................................... 1
Petroleum Occurrence ..................................................................................................................................... 1
Tectonostratigraphic Evolution ......................................................................................................................... 4
  Proterozoic and Early Paleozoic ....................................................................................................................... 4
  Middle and Late Paleozoic .............................................................................................................................. 4
  Jurassic and Cretaceous .................................................................................................................................. 4
  Cenozoic .......................................................................................................................................................... 6
Petroleum-System Elements ............................................................................................................................. 6
  Source Rocks ................................................................................................................................................ 6
  Reservoir and Seal Rocks ................................................................................................................................ 7
  Traps and Timing ............................................................................................................................................. 7
Assessment Units .......................................................................................................................................... 12
  Khatanga Saddle Assessment Unit ................................................................................................................. 12
    Geological Analysis of Assessment-Unit Probabilities .................................................................................. 12
    Geologic Analogs for Assessment .................................................................................................................. 12
  Yenisey-Khatanga Basin Assessment Unit ...................................................................................................... 16
    Geological Analysis of Assessment-Unit Probabilities .................................................................................. 16
    Geologic Analogs for Assessment .................................................................................................................. 16
Assessment Results ....................................................................................................................................... 19
Acknowledgments .......................................................................................................................................... 20
References Cited ............................................................................................................................................. 20

Appendixes

[Available for download at https://doi.org/10.3133/pp1824R]

1. Assessment Input Data for the Khatanga Saddle Assessment Unit.
2. Assessment Input Data for the Yenisey-Khatanga Basin Assessment Unit.
Figures

1. Map of Yenisey-Khatanga Basin Province, showing location of province and assessment units ..........................................................................................................................................................................................2
2. Map of Yenisey-Khatanga Basin Province, showing major structural features, approximate depth to economic basement, and locations of geologic cross sections and petroleum-system models used in assessment..............................................................................................................................3
3. Regional geologic cross sections of the Yenisey-Khatanga Basin Province ........................................5
4. Lithostratigraphic column and total petroleum system events chart for the Yenisey-Khatanga Basin Province ............................................................................................................................................................................8
5. Burial-history models for pseudowells, Payakhskoye and Balakhinskoye, in the Yenisey-Khatanga Basin, showing thermal maturity .........................................................................................................................10

Tables

1. Basins used as geologic analogs in assessment of the Khatanga Saddle Assessment Unit ........................................................................................................................................................................................................................................................................................13
2. Basins used as geologic analogs in assessment of the Yenisey-Khatanga Basin Assessment Unit ........................................................................................................................................................................................................................................................................................17
3. World statistics for oil and gas coproduct ratios, ancillary data, and depths ...........................................19
4. Assessment results (conventional undiscovered resources) for the Yenisey-Khatanga Basin Province ........................................................................................................................................................................................................................................................................................20
Chapter R

Geology and Assessment of Undiscovered Oil and Gas Resources of the Yenisey-Khatanga Basin Province, 2008

By Timothy R. Klett and Janet K. Pitman

Abstract

The U.S. Geological Survey (USGS) assessed the potential for undiscovered oil and gas resources of the Yenisey-Khatanga Basin Province as part of the USGS Circum-Arctic Resource Appraisal. The province is situated between the Taimyr-Kara high (Kara block, Central Taimyr fold belt, and South Taimyr fold belt) and the Siberian craton. The two assessment units (AUs) defined for this study—the Khatanga Saddle AU and the Yenisey-Khatanga Basin AU were assessed for undiscovered, technically recoverable, conventional resources. The estimated mean volumes of undiscovered resources for the Yenisey-Khatanga Basin Province are ~5.6 billion barrels of crude oil, ~100 trillion cubic feet of natural gas, and ~2.7 billion barrels of natural-gas liquids, all north of the Arctic Circle.

Yenisey-Khatanga Basin Province

Province Boundary Definition

The Yenisey-Khatanga Basin Province is situated between the Siberian craton to the south and the south slope of the Taimyr-Kara high to the north (figs. 1, 2). A north-northwest-trending contractional-deformation zone called the Pakhsino-Begichev Arch, which is the westward extent of the Verkhoynansk-Olenek fold and thrust zone, forms the province’s east boundary (Mikulenko, 1983; Grebenyuk and others, 1988). The fold and thrust zone extends from the neighboring Lena-Anabar Basin to the south, northward through Bol’shoi Begichev Island in Khatanga Bay, to Cape Tsvetkov on the Taimyr Peninsula. The front of this fold and thrust zone extends westward to the Tigiano-Anabar horst (fig. 3), which might involve thrust faulting as part of its structural configuration (Drachev, 2002; G.F. Ulmishek, written commun., 2008).

The Yenisey-Khatanga Basin is a northeastern structural arm of the West Siberian Basin (Baldin, 2004). Although the Mesozoic and Tertiary stratigraphic successions in the two basins have much in common, the basins are structurally separated by Mesozoic uplifts (Ulmishek, 2003). The Taimyr-Kara high, which bounds the northern margin of the Yenisey-Khatanga Basin, consists of the South and Central Taimyr fold belts in the south and the Kara block to the north (Ulmishek, 2003). The Yenisey-Khatanga Basin is a Mesozoic sag that formed above a late Permian and Early Triassic extensional- rift basin (Kontorovich and others, 1994). The Yenisey-Khatanga Basin is filled with 7 to 12 km of Mesozoic clastic rocks (Baldin and others, 1997).

Petroleum Occurrence

Petroleum was discovered in the Yenisey-Khatanga Basin Province in the early 1940s (1943–1945) in mainly Permian marine clastic rocks on the Khatanga Saddle. Because of poor reservoir quality (G.F. Ulmishek, written commun., 2006) and possibly extensive faulting (Danilkin, 1985), Mesozoic strata were considered noncommercial for petroleum, and exploration stopped in 1953. Exploration resumed in the western part of the Yenisey-Khatanga Basin Province in 1967, leading to the discovery of the Messoyakhskoye gas field and the North Soleninskoye gas-condensate field. Most of the discoveries were in Jurassic and Cretaceous rocks within anticlines. In 1979, the Deryabinskoye gas field was discovered in a nonanticlinal pinchout trap of Upper Jurassic and Berriasian sandstone. A total of 16 gas and gas-condensate fields and 4 oil fields had been discovered by 2008, most in the western part of the province. The gas fields in the western part of the province have been developed to supply natural gas to local industry in Noril’sk (fig. 2).
Figure 1. Map of Yenisey-Khatanga Basin Province, showing location of province and assessment units. Oil and gas field data from IHS Energy Group (2007). AU, assessment unit.
Figure 2. Map of Yenisey-Khatanga Basin Province, showing major structural features, approximate depth to economic basement, and locations of geologic cross sections and petroleum-system models used in assessment. Data from Persits and Ulmishek (2003) and IHS Energy Group (2007).
Tectonostratigraphic Evolution

The Yenisey-Khatanga Basin contains a regional system of arches and troughs that extend diagonally across the length of the basin for ~1,000 km from the Yenisey River to the Koryano-Tass arch (fig. 2). The arches formed in a pre-Jurassic intercontinental extensional basin (Kontorovich and others, 1994). The geologic cross sections in figure 3 show the characteristics of the basin fill.

Proterozoic and Early Paleozoic

The Yenisey-Khatanga Basin formed along the present-day northern margin of the Siberian craton as a northwest-oriented Neoproterozoic (Riphean) rift filled with 2 to 3 km of clastic sediment (Kontorovich and others, 1994). During the Paleozoic, the area became a passive margin in which as much as 4 km of Neoproterozoic (Vendian) through middle Paleozoic shelf carbonates and mudstone were deposited (Kontorovich and others, 1994). The area was a northward-dipping (present-day orientation) monocline until the end of the late Paleozoic (Stepanenko, 1988).

Middle and Late Paleozoic

The Siberian craton drifted northward from the Devonian through Triassic, moving from a warm dry climate at low to middle latitudes into a cooler humid climate at higher latitudes (Zonenshain and others, 1990). During the Devonian, the craton passed over a mantle plume (hot spot), causing magmatism and forming riftgrabens under the present-day Khatanga Saddle and the Yenisey-Khatanga Basin. In addition to carbonates, evaporites were deposited in the rift grabens and later deformd to form diapirs and other halokinetic structures on the Khatanga Saddle (Surkova, 1987; Matykhin and Sokolov, 1998). Organic-rich mudstone might also have been deposited within these rift grabens before evaporite deposition (G.F. Ulmishek, oral commun., 2006). In the middle Carboniferous, carbonate deposition was replaced by the deposition of terrigenous clastic sediment (Stepanenko, 1988; Kontorovich and others, 1994; Girshgorn, 1996).

On the basis of isotope-geochronologic data, the Central Taimyr fold belt is presumed to have formed by collision of island arcs with continental blocks during Neoproterozoic time (Vernikovsky, 1995). Whether Central Taimyr comprises an accretionary prism that collided with the North Taimyr terrane during the late Paleozoic to form the North Kara block (Zonenshain and others, 1990; Uflyand and others, 1991) or collided with the Siberian craton during the Neoproterozoic (late Riphean, 600–570 Ma; Bogdanov and others, 1998; Vernikovsky, 1998; Torsvik and Andersen, 2002) is unclear. Although early and middle Paleozoic ophiolites and subduction complexes have not been observed between the Central and South Taimyr terranes, such a collision might have been oblique or strike-slip (Vernikovsky, 1998). If the Central Taimyr terrane collided with the Siberian craton during the Neoproterozoic, the terrane would have become part of the Siberian passive margin (stable platform and shallow and open sea shelf) until the late Carboniferous (Zonenshain and others, 1990; Vernikovsky, 1998).

