U. S. Department of the Interior

U. S. Geological Survey

# South and North Barents Triassic-Jurassic Total Petroleum System of the Russian Offshore Arctic

Paper Edition

by

Sandra J. Lindquist[1]

## Open-File Report 99-50-N



**1999**

[1] Consulting Geologist, Contractor to U. S. Geological Survey, Denver, Colorado

# South and North Barents Triassic-Jurassic Total Petroleum System of the Russian Offshore Arctic[2]

Sandra J. Lindquist, Consulting Geologist
Contractor to the U.S. Geological Survey, Denver, CO
October, 1999

## FOREWORD

This report was prepared as part of the World Energy Project of the U.S. Geological Survey. In the project, the world was divided into 8 regions and 937 geologic provinces. The provinces have been ranked according to the discovered oil and gas volumes within each (Klett and others, 1997). Then, 76 "priority" provinces (exclusive of the U.S. and chosen for their high ranking) and 26 "boutique" provinces (exclusive of the U.S. and chosen for their anticipated petroleum richness or special regional economic importance) were selected for appraisal of oil and gas resources. The petroleum geology of these priority and boutique provinces is described in this series of reports. A detailed report containing the assessment results will be available separately, if such results are not reported herein. The priority South Barents Basin Province ranks 35th in the world, exclusive of the U.S. Even though a frontier exploratory basin, it's ranking would move to 29th if several adjacent fields that are part of the same major petroleum system are included within this greater South Barents area. The North Barents Basin is a boutique province.

The purpose of the World Energy Project is to aid in assessing the quantities of oil, gas, and natural gas liquids that have the potential to be added to reserves within the next 30 years. These potential resources reside either in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for the assessment unit (variable, but must be at least 1 million barrels of oil equivalent) or they occur as reserve growth of fields already discovered.

The *total petroleum system* constitutes the basic geologic unit of the oil and gas assessment. The total petroleum system includes all genetically related petroleum that occurs in shows and accumulations (discovered and undiscovered) that (1) has been generated by a pod or by closely related pods of mature source rock, and (2) exists within a limited mappable geologic space, together with the essential mappable geologic elements (source, reservoir, seal, and overburden rocks) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum. The total petroleum system concept is modified from Magoon and Dow (1994). The *minimum petroleum system* is defined as that part of a total petroleum system encompassing discovered shows and accumulations together with the geologic space in which the various essential elements have been proved by these discoveries.

---

[2] South and North Barents Triassic-Jurassic total petroleum system (# 105001), Eastern Barents Sea, South Barents Basin Priority Province (#1050), North Barents Basin Boutique Province (#1060), and part of Timan-Pechora Basin Province (#1008).

An *assessment unit* is a mappable part of a total petroleum system in which discovered and undiscovered fields constitute a single relatively homogenous population such that the chosen methodology of resource assessment based on estimation of the number and sizes of undiscovered fields is applicable. A total petroleum system might equate to a single assessment unit. If necessary, a total petroleum system may be subdivided into two or more assessment units such that each assessment unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to assess individually. Assessment units are considered *established* if they contain more than 13 fields, *frontier* if they contain 1-13 fields, and *hypothetical* if they contain no fields.

A graphical depiction of the elements of a total petroleum system is provided in the form of an event chart that shows (1) the time of deposition of essential rock units; (2) the time processes, such as trap formation, necessary for the accumulation of hydrocarbons; (3) the critical moment in the total petroleum system; and (4) the preservation time, if any.

A numeric code identifies each region, province, total petroleum system, and assessment unit; these codes are uniform throughout the project and will identify the same item in any of the publications. The code is as follows:

| Example | |
|---|---|
| Region, single digit | **3** |
| Province, three digits to the right of region code | 3**162** |
| Total Petroleum System, two digits to the right of province code | 3162**05** |
| Assessment unit, two digits to the right of petroleum system code | 316205**04** |

The codes for the regions and provinces are listed in Klett and others (1997).

Oil and gas reserves quoted in this report are derived from Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

Figures in this report that show boundaries of the total petroleum systems, assessment units, and pods of active source rocks were compiled using geographic information system (GIS) software. Political boundaries and cartographic representations were taken, with permission, from Environmental Systems Research Institute's ArcWorld 1:3 million digital coverage (1992), have no political significance, and are displayed for general reference only. Oil and gas field centerpoints, shown on these figures, are reproduced, with permission, from Petroconsultants, 1996.

## ABSTRACT

One major gas-prone petroleum system characterizes the sparsely explored South and North Barents Basin Provinces of the Russian Arctic in the eastern Barents Sea. More than 13 billion barrels of oil equivalent (79 trillion cubic feet of gas) known

ultimately recoverable gas reserves in seven fields were sourced from Triassic marine and continental shales and stored in Jurassic (97%) and Triassic (3%) marine and continental sandstone reservoir rocks. The basins contain 18-20 kilometers of pre-Upper Permian carbonate and post-Upper Permian siliciclastic sedimentary fill. Late Permian-Triassic(?) rifting and subsidence resulted in the deposition of as much as 9 kilometers of Triassic strata, locally injected with sills. Rapidly buried Lower Triassic source rocks generated hydrocarbons as early as Late Triassic into stratigraphic traps and structural closures that were modified periodically. Thermal cooling and deformation associated with Cenozoic uplift impacted seal integrity and generation processes, modified traps, and caused gas expansion and remigration.

## INTRODUCTION

In the terminology of the U.S. Geological Survey (USGS) World Energy Project, the eastern Barents Sea region of Russia contains two large Mesozoic basin provinces, South Barents and North Barents, separated by the Ludlov Saddle (fig. 1). The major petroleum system for this area has widespread, mature Triassic gas-prone shale source rocks with most identified reserves within Jurassic siliciclastic reservoir rocks. It is herein called the South and North Barents Triassic-Jurassic total petroleum system (#105001). There also are largely immature, oil-prone Jurassic shale source rocks (Bazhenov-Hekkingen stratigraphic equivalent of adjacent regions) associated with potential Jurassic and Cretaceous sandstone reservoirs. Paleozoic shaly carbonate source rocks (Devonian Domanik stratigraphic equivalent from the Timan-Pechora Basin), if present in the eastern area, might contribute gas and liquids to various reservoir rocks.

References listed in this report include a selection of those most recent and most pertinent to the subject matter. Not all are specifically cited in the text. Translations from original Russian papers are reported with the translated publication date. For one paper, Gramberg and others (1998), the translation date is ten years more recent than the original publication date. The Norwegian Petroleum Society (NPF) Special Publication No. 2 is referenced as 1993, although there are contradicting publication dates of 1992 (first page of all individual articles) and 1993 (title page) in the book. No stratigraphic column is presented for the region because only age nomenclature is used in the literature for most of the region.

## PROVINCE GEOLOGY

### Province Boundary and Geographic Setting

Both the South and North Barents Basin Provinces are located entirely within the eastern Barents Sea (the westernmost Russian Arctic offshore) (fig. 1). The priority South Barents Basin Province (#1050) is northwest of and adjacent to the Russian Timan-Pechora Basin Province (#1008; Lindquist, 1999) and west of the southern part of the Novaya Zemlya archipelago. South Barents is located between longitude 37° and 51° E. and between latitude 69° and 74.5° N., covering approximately 173,000 km$^2$. It contains 20 km of sedimentary fill.

