U.S. DEPARTMENT OF THE INTERIOR

U.S. GEOLOGICAL SURVEY

GEOLOGY AND NATURAL GAS POTENTIAL OF DEEP SEDIMENTARY BASINS IN THE FORMER SOVIET UNION

by

T.S. Dyman[1], V.A. Litinsky[2], and G.F. Ulmishek[1]

Open-File Report 99-381

[1]U.S. Geological Survey, P.O. Box 25046, MS 939, Denver, CO 80225

[2] Consultant, Aurora, CO 80011

TABLE OF CONTENTS

Geology and Natural Gas Potential of Deep Sedimentary Basins in the Former Soviet Union

by
T.S. Dyman, V.A. Litinsky, and G.F. Ulmishek

INTRODUCTION

Deep sedimentary basins in the Former Soviet Union (FSU) (having sedimentary rocks in excess of 4.5 km thick) include a total area greater than 3.9 million km^2. Some of these basins are among the deepest in the World with depths to basement exceeding 20 km (table 1). Deep basins occur in both offshore and onshore areas of the FSU and extend from the Arctic Shelf in the north, to the Sea of Okhotsk and the Kamchatka Peninsula in the east, the Central Asian republics in the south, and Ukraine in the west. These basins formed in a wide variety of plate-tectonic regimes and include rift basins, foreland basins, collisional passive margins, and pull-apart (small oceanic) basins.

In this report, we summarize the distribution of deep sedimentary basins, their geologic framework, and their potential for deep natural gas resources (fig. 1; table 1) in order to determine the future of deep undiscovered natural gas resources in the FSU. Some of the basins presented here contain oil and gas fields discovered at great depths. Other basins have not been deeply drilled, but the potential for future discoveries remains high. For many basins, little or no data are available--particularly for those basins in the Arctic offshore and Russian Far East (Oil and Gas Journal, 1998).

Six of these basins were chosen for discussion in this report, and their geologic and production characteristics are presented in the following sections. These basins include: Dnieper-Donets, Vilyuy, North Caspian, Middle Caspian, South Caspian, and Amu Darya basins (fig. 1). We selected these basins from a complete list in Table 1 based on an analysis of the geologic characteristics and production potential leading to future development of deep oil and gas resources. For each basin, we discuss the location, tectonic and sedimentary history, principal source and reservoir rocks, trapping mechanisms, and potential for deep production. Basin maps are from the Map of Petroleum Potential of the USSR (Gabrielyants, 1990) and from Gramberg and Pogrebitsky (1984) but have been simplified to include only the most important geologic features that pertain to the potential distribution of deep oil and gas resources. Each basin map includes basin boundary, major structural boundaries and faults. Existing gas fields are identified on our maps regardless of depth, and the portions of each basin below 4.5 km are shaded. Our primary emphasis in this report is on natural gas, but deep oil resources are also included in our summary because many deep plays in the FSU have both oil and gas potential.

Table 1 lists all known basins of the FSU that contain sedimentary rocks deeper than 4.5 km; it includes basin name, location, and size of the deep portions of the basin in km^2; maximum depth; chief reservoirs; plate-tectonic classification of basin; and notes on deep gas production potential for each basin.

This report was funded in part by the Gas Research Institute, Chicago, Illinois (contract no. 50942103366) and the Energy Resources Program of the U.S. Geological Survey, Denver, Colorado. We wish to acknowledge Vello Kuuskraa of Advanced Resources International, Arlington, VA and Tim Klett of the U.S. Geological Survey Central Energy Team, Denver, CO for their careful and thoughtful reviews of this manuscript.

BASIN DESCRIPTIONS

Dnieper-Donets Basin

Introduction

The Dnieper- Donets basin is an elongated depression located in the eastern part of Ukraine (figs. 1 and 2). The northeastern basin boundary is marked by the Voronezh regional high above which the Precambrian basement of the Russian craton is covered by a thin veneer of Paleozoic sedimentary rocks. The Ukrainian shield borders the basin to the southwest. The basin is separated from the Pripyat basin of Byelorus by the Loev-Bragin uplift to the northwest. The southeastern basin boundary includes anticlines of the Donbas foldbelt which gradually plunge into the basin and lose their tectonic expression (Law and others, 1998; Ulmishek and others, 1994).

The basin includes an area of about 23,000 km^2 that contain sedimentary rocks more than 4.5 km thick. The basin is a Late Devonian rift that separated the Ukrainian shield from the main body of the Precambrian Russian craton. The basement is encountered at a depth of 4 to 5 km in the northwestern part of the basin but dips along its strike southeastward such that it occurs at more than 15 km near the Donbas foldbelt (fig. 2). The Donbas foldbelt is a structurally inverted and deformed continuation of the rift (Kabyshev, 1987).

Tectonic and Sedimentary History

Middle Devonian clastic rocks were deposited on Proterozoic and Archaen basement and comprise a pre-rift platform sequence (fig. 3). Initial rifting occurred in the Late Devonian (Frasnian) and increased in intensity from the northwest to the southeast due to clockwise rotation of the Ukrainian shield relative to the Russian craton (Ulmishek and others, 1994). Oceanic crust underlies both the southeastern part of the Dnieper-Donets basin and the Donbas foldbelt. The rift was filled with carbonate and evaporite rocks of Frasnian and Famennian age. Concurrently, clastic rocks derived from the Ukrainian shield were deposited along the southeastern margin of the basin, and active volcanism occurred in the northwest. Total thickness of the synrift sequence is estimated at 5-6 km (Kabyshev, 1987). The synrift sequence is unconformably overlain by Carboniferous rocks.

The overlying Carboniferous to Lower Permian sequence was deposited in a post-rift sag that deepened southeastward along the rift strike. Thickness of the post-rift sequence increases in this direction to 8 km or more (fig. 2). The Carboniferous is primarily composed of fluvial and marine clastic rocks, but some Visean and Bashkirian carbonates are present on the margins in the basin (fig. 3). The Middle to Upper Carboniferous section is composed of rocks deposited in coastal settings and includes abundant coal beds. During the Early Permian, red beds, carbonates, and salt were deposited in the basin. The Upper Permian salt seal controls the major gas reserves of the basin (fig. 3). During the late Early Permian (Artinskian), a collision with micro-continents along the southern border of the Russian craton resulted in compressional stress and termination of the post-rift sag stage of basin development. The deepest part of the Paleozoic rift/sag basin was then structurally inverted, thrusted, and folded resulting in the Donbas foldbelt. The entire basin was subsequently uplifted and eroded (Law and others, 1998). Truncation of older rocks was greatest in the southeastern part of the basin.

Sedimentation resumed during the Triassic and continued into the Tertiary resulting mostly in marine clastic deposition (fig. 3). Pre-Tertiary uplift and erosion occurred in approximately the same areas which were affected by pre-Triassic erosion. Plastic flow of Devonian salt began in the Early Carboniferous, and formation of salt domes and plugs continued into Tertiary time (Kurilyuk and others, 1991).

Source Rocks

Knowledge of source rocks in the Dnieper-Donets basin is poor, especially in the southeastern part, because of a lack of deep drillhole data. At least two major source rocks are presumed to exist: Devonian (Famennian) and Lower Carboniferous (Visean) black shales (fig. 3). Devonian shales have not been cored in wells but their presence is indicated by geochemical analyses of oils (unpublished data, U.S. Geological Survey). Visean shales have total organic carbon (TOC) content ranging from 3 to 13 percent and are primarily gas generating Type III source rocks (Law and others, 1998). They are highly mature in the northwestern part of the basin and overmature elsewhere.

A third potential source rock, coals and carbonaceous shales of the Middle Carboniferous, is also a possible source of gas, but source rock data are not available from this interval (fig. 3) (Law and others, 1998). The average present-day temperature at a depth of 5 km is about 150 degrees C. Over most of the basin area, source rocks occur deeper than 5 km (Ammosov and others, 1977).

Reservoir Rocks

Most reservoirs in the Dnieper-Donets basin are found in Carboniferous to Lower Permian sandstones. Additionally, Lower Permian fractured carbonates are also productive in a few large gas fields including the giant Shebelinka field (figs. 2; 3). The largest reserves are concentrated in multiple productive intervals within the Lower Permian and Visean sections (Ulmishek and others, 1994). According to Khanin (1979), reservoir quality is good to depths of about 3-3.5 km (porosity--20 to 22 percent; permeability--hundreds of millidarcies), but decreases at greater depths such that porosity seldom exceeds 12 to 14 percent at 4.5 km except where overpressures occur. More recent data on reservoir quality was not available for this report.

At great depths, permeability is controlled primarily by fracturing. Porosity of some deep sandstone reservoirs (deeper than 5 km) may exceed 14 to 17 percent, and permeability may reach 300 md (Maksimov and others, 1984). Devonian carbonate reservoirs are not yet commercial, and data on reservoir properties are not available (Ulmishek and others, 1994).

Trap Types

The most common traps in the Dnieper-Donets basin are faulted anticlines associated with salt domes. Structural traps are also found in the shallower northeastern part of the basin and along the basin margins where Devonian salt is thin or absent. These traps are related to basement structures associated with Devonian rift development. A few gas accumulations have been discovered in stratigraphic traps in updip pinchout zones in sandstone beds. Very little exploration for stratigraphic traps has been conducted, but the potential for new discoveries is high (Ulmishek and others, 1994). Trapping mechanisms for potential basin-centered gas accumulations include abnormal pressures and lithologic controls on fracture development.

Deep Production

The Dnieper-Donets basin is the most explored deep basin in the FSU. By 1980, 137 prospects had been drilled to depths greater than 4.5 km (Krylov, 1980), and during the 1980s about 50 % of all exploratory wells drilled in the basin reached these depths (Aksionov, 1985), but only a few small deep pools are currently producing from Devonian and Mesozoic reservoirs. The principal reserves are gas, commonly with significant volumes of natural gas liquids (NGL) (table 2). Oil fields are present only in the shallower northwestern part of the basin.

Exploration and production wells in the deep Dnieper-Donets basin have encountered significant problems. Outdated seismic data have yielded insufficient resolution, and many wells have missed their targets. Deep drilling has also been complicated by significant overpressuring. About 30 to 40 % of tested wells flowed gas and/or oil (Krylov, 1980), but flow rates were commonly low due to poor reservoir quality. The FSU lacked appropriate technologies for stimulation of overpressured reservoirs at great depths. Low flow rates and small accumulation sizes of many discoveries have hindered further development.

Based on the presence of overpressures and gas shows in deep reservoirs, Law and others (1998) identified a large (more than 35,000 km^2) unconventional basin-centered gas accumulation in the Dnieper-Donets basin. They suggested that the accumulation could include as much as 7,000 m of Carboniferous rocks. Wells have tested gas, and proper reservoir stimulation practices could be used to develop a deep commercial accumulation.

Vilyuy Basin

Introduction

The Vilyuy basin is a Late Permian to Mesozoic sag superimposed on the eastern margin of the Siberian craton (figs. 1 and 4). The basin also includes a narrow foredeep along frontal thrusts of the Verkhoyansk foldbelt north and south of the sag. The eastern basin boundary adjoins the foldbelt, and the western boundary is associated with a pinchout zone of Mesozoic rocks. The base of the Permian dips eastward from a depth of a few hundred meters to more than 5 km, and maximum depth to basement reaches 12 km or more (fig. 4). Over approximately 115,000 km^2 of the total basin area, the basement is deeper than 4.5 km

(Simakov, 1986). Tectonically, the basin is a southwest-to-northeast trending Devonian rift with a superimposed foreland basin that is transverse to the rift trend (Kontorovich, 1994).

Tectonic and Sedimentary History

The Vilyuy basin is underlain by a Proterozoic to Lower Paleozoic basement sequence that has been penetrated only on the basin margins (fig. 5). A northeast-striking Middle to Late Proterozoic rift sequence is hypothesized to exist below uppermost Proterozoic carbonate and clastic rocks. Rifting also occurred along this same zone of weakness in the Devonian. The latter rift was filled with a thick sequence of volcanic rocks and salt. From Late Paleozoic through Jurassic, the Vilyuy basin was a passive continental margin dominated by clastic sedimentation under humid climatic conditions (Kontorovich, 1994). The entire Upper Paleozoic through Jurassic sequence in the basin thickens eastward from a few hundred meters to more than 5 km and grades from continental to marine rocks. The continental sequence commonly contains coal beds.

During Late Jurassic and Cretaceous time, the Siberian craton collided with a series of micro-continents that resulted in thrusting, deformation of the basin margin, and development of the Verkhoyansk foldbelt (Dmitriyevsky and others, 1995). A narrow foredeep formed to the west in front of the foldbelt and filled with Cretaceous continental sediments up to 2 km thick. Tertiary sediments are absent in the basin except in local depressions where they may be a few hundred meters thick (Kontorovich, 1994).

Based on interpretation of gravity data, a broad thrust system (up to 80-100 km wide) is presumed to exist adjacent to the Verkhoyansk foldbelt. This system is composed of intensively folded Paleozoic rocks that were thrust onto the eastern half of the foredeep. Gravity data suggest that the foredeep is much deeper under the thrust system than under the exposed part of the basin (Litinsky, 1977a; 1977b; Kontorovich, 1994).

Source Rocks

Source rocks for deep gas in the Vilyuy basin are believed to be Upper Permian shales enriched by coaly organic matter (Type III kerogen) from interbedded coals (fig. 5). The underlying Lower Permian and Carboniferous rocks are low in organic matter, and younger Triassic rocks are thermally immature with respect to hydrocarbon generation. A very rich (TOC content up to 20 %, type II kerogen) source rock unit of Middle Cambrian age (Kuonam Formation; fig. 5) is present on the basin margin and apparently dips to great depths in the central part of the basin. However, hydrocarbons directly attributed to the Kuonam Formation have not yet been discovered (Kontorovich, 1994).

Reservoir Rocks

Triassic and Jurassic sandstones in the western and central parts of the basin occur at depths of less than 3 km and have high porosity and permeability. These sandstones are laterally discontinuous, and well-developed seals are only locally present. Large gas reserves occur in Triassic reservoirs, but they are almost entirely concentrated in the Srednetyung field at an average depth of 2,700 m and in the Srednevilyuy field at an average depth of 2,400 m (Kontorovich, 1994) (fig. 4). Upper Permian reservoir rocks are fair to poor in quality, but they contain significant reserves simply because of the presence of the regional Lower Triassic shale seal at depths of 2,700 to 3,500 m. In general, sandstones of the Upper Permian to Jurassic section decrease in thickness eastward and are replaced by shales. Few adequate reservoir rocks are found in outcrops in the foldbelt and adjacent foredeep. Sandstones exhibit a significant loss of porosity with depth (Kontorovich, 1994).