During the late Permian and Early Triassic, extension, magmatism, and volcanism occurred in the Yenisey-Khatanga Basin (Kontorovich and others, 1994; Girshgorn, 1996). The present-day basin might be a failed rift superimposed on a rift passive margin. During the late Permian and Early Triassic, a triple junction was situated along the present-day northwestern margin of the Siberian craton (Allen and others, 2006). Rifting resulted in the emplacement of flood basalts across the Tunguska Basin and deposition of as much as 2 km of volcanic and volcanioclastic rocks in the western part of the Yenisey-Khatanga Basin. A central basin developed along the north edge of the Siberian craton, and a Triassic sea probably extended into the basin from the northeast, but conditions became lagoonal to continental southwestward (Kontorovich and others, 1994; Vernikovsky, 1995; Girshgorn, 1996). In the northeastern part of the basin (along the east coast of the Taimyr Peninsula), as much as 1.5 km of late Permian and Early Triassic rocks was deposited. These rocks contain marine and continental (freshwater) clastic rocks, with volcaniclastic rocks in the lower part of the section (Kazakov and others, 1982).

Jurassic and Cretaceous

Another major tectonic event associated with dextral transpression is assumed to have occurred during the Late Triassic and, possibly, 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). Middle Triassic and older rocks were eroded from the edges of the Yenisey-Khatanga Basin and redeposited in the basin center (Grebenyuk and others, 1988; Kontorovich and others, 1994).

Throughout the Jurassic, clastic deposition continued along the rifted passive margins of the Siberian craton. In the Yenisey-Khatanga Basin, a sag basin formed in which 3 to 4 km of sediment was deposited (Gramberg and others, 1988; Kontorovich and others, 1994) with as much as 2 km on the Khatanga Saddle (Lebchuk, 1990).

Contractional deformation of the Yenisey-Khatanga Basin during the Late Jurassic and Early Cretaceous has been suggested in many studies (for example, Baldwin and others, 1997). A system of diagonally orientated, faulted arches formed, upon which ~1 km of Middle Jurassic through Lower Cretaceous, pre-Valanginian rocks was subsequently eroded (Danilkin, 1984; Polyakova and others, 1986; Afanasenkov, 1988; Grebenyuk and others, 1988; Botneva and Frolov, 1996). Sediment eroded from the arches and the Siberian craton was deposited within the depressions as prograding clinoforms, grading upward into shallow-marine and deltaic strata (Lebchuk, 1990; Grebenyuk and others, 2003; Baldwin, 2004). The Upper Jurassic and Lower Cretaceous progradational succession contains three packages
Figure 3. Regional geologic cross sections of the Yenisey-Khatanga Basin Province. Locations shown on figure 2. Vertical red lines are locations of wells or pseudowells used for petroleum-generation models. Fm., Formation. Modified from Kazais (1976), Danilkin (1985), and Filipiov and others (1999).
of clinoforms of (1) Callovian through Kimmeridgian (only on the northwest slopes of the Rassokhin and Malokhet arches), (2) Volgian and Berriasian, and (3) Neocomian age (Lebchuk, 1990; Grebenyuk and others, 2003; Baldin, 2004). The arches within the Yenisey-Khatanga Basin separated the marine connection of the West Siberian Basin with the open sea to the northeast (Baldin and others, 1997).

The timing of formation of structures across the Yenisey-Khatanga Basin is, however, uncertain, possibly late Cenozoic. Upper Cretaceous rocks are absent on the arches but thick in the depressions (fig. 3). Kontorovich and others (1994) stated that 20–40 percent of local structural growth in the basin is attributable to neotectonic movements. Additionally, arches in the neighboring West Siberian Basin to the west primarily formed during the Oligocene and Neogene (G.F. Ulmishek, written commun., 2008). Other studies (for example, Kontorovich and others, 1994) suggest that the arches are structures that reflect earlier tectonic activity.

Cenozoic

Minor uplift (maximum 100 m) of the Yenisey-Khatanga Basin occurred during the Eocene (Stepanenko, 1988). Tectonic movements resumed in the Neogene. The amount of uplift increases from ~200 m in the east to 1,500 m in the west (Polyakova and others, 1986; Afanasenkov, 1984; Danilkin, 1984; Kontorovich and others, 1991; Botneva and Frolov, 1996). The Malokhet arch in the southwestern part of the basin was uplifted 900 m during this time (Kulakov and Makhotina, 1988).

Petroleum-System Elements

A single Proterozoic through Mesozoic composite total petroleum system (TPS) was identified for the Yenisey-Khatanga Basin province. A lithostratigraphic column and TPS events chart of petroleum-system elements are shown in figure 4.

Source Rocks

Middle and Upper Jurassic and Neocomian mudstones, containing 1.2–1.6 weight percent and as much as 6 weight percent total organic carbon (TOC), are the major petroleum-source rocks in the Yenisey-Khatanga Basin (Polyakova and others, 1986; Lebchuk, 1990; Kontorovich and others, 1991). These mudstones contain both type II and type III kerogen, with type III dominating (Fomin and Romakhina, 1989; Kontorovich and others, 1994).
Potential source rocks include Devonian, Permian, and Triassic mudstones (Botneva and Frolov, 1996), although no reliable information on Proterozoic and Paleozoic source rocks exists for the Yenisey-Khatanga Basin (Kontorovich and others, 1994). Organic-rich Proterozoic mudstone could exist in Riphean rift/sag basins but probably became overmature with respect to petroleum generation and generated dispersed petroleum before the Yenisey-Khatanga Basin formed during the Paleozoic (Stepanenko, 1988; Kontorovich and others, 1994; Botneva and Frolov, 1996). Presumed Devonian oil was collected from fractured Devonian limestone 470 m deep in the Komsomol’sk’y Mine on the Khatanga Saddle. Lower Permian marine mudstone on the Khatanga Saddle contains as much as 2 weight percent TOC (Grebenyuk and others, 1988; Stepanenko, 1988). Natural gas generated from Permian coal-bearing strata (containing coal beds maximally 1.5 m thick) might also contribute to petroleum accumulations along the Khatanga Saddle (Polyakova and others, 1984). Middle and Upper Triassic mudstone in the eastern part of the Yenisey-Khatanga Basin is TOC rich (Filipiov and others, 1999).

Heat flow has varied over time, and amounts of uplift and erosion vary and depend on position within the basin. Areas of tectonic uplift have higher geothermal gradients than deeper parts of the basin (Danilkin, 1984; Grebenyuk and others, 1988). Devonian through Permian extension was associated with higher heat flow (Botneva and Frolov, 1996). Maximum heat flow occurred at the beginning of the Triassic and decreased during the Jurassic and Cretaceous (Stepanenko, 1988; Botneva and Frolov, 1996). Although upper Paleozoic marine sediment entered the oil window during the early Mesozoic (Grebenyuk and others, 1988; Stepanenko, 1988), oil migration into Mesozoic rocks was limited because of the presence of Triassic volcanic rocks (Kontorovich and others, 1994).

Petroleum-generation modeling indicates that Jurassic and Lower Cretaceous strata were buried in the oil-generation window before the Cenozoic (fig. 5). Some of this section is presently in the gas window. The data of Afanasenkov (1988), Grebenyuk and others (1988), and Kontorovich and others (1994) support these interpretations. The models also indicate that oil generation begins at ~2 km depth with the main part of the window between 3 and 4 km. The top of the gas window is at ~6 km depth for both the Yenisey-Khatanga Basin and the Khatanga Saddle (fig. 5). This interpretation is supported by the models of Polyakova and others (1986), Stepanenko (1988), and Lebchuk (1990).

**Reservoir and Seal Rocks**

Jurassic and Lower Cretaceous clastic rocks are the primary reservoirs in the Yenisey-Khatanga Basin (Kontorovich and others, 1994). Fields are multipooled, with local reservoirs and traps (Kontorovich and others, 1994). Accumulations are structurally controlled, but reservoirs commonly pinch out (Kontorovich and others, 1994). Eight reservoir and seal pairs have been identified: five in the Jurassic, two in the Lower Cretaceous, and one in the Upper Cretaceous section.

Potential reservoirs include Proterozoic and Paleozoic carbonate and clastic rocks, as well as Permian and Triassic clastic rocks. Permian clastic rocks along the basin margin and on the Khatanga Saddle contain numerous shows of bitumen, crude oil, and natural gas (Gramberg and others, 1988). Proterozoic and Paleozoic mudstone, Paleozoic evaporites, Permian and Triassic mudstone, and Triassic volcanic rocks could serve as effective seals (Gramberg and others, 1988; Grebenyuk and others, 1988).