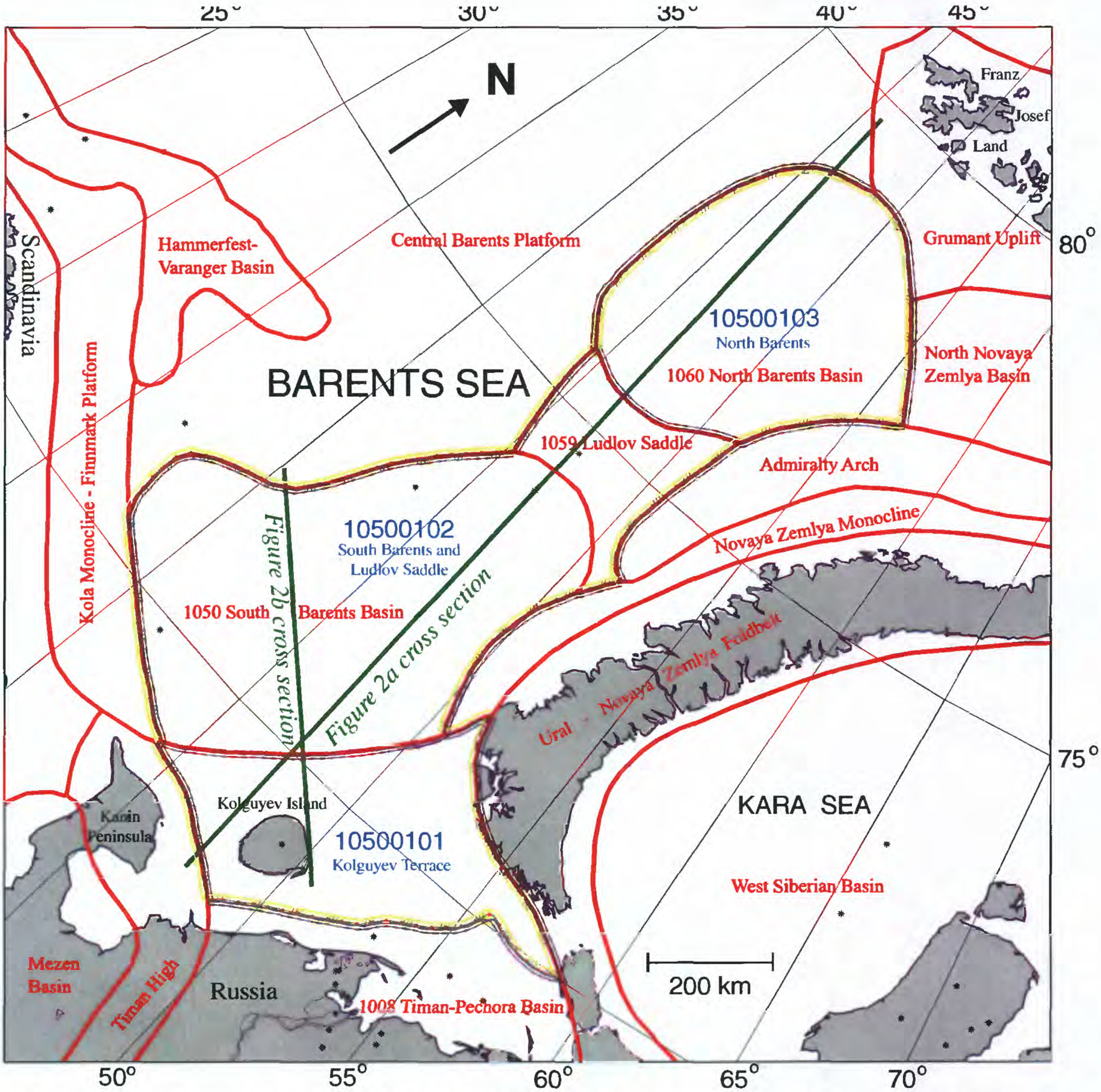
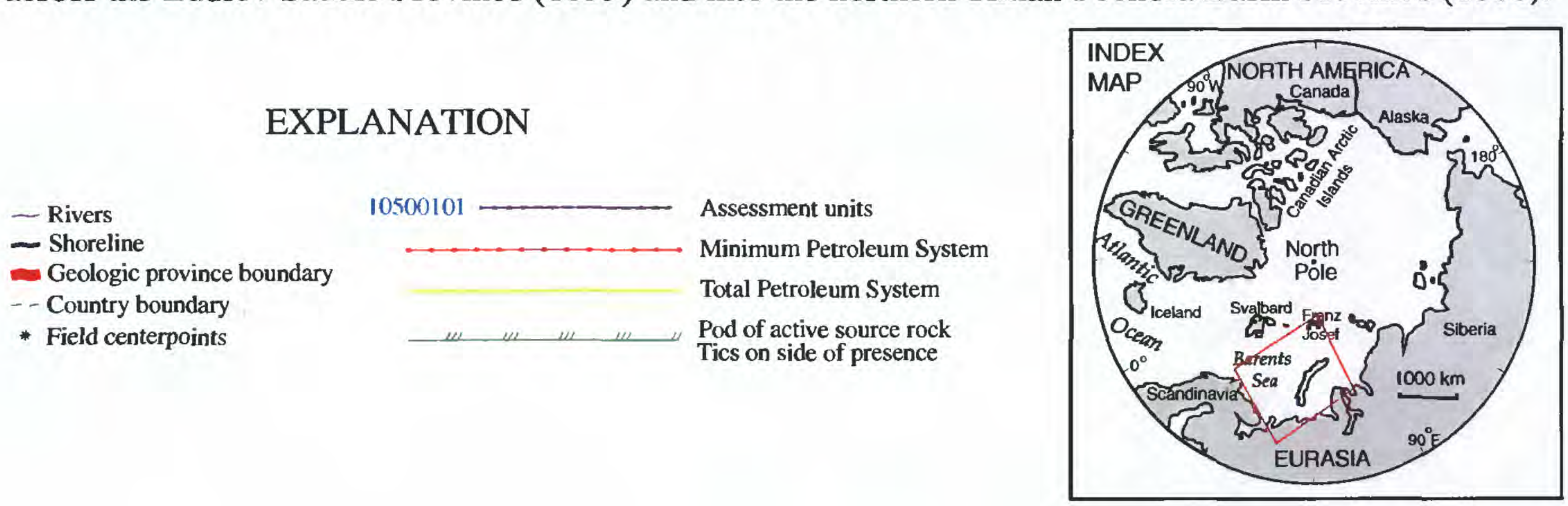



Figure 1. Location map of Triassic-Jurassic (105001) total petroleum system of the South (1050) and North (1060) Barents Basin Provinces in the Russian Barents Sea. The three assessment units extend across the Ludlov Saddle Province (1059) and into the northern Timan-Pechora Basin Province (1008).



The boutique North Barents Basin Province (#1060) is north of South Barents, but separated from it geographically by the subtle Ludlov Saddle (fig. 2a). Due north of North Barents is the Grumant Uplift, containing the islands of Franz Josef Land. The marine area to the west of both these basins includes the Central Barents Platform of Norway, Russia, and disputed Russian-Norwegian waters (fig. 2b). North Barents is located between longitude 42° and 57° E. and between latitude 75.5° and 79° N., covering approximately 106,500 $km^2$. It contains 18 km of sedimentary fill.

All water depths in both provinces are <350 km. The eastern Barents crustal block has drifted continuously northward since Cambrian time when it was in an equatorial position (Ustritskiy, 1991). Both basins are characterized by gravity maxima and low-intensity magnetic signatures (Bogolepov and others, 1992). Several solitary producing fields near but outside the South Barents Province outline are of the same total petroleum system and are included in the statistical treatment of field sizes and numbers. Those fields include N. Kildinskoye, Ludlovskoye, Tarkskoye, and Peschanoozer (fig. 3).

## Geologic setting

The tectonic history of the Euro-Asian Arctic is anchored by the Early Proterozoic (Karelian) orogeny, which established the stable Russian-European platform adjacent to the Archean Baltic Shield (Alsgaard, 1993; Dore, 1995; Bogdanov and others, 1996). Accreted and superimposed, latest Proterozoic (Baikalian) orogenic trends are oriented NW-SE, exemplified by the Kanin-Timan Ridge and the Kola Monocline southwest of the Timan-Pechora and Barents Provinces (fig. 1). Baikalian basement comprises the western and central Timan-Pechora Basin Province and possibly part of the South Barents Basin Province (Bogdanov and others, 1996; Gramberg, 1998). Karelian (or younger, Grenvillian) basement is likely present in more northern regions.

The Early Paleozoic Caledonian orogeny largely closed the Cambrian Iapetus (old Atlantic) Ocean and consolidated the Laurentia (Greenland/North America) and Baltic (Euro-Russian) continental plates, primarily impacting the more western Barents Sea but perhaps also establishing tectonic trends northeastward into at least part of the North Barents Basin. A remnant of the old Iapetus oceanic basin could have been preserved in this eastern Barents region, according to some plate tectonic models (Ustritskiy, 1991).