Trap types

Structural traps are dominant in most fields, although many pools are enhanced by stratigraphic pinchouts. The principal fields are found in large, local structures located on linear arches formed by partial inversion of the Devonian rift. Structures are primarily low relief anticlines.

Deep Production

Ten gas fields have been discovered in the basin. The principal reserves are found in Upper Permian and Triassic clastic reservoirs. All of the discovered gas pools occur at depths of less than 4 km, and no wells have been drilled deeper than 4.5 km. The potential for significant deep discoveries in conventionally-trapped reservoirs may be limited by a loss of porosity with increasing depth. Lower and Upper Permian rocks at depths of 4.5 to 5 km and deeper over most of the central part of the basin are regionally overpressured, and the presence of a basin-centered gas accumulation in low permeability reservoirs of this age is possible based on indirect data of Safronov and others (1997). Both autochthonous and allochthonous rocks of the Verkhoyansk overthrust belt also are highly prospective as basin-centered gas accumulations (Kontorovich, 1994).

North Caspian Basin

Introduction

The North Caspian basin occupies the northern part of the Caspian Sea and a low lying plain to the north (figs. 1 and 6). The basin is about 518,000 km^2 in area, all of which includes sedimentary rocks deeper than 4.5 km. The northern and western basin boundaries with the Volga-Ural basin are steep flexures along which the basement abruptly deepens to 10-12 km. In the central part of the basin, Precambrian basement is deeper than 20 km. The eastern boundary lies along the Ural foldbelt, and the southern continuation of which is buried under a thin veneer of Mesozoic rocks. In the south, the basin is bounded by the Karpinsky foldbelt west of the Caspian Sea and by the South Emba uplift east of the Caspian Sea. The basin is a rift underlain by oceanic crust (Malushin, 1985).

Tectonic and Sedimentary History

The North Caspian basin was formed by rifting of the Archean to Lower Proterozoic basement of the Russian craton. The rifting separated a continental crustal block presently expressed as a series of arches along the southern and eastern basin boundaries from the main body of the craton. The age of rifting is not known, although different models suggest a Late Proterozoic, Early Ordovician, or Middle Devonian rift event (Malushin, 1985).

The oldest rocks penetrated by drilling are Middle Devonian carbonates and clastic rocks in the northeastern part of the basin. Seismic data indicate that in the basin center, about 6 km of Lower Paleozoic rocks are present between Precambrian basement and the base of the Middle Devonian sequence. The upper Paleozoic through Tertiary basin fill is separated by Kungurian (uppermost Lower Permian) salt into subsalt and suprasalt sequences (fig. 7). The salt is deformed into domes and plugs; its original depositional thickness in the basin center is estimated to be about 4 km (Komissarova, 1986).

Stratigraphy of the subsalt sequence is complex and varies throughout the basin. In general, the sequence is principally composed of carbonate rocks on the basin margins and a poorly known deep-water basinal facies in the basin center. The top of the subsalt sequence occurs at a depth of about 10 km in the deepest parts of the basin. Shallow-water carbonate rocks along the basin margins contain the principal basin reserves primarily in the widespread Late Devonian through Early Permian reef reservoirs.

During much of the Late Paleozoic, the North Caspian basin was a deep water embayment of the Tethys Sea. Carbonate facies including reefs were formed on surrounding shelves, and deep-water black shales and turbidites were deposited under anoxic conditions in the basin center. Thrusting and orogeny in the Ural Mountains region to the east resulted in deposition of a thick Upper Carboniferous to Lower Permian clastic wedge in adjoining basin areas. The basin margins experienced uplift and erosion in pre-Permian time as a response to this orogenic compression.

During the late Early Permian (Artinskian, fig. 7), the basin collided with a system of micro- continents from the south resulting in development of the Karpinsky foldbelt and uplift of the South Emba high (fig. 6). The basin was subsequently separated from the Tethys Sea (except for a narrow strait in the southwestern corner) and was quickly filled with salt (Zonenshain and others, 1990).

The post-Early Permian depositional sequence is primarily composed of continental to shallow marine clastic rocks. Upper Permian and Triassic continental clastic rocks derived from the Ural uplift occur at the base of the sequence. Continental sedimentation was briefly interrupted by marine transgressions in middle Late Permian and Middle Triassic time. The overlying Jurassic to Tertiary stratigraphic sequence is composed of continental and marine clastic rocks (Beznosov, 1987).

Source Rocks

Because of their extreme depths, source rock characteristics in the central part of the basin are poorly known. They are most likely Upper Devonian to Lower Permian black shale intervals interbedded with deep water sandstone and siltstone turbidites. These rocks are basinal anoxic facies equivalent to the shallow-water carbonates and reefs of surrounding basin margins. This deep water facies has been penetrated by only a few wells because drilling has targeted carbonate reservoirs in shallow-water facies.

The North Caspian basin has a low geothermal gradient, and the top of oil window occurs at depths of up to 6 km. Source rocks are unlikely to exist in the suprasalt sequence, and oil and gas in suprasalt fields probably migrated from subsalt source rocks through migration pathways between salt domes from which the salt was completely withdrawn (Svetlakova, 1987).

Reservoir Rocks

Reservoir rocks in the subsalt sequence are almost exclusively shallow shelf and reef carbonates. Reservoir quality is highly variable and depends on facies, fracturing, and diagenetic alteration of the carbonate rocks. Pre-Permian erosion resulted in significant leaching of carbonates and formed the best reservoir quality in the supergiant fields. Only a few pools have been found in clastic rocks of the eastern and southeastern basin margins. These sandstone reservoirs have low permeabilities, and reservoir quality depends on fracturing. Pools in subsalt clastic reservoirs have not been commercially developed.

In the suprasalt sequence, productive sandstones of Jurassic and Cretaceous age occur at shallow to moderate depths and possess good reservoir properties. Loss of porosity with depth is substantial, and at 4.5 to 5 km, porosity of sandstones generally does not exceed 3%. Reservoir properties of sandstones in Upper Permian and Triassic continental rocks are much poorer, and these sandstones tend to lose porosity with depth rapidly (Proshlyakov and others, 1987).

Trap Types

Trapping mechanisms in the North Caspian basin are diverse. The giant Tengiz and Karachaganak fields (fig. 6), and some others are trapped by pinnacle reefs. Barrier reefs contain gas condensate fields on the northern and western margins of the basin, but the fields are much smaller. The unique Astrakhan field (fig. 6) occupies the crest of a regional arch. Several fields along the eastern and southeastern margins of the basin are trapped by anticlines that were probably formed by compressional stress related to the Ural foldbelt and South Emba high. Anticlines of the eastern basin margin are probably associated with thrusts. Fields producing from the suprasalt sequence are in various salt-controlled structural traps.

Deep Production

Principal oil and gas reserves in the basin occur in subsalt Upper Paleozoic rocks. Production from this sequence dates to the 1970s when several oil and gas fields were discovered (Maksimov, 1987). These fields include three supergiants: Astrakhan (gas), Karachaganak (gas condensate and oil), and Tengiz (oil) fields. Significantly smaller reserves (mostly oil) are found in suprasalt Upper Permian and Mesozoic rocks. Most fields producing from suprasalt reservoirs are located in the Emba producing region in the southeastern part of the basin (fig. 6).

Several deep accumulations exceeding 4.5 km are in Lower Permian and Carboniferous barrier reefs along the northern and western basin margins (fig. 7). Porosity of reef carbonates commonly ranges from 10 to 12% and permeability ranges from tens to hundreds of millidarcies. These fields contain gas with abundant condensate. Most of these fields are not currently in production because of relatively small reserves and significant overpressures, and data are not currently available for them.

The youngest reservoir at the giant Karachaganak gas field occurs at 3.7 km. A single massive sour gas and condensate pool with a thick (~300 m) oil leg is developed in an Upper

Devonian to Middle Carboniferous carbonate atoll overlain by a Lower Permian pinnacle reef. The height of the pool hydrocarbon column is about 1.5 km, indicating that production extends to a depth of more than 5.2 km. A well drilled in this field in the mid-1990s penetrated an oil pool in Middle Devonian rocks at a depth of about 5.5 km. No information on this discovery is currently available.

The top of the primary reservoir in the supergiant Tengiz oil field occurs at a depth of 4.0 km. The reservoir is developed in an Upper Devonian to Bashkirian atoll. Wells drilled to about 5.5 km did not reach the oil-water contact. The field is currently under development by a consortium of international and Russian companies. The oil pool is strongly overpressured, and dissolved gas contains up to 25% hydrogen sulfide (Maksimov, 1987).

Middle Caspian Basin

Introduction

The Middle Caspian basin lies in the eastern half of the North Caucasus region, the central part of the Caspian Sea, and the South Mangyshlak subbasin to the east (figs. 1 and 8). The southern basin boundary follows the Great Caucasus foldbelt on the west and the Karabogaz regional basement high on the east. The northern boundary extends along the Karpinsky ridge (a Mesozoic uplift over a deformed and inverted Paleozoic rift) and the Mangyshlak foldbelt (a deformed and inverted Triassic rift) east of the sea. On the west, the basin is bounded by the Stavropol arch which separates it from the Azov-Kuban basin (fig. 8). The western onshore part of the Middle Caspian basin is in Russia except for a small part in the southeast which is in Azerbaijan. The South Mangyshlak subbasin is in Kazakhstan. The basin is tectonically heterogeneous; its western part is a typical foreland basin, whereas the South Mangyshlak subbasin is on a crustal block between two uplifts, which was subjected to deep subsidence in the Mesozoic (Ulmishek, 1990). A large part of the basin (about 430,000 km^2) is deeper than 4.5 km (fig. 8). West of the Caspian Sea, the Terek-Sulak foredeep reaches a maximum depth to basement of 12 km. In the east, the deepest area includes the central part of the South Mangyshlak subbasin (fig. 8) (Ulmishek and Harrison, 1981).

Tectonic and Sedimentary History

Tectonic development of the Middle Caspian basin and Azov-Kuban basin to the northwest is generally similar (figs. 1; 9). Hercynian (Late Paleozoic) basement was rifted in latest Permian and Triassic time. Rifts were subsequently filled with a thick sequence of clastic and carbonate sediments. Volcanism occurred during the Late Triassic followed by a Late Triassic-Early Jurassic compressional event resulting in partial inversion of the rift grabens and erosion. One of the rifts was strongly deformed by thrusting and folding and is expressed in the present-day structure as the Mangyshlak foldbelt (Letavin, 1978). From Jurassic through Eocene time, much of the western part of the basin became a passive margin. Coastal coal-bearing Jurassic rocks thicken southwestward toward the Caucasus and pinch out northwestward on the Stavropol arch and its eastern slope (fig. 8). Rocks of Upper Jurassic and Neocomian age are predominantly carbonates and salt in the western Terek-Sulak foredeep (fig. 9). These rocks onlap and pinch out on the Stavropol arch. The remaining passive margin section is composed of Aptian to Albian clastic rocks, Late Cretaceous carbonates, and thin Paleocene to Eocene marls and calcareous shales (Ulmishek and Harrison, 1981).

The overlying Oligocene to lower Miocene Maykop Series is about 1.6 km thick. Thick olistostromes indicate incipient deformation and uplift in the Caucasus at this time. The overlying Upper Tertiary section is mainly composed of coarsening upward orogenic clastic rocks increasingly dominated through time by Caucasus provenance. The section is very thick (up to 5 to 6 km) in the narrow foredeep and thins rapidly northward on the foreland slope (Ulmishek and Harrison, 1981).

The South Mangyshlak subbasin developed as a gentle cratonic depression during the Jurassic through the Cenozoic. Lithologies and thicknesses of stratigraphic units in the Mesozoic to Lower Tertiary are similar to those in the rest of the basin, but the orogenic section is absent, and only a thin sequence is present above the moderately thick (up to 600 to 700 m) Maykop Series.

Source Rocks

Geochemical data on source rocks of the Middle Caspian basin are limited, but geologic and geochemical data suggest that several source rock intervals are present in different parts of the basin. The oldest source rocks occur in the Lower to Middle Triassic interval (fig. 9). They are documented by indigenous oil and gas accumulations within that same section. The source rocks commonly have TOC contents ranging from 1 to 4% and contain type II kerogen (Mirzoev and Dzhapuridze, 1979; Shablinskaya and others, 1990). These source rocks are responsible for some of the oils on the Prikum uplift and probably most of oils in the South Mangyshlak subbasin (Shablinskaya and others, 1990).

A second source rock interval occurs in the Middle Jurassic section (fig. 9). TOC contents range from 1 to 3%, and the organic matter is of mixed marine and terrestrial origin. These rocks have contributed most of the oils and gases now present on the Prikum arch and possibly some gas in the South Mangyshlak subbasin. A third source rock interval occurs in the lower part of the Maykop Series (fig. 9) and is composed of anoxic black shales with TOC contents reaching 7 to 8%. Maykop Series source rocks are mature in the foredeep and slope but immature to marginally mature in more northern areas and in the South Mangyshlak subbasin where burial depth was shallower. These source rocks generated most of the oil and gas found in the thrust belt of the northern Caucasus including large oil fields in the Groznyi area (fig. 8) (Sokolov and others, 1990).

Reservoir Rocks

Nearly the entire sedimentary interval of the basin, from the Triassic to the middle Miocene, is productive. Triassic rocks contain oil and some gas pools in the South Mangyshlak subbasin and on the Prikum arch, primarily in carbonate reservoir rocks (fig. 8). Lower to Middle Jurassic sandstones contain much of the rich oil and gas reserves in the South Mangyshlak subbasin (Ulmishek and Harrison, 1981). Most pools are at depths of 1.1 to 2.3 km. Sandstone reservoirs are heterogeneous but are generally characterized by high porosity and moderate to high permeability (Ulmishek and Harrison, 1981).

Reservoir quality of Jurassic sandstones of the Prikum area is fair to poor for oil but good for gas. Sandstones occur at greater depths here, commonly between 3.0 and 4.0 km. Porosity ranges from 12 to 18% and permeability is usually not higher than a few tens of millidarcies. Aptian and Albian sandstones contain the majority of reserves on the Prikum arch where most pools are at depths of 2.5 to 3.0 km. Porosity varies from 15 to 22% and permeability is usually 100 to 200 md (Maksimov, 1987).

Upper Cretaceous carbonates contain more than 50% of reserves in fields of the thrust belt along the northern boundary of the Great Caucasus (mainly in the Groznyi area) where reservoir properties are controlled by fracturing--non-fractured limestones are effectively impermeable. Middle Miocene sandstones also form reservoirs in this thrust belt. They commonly occur at shallow depths and possess excellent reservoir properties. Large gas reserves on the Stavropol arch are mainly in the Khadum Horizon at the base of the Maykop series. The pools are at or above 1.2 km deep. Porosity ranges from 30 to 40% and permeability often exceeds one darcy (Maksimov, 1987).