Surface temperature dropped by 20–25 °C at the end of the Oligocene (Kontorovich and others, 1994). Permafrost and gas hydrates could act as seals for shallow reservoirs (Kontorovich and others, 1994). On the basis of permafrost thickness and temperatures and pressures, the base of hydrate stability is at ~1-km depth (Kontorovich and others, 1994).

**Traps and Timing**

Traps for petroleum accumulation in the Yenisey-Khatanga Basin Province include arches, anticlines, and other structural highs; pinchouts along the basin margins and arches; traps associated with prograding sequences (clinoforms, topsets, submarine channels, gravity flows, and fans; Khmelevskii and others, 1990); salt-related structures on the Khatanga Saddle; and reservoirs associated with faulted basement rocks (Kontorovich and others, 1994). Structural traps formed as a result of Mesozoic or Cenozoic compression. According to petroleum-generation models, Lower Jurassic rocks started generating petroleum by Middle Jurassic time in deeper parts of the basin, and Middle and Upper Jurassic and Neocomian source rocks generated petroleum by Paleogene time, before and during deformation and trap formation (fig. 5). Petroleum migrated vertically (Stepanenko, 1988), but thick Upper Jurassic, Berriasian, and Valanginian mudstone could have complicated migration patterns (Kontorovich and others, 1994).

Recent tectonic movements have modified older structures and caused remigration, formation of new traps and new migration pathways, and destruction and dispersal of older accumulations (Grebenyuk and others, 1988; Kulakov and Makhotina, 1988). Gas expansion might have displaced crude oil from traps, escaping or forming oil legs. Some crude oil could have been cracked to natural gas (Polyakova and others, 1984; Grebenyuk and others, 1988). Destruction of previously trapped petroleum might account for degraded petroleum (bitumen) in Proterozoic and lower Paleozoic rocks along the Anabar structural high of the Siberian craton and locally within the Yenisey-Khatanga Basin (Stepanenko, 1988).
### The 2008 Circum-Arctic Resource Appraisal

**Sea level curve**
- 2008
- 2002
- 2000
- 2000
- 2000

**Average global temperature**
- 12.5
- 2.8
- 29.0
- 2.6
- 25.0
- 1.2
- 8.0
- 0.4
- 8.0
- 0.3
- 9.0
- 1.0

**Maturation and migration**
- Petroleum loss

---

**Geologic time scale**

| Source rocks | Petroleum system | Comments |
|--------------|------------------|----------|

#### Source rocks column:
- Petroleum system
- Ocean anoxic events
- Snowball Earth
- Continental clastic rocks
- Nearshore clastic rocks
- Offshore clastic rocks
- Volcanic and volcaniclastic rocks
- Carbonate rocks
- Organic-rich mudstone

#### Petroleum system column:
- Source rock presence
- Reservoir rock presence
- Trap presence
- Petroleum loss

#### Comments column:
- Zimnyaya
- Vimskaya
- Leont'yevskaya
- Malishevskaya
- Yuryung-Tumus
- Tochinskaya
- Khatanga Basin AU
- Yenisey-Khatanga Basin AU
- Balakhninskaya
- Ketparskaya/Kentar
- Dzhangodskaya
- Laydinsky
- Arangostakh Saybulakh Airkat
- Sigovskaya
- Deriyabinskaya
- Gol'chikhinskaya

---

**Figure 4. Lithostratigraphic column and total petroleum system events chart for the Yenisey-Khatanga Basin Province.** Data from Bobiliev (1985), Surkova (1987), Kulikov (1989), Lebchuk (1990), Krason and Finley (1993), Kontorovich and others (1994), and Filipiov and others (1999). 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).
Figure 4. Lithostratigraphic column chart for the Yenisey-Khatanga Basin Province. Data from Bobiliev (1985), Surkova (1987), Kulikov (1989), Lebchuk (1990), Krason and Finley (1993), Kontorovich and others (1994), and Filipov and others (1999). 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).
Figure 5. Burial-history models for pseudowells, Payakhskoye, A; and Balakhinskoye, B, in the Yenisey-Khatanga Basin, showing thermal maturity. See figure 3 for locations of wells. \( R_o \), vitrinite reflectance, in percent (%). Data from Afanasenkov (1988), Levchuk and Fomin (1988), Fomin and Romakhina (1989), Krason and Finley (1993), and Botneva and Frolov (1996). Petromod references are Wygrala (1989), Sweeney and Burnham (1990), and Integrated Exploration Systems (2008).
Figure 5.—Continued
**Assessment Units**

Two assessment units (AUs), the Khatanga Saddle AU and the Yenisey-Khatanga Basin AU, have been defined for the Yenisey-Khatanga Basin Province. For 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 oil and gas fields in each AU are reported in appendixes 1 and 2, and the geologic analog data used to evaluate the AUs are summarized in tables 1 and 2.

**Khatanga Saddle Assessment Unit**

The Khatanga Saddle AU, which comprises the eastern updip margin of the Yenisey-Khatanga Basin, is most likely the northward-plunging extension of the Anabar structural high of the Siberian craton (figs. 1, 2). The break in slope between the Khatanga Saddle and the Yenisey-Khatanga Basin is the west boundary of the AU. The AU is bounded on the east by the west edge of a north-south-trending fold and thrust front called the Paksino-Begichev arch, which might be a westward extent of the Verkhoyansk-Olenek contractional-deformation front. The Taimyr-Kara high (including the Kara block, the Central Taimyr fold belt, and the South Taimyr fold belt) and the frontal fault of the Kryano-Tass arch are the northern boundary of the AU (figs. 1, 2), and the Siberian craton bounds the southern margin. The area of the AU is ~45,000 km², 23 percent of which is offshore within Khatanga Bay.

The saddle is structurally complex, consisting of many inverted horsts and grabens intruded by Permian and Triassic basaltic sills. Stratigraphically, the AU includes the entire sedimentary section from Proterozoic through Mesozoic (Cretaceous). The section of Proterozoic (Riphean) through Silurian rocks is >3 km thick locally. A 2-km-thick section of Devonian and Carboniferous rocks is present in the northeastern part of the AU. Within the Yenisey-Khatanga Basin Province, the Mesozoic section is thinnest on the Khatanga saddle, with sedimentary thickness of no more than 1 to 2 km. Potential petroleum reservoirs include Paleozoic carbonate rocks and Proterozoic clastic and carbonate rocks. Traps are associated with salt domes and faulted anticlines.

Four petroleum discoveries—three oil fields and one gas field—were made in the AU, all of which are now abandoned (IHS Energy Group, 2007). All of these fields were smaller than the minimum size defined for this assessment. Accumulations in these fields are in Permian sandstone, and hydrocarbon shows were observed in Triassic and Jurassic sandstones. Crude oil is too heavy (API (American Petroleum Institute) gravity of 20–25°) and viscous (240–270 centistokes) to be produced from primary production operations; drilling and testing technologies at the time of discovery and production were inadequate to increase flow rates. Exploration ended by 1954 and has not resumed.

**Geological Analysis of Assessment-Unit Probabilities**

The probability that the Khatanga Saddle AU contains at least one field equal to or greater than the minimum field size of 50 million barrels of oil equivalent (MMBOE) defined for this assessment is estimated at 50 percent (0.50). The assessment input data are summarized below and reported in appendix 1.

**Charge Probability.**—A charge probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum field size (50 MMBOE), as indicated by reported shows in exploration wells and large amounts of bitumen along the flanks of the AU.

**Rock Probability.**—A rock probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum field size (50 MMBOE).

**Timing and Preservation Probability.**—A timing-and-preservation probability of 0.50 was estimated because the timing of petroleum generation relative to trap formation and preservation may not be conducive for fields of ≥50 MMBOE. Mesozoic tectonic events most likely destroyed many previously trapped petroleum accumulations.

**Geologic Analogs for Assessment**

Two analog datasets from the USGS Analog Database (Charpentier and others, 2007) were used to estimate the numbers and sizes of undiscovered fields in the Khatanga Saddle AU (table 1). The analog datasets have discovered fields larger than the minimum field size (50 MMBOE) defined for this assessment. Analog categories include both extensional and contractional structural settings and traps containing carbonate and clastic depositional systems (table 1). Four AUs are common to both analog datasets.