Late Paleozoic (Devonian and younger) rifting and subsequent continental collision were recorded in the carbonate-to-siliciclastic stratigraphic succession along the southern margins of the South Barents Basin. Collisions of the Laurentia/Baltic plate with the West Siberian plate (Permo-Triassic "Uralian" orogeny and Early Jurassic "Early Kimmerian" orogeny) tectonically defined the eastern boundaries of the Barents and Timan-Pechora Provinces by creating the Ural and Novaya Zemlya foldbelts (fig. 1) that supplied siliciclastic sediments westward to the foredeeps of the

Figure 2a. North-south structural cross section of South (#1050) and North (#1060) Barents Basin Provinces (after Johansen and others, 1993). There are just two areas of subsurface control to oldest Upper and Middle Triassic rocks, respectively, at depths of approximately 3.2 km each, on the Ludlov Saddle and on the south flank of the South Barents Basin. Thus, pre-Triassic age assignments for the thick basinal rocks could be different than shown. The dashed green and red lines mark approximate oil and gas windows (60°and 150°C) in pre-Cenozoic time (after Ostisty and Cheredeev, 1993). Cross section location is shown in figure 1.

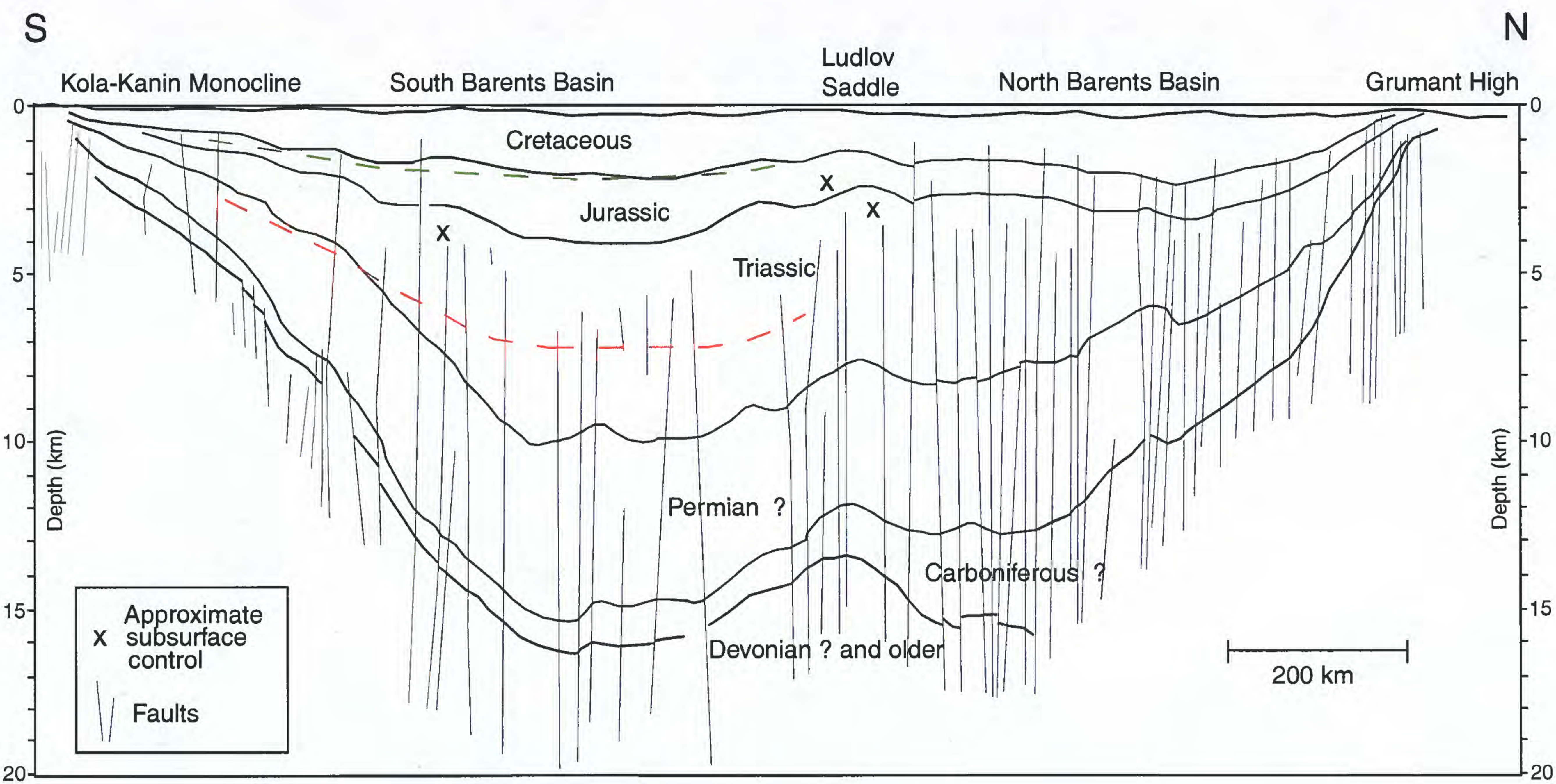
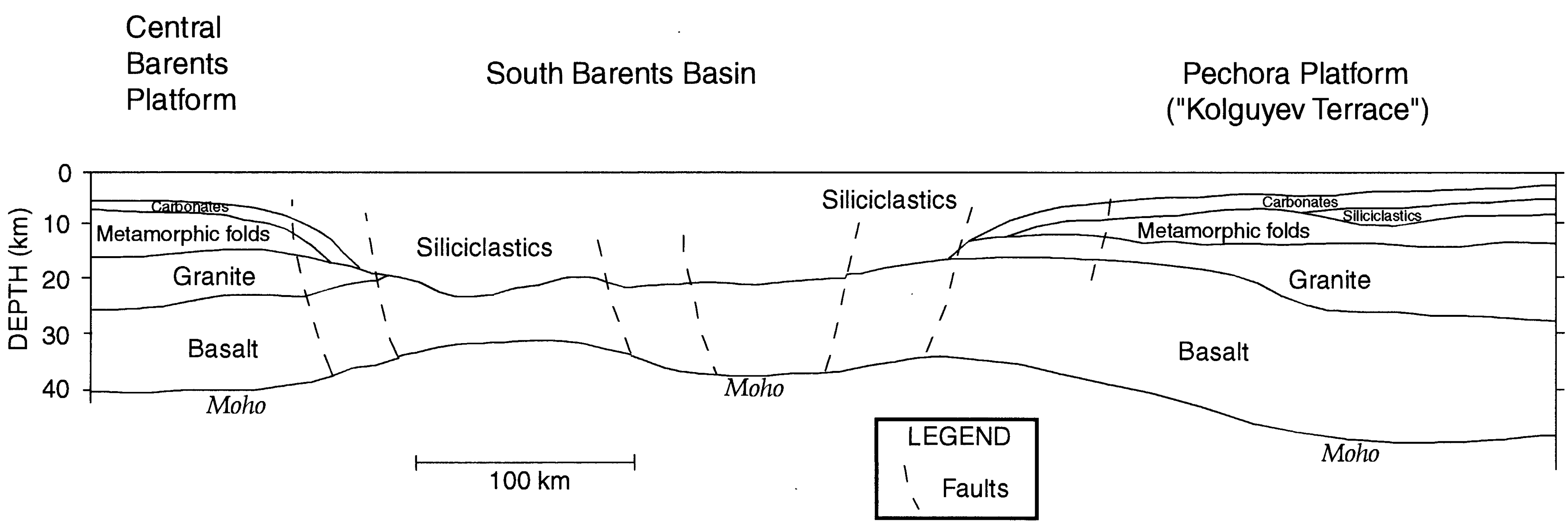


Figure 2b. NW-SE crustal cross section across the South Barents depression and adjacent platform areas from interpreted seismic, gravity, and magnetic data (after Gramberg and others, 1998). See text for discussion.