Trap Types

Much of the oil reserves in the basin occurs within structural traps in front of the Great Caucasus foldbelt. These are long and narrow faulted anticlines with closures commonly exceeding 1.0 km. Most of the anticlines are located along the leading edges of thrust sheets, but plastic flow of Maykop Series shales complicates the structural model. Oil and gas fields of the Prikum arch and Stavropol arch are in isometric, low relief anticlines over basement highs or Triassic reefs. Closure of the anticlines progressively decreases in younger horizons which indicates early structural growth. Structural traps of the South Mangyshlak subbasin are asymmetric anticlines that are underlain by thrusted Triassic rocks. Most of this structural growth in this region took place during the Miocene (Popkov, 1991).

In addition to structural traps, many pools are controlled by fracturing. These are pools in Triassic carbonates of the South Mangyshlak subbasin and in fractured lower Maykop Series shales of the Prikum arch. Very few stratigraphic traps have been found in the Middle Caspian basin.

Deep Production

The basin is primarily oil prone, but large gas reserves are present on the Stavropol arch. The largest oil and gas reserves are found in Middle Jurassic sandstones of the South Mangyshlak subbasin, in Upper Cretaceous carbonates and Miocene sandstones of the Terek-Sulak foredeep, in Lower Cretaceous sandstones of the Prikum arch, and in Oligocene sandstones of the Stavropol arch (Ulmishek and Harrison, 1981).

According to Maksimov (1987) and Petroconsultants (1997), oil and gas pools exceeding depths of 4.5 km have been discovered in 30 fields of the Middle Caspian basin. Most of the pools are classed as oil pools, but some of them are classed as oil and gas, and gas and condensate pools (table 2). Deep pools are found in two zones: (1) Triassic carbonate rocks mostly in the Prikum arch and (2) Upper Cretaceous carbonates in the Groznyi producing area in the western part of the Terek-Sulak foredeep (table 2). In the Groznyi area, a few pools are located in Lower Cretaceous sandstones. The primary reservoir rocks in the Triassic interval are carbonates of the Lower Triassic Neftekumsk Formation. Most of the pools occur in reef facies, in zones where reservoir properties are controlled by leaching and fracturing of the carbonates. A few pools have been developed and these currently produce oil.

In the Groznyi area, Cretaceous oil and gas pools have accumulated in high-amplitude thrust anticlines (Sobornov, 1995). Reservoir properties of both Upper Cretaceous limestones and Lower Cretaceous sandstones are dependent on fracturing. Away from the fracture zones along anticlinal crests, the rocks tend to be impermeable. Deep drilling in the area is extremely difficult because of overpressures approaching geostatic pressure in some fields and plasticity of thick Maykop Series shales. Data are not available to support or discount the presence of a deep basin-centered gas accumulation in the Middle Caspian basin.

South Caspian Basin

Introduction

The South Caspian basin occupies the southern, deep-water portion of the Caspian Sea, the surrounding shelf, and the onshore region (figs. 1 and 10). The northern basin boundary extends along the Great Caucasus foldbelt and offshore, along the Apsheron-Pribalkhan zone of uplifts. The basin is bounded on the south and east by the Lesser Caucasus, Elburz, and Kopet-Dag foldbelts (fig. 10). The basin is a typical intermontane depression surrounded by foldbelts of the Alpine system (Khanin, 1979). The basin area is about 207,000 km^2, and nearly all of this area includes sediments in excess of 4.5 km thick. In the central basin area, the basement may be as deep as 25 km. The basin occupies a part of Azerbaijan in the west, Turkmenistan in the east, and Iran in the south (fig. 10).

Tectonic and Sedimentary History

Earliest basin history is poorly understood because the oldest rocks occur only at great depths. Much of the offshore part of the basin is underlain by oceanic crust. Plate-tectonic reconstructions indicate that the basin was formed in Late Jurassic or Early Cretaceous time in conjunction with back-arc rifting of the northern margin of the Tethys Sea (Zonenshain and others, 1990). The Cretaceous to Early Tertiary interval is known only from outcrops along the basin margins where rocks are primarily composed of shallow-shelf carbonates and sandstones (fig. 11). These rocks were deposited in marine deep water (flysch) depositional environments in the area of the present-day Alpine foldbelts. The oldest rocks penetrated by wells in the basin are deep-water, organic-rich marine shales of the Oligocene-lower Miocene Maykop series (Bagir-Zade and others, 1987). These rocks are overlain by deep-water organic-rich shales and limestones of the Miocene Diatom Formation. Total thickness of this combined interval may reach several thousand meters. Both intervals contain the principal source rocks of the basin (fig. 11).

In latest Miocene time, the South Caspian basin was separated from the Tethys Sea by orogenic uplifts and became a large inland lake. The lake received clastic sediments from several large fluvial systems, the largest of which was the paleo-Volga River and its associated delta which developed in the western part of the Apsheron-Pribalkhan zone of uplifts. Several rivers brought sediments to the lake from the south, west, and east. The Pliocene Productive Series, which is as much as 5 km thick in the central basin area, was deposited under high subsidence rates (Amanniyazov, 1992). During the late Pliocene, the Caspian and Black Sea basins were connected during a marine transgression. Rapid subsidence and sedimentation continued into Quaternary time.

Rapid basin subsidence during Pliocene and Quaternary time may have prevented normal development of compaction in Maykop series shales. Recent compression, which mainly affected marginal areas of the basin, resulted in plastic flow of the shales and formation of linear anticlines with shale cores. Many anticlines contain active mud volcanoes with roots in the Maykop series and older(?) strata. The recent compressional event may be related to initiation of subduction of the South Caspian oceanic crust under the continental crust of the Middle Caspian basin (Granth and Baganz, 1996).

Source Rocks

Source rocks occur at great depths but are known largely from outcrops on the basin margins and from fragments of breccias associated with mud volcanoes. Two source rock units are present: deep-water black shales of the Oligocene-lower Miocene Maykop series and deep-water, anoxic shales of the middle Miocene Diatom Formation (fig. 11). The Diatom Formation directly overlies the Maykop series, and both units together are generally viewed as a single source rock. However, as revealed by recent geochemical data obtained by western companies, oils generated from each of the stratigraphic units contain a specific set of biomarkers. Both source rocks contain two or more percent TOC and mixed Types I and II kerogen (Piggott and others, 1996; Abrams and Narimanov, 1997).

The basin, especially its offshore part, is characterized by a very low geothermal gradient. In drilled structures, present-day temperatures (generally maximum temperatures) at a depth of 6 km do not exceed 120° C (Bagir-Zade and others, 1987). The average geothermal gradient is about 16° C/km (Buryakovsky and Dzhevanshir, 1990). The geothermal gradient and burial history indicate that the top of the oil window occurs at depths of 5.5 to 6.5 km and that the base occurs at 8 to 9 km. The top of the source rock interval in much of the basin area is in the upper part of the oil window. However, since the source rock section may be several kilometers thick, the lower part is probably in the gas window. This thermal regime and source rock richness result in gas generation as suggested by the large volumes of gas emitted from mud volcanoes annually (Yakubov, 1980).

Reservoir Rocks

Reservoir rocks of the Pliocene Productive Series are sandstones and siltstones. Reservoir properties of the sandstones vary depending on paleogeographic conditions of sedimentation. The best reservoir rocks are quartz-rich sandstones on the Apsheron-Pribalkhan Peninsula near Baku in the western Apsheron zone of uplifts offshore, and in adjacent areas. In this region, clastic sediments entered the basin from the paleo-Volga river which drained a large part of the Russian craton. Sandstones were deposited in deltaic and alluvial environments. At depths of 2 to 3 km, porosity varies from 15 to 30%, and permeability varies from several tens to 1,000 md. Very little porosity and permeability loss is observed to depths of 6 km (Kheirov and others, 1990). Preservation of good reservoir properties is related to the low geothermal gradient and widespread overpressuring (Proshlyakov and others, 1987). To the east and south, grain size decreases and clay content increases, resulting in poorer reservoir quality.

In the southwestern part of the basin, clastic rocks of the Productive Series were deposited by the paleo-Kura River system which drained a Caucasus source area of lithic-rich clastic and volcanic rocks. The resulting reservoirs are poor when compared to those of the Apsheron area. At depths of 2.5 to 3.0 km, porosity commonly does not exceed 20% and decreases to 12 to 14% at 5.0 km. The Krasnotsvet Formation in onshore areas of the eastern part of the basin is composed mainly of alluvial sandstones. Even at shallow depths sandstone porosity seldom exceeds 20% and permeability is a few tens of millidarcies. Reduction of porosity with depth is significant, and at 4.5 to 5 km, porosity varies from 8 to 14%. Better quality deltaic sandstones of the paleo-Amu-Darya River may be present offshore, but these areas have not yet been drilled.

Trap Types

Oil and gas fields in the South Caspian basin are controlled primarily by structural traps (table 2), although pool outlines are often associated with lateral stratigraphic changes. The dominant traps are compressional anticlinal folds grouped into long linear zones in onshore and shallow-shelf areas along the periphery of the basin. Fold amplitudes along the Apsheron-Pribalkhan zone of uplifts vary from 1 to 3 km in the lower part of the Productive Series to 0.3 to 1.5 km along the western and eastern basin margins (Amanniyazov, 1992). Folding took place in Pliocene-Quaternary time, and amplitudes of structures decrease upward in the section. Folds are strongly faulted and subdivided into distinct structural blocks. Vertical displacements along the faults vary widely from several meters to more than 2 km. Seismic data suggest that the cores of folds are composed of plastic shales of the Maykop Series. Many folds have active and buried mud volcanoes along their crests. Fold amplitudes on the eastern basin margin are usually smaller than on the western margin, but are still measured on a scale of hundreds of meters. In the central, deep-water part of the Caspian Sea, large, gentle structures have been mapped by seismic surveys. These structures have not been drilled and their origin is as yet unknown (Bagir-Zade and others, 1987).

Deep Production

Nearly all of the oil and gas reserves of the South Caspian basin are in clastic reservoirs of the Pliocene Productive Series in the west and its stratigraphic equivalent, the Krasnotsvet (Red Color) Formation in the east (table 1; fig. 11). Most of the oil reserves are concentrated in structures of the Apsheron-Pribalkhan zone of uplifts along the northern basin boundary (fig. 10) (Dikenshtein and others, 1983).

In the South Caspian basin, deep drilling began in the mid-1950s. By 1975, more than 500 wells had been drilled to depths exceeding 4.5 km, but only 300 of them reached their targets. The deepest well, Saatly-1 located in Azerbaijan, was projected to reach 11 km as part of the Soviet superdeep drilling program. The well reached a depth of more than 9 km in the early 1990s before the drilling program was canceled.

Twenty-two oil and gas pools have been discovered at depths greater than 4.5 km in the South Caspian basin (Krylov, 1980). Major deep drilling problems include overpressuring and the plasticity of shales. Petroconsultants database (1996) identifies 9 fields with reservoirs at great depths, 7 of which have been developed and produce oil. Several more fields are indicated by Maksimov (1987). Development of deep fields is economically feasible because sandstones of the Productive Series have high porosity and permeability. Both deep oil and gas potential of the South Caspian basin are believed to be very high (Bagir-Zade and others, 1988).

Amu-Darya Basin

Introduction

The Amu-Darya basin occupies the eastern part of the Turanian plate, which consists of Mesozoic basins and uplifts on Hercynian-Late Paleozoic basement east of the Caspian Sea (fig. 1). The south side of the basin is bounded by ranges of the Alpine fold system (fig. 12) including the Kopet-Dag foldbelt on the southwest and the Bandi-Turkestan and Gissar Ranges on the southeast and east. The northern end of the basin abuts the Kyzylkum regional basement uplift.

Tectonically, the basin is a deep Mesozoic and Tertiary sag overlying a Permian to Triassic rift system and includes a foredeep in front of the Kopet-Dag foldbelt. The larger western part of the basin is in Turkmenistan, its northeastern part is in Uzbekistan, and a small southeastern part is in Afghanistan. The basin is more than 10 km deep in the Murgab depression; it is 4.5 km deep over an area of more than 150,000 km^2 (fig. 12) (Simakov, 1986).

Tectonic and Sedimentary History

Basement rocks of the Amu-Darya basin are deformed and metamorphosed clastic wedges primarily of Carboniferous age. The Karakum and Karabogaz arches in the northeastern part of the basin are Hercynian micro-continents with Precambrian and early Paleozoic metamorphic rocks intruded by granites (fig. 12). This basement sequence was rifted in Late Permian and Triassic time (fig. 13), but the rift structure is poorly known because of thick overlying rocks and the absence of outcrops (Gabrielyants and others, 1991).

The overlying Jurassic through Paleogene sequence was deposited on a passive margin separated from the Tethyan subduction zone by marginal seas (fig. 13). The lower Middle Jurassic sequence, which is up to one km thick, lies unconformably on Triassic rocks and onlaps basement highs. This interval is mainly composed of continental coal-bearing clastic rocks and locally of volcanic rocks (fig. 13). Marine beds appear in the mid-Jurassic (upper Bajocian) and become increasingly common upward in the section in the southern part of the basin. During the Late Jurassic a transgressive carbonate sequence was deposited on the northeastern and possibly southern margins of the Murgab depression where a deep-water marine basin was being formed. This basin was filled by a thick (up to 1.2 km) latest Jurassic (Tithonian) evaporite unit (Gaurdak Formation; Maksimov and others, 1986). Lower Cretaceous marine carbonate and clastic rocks lie unconformably on Jurassic rocks. The section includes a continental interval with a widespread sandstone bed (Shatlyk Formation) that is the main gas producer in the basin. The Upper Cretaceous section is about 1.2 km thick and consists mainly of clastic rocks that laterally grade into carbonates in the Kopet-Dag foredeep. Marine carbonate and clastic rocks are abundant in the Lower Tertiary (Paleogene) sequence which forms the top of the passive margin sequence (Dikenshtein and others, 1983).

Thrusting and orogeny in the Kopet-Dag foldbelt started in the late Oligocene (late Paleogene) and has continued to the present time. This uplifted terrane gradually became the main source of clastic detritus which included marine sediments in the Miocene and continental sediments in the Pliocene. The collision of Eurasia with India resulted in deformation of the eastern part of the Mesozoic-Paleogene sedimentary basin and formation of the Gissar Range. This deformed area is designated as the Afghan-Tajik basin (fig. 12).