**Number of Undiscovered Fields.**—The number of undiscovered fields was estimated by comparing the field densities (estimated numbers of undiscovered fields plus numbers of discovered fields containing >50 MMBOE per 1,000 km²) of the two combined analog datasets (table 1). The median and maximum densities of discovered fields are 0.2 and 1.1 fields per 1,000 km², respectively, whereas the median and maximum densities of discovered plus undiscovered fields are 0.3 and 1.6 fields per 1,000 km², respectively. Minimum, median, and maximum densities of 0.02, 0.22, and 1.1, respectively, were used in this assessment. The total minimum, median, and maximum numbers of undiscovered fields are 1, 10, and 50, respectively (see appendix 1). A slightly gas rich oil/gas mixture of 0.4 (0.1–0.8) was assumed because Proterozoic and Paleozoic source rocks might be overmature with respect to crude-oil generation. The estimated numbers of undiscovered oil fields are 0 (minimum),
| Province name (assessment unit number) | Structural setting | Trap system | Depositional system | Field density (fields >50 MMBOE per 1,000 km²) | Field size distribution | Exploration maturity | Maximum field size (MMBOE) |
|----------------------------------------|--------------------|-------------|---------------------|-----------------------------------------------|------------------------|---------------------|--------------------------|
|                                       |                    |             |                     | Number of discovered fields | Number of discovered and undiscovered fields | Number of fields | Median oil field size (>50 MMB) | Percent oil by volume in fields >50 MMB | Percent oil by volume in fields >50 MMB |
| Middle Caspian Basin (11090101)        | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf; Paralic clastics | 0.38 | 1.15 | 116 | 61 |
| Amu-Darya Basin (11540101)             | Compressional      | Compressional anticlines, folds, thrusts; Basement-involved block structures | Paralic clastics; Carbonate shelf | 0.12 | 0.13 | 111 | 94 |
| Amu-Darya Basin (11540102)             | Passive            | Compressional anticlines, folds, thrusts; Stratigraphic undeformed | Paralic clastics; Carbonate shelf | 0.17 | 0.29 | 110 | 97 |
| Amu-Darya Basin (11540103)             | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.08 | 0.09 | 149 | 96 |
| Rub Al Khali Basin (20190101)          | Compressional; Extensional | Compressional anticlines, folds, thrusts | Carbonate shelf | 0.09 | 0.18 | 204 | 90 |
| Rub Al Khali Basin (20190102)          | Compressional      | Compressional anticlines, folds, thrusts; Salt-induced structures | Carbonate shelf | 0.54 | 0.80 | 175 | 95 |
| Rub Al Khali Basin (20190103)          | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf | 0.27 | 0.55 | 109 | 54 |
| Zagros Fold Belt (20300101)            | Compressional      | Compressional anticlines, folds, thrusts | Continental clastics; Carbonate shelf | 0.20 | 0.57 | 162 | 79 |
| Zagros Fold Belt (20300102)            | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf; Continental clastics | 0.19 | 0.59 | 126 | 83 |
| Zagros Fold Belt (20300201)            | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf | 0.30 | 1.55 | 213 | 57 |
| Junggar Basin (31150101)               | Compressional      | Compressional anticlines, folds, thrusts; Basement-involved block structures | Continental clastics | 0.11 | 0.17 | 121 | 98 |
| Sichuan Basin (31420101)               | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf | 0.07 | 0.12 | 98 | 89 |
| Tarim Basin (31540101)                 | Compressional      | Compressional anticlines, folds, thrusts; Basement-involved block structures | Carbonate shelf; Paralic clastics | 0.02 | 0.13 | 112 | 14 |
| North Carpathian Basin (40470101)      | Passive            | Compressional anticlines, folds, thrusts | Paralic clastics; Slope, clinoforms, turbidites | 0.22 | 0.27 | 119 | 99 |
| North Carpathian Basin (40470201)      | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics; Slope, clinoforms, turbidites | 0.09 | 0.10 | 77 | 98 |
| San Jorge Basin (60580102)             | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.07 | 0.29 | 124 | 99 |
Table 1. Basins used as geologic analogs in assessment of the Khatanga Saddle Assessment Unit. —Continued

| Province name (assessment unit number) | Structural setting | Trap system | Depositional system | Field density (fields >50 MMBOE per 1,000 km²) | Field size distribution | Exploration maturity | Maximum field size (MMBOE) |
|--------------------------------------|--------------------|-------------|---------------------|-----------------------------------------------|-------------------------|----------------------|--------------------------|
|                                       |                    |             |                     | Number of discovered fields | Number of discovered and undiscovered fields | Median oil field size (>50 MMB) | Percent oil by volume in fields >50 MMB |
| Middle Magdalena (60900101)          | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 1.13 | 1.25 | 177 | 99 |
| Middle Magdalena (60900102)          | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.73 | 0.92 | 115 | 91 |
| Llanos Basin (60960101)              | Compressional; Extensional | Compressional anticlines, folds, thrusts | | | | | |
| Llanos Basin (60960102)              | Compressional; Extensional | Compressional anticlines, folds, thrusts | | | | | |
| East Venezuela Basin (60980101)      | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.64 | 1.38 | 187 | 73 |
| East Venezuela Basin (60980102)      | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.07 | 0.46 | 90 | 16 |
| Maracaibo Basin (60990102)           | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.44 | 0.60 | 112 | 90 |
| Greater Antilles Deformed Belt (61170101) | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf | 0.02 | 0.03 | 102 | 67 |
| Median                               |                    |             |                     | 0.18 | 0.37 | 120 | 89 | 874 |
| Mean                                 |                    |             |                     | 0.26 | 0.51 | 132 | 78 | 6,926 |
| Rifted passive margins and foreland basins with mixed carbonate and clastic depositional systems | | | | | | | |
| Timan-Pechora Basin (10080102)       | Compressional      | Basement-involved block structures; Paleogeomorphic | Paralic clastics; Carbonate shelf | 0.26 | 0.44 | 115 | 74 |
| Timan-Pechora Basin (10080103)       | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics; Carbonate shelf | 0.01 | 0.23 | 103 | 53 |
| Volga-Ural Region (10150101)         | Passive            | Basement-involved block structures; Paleogeomorphic | Paralic clastics; Carbonate shelf | 0.25 | 0.29 | 114 | 100 |
| Volga-Ural Region (10150102)         | Compressional      | Basement-involved block structures | Paralic clastics; Carbonate shelf | 0.14 | 0.14 | 116 | 100 |
| Middle Caspian Basin (11090101)      | Compressional      | Compressional anticlines, folds, thrusts | Carbonate shelf; Paralic clastics | 0.38 | 1.15 | 116 | 61 |
| Amu-Darya Basin (11540101)           | Compressional      | Compressional anticlines, folds, thrusts; Basement-involved block structures | Paralic clastics; Carbonate shelf | 0.12 | 0.13 | 111 | 94 |
| Nepa-Botuoba Arch (12100101)         | Compressional      | Basement-involved block structures; Stratigraphic undeformed | Paralic clastics; Carbonate shelf | 0.02 | 0.07 | 117 | 76 |
| Ma’Rib-Al Jawf/Masila Basin (20040101) | Extensional        | Extensional grabens and other structures related to normal faulting | Paralic clastics; Carbonate shelf | 0.20 | 0.41 | 100 | 66 |
Table 1.  Basins used as geologic analogs in assessment of the Khatanga Saddle Assessment Unit. —Continued

| Province name (assessment unit number) | Structural setting | Trap system | Depositional system | Field density (fields >50 MMBOE per 1,000 km²) | Field size distribution | Exploration maturity | Maximum field size (MMBOE) |
|---------------------------------------|--------------------|-------------|---------------------|-----------------------------------------------|------------------------|---------------------|---------------------------|
|                                       |                    |             |                     | *Number of discovered fields                  | Number of discovered and undiscovered fields | Median oil field size (>50 MMB) | Percent oil by volume in fields >50 MMB |
| Fahud Salt Basin (20160201)           | Compressional; Extensional | Compressional anticlines, folds, thrusts | Paralic clastics; Carbonate shelf margin, reefs | 0.23 | 0.28 | 223 | 92 |
| Zagros Fold Belt (20300101)           | Compressional       | Compressional anticlines, folds, thrusts | Carbonate shelf margin, reefs, Slope, clinoforms, turbidites | 0.20 | 0.57 | 162 | 79 |
| Zagros Fold Belt (20300102)           | Compressional       | Compressional anticlines, folds, thrusts | Continental clastics; Carbonate shelf | 0.19 | 0.59 | 126 | 83 |
| Pelagian Basin (20480101)             | Compressional; Extensional | Extensional grabens and other structures related to normal faulting; Transtensional and transpressional | Carbonate shelf; Continental clastics | 0.12 | 0.19 | 157 | 94 |
| Pelagian Basin (20480201)             | Compressional; Extensional | Extensional grabens and other structures related to normal faulting; Transtensional and transpressional | Carbonate shelf; Paralic clastics | 0.01 | 0.02 | 63 | 66 |
| Tarim Basin (31540101)                | Compressional       | Compressional anticlines, folds, thrusts; Basement-involved block structures | Paralic clastics; Carbonate shelf | 0.02 | 0.13 | 112 | 14 |
| Bombay (80430101)                     | Extensional         | Basement-involved block structures; Stratigraphic undeformed | Paralic clastics; Carbonate shelf | 0.06 | 0.11 | 106 | 82 |
| Median                                |                    |             |                     | 0.14 | 0.23 | 115 | 79 | 1,666 |
| Mean                                  |                    |             |                     | 0.15 | 0.32 | 123 | 76 | 8,007 |

Summary of all geologic analogs used for Khatanga Saddle assessment

|                     |                    |             |                     |                                           | Number of undiscovered fields | Median oil field size (>50 MMB) | Percent oil by volume in fields >50 MBB |
|---------------------|--------------------|-------------|---------------------|-------------------------------------------|-----------------------------|-------------------------------|---------------------------------------|
| Median              |                    |             |                     |                                           | 0.15 | 0.29 | 116 | 86 | 1,025 |
| Mean                |                    |             |                     |                                           | 0.22 | 0.43 | 129 | 78 | 5,810 |
| Maximum             |                    |             |                     |                                           | 1.13 | 1.55 | 223 | 100 |
4 (median), and 40 (maximum); and the estimated numbers of undiscovered gas fields are 1 (minimum), 6 (median), and 45 (maximum) (see appendix 1).