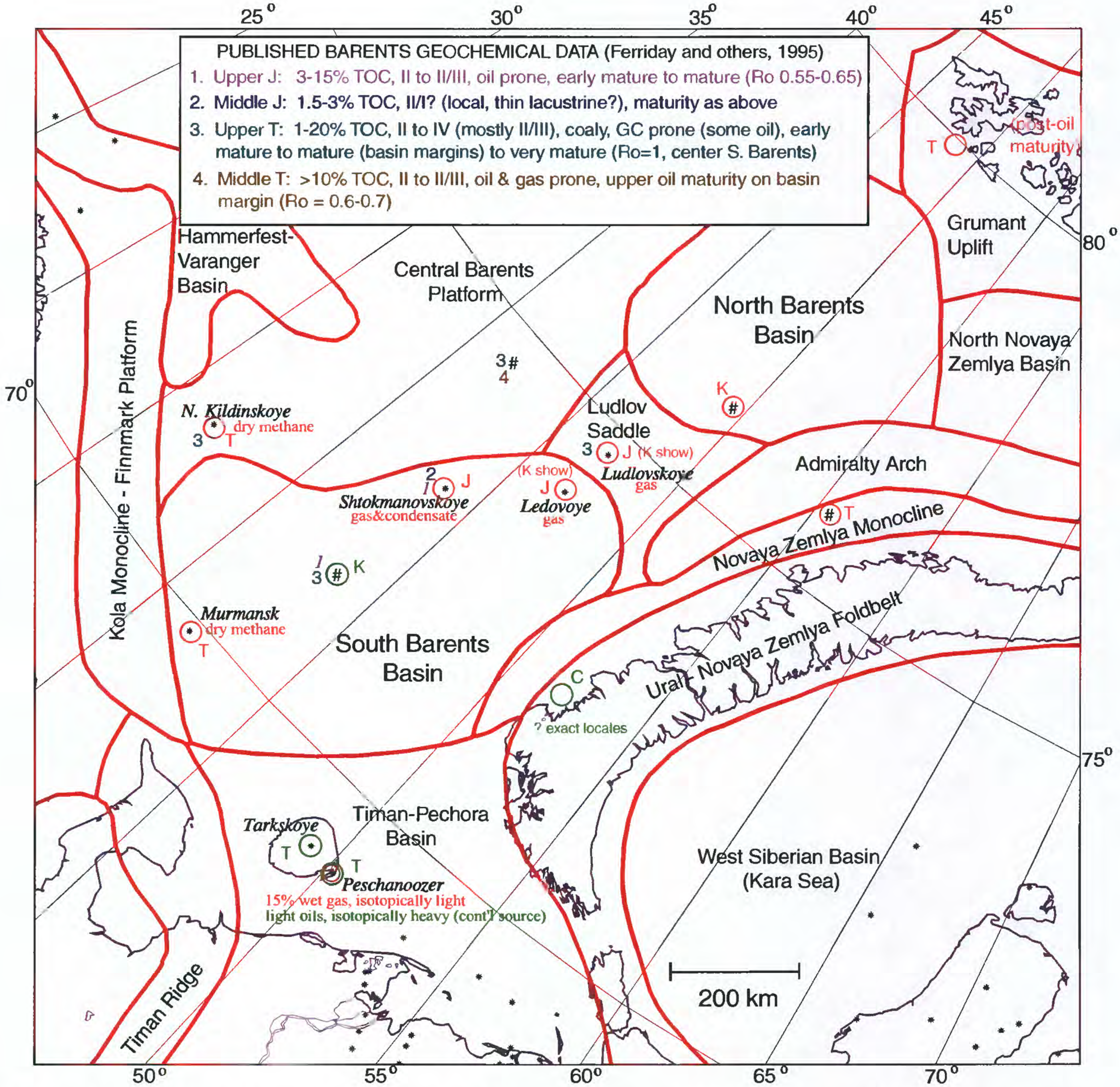



Figure 3. Fields, hydrocarbon shows, and geochemical data for the eastern Barents Sea region.

EXPLANATION

- Rivers (ESRI ArcWorld3M)
- Shoreline
- Geologic Province boundary
- Country Boundary
- * Field Centerpoints
- \# Wells with show or geochemical data
- ○ oil show or production
- ○ gas show or production

Reservoir or source rock: K = Cretaceous, J = Jurassic, T = Triassic,
C = Upper Paleozoic Carbonates (Dev., Carb., Lower Perm)

eastern Barents Sea and the Timan-Pechora Basin. Eastern Barents subsidence and sedimentation rates were probably greatest during latest Permian and Triassic times (Ostisty and Cheredeev, 1993) (fig. 2a). The Ludlov Saddle separating the South and North Barents Basins is Mesozoic in age, possibly as old as Triassic, and contains east-west trending anticlines and synclines.

The exact origin of the mostly Mesozoic eastern Barents basins and the age of the basin floors are uncertain. Remnant Cambrian (Iapetus) ocean floor might be present locally (Ustritskiy, 1991). Similar basins exist northeastward within the North Kara Sea. Gramberg and others (1998) propose a Late Permian-Triassic rifting origin from mantle diapirism, which explains the gravity maxima. Crust of the basin centers is thin and oceanic, with basalts of presumed Late Paleozoic age and a typical Moho depth of 30 km (fig. 2b). In contrast, surrounding platform areas contain additional continental crust to 15 km in thickness above the basalts, with the Moho at an average depth of 45 km. East Barents magnetic rocks are known or postulated to exist in the basement, locally within Devonian carbonates, in the basin centers as sills within Triassic siliciclastics, and in the northern regions of Franz Josef Land and Svalbard within Jurassic through Early Cretaceous rocks.

Cenozoic uplift associated with the opening of the Greenland Sea and the Arctic Ocean resulted in regional erosion ranging from probably hundreds of meters to several kilometers over the entire Barents Sea (Nyland and others, 1992; Dore, 1995). Late Cretaceous and Tertiary rocks are generally thin to absent from the eastern Barents region.

## Exploration history

Bathymetric studies, bottom samples and earliest seismic surveys in the Barents Sea were acquired during the 1960s, followed in the 1970s by more detailed seismic exploration and the acquisition of gravity and aeromagnetic data to nearly latitude 80° N. Some island drilling was accomplished during the 1970s, with Franz Josef Land and Svalbard containing wells to 3-km-depths. The first offshore location was tested in 1982/1983 at Murmansk field in the southern South Barents Basin.

More than 250,000 km of eastern Barents seismic data have been acquired with a typical 1-6 km spacing in the South Barents Basin and a typical 20-40 km spacing in the North Barents Basin (Johansen and others, 1993; Malovitsky and Matirossyan, 1995). At least 30 major structures have been identified.

The deepest regional well was drilled to a depth of 4524 m in Lower Triassic rocks within the central South Barents Basin (Petroconsultants, 1996). Carboniferous limestones are the oldest rocks penetrated at 4005 m total depth in a well just east of these provinces on the Novaya Zemlya monocline (fig. 1).

## PETROLEUM OCCURRENCE

Seven fields thus far characterize the South and North Barents Triassic-Jurassic gas-dominated total petroleum system – three within the South Barents Basin province outline and four from adjacent areas (fig. 3, table 1). Just one well has been drilled within the North Barents Basin province outline, and no production has been established. Based on the Petroconsultants (1996) data base used in this USGS assessment, the three South Barents fields contain 11.8 BBOE (70+ TCF) in ultimately recoverable reserves, ranking 35$^{th}$ in the world. Adding the four surrounding fields increases the reserve number to 13.2 BBOE (79 TCF) and the ranking to 29$^{th}$ in the world. Widespread Lower Triassic shale source rocks are at gas-stage maturity in the central basin areas and at oil-stage maturity around the basin margins (fig. 2a).

Of the seven fields, the central area's Shtokmanovskoye, Ludlovskoye and Ledovoye fields – accounting for 97% of the known, ultimately recoverable reserves – produce dry methane gas with a trace of condensate from Jurassic sandstones (fig. 3). Vertical migration paths are required to charge those multi-pay reservoir rocks.

Shtokmanovskoye, with the most field reserves in the province, contains gas and condensate with 42°-52° API gravity, low sulfur (0.02%), a pristane/phytane ratio of 5 to 6, high $C_{24}$ tetracyclic terpanes compared with $C_{23}$-$C_{26}$ tricyclic terpanes, low $C_{27}$, and a small sterane/triterpane ratio (Ferriday and others, 1995). The hydrocarbons were generated from marine and terrigenous source rocks at about 0.9 %$R_o$. The younger and shallower Shtokmanov Callovian accumulation is more biodegraded than the older, deeper Bajocian accumulation, but it is slightly lighter isotopically ($\delta^{13}C$ of –27.5 to –29 ppt Callovian vs. $\delta^{13}C$ of –27 to –28 ppt Bajocian). Although this isotopic difference might not be significant, the observation led Ferriday and others (1995) to suggest that the younger and shallower Callovian accumulation contains a contribution from a carbonate source rock such as the Devonian Domanik. The maturation and migration history for such an occurrence would be difficult to explain, even if those source rocks were present.

Dry methane is also trapped in two southwestern fields within Triassic sandstone reservoirs, North Kildinskoye and Murmansk – accounting for 2.8% of the known, ultimately recoverable reserves. A greater lateral component of migration is required to charge those fields from the basin centers. The gas $\delta^{13}C$ there is characterized by –34 to –37 ppt (Zakharov and Kulibakina, 1997).