Source Rocks

The main source rocks of the Amu-Darya basin occur in the subsalt Jurassic section. Suprasalt rocks have minor source potential but are the primary reservoirs. Migration of hydrocarbons through the thick, substantially undeformed salt formation presents a significant problem. One proposed model suggests updip lateral migration of gas southward along Jurassic rocks to the salt pinch-out zone, then vertical migration upward into Lower Cretaceous sandstones, and updip lateral migration northward to traps in the sandstones. This model is possible due to the opposite tilt of Jurassic and Lower Cretaceous beds (Akramkhodzhaev and Egambergiev, 1985).

Organic-rich black shale of the Upper Jurassic Khodzhaipak Formation is a well known source rock on Bukhara and Chardzhou structural terraces (steps) of the northeastern basin margin (fig. 12). The Khodzhaipak Formation has high TOC contents and contains Type II kerogen. In the Murgab depression, the Upper Jurassic carbonate section laterally grades into deep-water calcareous shales, but few wells have penetrated these subsalt rocks and geochemical information is not available. Based on regional data on depositional environments, these rocks should have a significant source rock potential. The Khodzhaipak Formation occurs at shallower depths and is presently in the oil window (Akramkhodzhaev and Egambergiev, 1985).

The most likely source for deep gas in the Amu-Darya basin is the thick lower Middle Jurassic coal-bearing clastic sequence. Middle Jurassic source rocks reached maturity in the Early Cretaceous. By the time structural traps developed during the Late Tertiary, these rocks had subsided deep into the gas window.

Reservoir Rocks

Gas-producing Cretaceous reservoir rocks occur at depths not exceeding 3 km. About 50% of the gas reserves of the basin are found in quartzose sandstones of the Lower Cretaceous Shatlyk Formation. The sandstones are generally characterized by porosity varying from 17 to 23% and permeabilities ranging from one to several hundred millidarcies. For discovered fields at about 4 km depth, porosity of Shatlyk sandstones is 18 to 20%. Reservoir quality of other Cretaceous horizons is variable (Maksimov and others, 1986).

Principal Jurassic reservoirs are Upper Jurassic carbonates, primarily reefs, on the Bukhara and Chardzhou structural steps (fig. 12). Reservoir properties of these carbonates are variable and depend primarily on diagenetic factors. Porosity usually averages 10 to 15%, but in some fields reaches 20%. No significant loss of porosity with depth has been identified to depths of up to 3.5 km. Lower-Middle Jurassic sandstones are gas productive in several fields that are mainly located on the northern margin of the basin at depths averaging 2 to 2.5 km. Reservoir quality of these rocks is poor. Even at shallow depths, porosity ranges from 7 to 15% and permeability is low (Maksimov and others, 1986).

Trap Types

Two principal trap types control the majority of fields in the basin. The first type includes structural traps that control gas accumulations in Cretaceous reservoirs. These traps are gentle platform-type uplifts that are related to local basement highs on the Karakum arch in the northwestern part of the basin (fig. 12). In the rest of the basin, relationships have not been identified between traps and basement tectonics, but traps probably formed in Late Tertiary (Neogene) time associated with regional compression. Most of traps in the Upper Jurassic carbonate section are reefs (pinnacles and atolls). Several fields are known to have combination traps formed by marginal barrier reefs associated with anticlines. The reef zone may have extended from the Chardzhou step in the northeast around the southern margin of the Murgab depression where the Upper Jurassic occurs at depths of about 5 km. Anticlines are also productive north and northeast of the reef zone (Dikenshtein and others, 1983).

The largest gas field in the basin, the Douletabad-Donmez field, is located at the southern end of the basin in a pinch-out zone of Jurassic salt along a southward dipping monocline (fig. 12). Primary reservoirs are highly permeable (up to 700 md) gas saturated sandstones of the Shatlyk Formation in a hydrodynamic trap. Average depth to production is about 3.1 km (Maksimov and others, 1986).

Deep Production

The Amu-Darya basin is the second most important gas producing basin in the FSU (after the West Siberian basin). Oil and gas resources are concentrated in two stratigraphic intervals: Lower Cretaceous clastic and Upper Jurassic carbonate rocks. Most of the gas in the Amu-Darya basin is sweet gas currently produced from Lower Cretaceous reservoirs in several giant and one supergiant field (Douletabad-Donmez field) at depths averaging 3 km. Upper Jurassic carbonate rocks are productive mainly in the northeastern part of the basin (Bukhara and Chardzhou structural steps northeast of the Murgab depression; fig. 12). They contain both sour gas and condensate fields and oil fields. Recently, large gas reservoirs were discovered at depths of about 5 km in the Yashlar field area on the southern margin of the Murgab depression (fig. 12).

According to Petroconsultants (1996), four deep fields have been discovered in the basin but have not been developed (see table 2). Potential deep prospects are likely in Lower to Middle Jurassic clastic and Upper Jurassic carbonates rocks. Clastic reservoirs have poor reservoir quality at shallower depths and are considered high risk. Carbonate reservoirs have good porosity and permeability but contain hydrogen sulfide. In shallow fields of the Bukhara and Chardzhou steps, the amount of hydrogen sulfide in Upper Jurassic reservoirs varies from near zero to 6%. This value will most likely increase with increasing depth and temperature. In some older wells in the Yashlar field, hydrogen sulfide content reached 25 percent (Maksimov and others, 1986).

Deep drilling is also complicated by very high overpressures in the Amu-Darya basin. Reservoir pressures in brine-bearing carbonate beds within the salt formation are nearly equal to geostatic pressure.

SUMMARY

Sedimentary basins in the former Soviet Union (FSU) are among the deepest in the World with depths to basement exceeding 20 km in the North Caspian, South Caspian, and South Barents basins. Deep basins occur in both offshore and onshore areas of the FSU and extend from the Arctic Shelf in the north, to the Sea of Okhotsk and the Kamchatka Peninsula in the east, to the Central Asian republics in the south, and to Poland and Romania in the west. These basins formed in a wide variety of plate-tectonic regimes and include rift basins (e.g. Dnieper-Donets basin), foreland basins (e.g. Volga-Ural and Timan-Pechora basins), and collisional passive margins (e.g. Afghan-Tajik basin).

Six basins (Dnieper-Donets, Vilyuy, North Caspian, Middle Caspian, South Caspian and Amu-Darya basins) have the greatest potential for deep gas resources based on data available to us and are summarized in this report.

Source and reservoir rocks range in age from Proterozoic to Tertiary. Major source rocks include the Devonian Domanik Formation of the North Caspian and Timan-Pechora basins and siliceous shales of the Maykop Series of the South Caspian basin. Both carbonate and clastic reservoirs are abundant. Reservoirs are predominantly clastic in the Vilyuy, West Siberian, Dnieper-Donets, and South Caspian basins, whereas the North Caspian basin contains predominantly carbonate reservoirs.

REFERENCES

Abrams, M.A., and Narimanov, A.A., 1997, Geochemical evaluation of hydrocarbons and their potential sources in the western South Caspian depression, Republic of Azerbaijan: Marine and Petroleum Geology, v. 14, no. 4, p. 451-468.

Aksionov, A.A., ed., 1985, Petroleum potential at great depths (Perspektivy neftegazonosnosti bolshikh glubin): Moscow, Nauka, 96 p.

Akramkhodzhaev, A.M., and Egambergiev, M.E., 1985, Rocks of the Upper Jurassic Khodzhaipak Formation-- possible Central Asian analogs of bazhenites: Geologia Nefti i Gaza, no. 2, p. 19-24.

Amanniyazov, K.N., ed., 1992, Morphostructures, neotectonics and history of development of the South Caspian petroleum basin (Morfostructury, neotektonika i istoriya razvitiya Yuzhno-Kaspiyskogo neftegazonosnogo basseyna): Ylym, Ashgabad, Turkmenistan, 156 p.

Ammosov, I.I., Gorshkov, V.I., Grechishnikov, N.P., and Kalmykov, G.S., 1977, Paleogeothermal criteria of distribution of oil fields (Paleogeotermicheskie kriterii razmeshcheniya neftyanykh zalazhey): Moscow, Nedra, 158 p.

Bagir-Zade, F.M., Kerimov, K.M., and Salayev, S.G., 1987, Deep geologic framework and petroleum productivity of the South Caspian megadepression (Glubinnoye stroeniye I neftegazonosnost Yuzhno-Kaspiyskoy megavpadiny): Baku, Azerbaijan, Azerbaijanskoye Gosudarstvennoye Izdatelstvo, 304 p.

Beznosov, N.V., ed., 1987, Stratigraphy of petroleum provinces of the USSR (Spravochnik po stratigrafii neftegazonosnykh provintsiy SSSR): Nedra, Moscow, 336 p.

Buryakovsky, L.A., and Dzhevanshir, R.D., 1990, Reservoir rocks of the South Caspian petroleum basin and prediction of their quality at great depths, in Proshlyakov, B.K., ed., Reservoir rocks at great depths (Porody-kollektory na bolshikh glubinakh): Moscow, Nauka, p. 147-155.

Dikenshtein, G.Kh., Maksimov, S.P., and Semenovich, V.V., eds., 1983, Petroleum provinces of the USSR (Neftegazonosnye provintsii SSSR): Moscow, Nedra, 271 p.

Dmitrievsky, A.N., Lobkovsky, L.I., Balanyuk, I.E., Ilyukhin, L.N., and Dongaryan, L.S., 1995, Geodynamic criteria of differential prognosis of hydrocarbons (on example of Vilyuy-Cis-Verkhoyan sedimentary basin) (Geodinamicheskiye kriterii razdelnogo prognoza uglevodorodov na primere Vilyuysko-Priverkhoyanskogo osadochnogo basseyna). Geologiya, Metody Razvedki i Otsenki Mestorozhdeniy Toplivno-Energeticheskogo Syrya, Obzor: AOZT Geoinformmark, 53 p.

Gabrielyants, G.A., ed., 1990, Map of petroleum regions of the USSR: Ministry of Geology of USSR, scale 1:2,500,000.

Gabrielyants, G.A., Dikenshtein, G.Kh., Kapustin, I.N., Kiryukhin, N.G., and Razmyshlyaev, A.A., 1991, Regional geology of hydrocarbon-bearing regions of the USSR (Regionalnaya geologiya neftegazonosnykh territoriy SSSR): Moscow, Nedra, 284 p.

Gramberg, I.S., and Pogrebitsky, Yu. E., eds., 1984, Geological structure and economic minerals of the USSR. Vol. 9. Seas of the Soviet Arctic (Geologicheskoe stroenie i zakonomernosti razmeshcheniya poleznykh iskopaemykh): Leningrad, Nedra, 280 p.

Granath, J.W., and Baganz, O.W., 1996, A review of Neogene subsidence mechanism for the South Caspian basin: AAPG/ASPG Research Symposium--Oil and Gas Petroleum Systems in Rapidly Subsiding Basins, October 6-9, 1996, Baku, Azerbaijan, Abstracts, unpaginated.

Kabyshev, B.P., 1987, Paleotectonic studies and petroleum productivity of aulacogens (Paleotektonicheskiye issledovaniya I neftegazonosnost v avlakogennykh oblastyakh): Leningrad, Nedra, 192 p.

Khanin, V.A., 1979, Siliciclastic reservoir rocks for oil and gas at great depths (Terrigennye porody-kollektory nefti i gaza na bolshikh glubinakh): Moscow, Nedra, 140 p.

Kheirov, M.B., Daidbekova, E.A., and Dzhavadov, Ya.D., 1990, Reservoir rocks and seals of Mesozoic-Cenozoic rocks of Azerbaijan, in Proshlyakov, B.K., ed., Reservoir rocks at great depths (Porody-kollektory na bolshikh glubinakh): Moscow, Nauka, p. 155-164.

Komissarova, I.N., 1986, Main characteristics of ancient and modern salt accumulation in the North Caspian depression, *in* New data on geology of salt-bearing basins of the Soviet Union (Novye dannye po geologii solenosnykh basseynov Sovetskogo Soyuza): Moscow, Nauka, p. 171-180.

Kontorovich, A.E., ed., 1994, Petroleum basins and regions of Siberia, Volume 4, Lena-Viliuy basin (Neftegazonosnye basseyny i regiony Sibiri, vyp. 4, Leno-Viliuyskiy basseyn): Novosibirsk, Russia, OIGGM, 108 p.

Krylov, N.A., 1980, ed., Oil and gas productivity at great depths (Neftegazonosnost bolshikh glubin): Moscow, Nauka, 119 p.

Kurilyuk, L.V., Vakarchuk, G.I., Slobodyan, V.P., and Khmel, F.F., 1991, Paleozoic salt formations of the Dnieper-Donets depression: Sovetskaya Geologia, no. 4, p. 15-21.

Law, B.E., Ulmishek, G.F., Clayton, J.L., Kabyshev, B.P., Pashova, N.T., and Krivosheya, V.A., 1998, Basin-centered gas evaluated in Dnieper-Donets basin, Donbas Foldbelt: Ukraine, Oil and Gas Journal, v. 96, no. 47, p. 74-78.

Letavin, A.I., 1978, Tafrogennyi kompleks molodoy platformy yuga SSSR (Taphrogenic complex of the young platform of southern USSR): Moscow, Nauka, 148 p.

Litinsky, V.A., 1972a, Supposed continental continuation of the Gakkel Middle Arctic Ridge rift: Tektonika dna morey, okeanov i ostrovnykh dug, vypusk 10 (Tectonics of the floor of seas, oceans, and island arcs, issue 10): Yuzhno-Sakhalinsk, p. 32-33.

Litinsky, V.A., 1972b, Deep faults of the floor of the Laptev Sea and the western part of the East Siberian Sea based on geophysical data: Tektonika dna morey, okeanov i ostrovnykh dug, vypusk 10 (Tectonics of the floor of seas, oceans, and island arcs, issue 10), Yuzhno-Sakhalinsk, p. 34-36.

Litinsky, V.A., 1977a, The junction of the northern part of the Cis-Verkhoyansk basin and the Verkhoyansk meganticlinorium by geophysical data: Geologia i neftegazonosnost mezozoiskikh progibov severa Sibirskoy platformy (Geology and petroleum potential of the northern part of the Siberian craton): Leningrad, NIIGA, p. 63-81.

Litinsky, V.A., 1977b, Structures of the basement of the Cis-Verkhoyansk Lowland and adjacent territories and seas based on geophysical data: Tektonika Arktiki. Skladchatyi fundament shelífovykh sedimentatsionnykh basseynov (Tectonics of the Arctic. The folded basement of shelf sedimentary basins): Leningrad, NIIGA, p. 98-121.

Maksimov, S.P., ed., 1987, Oil and gas fields of the USSR (Heftyanye i gazovye mestorozhdeniya SSSR): volumes 1 and 2, Moscow, Nedra, 360 and 304 p.