Sizes of Undiscovered Fields.—The estimated minimum, median, and maximum sizes of undiscovered oil and gas fields in the Khatanga Saddle AU are reported in appendix 1. 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 fields in the AU are 100 MMB of crude oil and 400 BCF of natural gas. The median undiscovered oil-field size (100 MMBOE) is slightly smaller than the median field size in the analog dataset (116 MMBOE). The low-probability maximum field size of 1,000 MMBOE approximates the median size of the maximum values of the combined analog datasets, 1,000 MMBOE (see appendix 1). On an oil-equivalent basis, the median (400 BCF) and maximum (4,000 BCF) sizes of undiscovered gas fields are smaller than those of undiscovered oil fields because of a greater risk for preservation (see appendix 1).

Expected Maximum Size of Undiscovered Fields.—The expected maximum sizes of undiscovered fields are based on the analog dataset: 200 million barrels (MMB) for undiscovered oil fields and 900 BCF (150 MMBOE) for undiscovered gas fields. The expected maximum size of gas fields is slightly smaller than that of oil fields because of a greater risk for preservation. These sizes are reduced in this AU from the median of the largest discovered size of analog fields because of the complex tectonic history and uplift since petroleum generation.

Petroleum Composition and Properties of Undiscovered Fields.—Oil/gas mixture, coproducts, and petroleum-quality properties used in assessing this AU are based on the fields discovered in this AU and those from global statistics (table 3).

Yenisey-Khatanga Basin Assessment Unit

The Yenisey-Khatanga Basin AU coincides with the main part of the Yenisey-Khatanga Basin. The AU is bounded on the east by the Khatanga Saddle, on the north by the Taimyr fold and thrust belt, and on the south by the Siberian craton. On the west, the Yenisey-Khatanga Basin borders the West Siberian Basin (figs. 1, 2). The west boundary of the AU is somewhat arbitrary but is approximately delineated by the extent of the Tanam structural terrace, the Noskovsky Trough, and the southwest slope of the Taimyr fold and thrust belt (figs. 1, 2). Stratigraphically, the AU includes the sedimentary section from Upper Permian through Cretaceous. The area of the AU is ~345,000 km², 4 percent of which is offshore within Yenisey Bay (Ust’ Yenisey).

Three producing gas fields and nine discoveries, four of which are awaiting development approval, are present in this AU (IHS Energy Group, 2007). Only one oil field was discovered as of 2007, although some oil legs are present in the gas fields. The sizes of the three producing gas fields exceed the specified minimum field size of 50 MMBOE. Discovered fields in the Yenisey-Khatanga Basin AU have reservoirs primarily in Jurassic and Lower Cretaceous sandstones. Potential reservoirs include Permian and Triassic sandstones. Traps in discovered fields are associated with simple and faulted anticlines but could include combination and stratigraphic traps associated with deltaic and progradational (slope, clinoform, and turbidite) sandstone reservoirs. Most of the anticlines in this AU have been tested; exploration is now focused on pinchouts along structures and within clinoforms (Grebenyuk and others, 2003).

Geological Analysis of Assessment-Unit Probabilities

The probability that the Yenisey-Khatanga Basin AU contains at least one field equal to or greater than the minimum field size is 100 percent (1.00). The assessment input data are summarized below and reported in appendix 2.

Charge Probability.—A charge probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum field size (50 MMBOE).

Rock Probability.—A rock probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum field size (50 MMBOE).

Timing and Preservation Probability.—A timing-and-preservation probability of 1.00 was estimated because the AU area has a petroleum system sufficient to charge one field equal to or greater than the minimum field size (50 MMBOE) and because oil and gas fields are known to be present in the AU.

Geologic Analogs for Assessment

Two different analog datasets were used to estimate the number of undiscovered fields for the Yenisey-Khatanga Basin AU: (1) rift/sag basins that were subsequently compressed (7 analogs); and (2) basins with slope, clinoform, and turbidite depositional systems (20 analogs) (table 2). The analog datasets contain primarily clastic reservoir rocks and have discovered fields of sizes equal to or greater than the minimum field size (50 MMBOE).

Number of Undiscovered Fields.—The number of undiscovered fields was estimated from the two combined analog datasets (table 2). The median and maximum densities of discovered fields in the combined analog datasets are 0.1 and 0.7 fields per 1,000 km², respectively, whereas the median and maximum densities of discovered plus undiscovered fields are 0.3 and 1.7 fields per 1,000 km², respectively. Minimum, median, and maximum, respectively densities of <0.01, 0.2, and 0.3, respectively, were used in this assessment. The median density of 0.2 falls between the median densities of the analog datasets and the maximum density of 0.3 approximates the density of the neighboring West Siberian Basin AUs (0.35, included in the analog dataset, table 2). The total minimum, median, and maximum numbers of undiscovered fields are 1,
Table 2. Basins used as geologic analogs in assessment of the Yenisey-Khatanga Basin Assessment Unit.

[Analog data from Charpentier and others (2008). Asterisk (*), not reported in analog database; gas volumes are nonassociated; MMBOE, million barrels of oil equivalent; MMB, millions of barrels]