Oil and wet gas occur in Triassic sandstones in two southeastern fields at Kolguyev Island near the Russian coastline. Peschanoozer and Tarkskoye fields contain 0.2% of the petroleum system's known, ultimately recoverable reserves. The oil at Peschanoozer is characterized by approximately 42° API gravity and 2200-2500 cu ft/bbl GOR (Petroconsultants, 1996). The oil is low in sulfur and paraffin and has $\delta^{13}C$ of –27 ppt; whereas, the gas has $\delta^{13}C$ of –41 to –42 ppt (Zakharov and Kulibakina, 1997). Gas presence in these basin-margin fields requires a major lateral

Table 1. Producing fields in the South and North Barents Triassic-Jurassic total petroleum system.

| FIELD | LOCATION | DISCOVERY DATE | RESERVOIR |
|---|---|---|---|
| Ledovoye | South Barents | 1991 | Jurassic |
| Ludlovskoye | Ludlov Saddle | 1990 | Jurassic |
| Murmansk | South Barents | 1984 | Triassic |
| N. Kildinskoye | Central Barents | 1983 | Triassic |
| Peschanoozer | Timan-Pechora | 1982 | Triassic |
| Shtokmanovskoye | South Barents | 1988 | Jurassic |
| Tarkskoye | Timan-Pechora | 1988 | Triassic |

component of migration from the basin centers. It has been suggested that southward migrating thermal Triassic gas from the South Barents Basin has come into contact with and has dissolved oil from Paleozoic carbonate accumulations, then continued migrating laterally and vertically into Triassic reservoir rocks where the gas subsequently underwent phase differentiation (Clarke, 1999).

Additional gas shows occur in Triassic rocks of the Franz Josef Land islands and in an offshore well west of the Novaya Zemlya archipelago as far north as the southern part of the North Barents Basin (fig. 3). Gas shows also occur in Cretaceous reservoir rocks in wells on the Ludlov Saddle and in the southern North Barents Basin. Two oil shows also have been reported in Cretaceous rocks penetrated in the center of the South Barents Basin and in Paleozoic carbonate rocks somewhere along the west coast of southern Novaya Zemlya. The former could have been sourced from Jurassic shale source rocks at early-stage maturity to oil in the central basin areas and the latter sourced from remnant Devonian source rocks of the northeastern Timan-Pechora Basin Province.

## SOURCE ROCK

### Major Source Rock – Triassic

During the Triassic Period, the eastern Barents region drifted from about latitude 40° to 60° N. (Leith and others, 1993). The paleogeographic setting was a shallow epicontinental sea with local areas of upwelling and restricted circulation and a climate that varied regionally from semi-arid to humid. Eastern Barents subsidence was rapid, probably exceeding 150 mm/1000 years (Ostisty and Cheredeev, 1993). Ulmishek suggests that Late Triassic sedimentation rates might have been as high as 1000 mm/1000 years (oral communication, 1999).

Major siliciclastic provenance was from southern and eastern areas, with lesser sediment contributions from northern and northeastern directions. Southeastward marine transgressions occurred, but eastern Barents organic matter is still considerably more humic than in other Arctic regions such as northern Alaska and the Canadian Sverdrup Basin. Similar depositional and tectonic conditions actually existed from Late Permian through Early Jurassic time, but best eastern Barents source rocks are probably Early and Middle Triassic in age (fig. 4).

Eastern Barents Triassic source rocks are medium to dark shales, locally coaly, that contain type II (oil-prone) to type IV (as per Ferriday and others, 1995; gas-prone) kerogen (fig. 3, limited subsurface data). This total petroleum system is probably gas dominated because of the abundance of gas-prone kerogen, the rapid burial, and the relatively advanced stage of thermal maturity for large areas of Lower Triassic rocks in the basins (fig. 2a). Gross shale thickness ranges from hundreds to thousands of meters. Subsurface total organic carbon (TOC) content is variable to 20 wt% (2-8 wt% typical), and hydrogen index (HI) ranges from 200-500 mg/g TOC (Leith and others, 1993; Ferriday and others, 1995).

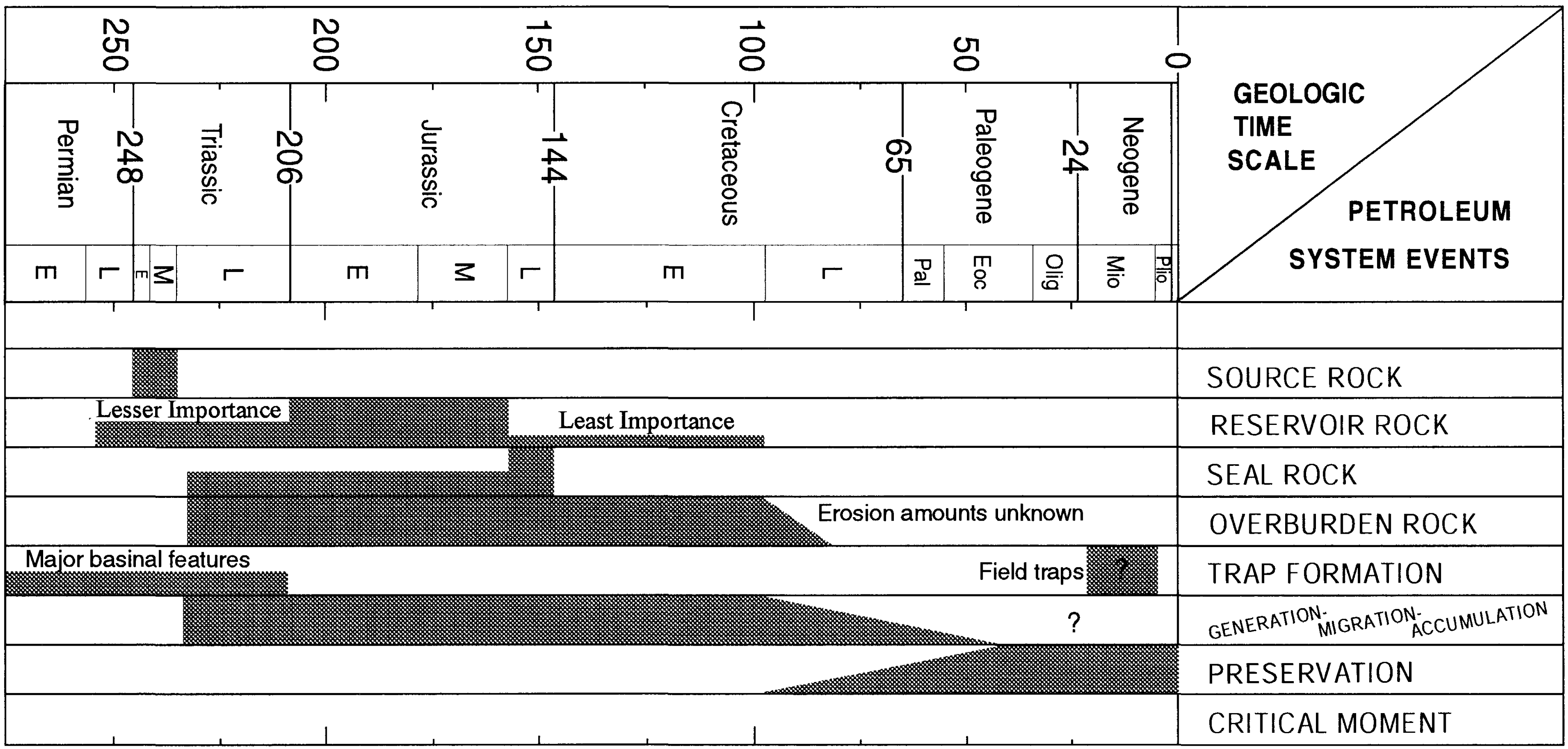
Figure 4. Total petroleum system events chart.

Province Name: South and North Barents Basin (includes part of Timan-Pechora)

TPS Name: 105001, Triassic-Jurassic

Author(s): S.J. Lindquist

Date: October, 1999



Other Source Rocks – Jurassic and Possible Devonian

A Late Jurassic warm and humid climate coincided with a sea level maximum and localized conditions of restricted bottom-water circulation in the Arctic region (Leith and others, 1993). Dark gray to black, bituminous marine shales tens of meters thick were deposited in several-hundred-meter water depths, but these source rocks are largely thermally immature in the eastern Barents basins (Oknova, 1993). They are the Bazhenov and Hekkingen stratigraphic equivalents of adjacent regions in Russia and Norway, respectively, where they do reach thermal maturity.