Maksimov, S.P., Dikenshteyn, G.Kh., and Lodzhevskaya, M.I., 1984, Formation and distribution of oil and gas pools at great depths (Formirovaniye i razmeshcheniye zalezhey nefti I gaza na bolshikh glubinakh): Moscow, Nedra, 288 p.

Maksimov, S.P., Kleschev, K.A., and Shein, V.S., eds., 1986, Geology and geodynamics of petroleum-bearing regions of the southern USSR (Geologiya i geodynamika neftegazonosnykh territoriy yuga SSSR): Moscow, Nedra, 232 p.

Malushin, I.I., 1985, Genesis of the North Caspian depression: Sovetskaya Geologia, no. 10, p. 72-77.

Mirzoev, D.A., and Dzhaparidze, L.I., 1979, Determination of catagenesis of dispersed organic matter and stages of oil and gas generation in sedimentary sequences of the platform cover of eastern North Caucasus, *in* Vassoevich, N.B., and Timofeev, P.P., eds., Neftematerinskie svity i printsypy ikh diagnostiki (Oil-source formations and principles of their identification): Moscow, Nauka, p. 200-209.

Oil and Gas Journal, 1998, Russians to seek exploration in difficult Far East basins: Oil and Gas Journal, June 1, 1998, p. 79-80.

Petrocunsultants Corp., 1996, Petroleum Exploration and Production Database through 1996: Petroconsultants, Inc., Geneva, Switzerland.

Popkov, V.I., 1991, Role of horizontal compression in formation of platform anticlines of Mangyshlak and Ustyurt: Geologia Nefti I Gaza, no. 7, p. 2-6.

Proshlyakov, B.K., Galyanova, T.I., and Pimenov, Yu.G., 1987, Reservoir properties of sedimentary rocks at great depths (Kollektorskiye svoystva osadochnykh porod na bolshikh glubinakh): Moscow, Nedra, 201 p.

Rudkevich, M.Ya., Ozeranskaya, L.S., Chistyakova, N.F., Kornev, V.A., and Maksimov, E.M., 1988, Oil- and gas-productive complexes of the West Siberian basin (Neftegazonosnye kompleksy Zapadno-Sibirskogo basseyna): Moscow, Nedra, 304 p.

Safranov, A.F., Bubnov, A.V., and Ivensen, G.V., 1997, Gas productivity of Permian rocks of the Khapchagay megaswell: Otechestrenuaya Geologiya, no. 8, p. 33-35.

Shablinskaya, N.V., Budanov, G.F., and Lazarev, V.S., 1990, Promezhutochnye kompleksy platformennykh oblastey SSSR I ikh neftegazonosnost (Intermediate complexes of the platform regions of the USSR and their petroleum potential): Leningrad, Nedra, 180 p.

Simakov, S.N., ed., 1986, Prediction and assessment of oil and gas resources at great depths (Prognoz i otsenka neftegazonosnosti nedr na bolshikh glubinakh): Leningrad, Nedra, 248 p.

Sobornov, K.O., 1995, Geologic framework of the petroleum productive thrust belt of eastern Caucasus: Geologia Nefti I Gaza, no. 10, p. 16-21.

Sokolov, B.A., Korchagina, Yu. I., Mirzoev, D.A., Sergeeva, V.N., Sebernov, K.O., and Fadeeva, N.P., 1990, Neftegazoobrazovanie I neftegazonakoplenie v Vostochnom Predkavkazye (Oil and gas generation and accumulation in eastern North Caucasus: Moscow, Nauka, 204 p.

Svetlakova, E.A., 1987, Model of formation regularities of distribution of hydrocarbon pools in the North Caspian basin, *in* Krylov, N.A., and Nekhrikova, N.A., eds., Petroleum potential of the North Caspian basin and adjacent areas (Neftegazonosnost Prikaspiyskoy vpadiny i sopredelnykh rayonov), Nauka, Moscow, p. 151-154.

Ulmishek, G.F., 1990, Uzen field, *in* Beaumont, E.A., and Foster, N.H., compilers, Structural traps III, Treatise of petroleum geology, Atlas of oil and gas fields: American Association of Petroleum Geologists, p. 281-298.

Ulmishek, G., and Harrison, W., 1981, Petroleum geology and resource assessment of the Middle Caspian basin, USSR, with special emphasis on the Uzen field: Argonne National Laboratory Report ANL/ES-116, 146 p.

Ulmishek, G.F., Bogino V.A., Keller, M.B., and Poznyakevich, Z.L., 1994, Structure, stratigraphy, and petroleum geology of the Pripyat and Dnieper-Donets basin, Byelarus and Ukraine, *in* Landon, S.M., ed., Interior rift basins: American Association of Petroleum Geologists Memoir 59, p. 125-156.

Yakubov, A.A., 1980, Mud volcanism of the Soviet Union and its relation to the petroleum productivity (Gryazevoy vulkanizm Sovetskogo Soyuza i ego svyaz s neftegazonosnostyu): Elm, Baku, Azerbaijan, 166 p.

Zonenshain, L.P., Kuzmin, M.I., and Natapov, L.M., 1990, Tectonics of lithospheric plates of the USSR territory (Tektonika litocfernykh plit territorii SSSR): Moscow, Nedra, vol. 1, 328 p.

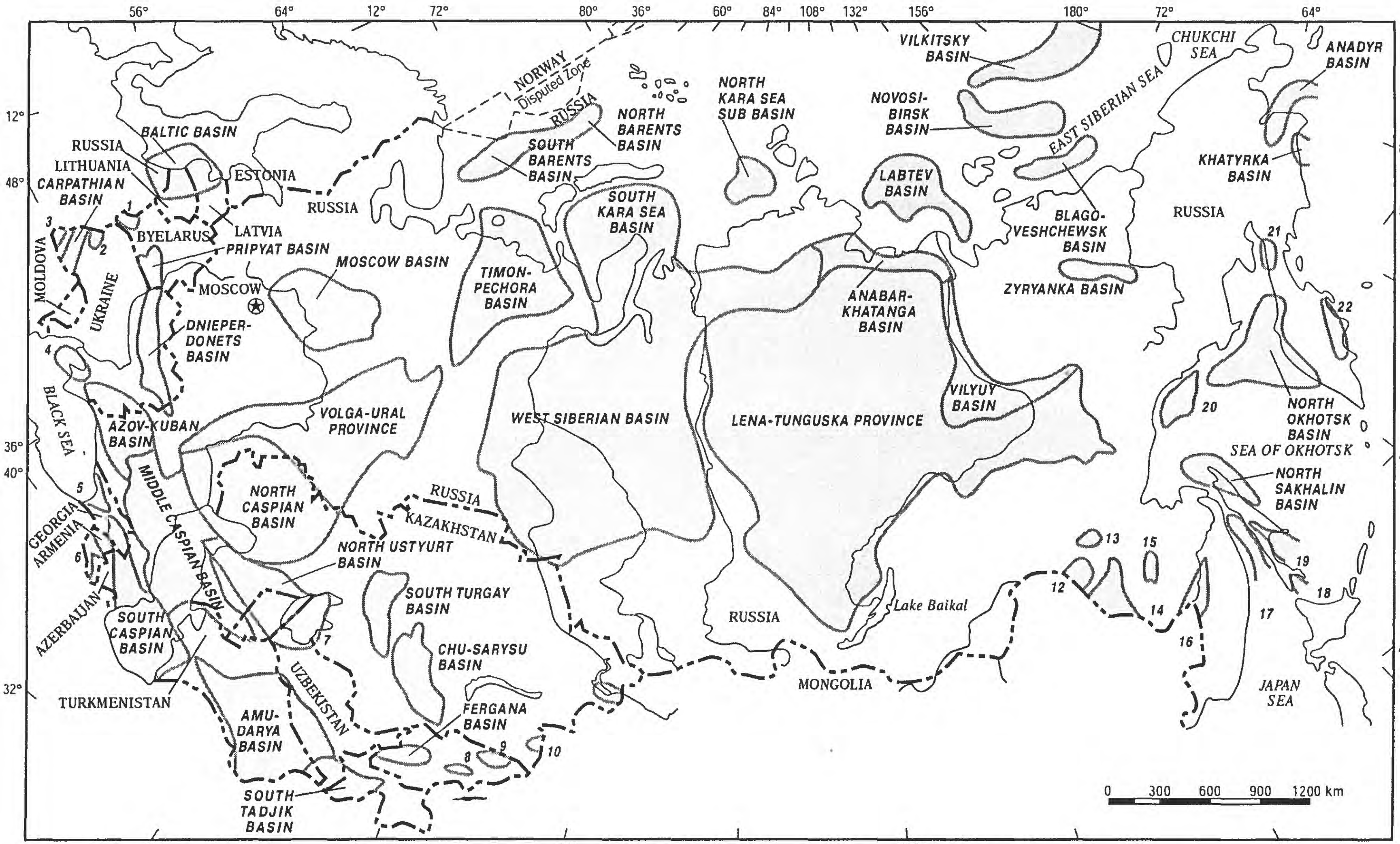

Figure 1. Map of sedimentary basins of the Former Soviet Union. Numbered basins as follows: 1, Brest; 2, Lvov; 3, Transcarpathian; 4, North Black Sea--Crimean; 5, Rioni; 6, Araks; 7, East Aral; 8, Naryn; 9, Issyk--Kul; 10, Ili; 11, Zaysan; 12, Ushumun; 13, Upper Zeya; 14, Zeya--Bureya; 15, Upper Bureya; 16, Middle Amur; 17, West Sakhalin; 18, Aniva; 19, South Sakhalin; 20, West Okhotsk; 21, Kinkil; 22, East Kamchatka.

Figure 2. Map of Dnieper-Donets basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km. LBU, Loev-Bragin uplift.

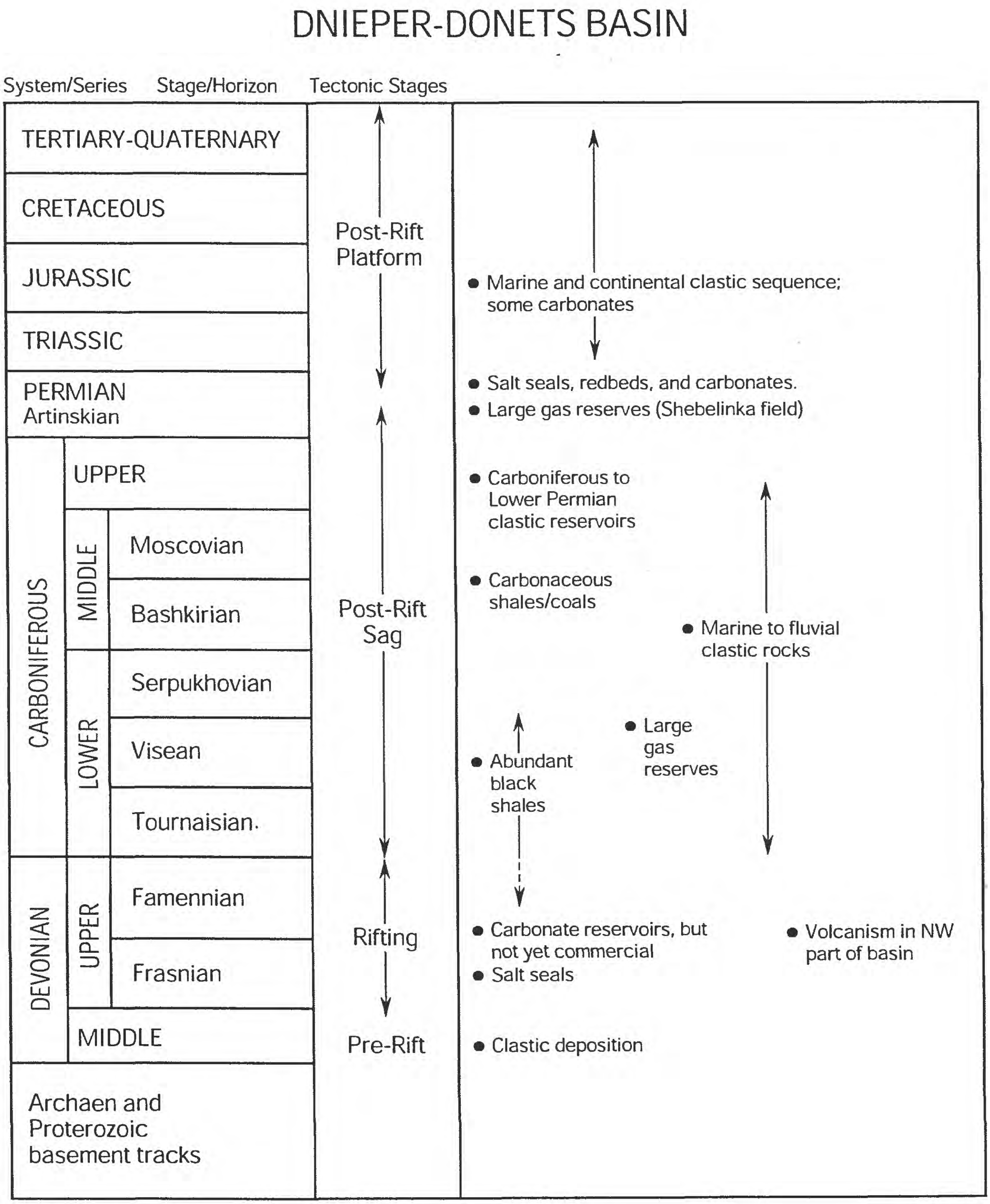

Figure 3. Generalized stratigraphic column of Dnieper-Donets basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