| Province name (assessment unit number) | Structural setting | Trap system | Depositional system | Field density (fields >50 MMBOE per 1,000 km²) | Field size distribution | Exploration maturity | Maximum field size (MMBOE) |
|----------------------------------------|--------------------|-------------|---------------------|-----------------------------------------------|------------------------|---------------------|--------------------------|
|                                        |                    |             |                     | *Number of discovered fields                  | Number of discovered and undiscovered fields | Median oil field size (>50 MMB) | Percent oil by volume in fields >50 MMB |
| Compressed rift/sag basins              |                    |             |                     |                                               |                        |                     |                          |
| Middle Caspian Basin (11090201)         | Compressional      | Compressional anticlines, folds, thrusts; Basement-involved block structures | Paralic clastics | 0.09 | 0.15 | 142 | 95 |
| North Ustyurt Basin (11500101)          | Compressional      | Compressional anticlines, folds, thrusts | Paralic clastics | 0.16 | 0.29 | 251 | 82 |
| North Ustyurt Basin (11500201)          | Compressional      | Local uplifts of uncertain origin | Paralic clastics | 0.01 | 0.04 | 105 | 84 |
| West Siberian Basin (11740101)          | Compressional      | Basement-involved block structures; Stratigraphic undeformed | Paralic clastics; Slope, clinoforms, turbidites | 0.15 | 0.32 | 132 | 79 |
| West Siberian Basin (11740301)          | Compressional      | Compressional anticlines, folds, thrusts | Continental clastics; Paralic clastics | 0.15 | 0.35 | 224 | 92 |
| Malay Basin (37030101)                  | Compressional      | Basement-involved block structures | Paralic clastics; Continental clastics | 0.36 | 0.51 | 186 | 94 |
| Malay Basin (37030201)                  | Compressional      | Basement-involved block structures | Paralic clastics; Continental clastics | 0.15 | 0.32 | 142 | 84 |
| Median                                  |                    |              |                     |                                               |                        |                     |                          |
| Mean                                    |                    |              |                     |                                               |                        |                     |                          |
| Baram Delta/Brunei-Sabah Basin (37010102) | Compressional     | Extensional grabens and other structures related to normal faulting | Slope, clinoforms, turbidites | 0.09 | 0.28 | 100 | 39 |
| Bonaparte Gulf Basin (39100201)         | Compressional      | Extensional grabens and other structures related to normal faulting | Slope, clinoforms, turbidites | 0.03 | 0.14 | 95 | 8 |
| Bonaparte Gulf Basin (39100301)         | Compressional      | Extensional grabens and other structures related to normal faulting | Paralic clastics; slope, clinoforms, turbidites | 0.03 | 0.14 | 112 | 68 |
| Browse Basin (39130101)                 | Extensional        | Extensional grabens and other structures related to normal faulting | Paralic clastics; slope, clinoforms, turbidites | 0.02 | 0.14 | 125 | 48 |
| Northwest Shelf (39480101)              | Extensional        | Extensional grabens and other structures related to normal faulting | Paralic clastics; slope, clinoforms, turbidites | 0.40 | 1.53 | 108 | 56 |
| Northwest Shelf (39480201)              | Extensional        | Extensional grabens and other structures related to normal faulting | Paralic clastics; slope, clinoforms, turbidites | 0.00 | 0.02 | 111 | 41 |
| Pannonian Basin (40480101)              | Extensional        | Stratigraphic undeformed; Gravity-induced growth faults; Basement-involved block structures | Paralic clastics; slope, clinoforms, turbidites | 0.11 | 0.09 | 102 | 98 |
| Pannonian Basin (40480201)              | Extensional        | Stratigraphic undeformed; gravity-induced growth faults; basement-involved block structures | Paralic clastics; slope, clinoforms, turbidites | 0.15 | 0.13 | 95 | 99 |
| Province name (assessment unit number)                        | Structural setting              | Trap system                                      | Depositional system                              | Field density (fields >50 MMBOE per 1,000 km²) | Number of discovered fields | Number of discovered and undiscovered fields | Field size distribution (MMBOE) | Exploration maturity | Percent oil by volume in fields >50 MMB | Maximum field size (MMBOE) |
|--------------------------------------------------------------|---------------------------------|--------------------------------------------------|--------------------------------------------------|-----------------------------------------------|----------------------------|---------------------------------------------|---------------------------------|---------------------|---------------------------------|-------------------------|
| Po Basin (40600101)                                          | Compressional                   | Stratigraphic undeformed; compressional           | Slope, clinoforms, turbidites                    | 0.21                                          | 0.35                       | 110                                         | 76                              |                     |                                 |                         |
| Sergipe-Alagoas Basin (60290102)                             | Extensional                     | Gravity-induced growth faults                     | Slope, clinoforms, turbidites                    | 0.09                                          | 0.51                       | 105                                         | 5                               |                     |                                 |                         |
| Campos Basin (60350101)                                      | Extensional                     | Salt-induced structures                           | Slope, clinoforms, turbidites                    | 0.74                                          | 1.74                       | 178                                         | 55                              |                     |                                 |                         |
| Santa Cruz-Tarija Basin (60450101)                           | Compressional                   | Compressional anticlines, folds, thrusts         | Paralic clastics; slope, clinoforms, turbidites  | 0.19                                          | 0.38                       | 115                                         | 68                              |                     |                                 |                         |
| Neuquen Basin (60550103)                                     | Compressional; extensional      | Extensional grabens and other structures related to normal faulting | Slope, clinoforms, turbidites                    | 0.65                                          | 0.76                       | 130                                         | 98                              |                     |                                 |                         |
| Tobago Trough (61030101)                                     | Compressional; extensional      | Extensional grabens and other structures related to normal faulting | Paralic clastics; slope, clinoforms, turbidites  | 0.38                                          | 0.94                       | 128                                         | 42                              |                     |                                 |                         |
| West-Central Coastal (72030201)                              | Passive                          | Salt-induced structures                           | Slope, clinoforms, turbidites                    | 0.05                                          | 0.14                       | 114                                         | 24                              |                     |                                 |                         |
| West-Central Coastal (72030202)                              | Passive                          | Stratigraphic undeformed                         | Slope, clinoforms, turbidites                    | 0.01                                          | 0.49                       | 140                                         | 23                              |                     |                                 |                         |
| Orange River Coastal (73030101)                              | Extensional                     | Stratigraphic undeformed                         | Slope, clinoforms, turbidites                    | 0.00                                          | 0.01                       | 110                                         | 50                              |                     |                                 |                         |
| Bombay (80430102)                                            | Extensional                     | Extensional grabens and other structures related to normal faulting; stratigraphic undeformed | Continental clastics; slope, clinoforms, turbidites | 0.20                                          | 0.24                       | 114                                         | 88                              |                     |                                 |                         |
| Ganges-Brahmaputra Delta (80470302)                          | Compressional                   | Compressional anticlines, folds, thrusts; gravity-induced growth faults | Continental clastics; slope, clinoforms, turbidites | 0.05                                          | 0.18                       | 116                                         | 41                              |                     |                                 |                         |
| Irrawaddy (80480102)                                         | Compressional; extensional      | Compressional anticlines, folds, thrusts; gravity-induced growth faults; Stratigraphic undeformed | Paralic clastics; slope, clinoforms, turbidites  | 0.01                                          | 0.04                       | 107                                         | 37                              |                     |                                 |                         |
| Median                                                       |                                 |                                                  |                                                  | 0.09                                          | 0.21                       | 112                                         | 49                              |                     |                                 | 575                     |
| Mean                                                         |                                 |                                                  |                                                  | 0.17                                          | 0.41                       | 116                                         | 53                              |                     |                                 | 1,075                  |
| **Summary of all geologic analogs used for Yenisey-Khatanga Basin assessment** |                                 |                                                  |                                                  | 0.11                                          | 0.28                       | 114                                         | 68                              |                     |                                 | 850                     |
| Median                                                       |                                 |                                                  |                                                  | 0.17                                          | 0.39                       | 128                                         | 62                              |                     |                                 | 4,361                  |
| Mean                                                         |                                 |                                                  |                                                  | 0.74                                          | 1.74                       | 251                                         | 99                              |                     |                                 |                         |
Table 3. World statistics for oil and gas coproduct ratios, ancillary data, and depths.

| Variable | Minimum | Median | Maximum |
|----------|---------|--------|---------|
| 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 |
| API gravity (degrees) | 20 | 38 | 55 |
| Viscosity (centipoise) | 0.01 | 3 | 30 |
| Sulfur content of oil (percent) | 0 | 0.3 | 1.5 |
| Inert gas content (percent) | 0 | 2 | 10 |
| Carbon dioxide content (percent) | 0 | 1.5 | 10 |
| Hydrogen sulfide content (percent) | 0 | 0.5 | 3.5 |
| Depth (m) of water (if applicable) | 0 | 50 | 2,700 |
| Drilling Depth (m) | 350 | 2,000 | 7,000 |

62, and 112, respectively (see appendix 2). Oil/gas mixtures of 0.1 (minimum), 0.3 (mode), and 0.5 (maximum) were assumed because of gas-prone kerogen type in Mesozoic source rocks. The estimated numbers of undiscovered oil fields are 0 (minimum), 20 (median), and 60 (maximum); and the estimated number of undiscovered gas fields are 1 (minimum), 45 (median), and 100 (maximum) (see appendix 2).

**Sizes of Undiscovered Fields.**—The estimated minimum, median, and maximum sizes of undiscovered oil and gas fields in the Yenisey-Khatanga Basin AU are reported in appendix 2. The minimum sizes of undiscovered fields defined for the AU are 50 MMB of crude oil and 300 BCF of natural gas (6 BCF=1 MMBOE). The median field size of 150 MMBOE approximates the median size of the rift/sag-basin analog dataset, 142 MMBOE, but exceeds the median field size of the combined analog dataset (114 MMBOE). This median field size is consistent with the average size of discovered fields in this AU and the neighboring Northern West Siberian Onshore Gas AU (median size 200–300 MMBOE, included in the analog dataset). The low-probability maximum field sizes of 4,000 MMB for undiscovered oil fields and of 24,000 BCF for undiscovered gas fields approximate the mean of the maximum field sizes in the combined analog datasets.

**Expected Maximum Size of Undiscovered Fields.**—The expected maximum sizes of undiscovered fields are based on the analog dataset, with a smaller oil-field than gas-field size, to be consistent with the sizes of discovered fields in this AU: ~1,000 MMB for undiscovered oil fields and 9,000 BCF (1,500 MMBOE) for undiscovered gas fields. These sizes are based on a distribution of sizes of the fields in this and neighboring AUs and are constrained by the discovery history.

**Petroleum Composition and Properties of Undiscovered Fields.**—Oil/gas mixture, coproducts, and petroleum-quality properties used in assessing this AU (table 3) are based on the fields discovered in this AU and in the neighboring Northern West Siberian Onshore Gas AU, which has a similar geologic setting, source rocks, reservoir rocks, and traps.

**Assessment Results**

The assessment results for the Khatanga Saddle and Yenisey-Khatanga Basin AUs in the Yenisey-Khatanga Basin Province are summarized in table 4. Estimates represent undiscovered, technically recoverable, conventional petroleum resources.

Given the probability of 0.5 for a field of minimum size (see appendix 1), there is a 50-percent chance (F50) that no crude-oil or natural-gas resources exist in the Khatanga Saddle AU (table 4). The risked mean undiscovered crude-oil resource is 327 MMB, with a 95-percent chance (F95) of 0 MMB and a five-percent chance (F5) of 1,376 MMB. The risked mean volume of undiscovered nonassociated natural gas resource is 1,797 BCF, with an F95 of 0 BCF, an F50 of 0 BCF, and an F5 of 6,764 BCF. The largest expected size of an undiscovered oil
The overall probability for oil and gas fields in the Yenisey-Khatanga Basin AU is 1.00 (see appendix 2). The mean undiscovered crude-oil resource is 5,257 MMB, with an F95 of 2,201 MMB, an F50 of 4,847 MMB, and an F5 of 9,716 MMB (table 4). The mean volume of undiscovered nonassociated natural-gas resource is 68,884 BCF, with an F95 of 38,629 BCF, an F50 of 66,089 BCF, and an F5 of 108,413 BCF. The maximum size of an expected undiscovered oil field is ~1,100 MMB (not reported in appendix 2), and the maximum size of an expected undiscovered gas field is ~9,100 BCF (not reported in appendix 2).

The total estimated mean undiscovered petroleum resource in the Yenisey-Khatanga Basin Province AU is 5,584 MMB of crude oil, 99,957 BCF of associated and nonassociated natural gas, and 2,675 MMB of natural-gas liquids (table 4). Additional statistics are listed in table 2.

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 the AUs in all Arctic basins. Using this approach, the probabilities were consistently applied throughout the Arctic region.

### 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 Geographic Information System (GIS) support, and Donald L. Gautier and Gregory F. Ulmishek for their helpful reviews of the manuscript.