Arctic Upper Jurassic source rocks are thicker but lower in TOC away from the eastern Barents basins. In the North American Arctic, thicknesses range from hundreds to 1000 m, and TOCs range from 1-9 wt%. In contrast, central and southern Barents subsurface TOCs can reach 15-25 wt%, but with thicknesses of just 20-30 m (Leith and others, 1993). Norwegian Barents Sea thicknesses approach 100 m. Kerogen types are generally more oil-prone upward and range from type III to amorphous type II. An early-oil stage of thermal maturity possibly is reached at Upper Jurassic level in the deepest basin areas (figs. 2 and 3).

The presence of Devonian Domanik-equivalent, oil-prone, shaly basinal carbonate source rocks is unproven much north of the coastline in the Timan-Pechora Basin Province (see Lindquist, 1999, and cited references therein) and such facies are missing on Kolguyev island. If present in the Barents basins, Devonian source rocks would be overmature except for the eastern basin flanks along the Novaya Zemlya archipelago. Devonian source rock facies are known to exist in the North Kara depression on the east side of the Novaya Zemlya archipelago (Borisov and others, 1995).

## OVERBURDEN ROCK AND THERMAL HISTORY

Triassic rocks possibly reach a maximum of 8-9 km in thickness (rifting origin?), and facies range from continental and deltaic to submarine canyon (Ryabukhin and Zinin, 1993). Total thickness and facies vary significantly areally, and interbedded sills are common in the basin centers. The regional thermal gradient was probably highest during this geologic period because of rifting and the associated magmatic activity. Overburden sequences in basin depocenters contain approximately 2 km each of Jurassic and Cretaceous rocks – mostly siliciclastics of shallow marine origin. Preserved post-Cretaceous strata are typically less than 1 km thick, but Cenozoic uplift resulted in significant thermal cooling and possibly as much as hundreds of meters of eastern Barents erosion. It is possible that there was Paleogene deposition and Neogene uplift and erosion. Prior to Cenozoic cooling, the oil generation window ranged from about 2 to 8 km deep in the basin centers (corresponding to 60°–150° C, fig. 2a) (Ostisty and Cheredeev, 1993). Considering the higher Triassic thermal gradient, hydrocarbon generation from Lower and Middle Triassic source rocks probably began by Late Triassic time.

## TRAP STYLE

All discovered fields and wildcat wells are on structural closures, but many structural closures remain untested. Some basin-scale folds and faults relate back to the Uralian (Permo-Triassic) orogeny and the Early Kimmerian (Early Jurassic) orogeny. Penecontemporaneous folding and faulting during Triassic rifting and subsidence affected the facies distribution and initiated formation of the Ludlov Saddle. Uplift associated with the Cenozoic opening of the Arctic Ocean and/or with glacial isostacy resulted in the erosion of post-Neocomian strata and in further structural deformation. Uplift and pressure decrease also caused the expansion of existing gas accumulations, remigration of trapped hydrocarbons, possible loss of seal integrity, and local halting of hydrocarbon generation.

Jurassic reservoir sandstones are stratigraphically more continuous and generally better in reservoir quality than their Triassic counterparts. Thus, some Jurassic accumulations could be characterized as true structural closure or faulted structural closure traps. Ninety-seven percent of the known recoverable reserves in the eastern Barents region are in Jurassic reservoir rocks (Petroconsultants, 1996).

Undertested are the undrilled structural closures and fault traps, drapes, stratigraphic onlaps, stratigraphic pinch-outs, stratigraphic and structural erosional traps, and diagenetic traps for all potential reservoir horizons in Triassic, Jurassic and Cretaceous sandstones.

### Discovery History

Fields of the Triassic-Jurassic total petroleum system in the eastern Barents basins were discovered between 1982 and 1991 (table 1), but only one (Peschanoozer) has been developed. The first four fields, discovered between 1982 and 1988 in the southern regions, had Triassic reservoir rocks (fig. 3). Peschanoozer (1982) on Kolguyev Island in the northern Timan-Pechora offshore produces oil, gas and condensate from Lower Triassic sandstones. North Kildinskoye (1983), just west of the South Barents Basin province boundary, and Murmansk (1984) in the southern South Barents Basin contain dry gas in Lower to Middle Triassic sandstones. Tarkskoye (1988) on Kolguyev Island in the northern Timan-Pechora offshore produces oil from Triassic rocks.

In 1988, Shtokmanovskoye was discovered in the northwestern South Barents Basin (fig. 3). This field contains gas and some condensate in four Middle and Upper Jurassic sandstone horizons. Published reserve figures include 141 TCF (Oil and Gas Journal, 1990), 88 TCF (Dore, 1995) and 117 TCF (Malovitsky and Matirossyan, 1995), making it the largest province field in terms of reserves.

Ludlovskoye, discovered in 1990 on the Ludlov Saddle, tested gas and minor condensate from Middle and Upper Jurassic sandstones. Ledovoye, discovered a year later between Shtokmanovskoye and Ludlovskoye, tested gas from Middle

Jurassic sandstones. Prisyazhniy (1995) reported 177 TCF reserves for all five offshore eastern Barents fields (excluding the two Kolguyev Island fields).

## RESERVOIR ROCK

### Major Reservoir Rock – Jurassic

Jurassic sedimentation rates declined considerably from those in Triassic time (>150 mm to <35 mm/1000 years; Ostisty and Cheredeev, 1993), and there is a maximum Jurassic thickness of 2 km in the basin centers. Lower and Middle Jurassic strata are marine and deltaic facies with a high proportion of sandstone; Upper Jurassic strata are deeper marine facies with greater volumes of shale. Coals are common locally. Regionally, Jurassic facies are more terrigenous southeastward toward the Timan-Pechora shelf and coastline. Jurassic and Cretaceous volcanism affected northern provenance from the islands of Franz Josef Land.

Known Jurassic sandstone reservoir rocks are thickest and best in reservoir quality on paleohighs (Zakharov and Yunov, 1995). The three fields producing from Jurassic reservoir rocks have net pay thicknesses ranging from 8-76 m, porosity ranging from 15-25% and permeability ranging from hundreds of millidarcies to more than one darcy (Zakharov and Yunov, 1995; Petroconsultants, 1996). There are four stacked reservoir sandstones at the largest field, Shtokmanovskoye. Jurassic reservoir rocks are underexplored, with but little drilling to evaluate their potential.

### Other Reservoir Rocks – Triassic and Cretaceous

Eastern Barents Triassic rocks record numerous transgressive/regressive cycles and possible erosional episodes (Johansen and others, 1993). Known reservoir rocks are more discontinuous than their Jurassic counterparts and are commonly overpressured. Sediment transport directions were predominantly westward and northward during a time of rapid basinal subsidence. A maximum Triassic thickness of 9 km characterizes the basin centers. Facies vary from fluvial/alluvial to deltaic to deep marine, and clinoforms on seismic data correspond to depositional water depths as great as 1200 m (Semenovich and Nazaruk, 1992).

Sandstone mineralogy is commonly lithic-rich, but still with "good" porosity (Oknova, 1993). The known fields produce from Lower Triassic sandstones (Charkabozh Formation) and are characterized by porosity ranging from 13-24%, permeability ranging from tenths to nearly 200 millidarcies, and net pay ranging from 3-12 m (Petroconsultants, 1996). Best prospectivity is at marine-to-continental facies transitions, but hydrocarbon recoveries are commonly low (20-30%) and reserves small (20-35 mmboe) from stratigraphic traps (Zakharov and Kulibakina, 1997). Triassic reservoir rocks are underexplored because of sparse drilling.

Cretaceous rocks (probably mostly Lower Cretaceous) have a maximum thickness of approximately 2 km in the eastern Barents region, and no economic accumulations have yet been found in them. They include widespread continental to shelf shales and sandstones that prograded southward in Neocomian time (Johansen and others, 1993). Thus, more proximal and sand-rich Cretaceous facies might be preserved in the sparsely drilled North Barents basin. Neocomian sandstones are important reservoir rocks in the West Siberian Basin east of the Novaya Zemlya archipelago. No information has been published regarding reservoir quality of Cretaceous sandstones in the eastern Barents region.