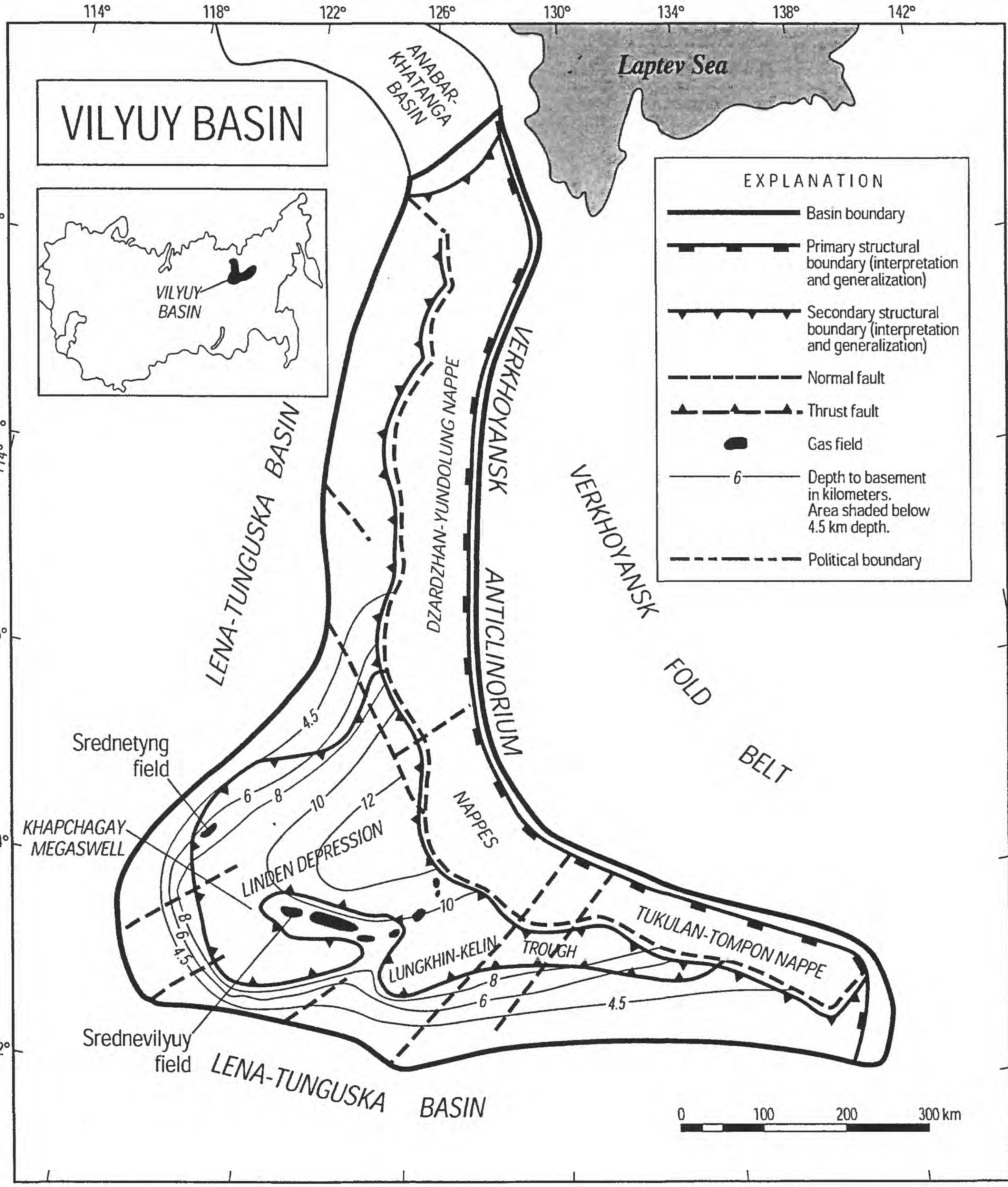

Figure 4. Map of Vilyuy basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km.

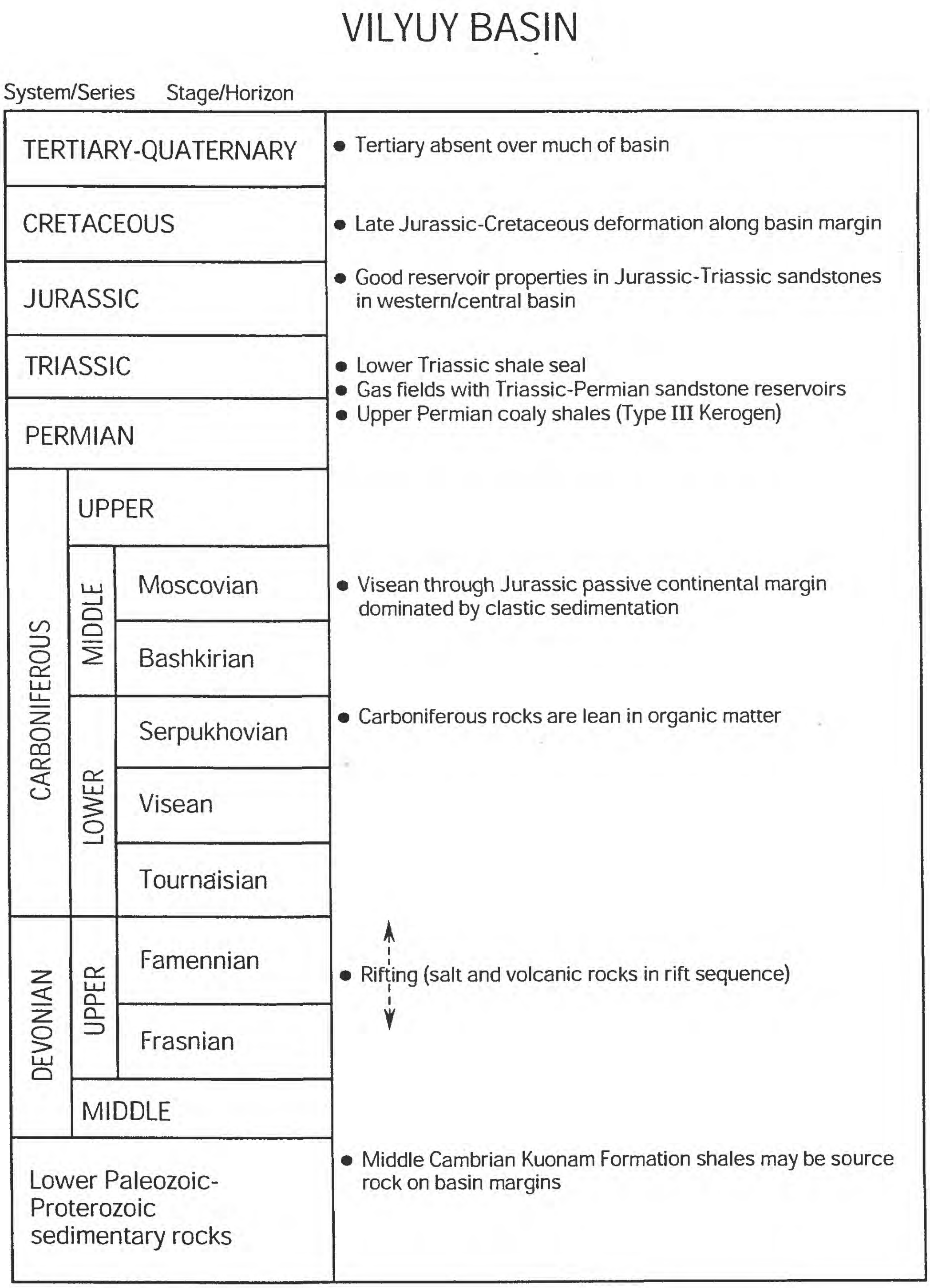

Figure 5. Generalized stratigraphic column of Vilyuy basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

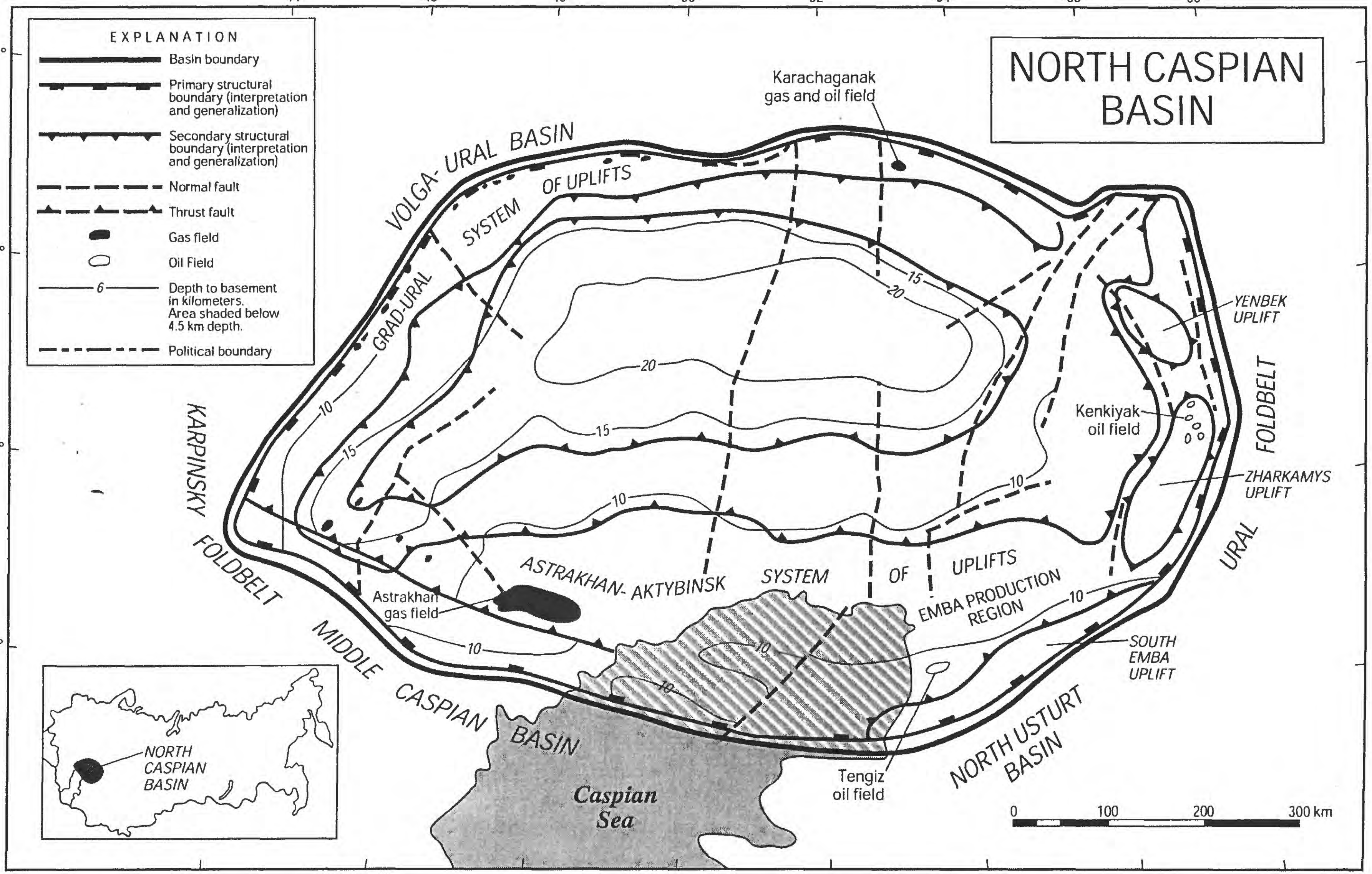

Figure 6. Map of North Caspian basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km.

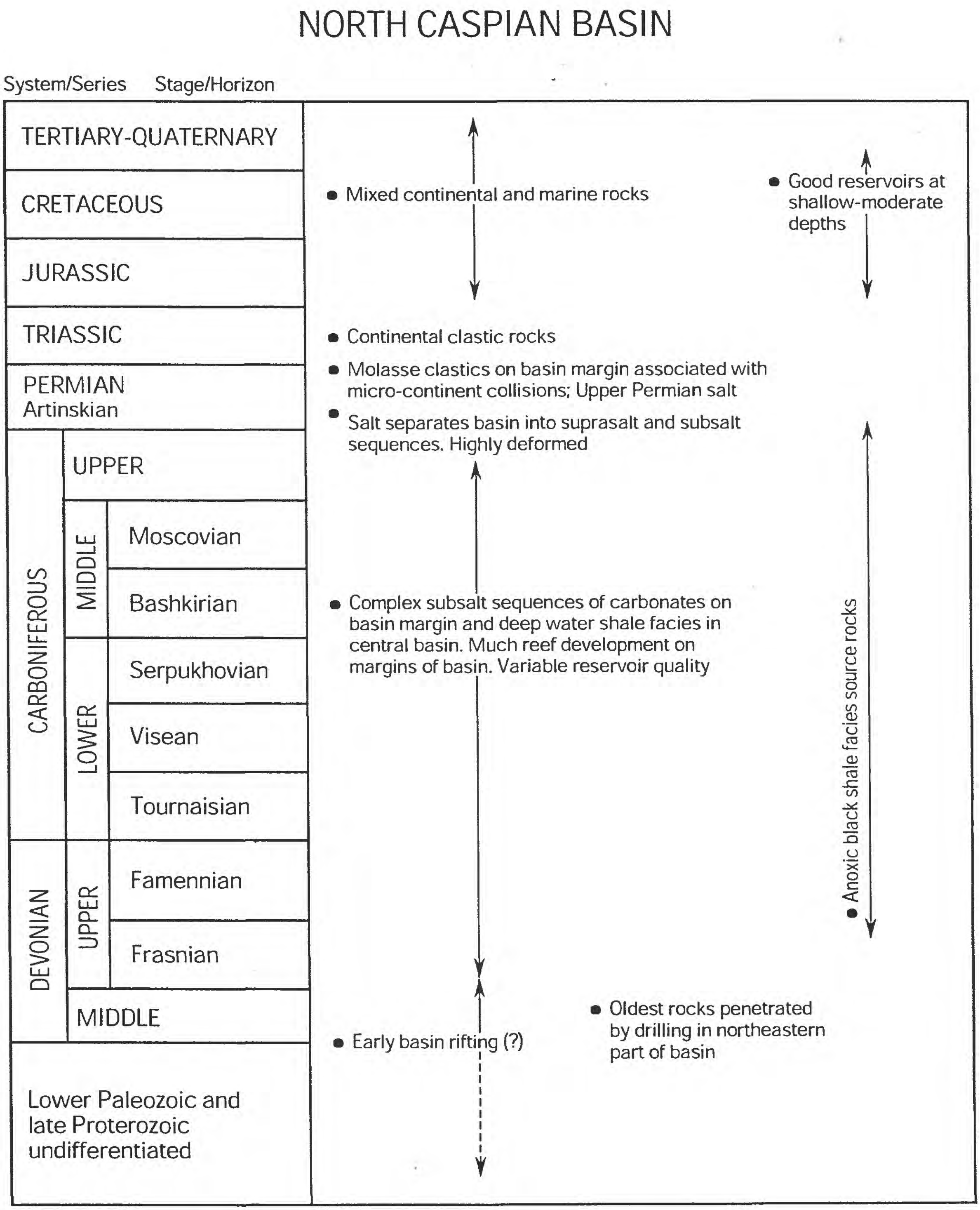

Figure 7. Generalized stratigraphic column of North Caspian basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