### References Cited

Afanasenkov, A.P., 1988, Catagenic alterations of disseminated organic matter of the Jurassic-Cretaceous sediments of the Yenisey-Khatanga oil-gas region: Petroleum Geology, v. 22, no. 5, p. 206–216 [translated from Geochimicheskiye i geofizicheskiye metody pryamikh poiskov zalezhey uglevodorodov v Yenisey-Khatanga pragibe: Leningrad, PGO “Sevmorgeologiya,” 1984, p. 69–80].

Allen, M.B., Anderson, L., Searle, R.C., and Buslov, M., 2006, Oblique rift geometry of the West Siberian Basin—Tectonic setting for the Siberian flood basalts: Journal of the Geological Society, London, v. 163, p. 901–904.

Baldin, V.A., 2004, Ust’-Yenisey oil-gas region—new territory for increasing hydrocarbon reserves in West Siberia: Petroleum Geology, v. 38, p. 225–235 [translated from Geologiya Nefti i Gaza, 2003, no. 2, p. 16–25].

Baldin, V.A., Kunin, K.N., and Kunin, N.Ya., 1997, New ideas on structure and genesis of diagonal system of arches in the Yenisey-Khatanga downwarp: Petroleum Geology, v. 31, no. 4, p. 416–424 [translated from Geologiya Nefti i Gaza, 1997, no. 3, p. 26–34].

Barrett, P., 2003, Paleoclimatology—cooling a continent: Nature, v. 421, p. 221–223.

Bobilev, V.V., 1985, Cyclic pattern of the Mesozoic-Cenozoic mega-complex of the North of the Siberian platform: Spesificchnost’ geologicheskikh usloviy I neftegasonosnosti Sibiri pri biborenapravleniy poiskovo-rasvedochnikh rabot, Moscow, VNIGRI [in Russian].

### Table 4. Assessment results (conventional undiscovered resources) for the Yenisey-Khatanga Basin Province.

| Total petroleum systems and assessment units | AU probability | Field type | Field (MMB) | Gas (BCF) | NGL (MMB) |
|---------------------------------------------|---------------|-----------|-------------|-----------|-----------|
| Assessment results—Proterozoic-Paleozoic composite total petroleum system | | | | | | | | | | | | | | | | | | | | | |
Bogdanov, N.A., Khain, V.E., Vernikovsky, V.A., Drachev, S.S., Kostyuchenko, S.L., Kouzminchev, A.B., Rosen, O.M., Sekretov, S.B., Senin, B.V., and Shipilov, E.V., 1998, Continental accretion in the Taymyr part of the Eurasian Basin margin [abs.]: Proceedings of the International Conference on Arctic Margins (1998), p. 32–33.

Botneva, T.A., and Frolov, S.B., 1996, Conditions of formation of hydrocarbon accumulations in sedimentary cover of Yenisey-Lena system of downwarps: Petroleum Geology, v. 30, no. 1, p. 48–55 [translated from Geologiya Nefti i Gazu, 1995, no. 5, p. 36–41].

Charpentier, R.R., Klett, T.R., and Attanasi, E.D., 2008, Database for assessment unit-scale analogs, exclusive of the United States: United States Geological Survey Open-File Report 2007–1404, 61 p.

Danilkin, S.M., 1984, Forecast for petroleum potential of the eastern part of the Yenisey-Khatanga trough: Sovetskaya Geologiya, no. 1, p. 25 [in Russian].

Danilkin, S.M., 1985, Istoriya formirovaniya i neftegazonosnost' Yenisey-Lenskoy sistemy progibov [History of formation and oil and gas presence in the Yenisei-Lena foredeep system]: Sovetskaya Geologiya, no. 6, p. 6–14 [in Russian].

Drachev, S.S., 2002, On the basement tectonics of the Laptev Sea Shelf: Geotectonics, v. 36, no. 6, p. 483–497.

Filipiov (Filippov), Yu.A., Boldushevskaya, L.N., Kontorovich, A.A., Krinin, V.A., and Fomin, A.N., 1999, Catagenesis of organic matter and phase composition of hydrocarbon pools of northwest frame of Siberian craton: Petroleum Geology, v. 33, no. 4, p. 359–370 [translated from Geologiya Nefti i Gazu, 1998, no. 12, p. 25–33].

Fomin, A.N., and Romakhina, G.A., 1989, Catagenesis of dispersed organic materials of Jurassic-Cretaceous deposits of the western Yenisei-Khatanga Trough: Soviet Geology and Geophysics, v. 30, no. 11, p. 88–91.

Frakes, L.A., Francis, J.E., and Syktus, J.I., 1992, Climate modes of the Phanerozoic—The history of the Earth’s climate over the past 600 million years: Cambridge, U.K., Cambridge University Press, 274 p.

Girshgorn, L. Sh., 1996, Structural-formational characteristics of pre-Jurassic sediments of the north of West Siberia from seismo-geological analysis: Petroleum Geology, v. 30, no. 3, p 243–249 [translated from Sovremennyye geofizicheskiye metody pri reshenii zadach neftyannykh geologii: Moscow, Nauka, 1988, p. 72–80].

Golonka, J., and Kiessling, W., 2002, Phanerozoic time scale and definition of time slices, in Kiessling, W., Flügel, E., and Golonka, J., eds., Phanerozoic reef patterns: Society of Economic Paleontologists and Mineralogists Special Publication 72, p. 11–20.

Gradstein, F.M., Ogg, J.G., Smith, A.G., Agterberg, F.P., Bleeker, W., Cooper, R.A., Davydov, V., Gibbard, P., Hinov, L.A., House, M.R., Lourens, L., Luterbacher, H.P., McArthur, J., Melchin, M.J., Robb, L.J., Shergold, J., Villeneuve, M., Wardlaw, B.R., Ali, J., Brinkhuis, H., Hilgen, F.J., Hooker, J., Howarth, R.J., Knoll, A.H., Laskar, J., Monechi, S., Plumb, K.A., Powell, J., Raffi, I., Röhl, U., Sadler, P., Sanfilippo, A., Schmitz, B., Shackleton, N.J., Shields, G.A., Strauss, H., Van Dam, J., van Kolfschoten, T., Veizer, J., and Wilson, D., 2004, A geologic time scale: Cambridge, U.K., Cambridge University Press, 589 p.

Gramberg, I.S., Bro. Ye.G., and Sorokov, D.S., 1988, Oil-gas bearing units of the Mesozoic downwarps of the north of the Siberian platform: Petroleum Geology, v. 20, no. 5, p. 217–219 [translated from Neftegazonosnost' Sibiri i Dal'nogo Vostoka: Novosibirsk, “Nauka,” 1981, p. 42–47].

Grebenyuk, V.V., Gurari, F.G., Lugovtsov, A.D., Moskvin, V.I., 1988, Specifics of oil-gas formation in the Mesozoic depressions of the Siberian platform: Petroleum Geology, v. 19, no. 12, p. 602–605 [translated from Geologiya i neftegazonosnost' mesozoiiskikh sedimentatsionnykh basseinov Sibiri: Akademii Nauk SSSR, Akademiiia Nauk SSSR, Sibirskoe Otdelenie, Trudy Institut Geologii i Geofiziki, 1983, no. 532, p. 132–139].

Grebenyuk, V.V., Divina, T.A., and Krol’, L.A., 2003, Facies-tectonic zonality of subsurface of Yenisey-Khatanga basin and prospects for new discoveries: Petroleum Geology, v. 37, p. 223–229 [translated from Geologiya, Geofizika i Razrabotka Neftyanych i Gazovnych Mestorozhdeny, 2002, no. 9, p. 14–18].

Hardenbol, J., Thierrt, J., Farley, M.B., Jacquin, T., de Graciansky, P.-C., and Vail, P.R., 1998, Mesozoic and Cenozoic sequence chronostratigraphic framework for European basins, in de Graciansky, P.-C., Hardenbol, J., Jacquin, T., and Vail, P.R., eds., Mesozoic and Cenozoic sequence stratigraphy of European basins: Society of Economic Paleontologists and Mineralogists Special Publication 60, p. 3–13.

Hunt, J., 1996, Petroleum geochemistry and geology (2d ed.): New York, W.H. Freeman and Co., 743 p.

IHS Energy Group, 2007 [includes data current through October 2007], International exploration and production database: Englewood, Colo., IHS Energy Group [database available from IHS Energy Group, 15 Inverness Way East, D205, Englewood, CO 80112, U.S.A.].

Inger, S., Scott, R.A., and Golinenko, B.G., 1999, Tectonic evolution of the Taimyr Peninsula, northern Russia—implications for Arctic continental assembly: Journal of the Geological Society, London, v. 156, p. 1069–1072.

Kazais, V.I., 1976, Structure of the Yenisei-Khatanga Trough, derived from geophysical data: U.S.S.R. Academy of Sciences, Earth Science Sections, Transactions (Doklady), v. 220, no. 1–6, p. 45–47, 1975. [In Russian.]
Kazakov, A.M., Dagit, A.S., and Kurushin, N.I., 1982, Osnovnie chert' paleogeografii triasa severa sredney siberi (The main features of Triassic paleogeography of north-central Siberia), in Trofimuk, A.A., ed., Geologiya i neftegazonosnost Yenisey-Khatangskogo basseyna (Geology and presence of oil and gas of the Enisei-Khatangsk Basin): Institut Geologii i Geofiziki Trudy, no. 514, Izdatel'ctvo “Nauka,” Sibirskoye Otdeleniye, Moscow, p. 54–75. [In Russian.]