## SEAL ROCK

Thick and widespread Mesozoic marine to continental shales are good to excellent local and regional seals in the eastern Barents basins. The major regional seal for this Triassic-Jurassic total petroleum system is an areally extensive, 400-600-m-thick Upper Jurassic to Neocomian marine shale with a mixed-layer clay mineralogy (Oknova, 1993; Zakharov and Yunov, 1995). Older Jurassic shales of local to regional areal extent have thicknesses of 50-300 m (Khain and others, 1993; Zakharov and Yunov, 1995). Triassic shales also provide good local seals (Semenovich and Nazaruk, 1992; Oknova, 1993; Zakharov and Kulibakina, 1997), as do Lower Cretaceous shales (Johansen and others, 1993).

## ASSESSMENT UNITS

Three assessment units are used to characterize the South and North Barents Triassic-Jurassic total petroleum system for the purposes of resource prediction. No appropriate field growth function was identified for this petroleum system, and none was used in the assessment process.

The "Kolguyev Terrace" (#10500101) assessment unit is a 79,000-$km^2$ area in the northernmost, offshore Timan-Pechora Basin Province #1008 (including Kolguyev Island with 5% of the area), adjacent to and southeast of the South Barents physiographic basin and geologic province (fig. 1). Kolguyev Island contains two small fields producing oil and wet gas from discontinuous Triassic sandstone reservoirs in folded and faulted traps. Triassic and older source rocks are absent on the island, and lateral migration from the Triassic source rocks of the South Barents Basin is assumed. Stratigraphic traps also are expected. The area contains abundant and excellent Mesozoic shale seals. This frontier assessment unit is predicted to contain somewhat more gas reserves than oil reserves in reservoir rocks and traps similar to what have been discovered, but perhaps with additional Jurassic sandstone reservoirs. Significant lateral migration is required from the thermally mature shale source rocks in the South Barents Mesozoic depocenter. Water depths range from 0-80 m, and seasonal ice pack affects the area.

The "South Barents and Ludlov Saddle" (#10500102) assessment unit includes the entire South Barents Basin Province #1050 (170,000 $km^2$) and the northerly adjacent Ludlov Saddle Province #1059 (26,000 $km^2$) (fig. 1). Four large, unproduced gas fields with Jurassic and Triassic sandstone reservoir rocks characterize this greater South Barents frontier assessment unit. Jurassic sandstones are more continuous, have better reservoir properties, and contain more known reserves than their Triassic counterparts; hence their inclusion in the total petroleum system name. Cretaceous sandstone reservoirs are also possible. Known traps are anticlines, and stratigraphic complexity is expected to also play a role in hydrocarbon accumulation. Source rocks are gas-prone and gas-and-oil-prone Lower Triassic shales thermally mature to oil on the basin margins and to gas in the basin center. Mesozoic shales are seals, with thick Upper Jurassic shales comprising a regional seal. Water depths range from 10-350 m, and seasonal ice pack affects the area.

The "North Barents" (#10500103) hypothetical assessment unit includes the entire "boutique" North Barents Basin Province (#1060) (fig. 1). Reservoir rocks are presumed to be Mesozoic siliciclastics, with seals and traps similar to those in the South Barents and Ludlov Saddle assessment unit, but the Jurassic System might be shalier here than in South Barents. Thus, favorable rock attributes are at slightly greater risk than in South Barents and Ludlov Saddle, but source rock quality, thermal maturity history and migration scenarios are probably similar. Water depths range from 70-350 m, and seasonal ice pack affects the area.

## SELECTED REFERENCES


Alekhin, S.V., 1988, The nature of the "strange" horizons in the Triassic sequence of the South Barents basin: International Geology Review, v. 30, no. 7, p. 745-750. *Translated from Sovetskaya geologiya, no. 9, p. 61-65, 1988.*

Alekhin, S.V., 1992, Neocomian sedimentary rocks of Barents Sea shelf: Petroleum Geology, v. 26, no. 11-12, p. 418-420. *Translated from Geologiya Nefti i Gaza, no. 2, p. 9-12, 1991.*

Alekhin, S.V., Baturin, G.D., Verba, M.L., Grigor'yev, M.N., Daragan-Suchsheva, L.A., and Shipel'kevich, Yu.V., 1992, Seismostratigraphic model of the sedimentary section of the Barents Sea shelf: Petroleum Geology, v. 26, no. 1-2, p. 1-6. *Translated from Osadochnyye basseyny i neftegazonosnost, Moscow, Nauka, p. 99-107, 1989.*

Alsgaard, P.C., 1993, Eastern Barents Sea Late Palaeozoic setting and potential source rocks, *in* Vorren, T.O., Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., Arctic Geology and Petroleum Potential: NPF (Norwegian Petroleum Society) Special Publication 2, Amsterdam, Elsevier, p. 405-418.

Bogdanov, N.A., Khain, V.E., Bogatsky, V.I., Kostyuchenko, S.L., Senin, B.V., Shipilov, E.V., and Sobolev, S.F., 1996, Tectonic map of the Barents Sea region and the northern part of the European Russia: Moscow, Institute of the Lithosphere, Russian Academy of Sciences, 1:2,500,000. Plus explanatory notes.

Bogolepov, A.K., Zhuravlev, V.A., Shipilov, E.V., and Yunov, A.Yu., 1992, Deep structure of the western sector of the Eurasian-Arctic continent-to-ocean transition zone: International Geology Review, v. 34, no. 3, p. 240-249.

Borisov, A.V., Vinnikovskiy, V.S., Tanygil, I.A., and Fedorovskiy, O., 1995, Shelf of Barents and Kara seas – new large resource base of Russia (structure and main exploration directions): Petroleum Geology, v. 29, no. 9-10, p. 301-308. *Translated from Geologiya Nefti i Gaza, no. 1, p. 4-8, 1995.*

Bro, Ye.G., Pchelina, T.M., Preobrazhenskaya, E.N., Ronkina, Z.Z., Voytsekhovskaya, A.G., Krasnova, V.L., and Mozhayeva, O.V., 1991, Sedimentary cover of the Barents Sea shelf from drilling data on islands: Petroleum Geology, v. 25, no. 7-8, p. 239-243. *Translated from Problemy neftegazonosnosti mirovogo okeana: Moscow, Nauka, p. 191-197, 1989.*

Clarke, J., 1999, Kolguyev Island, Barents Sea: Internet Geology Newsletter No. 16, October, 25, 1999, (http://geocities.com/internetgeology).
Dore, A.G., 1995, Barents Sea geology, petroleum resources and commercial potential: Arctic, v. 48, no. 3, p. 207-221.
Environmental Systems Research Institute Inc., 1992, ArcWorld 1:3M digital database: Environmental Systems Research Institute, Inc. (ESRI), available from ESRI, Redlands, CA, scale: 1:3,000,000.
Ferriday, I.L., Borisov, A., Gudkova, A., Hall, P.B., Vinnikovsky, V., Bakken, K.A., and Bjoroy, M., 1995, Source rock potential and the characterization of finds in the Russian part of the Barents Sea: Petroleum Exploration and Production in Timan-Pechora Basin and Barents Sea, Collected Reports of International Conference, August 15-17, 1994, St. Petersburg, All Russian Petroleum Scientific-Research Geological Exploration Institute (VNIGRI) and Continental Shelf and Petroleum Technology Research Institute (IKU), p. 43-44.
Gramberg, I.S., and others, 1998, Barents shelf platform: Petroleum Geology, v. 24, no. 5-6, p. 141-186. *Translated from Leningrad, Nedra, PGO Sevmorgeologiya, 263 p., 1988.*
Gramberg, I.S., and Suprunenko, O.I., 1995, Oil and gas resources of the Barents Sea shelf: Petroleum Exploration and Production in Timan-Pechora Basin and Barents Sea, Collected Reports of International Conference, August 15-17, 1994, St. Petersburg, All Russian Petroleum Scientific-Research Geological Exploration Institute (VNIGRI) and Continental Shelf and Petroleum Technology Research Institute (IKU), p. 36-41.
Heafford, A.P., 1988, Carboniferous through Triassic stratigraphy of the Barents shelf, *in* Harland, W.B., and Dowdeswell, E.K., eds., Geological Evolution of the Barents Shelf Region: London, Graham and Trotman, p. 89-108.
Johansen, S.E., Ostisty, B.K., Birkeland, O., Fedorovsky, Y.F., Martirosjan, V.N., Bruun Christensen, O., Cheredeev, S.I., Ignatenko, E.A., and Margulis, L.S., 1993, Hydrocarbon potential in the Barents Sea region: play distribution and potential, *in* Vorren, T.O., Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., Arctic Geology and Petroleum Potential: NPF (Norwegian Petroleum Society) Special Publication 2, Amsterdam, Elsevier, p. 273-320.
Kelly, S.R.A., 1988, Jurassic through Cretaceous stratigraphy of the Barents shelf, *in* Harland, W.B., and Dowdeswell, E.K., eds., Geological Evolution of the Barents Shelf Region: London, Graham and Trotman, p. 109-130.
Khain, V.Ye., Kleshchev, K.A., Sokolov, B.A., and Shein, V.S., 1993, Tectonics and geodynamic conditions for oil and gas occurrence in the USSR: Petroleum Geology, v. 27, no. 7-8, p. 267-274. *Translated from Aktual'nyye problemy tektoniki SSSR, Nauka, p. 46-54, 1988.*
Klett, T.R., Ahlbrandt, T.A., Schmoker, J.W., and Dolton, G.L., 1997, Ranking of the world's oil and gas provinces by known petroleum volumes: U.S. Geological Survey Open-File Report 97-463, one CD-ROM.
Kunin, N.Ya., Usenko, S.V., Vinogradov, A.V., and Kerusov, I.N., 1990, Regional seismostratigraphy of the sedimentary section beneath the Barents Sea: International Geology Review, v. 32, no. 1, p. 34-46.
Kuranova, L.V., Plekhotkina, L.A., and Kosenkova, N.N., 1998, Conditions of sediment accumulation and formation of pools in Peschanoozer gas-condensate-oil field: Petroleum Geology, v. 32, no. 2, p. 151-156. *Translated from Razvedka i Okhrana Nedr, no. 5, p. 28-31, 1997.*
Leith, T.L., Weiss, H.M., Mork, A., Arhus, N., Elvebakk, G., Embry, A.F., Brooks, P.W., Stewart, K.R., Pchelina, T.M., Bro, E.G., Verba, M.L., Danyushevskaya, A., and Borisov, A.V., 1993, Mesozoic hydrocarbon source-rocks of the Arctic region, *in* Vorren, T.O.,

Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., Arctic Geology and Petroleum Potential: NPF (Norwegian Petroleum Society) Special Publication 2, Amsterdam, Elsevier, p. 1-25.

Lindquist, S.J., 1999, The Timan-Pechora basin province of northwest Arctic Russia: Domanik – Paleozoic total petroleum system: U.S. Geological Survey Open-File Report 99-50-G, 24 pages, 15 figures, 2 tables.

Magoon, L.B., and Dow, W.G., 1994, The petroleum system, *in* Magoon, L.B., and Dow, W.G., eds., The Petroleum System – from Source to Trap: A.A.P.G. Memoir 60, Tulsa, American Association of Petroleum Geologists, p. 3-23.

Malovitsky, Ya.P., and Matirossyan, V.N., 1995, The Barents shelf investigations: main results, *in* Hanslien, S., ed., Petroleum Exploration and Exploitation in Norway: NPF (Norwegian Petroleum Society) Special Publication 4, Amsterdam, Elsevier, p. 321-331.

Mork, A., Vigran, J.O., Korchinskaya, M.V., Pchelina, T.M., Fefilova, L.A., Vavilov, M.N., and Weitschat, W., 1993, Triassic rocks in Svalbard, the Arctic Soviet islands and the Barents Shelf: bearing on their correlations, *in* Vorren, T.O., Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., Arctic Geology and Petroleum Potential: NPF (Norwegian Petroleum Society) Special Publication 2, Amsterdam, Elsevier, p. 457-479.

Nyland, B., Jensen, L.N., Skagen, J., Skarpnes, O., and Vorren, T., 1992, Tertiary uplift and erosion in the Barents sea: magnitude, timing and consequences, *in* Larsen, R.M., Brekke, H., Larsen, B.T., and Talleraas, E., Structural and Tectonic Modelling and its Application to Petroleum Geology: NPF (Norwegian Petroleum Society) Special Publication 1, Amsterdam, Elsevier, p. 153-162.

Oil and Gas Journal, 1990, Soviet exploration success spreads from Barents into Kara Sea: Oil and Gas Journal, v. 88, no. 32, p. 28-30, 32.

Oknova, N.S., 1993, Oil-gas prospects of the upper Permian-Mesozoic sediments of the Pechora-Barents sea basin: Petroleum Geology, v. 27, no. 5-6, p. 164-167. *Translated from Geologiya Nefti i Gaza, no. 11, p. 9-11, 1992.*

Ostisty, B.K., and Cheredeev, S.I., 1993, Main factors controlling regional oil and gas potential in the west Arctic, former USSR, *in* Dore, A.G., ed., Basin Modelling: Advances and Applications, NPF (Norwegian Petroleum Society) Special Publication 3, Amsterdam, Elsevier, p. 591-597.

Ostisty, B.K., and Fedorovsky, Y.F., 1993, Main results of oil and gas prospecting in the Barents and Kara Sea inspire optimism, *in* Vorren, T.O., Bergsager, E., Dahl-Stamnes, O.A., Holter, E., Johansen, B., Lie, E., and Lund, T.B., Arctic Geology and Petroleum Potential: NPF (Norwegian Petroleum Society) Special Publication 2, Amsterdam, Elsevier, p. 243-252.

Pavlenkin, A.D., 1990, Caledonian rifting on the Barents Sea shelf: Petroleum Geology, v. 24, no. 9-10, p. 291-293. *Translated from Geology of the Barents-Kara shelf: Leningrad, PGO Sevmorgeologiya, p. 29-33, 1985.*

Petroconsultants, 1996, Petroleum Exploration and Production Database: Petroconsultants, Inc., P.O. Box 740619, 6600 Sands Point Drive, Houston TX 77274-0619, USA or Petroconsultants, Inc., P.O. Box 152, 24 Chemin de la Mairie, 1258 Perly, Geneva, Switzerland.

Prisyazhniy, V.N., 1995, Prospects of the development of the Barents and Pechora seas shelf: Petroleum Exploration and Production in Timan-Pechora Basin and Barents Sea, Collected Reports of International Conference, August 15-17, 1994, St. Petersburg, All Russian Petroleum Scientific-Research Geological Exploration Institute (VNIGRI) and Continental Shelf and Petroleum Technology Research Institute (IKU), p. 31-35.

Ryabukhin, G.Ye., and Zinin, V.A., 1993, Oil-gas prospects of the Triassic complexes of the shelf of the Arctic seas of Russia: Petroleum Geology, v. 27, no. 7-8, p. 251-254. *Translated from Geologiya Nefti i Gaza, no. 12, p. 2-5, 1992.*

Semenovich, V.V., and Nazaruk, V.V., 1992, Oil-gas potential of southeast shelf of Barents Sea: Petroleum Geology, v. 26, no. 11-12, p. 404-409. *Translated from Geologiya Nefti i Gaza, no. 6, p. 2-6, 1992.*

Ulmishek, G., 1982, Petroleum geology and resource assessment of the Timan-Pechora basin, USSR, and the adjacent Barents-northern Kara shelf: Argonne, IL, Argonne National Laboratory, Energy and Environmental Systems Division, Report ANL/EES-TM-199, 197 p.

Ulmishek, G., 1985, Geology and petroleum resources of the Barents-northern Kara shelf in light of new geologic data: Argonne, IL, Argonne National Laboratory, Energy and Environmental Systems Division Report ANL/ES-148, 89 p.

Ustritskiy, V.I., 1991, Tectonic nature of the Barents-north Kara mega-downwarp: Petroleum Geology, v. 25, no. 7-8, p. 236-238. *Translated from Problemy neftegazonosnost mirovogo okean: Moscow, Nauka, p. 182-191, 1989.*

Zakharov, Ye.V., and Kulibakina, I.B., 1989, Prospects for discovery of oil and gas in the Jurassic complex of the Arctic seas of the USSR: International Geology Review, v. 31, no. 6, p. 635-638. *Tranlsated from Sovetskaya geologiya, no. 5, p. 33-38, 1988.*

Zakharov, Ye.V., and Kulibakina, I.B., 1997, Oil-gas prospects of Triassic complex on shelf of Barents and Pechora seas: Petroleum Geology, v. 31, no. 3, p. 260-265. *Tranlsated from Geologiya Nefti i Gaza, no. 10, p. 21-25, 1996.*

Zakharov, Ye.V., and Yunov, A.Yu., 1995, Direction of exploration for hydrocarbons in Jurassic sediments on the Russian shelf of the Barents Sea: Petroleum Geology, v. 29, no. 1-2, p. 32-36. *Translated from Geologiya Nefti i Gaza, no. 2, p. 13-15, 1994.*