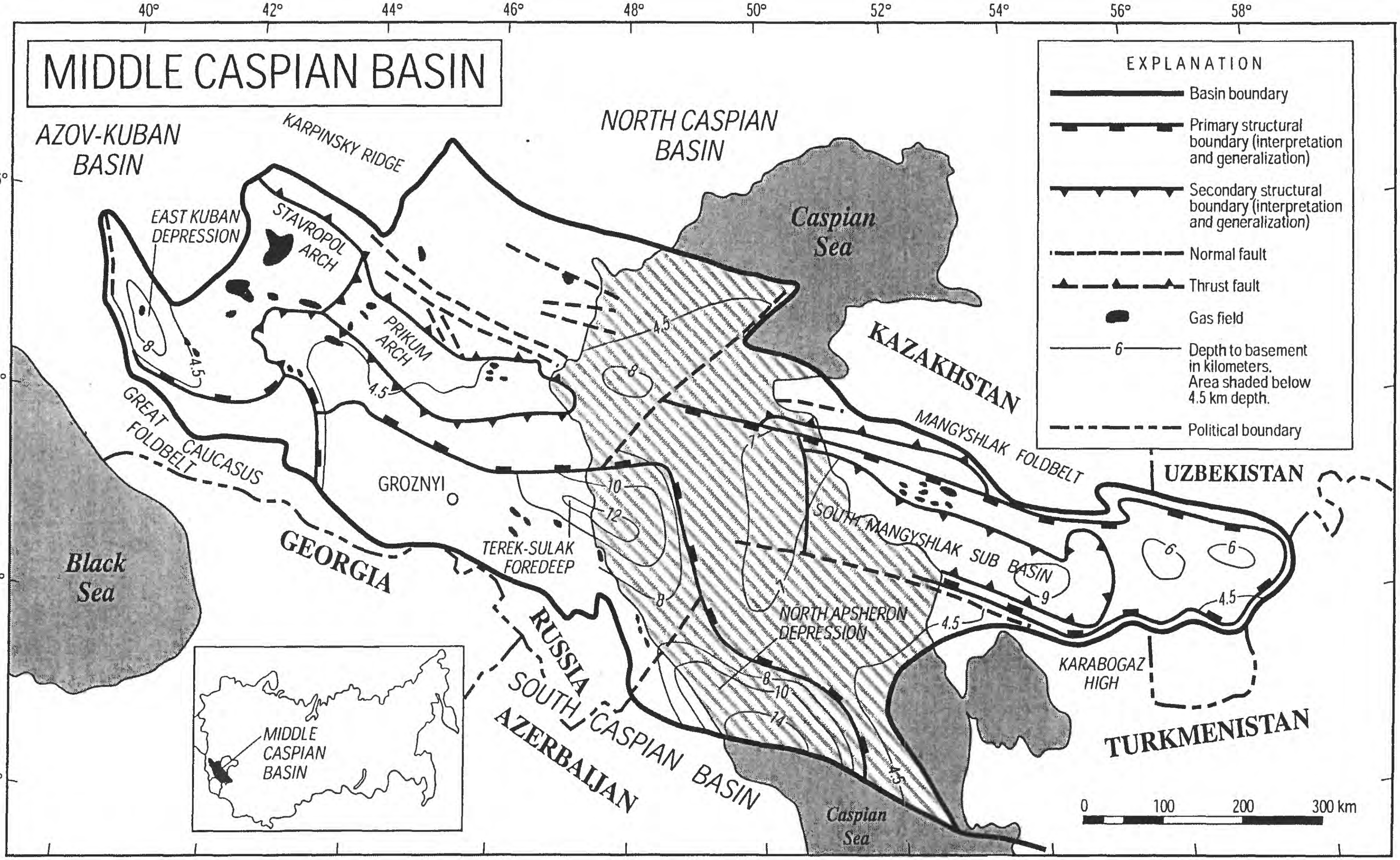

Figure 8. Map of Middle Caspain basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km.

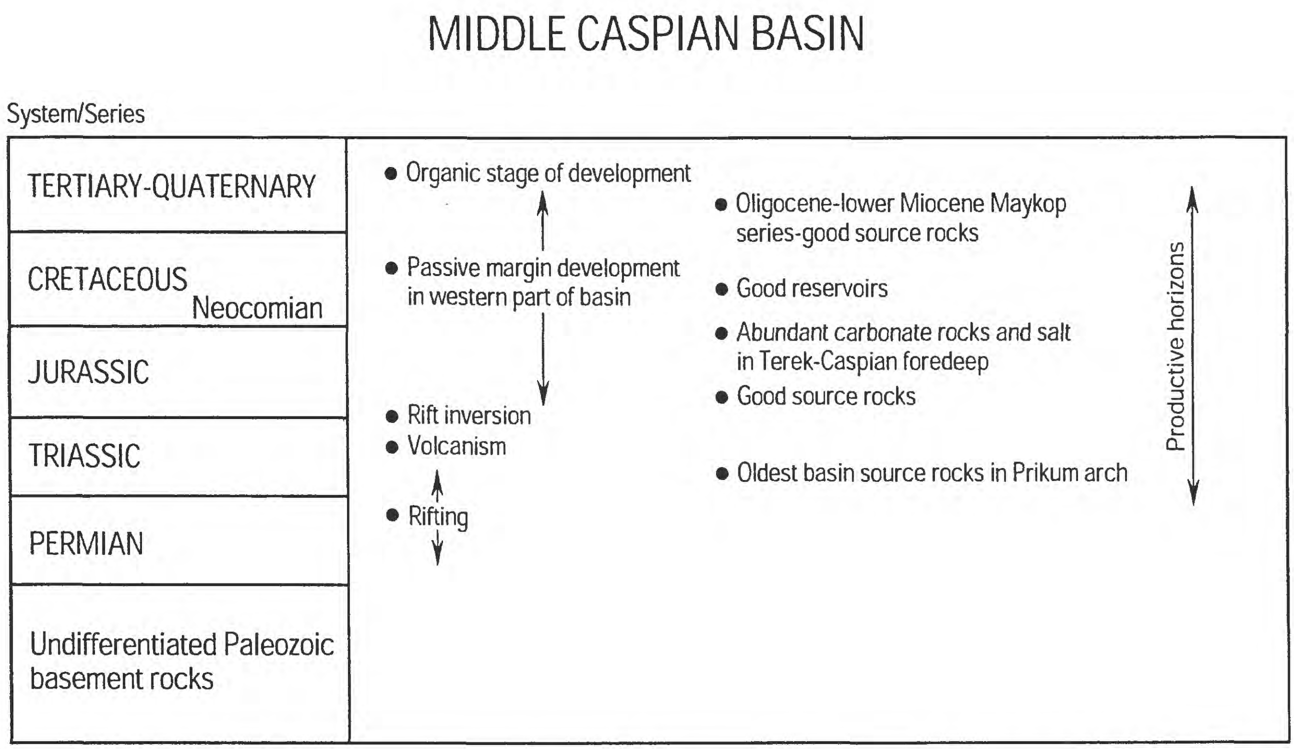

Figure 9. Generalized stratigraphic column of Middle Caspian basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

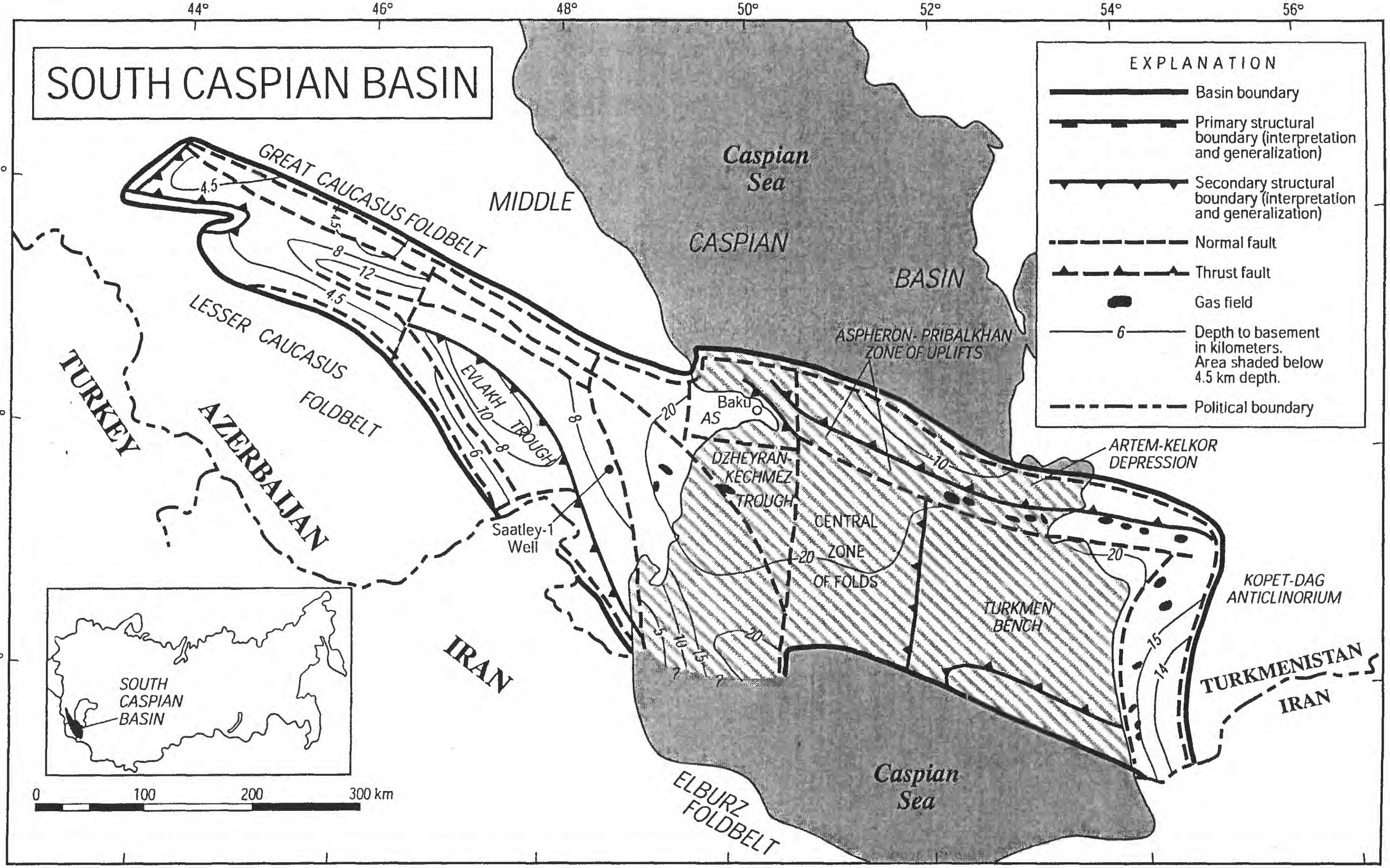

Figure 10. Map of South Caspian basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km.

SOUTH CASPIAN BASIN

System/Series		
TERTIARY-QUATERNARY	• Recent compression • Pliocene Productive Series and Krasnotsvet Formation—key reservoirs • Miocene Diatom Formation (good source rock) • Oligocene-lower Miocene Maykop Series—oldest rocks encountered in basin (good source rock) • Cretaceous-Early Tertiary marine rocks only known from outcrops along basin margins	• Late Miocene basin separation from Tethys—lake development (clastic fluvial sedimentary rocks)
CRETACEOUS		
JURASSIC	• Back-arc rifting of northern Tethys—early basin formation on oceanic crust	

Figure 11. Generalized stratigraphic column of South Caspian basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

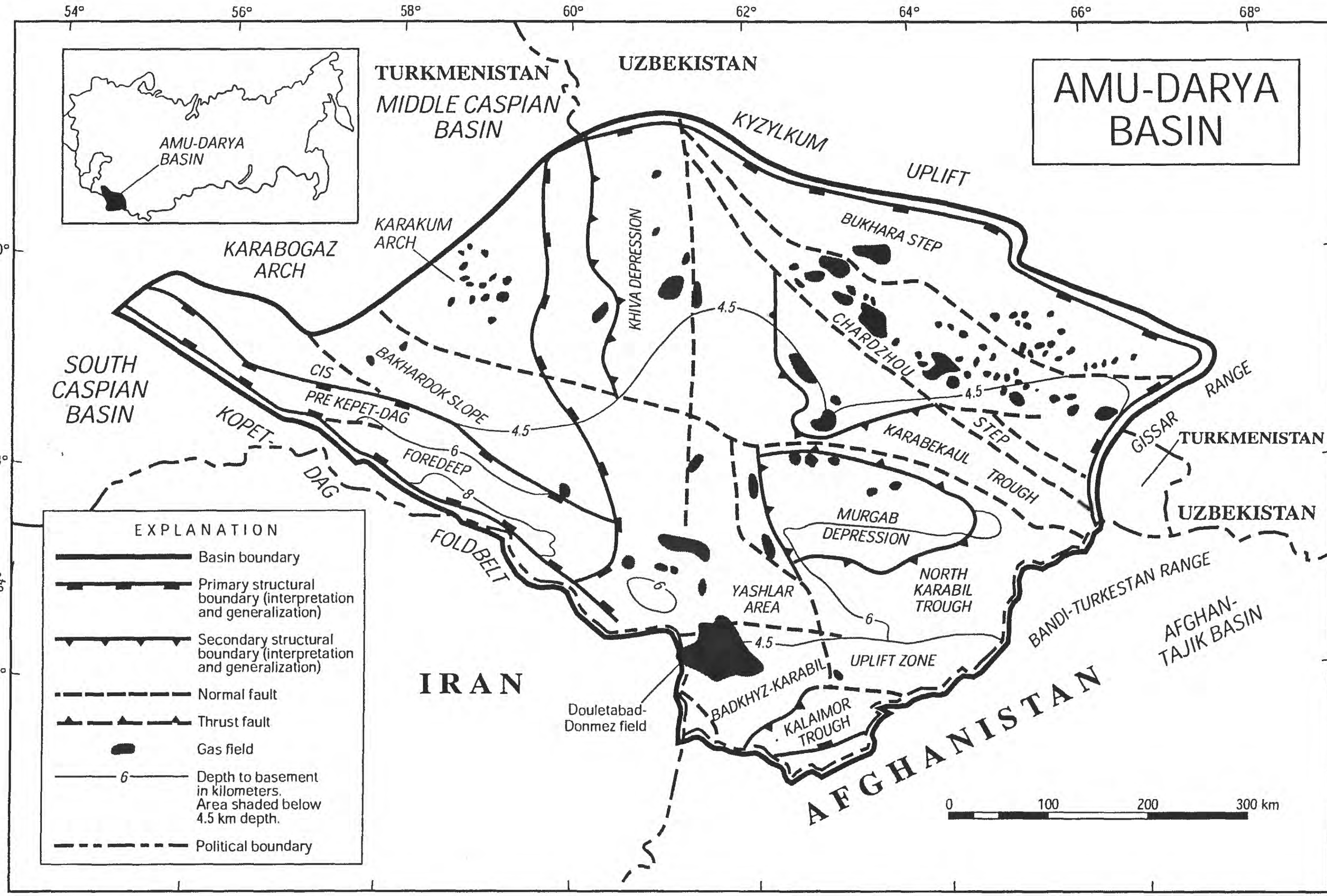

Figure 12. Map of Amu-Darya basin showing political boundaries, gas fields, and major geological and geographic features discussed in text. Shaded area represents portion of basin with sedimentary rocks below 4.5 km.