Khmelnitskiy (Khmelnitskiy), V.B., Shlyakhter, V.V., Kuznetsov, L.L., Kulikov, D.P., Khmelnitskiy, V.B., Azarnov, A.N., Nakaryakov, V.D., Polyakova, I.D., Sibgatullin, V.G., Soboleva, Ye.I., Starosel'tsev, V.S., and Stepanenko, G.F., 1994, Oil and gas bearing regions of the Siberia, issue 3, Yenisei-Khatangsk Basin (Neftegazonnyye basseiny i regioni Sibiri, vypusk 3, Yenisei-Khatangskiy basseyne): Novosibirsk, Russia, 71 p. [In Russian.]

Khmelevskii (Khmelevskiy), V.B., Shlyakhter, V.V., Kuznetsov, L.L., Kulikov, D.P., Khmelevskii, V.B., Azarnov, A.N., Nakaryakov, V.D., Polyakova, I.D., Sibgatullin, V.G., Soboleva, Ye.I., Starosel’tsev, V.S., and Stepanenko, G.F., 1994, Oil and gas bearing regions of the Siberia, issue 3, Yenisei-Khatangsk Basin (Neftegazonnyye basseiny i regioni Sibiri, vypusk 3, Yenisei-Khatangskiy basseyne): Novosibirsk, Russia, 71 p. [In Russian.]

Kontorovich, A.Eh., Grebenyuk, V.V., Kuznetsov, L.L., Kulikov, D.P., Khmelevskii, V.B., Azarnov, A.N., Nakaryakov, V.D., Polyakova, I.D., Sibgatullin, V.G., Soboleva, Ye.I., Starosel’tsev, V.S., and Stepanenko, G.F., 1994, Oil and gas bearing regions of the Siberia, issue 3, Yenisei-Khatangsk Basin (Neftegazonnyye basseiny i regioni Sibiri, vypusk 3, Yenisei-Khatangskiy basseyne): Novosibirsk, Russia, 71 p. [In Russian.]

Kontorovich, A.Eh., Bekin, V.E., Grebenyuk, V.V., Kuznetsov, L.L., and Nakaryakov, V.D., 1991, Khatanga-Vilyuy Upper Paleozoic-Mesozoic petroleum province [abs.]: American Association of Petroleum Geologists Bulletin, v. 75, no. 8, p. 1414.

Krasin, J., and Finley, P.D., 1993, Messoyakh gas field—Russia, West Siberia Basin, in Beaumont, E.A., and Foster, N.H., eds., Structural traps VII, in Atlas of oil and gas fields: American Association of Petroleum Geologists Treatise of Petroleum Geology, p. 197–220.

Kulak, Yu.N., and Makhotina, G.P., 1988, Recent tectonics of the Yenisey-Khatanga regional downwarp: Petroleum Geology, v. 22, no. 8, p. 366–369 [translated from Noveyshaya tektonika Sibiry i yeye vliyaniye na neftegazonosnost': Moscow, Nauka, 1985, p. 77–85].

Lebuchuk (Levchuk), M.A., 1990, Lithology and oil-gas prospects of Jurassic sediments of Yenisey-Khatanga downwarp: Petroleum Geology, v. 24, no.11–12, p. 309–326 [translated from Novosibirsk, Izdatelstvo “Nauka,” Sibirskoye Otdeleniye, 1985, no. 624, 165 p.].

Levchuk, M.A., and Fomin, A.N., 1988, Catagenesis of Jurassic sediments of the east part of the Yenisey-Khatanga downwarp: Petroleum Geology, v. 19, no. 12, p. 599–601.

Matykhin, R.G., and Sokolov, P.N., 1998, New data on Middle Paleozoic salt of Siberian craton: Petroleum Geology, v. 32, no. 1, p. 79–86 [translated from Problemy morskogo i kontinental'nogo galogeneza: Novosibirsk, Nauka, 1991, p. 72–83].

Mikulenko, K.I., 1983, The tectonics of the sedimentary cover of the margin depressions of the Siberian platform (in connection to petroleum potential), in Trofimuk, A.A., and Karogodin, Yu.N., eds., Geologiya i neftegazonosnost' mezozoyiskikh sedimentatsionnykh basseynov Siberia (The geology and oil- and gas-bearing nature of the Mesozoic sedimentary basins of Siberia): Institut Geologii i Geofiziki Trudy, no. 532, Izdatel’ctvo “Nauka,” Sibirskoye Otdeleniye, Novosibirsk, p. 90–104. [In Russian.]

Persits, F.M., and Ulmishek, G.F., 2003, Maps showing geology, oil and gas fields, and geologic provinces of the Arctic: U.S. Geological Survey Open-File Report 97–470–J, CD-ROM.

Polyakova, I.D., Kolganova, M.M., Soboleva, Ye.I., and Stepanenko, G.F., 1986, Geochemical criteria of oil-gas potential of the north of the Siberian platform: Petroleum Geology, v. 21, no. 11, p. 526–529 [translated from Trofimuk, A.A., ed., Geologiya i neftegazonosnost Yenisey-Khatangskogo basseyna (Geology and presence of oil and gas of the Enisei-Khatangsk Basin): Institut Geologii i Geofiziki Trudy, no. 514, Izdatel’ctvo “Nauka,” Sibirskoye Otdeleniye, Moscow (Academy of Sciences of the USSR, Siberian Branch, Institute of Geology and Geophysics), 1982, p. 119–132].

Polyakova, I.D., Soboleva, Ye.I., and Stepanenko, G.F., 1984, Intensity of emigration of liquid hydrocarbons and of generation of gas hydrocarbons from oil-gas-bearing complexes of the Khatanga-Vilyuy oil-gas province: Petroleum Geology, v. 19, no. 12, p. 606–609 [translated from Trofimuk, A.A., and Karogodin, Yu.N., eds., Geologiya i neftegazonosnost’ mezozoyiskikh sedimentatsionnykh basseynov Siberia (The geology and oil- and gas-bearing nature of the Mesozoic sedimentary basins of Siberia): Institut Geologii i Geofiziki Trudy, no. 532, Izdatel’ctvo “Nauka,” Sibirskoye Otdeleniye, Novosibirsk, 1983, p. 140–147].

Stepanenko, G.F., 1988, History of hydrocarbon reservoirs in the Anabar-Khatanga Saddle: Soviet Geology and Geophysics, v. 29, no. 2, p. 37–42 [translated from Geologiya i Geofizika, 1988, v. 29, no. 2, p. 41–47].

Sorkova, V.S., 1987, Megakomplekspy i glubinnoya struktura zemnoiy kory neftegazonosnykh provintsii Sibirskoyi platformi: Moscow, “Nedra,” Sibirskiy Nauchno-Issledovatelskiy Institut Geologii, Geofiziki i Mineralnogo Syrya (SNIGIMS), 203 p. [In Russian.]

Sweeney, J.J., and Burnham, A.K., 1990, Evaluation of a simple model of vitrinite reflectance based on chemical kinetics: American Association of Petroleum Geologists Bulletin, v. 74, p. 1559–1570.

Torsvik, T.H., and Andersen, T.B., 2002, The Taimyr fold belt, Arctic Siberia—timing of prefold remagnetisation and regional tectonics: Tectonophysics, v. 352, no. 3–4, p. 335–348.
Uflyand, A.K., Natapov, L.M., Lopatin, V.M., and Chernov, D.V., 1991, The tectonic nature of the Taymyr Peninsula. Geotectonics, v. 25, no. 6, p. 512–523.

Ulmishek, G.F., 2003, Petroleum geology and resources of the West Siberian Basin, Russia. U.S. Geological Survey Bulletin 2201-G, 49 p.

Ulmishek, G.F., and Klemme, H.D., 1990, Depositional controls, distribution, and effectiveness of world’s petroleum source rocks. U.S. Geological Survey Bulletin B-1931, 59 p.

Vernikovsky, V.A., 1995, The geodynamic evolution of the Taimyr folded area. Tikhookeanskaya Geologiya, v. 14, no. 4, p. 71–80.

Vernikovsky, V.A., 1998, Taimyr fold area—evolution of the Earth crust and the main problems of tectonics [abs.]: Proceedings of the Third International Conference on Arctic Margins (1998), p. 196–197.

Wygrala, B.P., 1989, Integrated study of an oil field in the southern Po Basin, northern Italy. Berichte der Kernforschungsanlage Julich, no. 2313, 217 p.

Zonenshain, L.P. (Zonenshayn, L.P.), Kuzmin, M.I., and Natapov, L.M., 1990, Geology of the USSR—a plate-tectonic synthesis (Geodynamics Series, v. 21). American Geophysical Union, 242 p.
Appendixes

Appendix files are available online only, and may be accessed at https://doi.org/10.3133/pp1824R.

1. Assessment Input Data for the Khatanga Saddle Assessment Unit.
2. Assessment Input Data for the Yenisey-Khatanga Basin Assessment Unit.