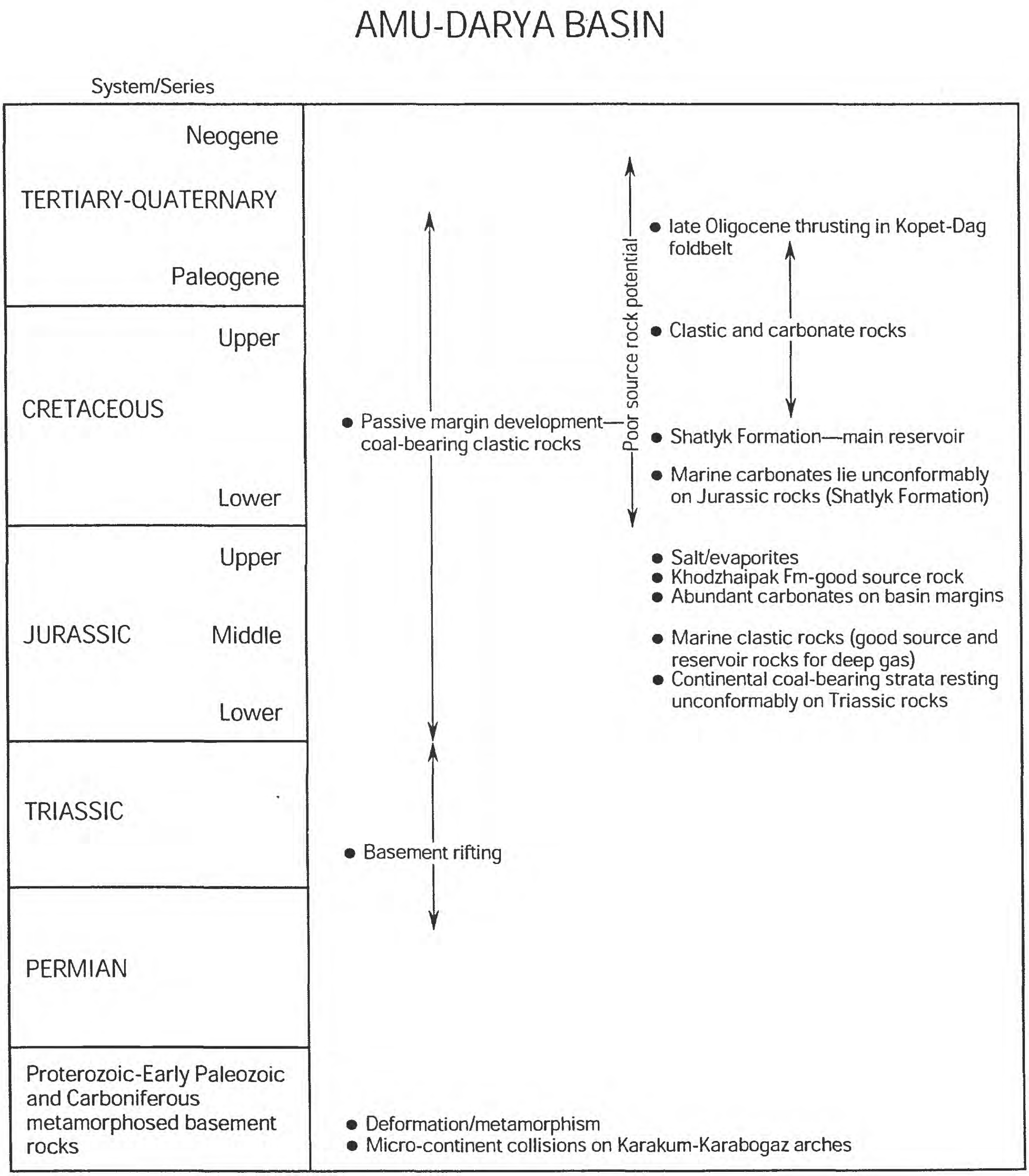

Figure 13. Generalized stratigraphic column of Amu-Darya basin illustrating major geologic events, primary source and reservoir rocks, and basin history.

Table 2. Geologic data for 21 representative deep fields and reservoirs in the Dnieper-Donets, North Caspian, MIddle Caspian, South Caspian, and Amu Darya basins. Not all deep fields and reservoirs identified. Data not available for Vilyuy basin. Dashed line indicates missing data. In some cases, additional reservoirs may exist for fields listed. Cumulative production totals from Petroconsultants field file (1997) as follows are for entire former Soviet Union because individual field values are proprietary to Petroconsultants field file: oil = 841.5 million barrels (Mmbo), gas = 4,771.3 billion cubic feet, and condensate = 346.4 Mmbo. Reported year for cumulative production ranges from 1990 to 1994. Cumulative production totals must be considered minimum values because no data were available for many of the fields listed. Disc year, discovery year of field; Age, geologic age of producing formation where Carb is Carboniferous, Dev is Devonian, Perm is Permian, Plio is Pliocene, and Jur is Jurassic; Lithology, primary lithology of field/reservoir listed; Depth, depth to top of reservoir in meters; Trap, dominant trap type of field where struct is structural and strat is stratigraphic; Oil cum, cumulative oil production for field through reported year (in parentheses); Gas cum, cumulative gas production of field through reported year (in parentheses); Con cum, cumulative condensate production of field through reported year (in parentheses); Type, type production for field where "o" is oil, "g" is gas, and "c" is condensate.

Country	Basin	Field name	Type	Disc. year	Age	Lithology	Ave. depth	Trap
Ukraine	Dnieper-Donets	Krasnozavodskoye	g-c	1987	Lower Carboniferous	clastic	5,447	Structural
Ukraine	Dnieper-Donets	Berezovskoye	g-c	1978	Middle Carboniferous	clastic	4,567	Structural
Ukraine	Dnieper-Donets	Gadyachskoye	g-c	1972	Lower Carboniferous	clastic	4,830	Stratigraphic
Ukraine	Dnieper-Donets	Bogatoy	g-c	1976	Lower Carboniferous	clastic-carb.	4,450	--
Kazhakstan	N. Caspian	Karachaganak	g-c-o	1979	Middle Devonian	clastic	5,630	Structural
Russia	N. Caspian	Upryamovo	o-g	1989	Lower Permian	carbonate	5,935	Structural
Kazhakstan	N. Caspian	Karatobe	o	1966	--	clastic	5,143	Structural
Russia	Middle Caspian	Arak-Dalatarek	o	1981	Lower Cretaceous	--	4,950	--
Russia	Middle Caspian	Gudermes-Vostochny	o	1985	Upper Cretaceous	carbonate	4,560	Stratigraphic
Chechnya	Middle Caspian	Andreyevo	o-g	1978	Upper Cretaceous	--	5,612	--
Russia	Middle Caspian	Norolak-Arkabash	g-c	1983	Upper Cretaceous	carbonate	5,341	Structural
Russia	Middle Caspian	Yubileynoe	o	1971	Lower Triassic	carbonate	4,470	--
Azerbaijan	S. Caspian	Garasu-Deniz	o-g	1974	--	--	4,710	Structural
Azerbaijan	S. Caspian	Zyrya	o-g-c	1955	Pliocene	clastic	4,560	Strucural
Azerbaijan	S. Caspian	Bakhar	g-c-o	1963	--	--	4,800	Structural
Azerbaijan	S. Caspian	Bulla-Deniz	g-c-o	1973	Pliocene	clastic	4,890	Structural
Turkmenistan	S. Caspian	Barsa-Gel'mes	o-g-c	1962	Plicene	clastic	4,900	Stratigraphic
Azerbaijan	S. Caspian	Yuzhnoe	g-c	1962	Pliocene	clastic-carb.	4,700	--
Afghanistan	Amu Darya	Shakhmolla	g	1988	Middle Jurrasic	clastic	4,880	Structural
Turkmenistan	Amu Darya	Karadzhanlak-Zapadny	g	1986	Lower Jurrasic	carbonate	4,747	Structural
Turkmenistan	Amy Darya	Miana	g	1985	Lower Jurrasic	carbonate	4,500	Structural

Table 1. Geologic data for deep gas basins and areas of the Former Soviet Union. Basin size, aerial extent of portion of basin below 4.5 km.

Basins sorted by size.

Basin	Location	Size (sq. km)	Chief deep reservoir	Max. depth	Deep gas possibilities	Basin classification
North Caspian	Northern part of Caspian Sea	518,000	Permian-Carb-Devonian (carb)	20 km +	Good, overpressures	Rift basin
Middle Caspian	Eastern part of North Caucasus	430,000	Cretaceous-Triassic (carb-clastic)	12 km	Good-overpresures	Foreland basin
West Sib.- S. Kara Sea	Western Siberia	405,000	Paleozoic-Mesozoic (carb)	12 km	Unknown	Jurassic-Tertiary sag-Triassic rift basin
Lena-Tunguska	Siberian craton	385,000	Middle-Late Proterozoic (carb-clastic)	7 km +	Unknown	Rift basin
South Caspian	Turkmenistan-Iran-Azerbaijan	207,000	Pliocene (clastic)	25 km	Excellent	Intermontane depression of Alpine System
Amu-Darya	Uzbekistan-Afghanistan	150,000	Jurassic (carb-clastic)	10 km +	Good-major gas producer of FSU	Mesozoic-Tertiary sag over Mes.-Perm. rift
Vilyuy	Eastern margin Siberian craton	115,000	Permian (clastic)	12 km +	Basin-centered gas possibilities	Rift-foreland basin complex
Timan-Pechora	Northeastern European Russia	68,000	Devonian, Silurian	12 km	Good, H2S problems	Foreland basin
Volga-Ural	Eastern European Russia	55,000	Devonian, Carboniferous, Permian	10 km +	Good, but in limited areas	Foreland basin
North Ustyurt	Kazakhstan	43,000	Paleozoic Carb?-clastic)	11 km +	Unknown	Mesozoic-Tertiary sag-complex
Azov-Kuban	Western part of North Caucasus	25,000	Cretaceous-Jurassic (clastic)	12 km +	Fair-overpressures	Foreland basin
Dnieper-Donets	Eastern Ukraine	23,000	Permian-Carb (carb-clastic)	15 km	Good-overpress., basin-centered (?)	Rift basin
North Sakhalin	Northern part of Sakhalin Island	20,000	Miocene-Pliocene (clastic)	11 km	Unknown	Rift/delta
Afghan-Tajik	Tajikistan-Uzbekistan	17,000	Jurassic (carb)	14 km	Unknown-H2S problems	Collisional passive margin
Fergana	Uzbekistan-Tadjikistan-Kyrgystan	5,000	Paleogene (carb-clastic)	10 km	Good-overpressures	Intermontane depression of AlpineSystem
Carpathian	Ukraine	4,000	Paleogene-Mesozoic (clastic)	8 km +	Good	Thrusted fold belt-flysch basin
North Okhotsk	Sea of Okhotsk	na	Cretaceous-Tertiary (clastic)	10 km +	Unknown	Rift basins-horst/graben complexes
South Barents	Arctic Shelf	na	Triassic-Jurassic(?) (carb-clastic)	20 km	Unknown	Paleozoic rift basin
North Barents	Arctic Shelf	na	Triassic-Jurassic(?) (carb-clastic)	15 km	Unknown	Paleozoic rift basin
North Kara Sea	Arctic Shelf	na	Triassic-Jurassic(?) (carb-clastic)	10 km	Unknown	Paleozoic rift basin
Laptev Sea	Arctic Shelf	na	na	12 km +	Unknown	Complex rift basin
Blagoveshchensk	Arctic Shelf	na	na	6 km	Unknown	Unknown
Novosibirsk	Arctic Shelf	na	Cretaceous-Tertiary (?)	na	Unknown	Unknown
Vilkitsky	Arctic Shelf	na	Cretaceous-Tertiary (?)	na	Unknown	Unknown
Anabar-Khatanga	E. part Siberian craton	na	Triassic-Permian (clastic?)	8 km +	Unknown	Deformed rift basin

Table 1 continued. Geologic data for deep gas basins and areas of the Former Soviet Union. Basin size, aerial extent of portion of basin below 4.5 km. Basins sorted by size.

Basin	Deep gas production?	Potential source and reservoir rocks			
North Caspian	Yes	Devonian-Permian black shales			
Middle Caspian	Yes	Jurassic, Triassic, Tertiary			
West Sib.- S. Kara Sea	No, but 80% of gas overall in Russia	L.-M. Jurassic Tyumen Fm., U. Jurassic Bazhenov Fm.			
Lena-Tunguska	No	Proterozoic			
South Caspian	Yes, much deep drilling	Miocene Maykop Series, Diatom Fm.			
Amu-Darya	Yes, but not developed	Jurassic black shales, coal-bearing rocks			
Vilyuy	No	Permian, Middle Cambrian			
Timan-Pechora	No	Devonian Domanik Fm.			
Volga-Ural	Yes, minor amount	Devonian Domanik Fm., Permian shales			
North Ustyurt	No	Paleozoic			
Azov-Kuban	Yes	Miocene Maykop Series, Jurassic			
Dnieper-Donets	Yes, most explored deep basin in FSU	Devonian and Visean black shales			
North Sakhalin	No	Miocene siliceous shales			
Afghan-Tajik	No	Jurassic basinal shales, coal-bearing rocks (?)			
Fergana	No--some deep oil production	Eocene Suzak Fm. (?), Jurassic coal-bearing rocks			
Carpathian	No--4 oil fields only, some deep drilling	Oligocene Menilite Fm., Jurassic black shales			
North Okhotsk	No production in basins/subbasins	Miocene-Oligocene siliceous shales, L. Tertiary coals			
South Barents	No, but shallow prod. (Shtokman gas field)	Jurassic-Triassic (?)			
North Barents	No	Jurassic-Triassic (?)			
North Kara Sea	No	Jurassic-Triassic (?)			
Laptev Sea	No	Cretaceous-Tertiary coal-bearing rocks (?)			
Blagoveshchensk	No	Unknown			
Novosibirsk	No	Unknown			
Vilkitsky	No	Unknown			
Anabar-Khatanga	No	Permian coal-bearing rocks (?), Cambrian Kuonam Fm.			