Petroleum Geology and Resources of the Middle Caspian Basin, Former Soviet Union

By Gregory F. Ulmishek

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Petroleum Geology and Resources of the Middle Caspian Basin, Former Soviet Union

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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 (U.S. Geological Survey World Energy Assessment Team, 2000). 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.

The purpose of this effort 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 volumes either reside 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 occur as reserve growth of fields already discovered.

The petroleum system constitutes the basic geologic unit of the oil and gas assessment. The total petroleum system includes all genetically related petroleum found in shows and accumulations (discovered and undiscovered) that has been generated by a pod or by closely related pods of mature source rock. This petroleum exists within a limited mappable geologic space, together with the essential mappable geologic elements (source, reservoir, and seal) that control the fundamental processes of generation, expulsion, migration, entrapment, and preservation of petroleum.

An assessment unit is a mappable part of a total petroleum system in which discovered and undiscovered fields constitute a single relatively homogeneous 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.

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 U.S. Geological Survey World Energy Assessment Team (2000).

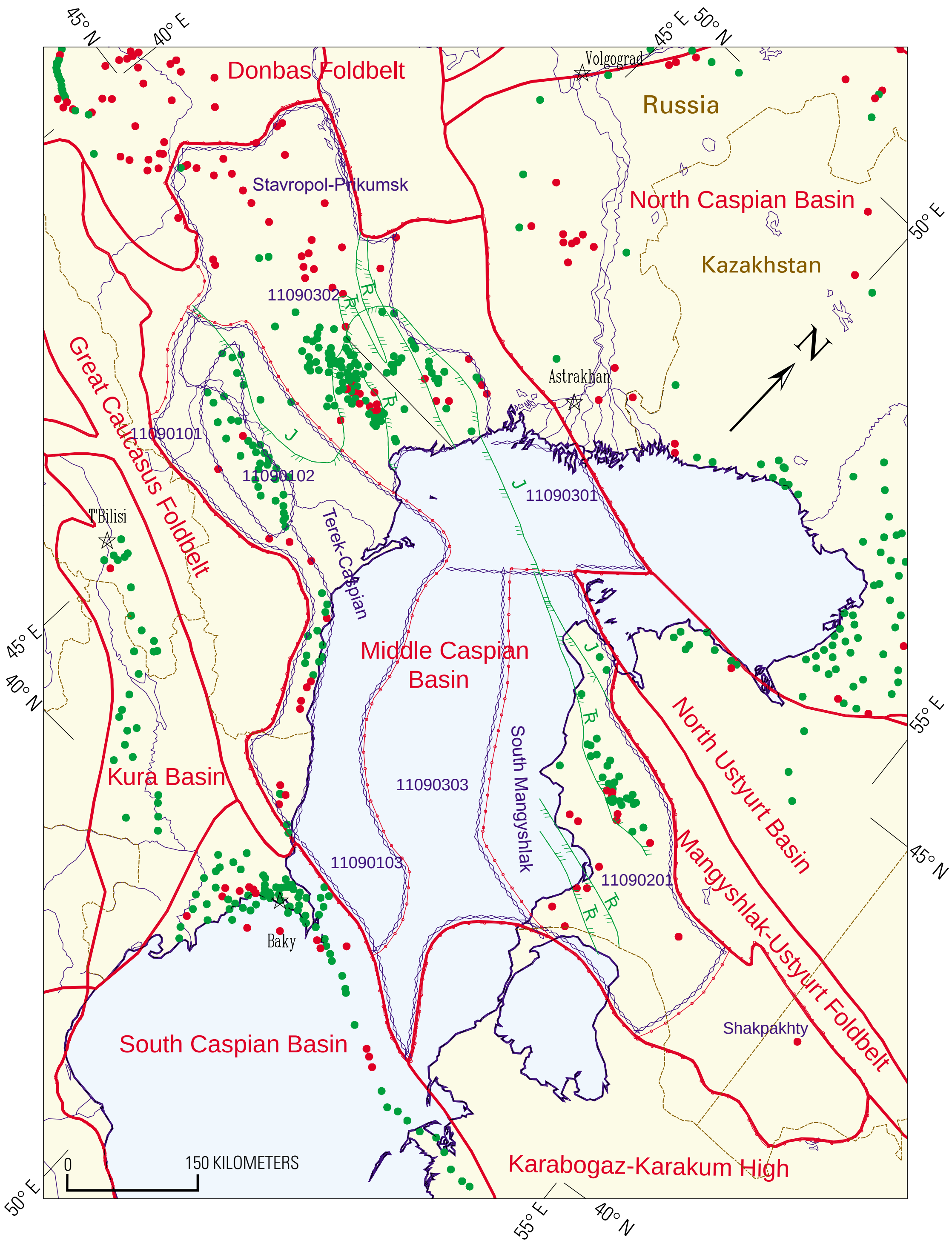
Oil and gas reserves quoted in this report are derived from Petroleum Exploration and Production database (Petroconsultants, 1996) and other area reports from Petroconsultants, Inc., unless otherwise noted.

A map, figure 1 of this report, shows boundaries of the total petroleum systems, assessment units, and pods of active source rocks; it was 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 this map, are reproduced, with permission, from Petroconsultants (1996).

Abstract

The Middle Caspian basin occupies a large area between the Great Caucasus foldbelt and the southern edge of the Precambrian Russian craton. The basin also includes the central part of the Caspian Sea and the South Mangyshlak subbasin east of the sea. The basin was formed on the Hercynian accreted terrane during Late Permian–Triassic through Quaternary time. Structurally, the basin consists of the fold-and-thrust zone of the northern Caucasus foothills, the foredeep and foreland slope, the Stavropol-Prikumsk uplift and East Manych trough to the north of the slope, and the South Mangyshlak subbasin and slope of the Karabogaz arch east of the Caspian Sea. All these major structures extend offshore.

Four total petroleum systems (TPS) have been identified in the basin. The South Mangyshlak TPS contains more than 40 discovered fields. The principal reserves are in Lower–Middle Jurassic sandstone reservoirs in structural traps. Source rocks are poorly known, but geologic data indicate that they are in the Triassic taphrogenic sequence. Migration of oil and gas significantly postdated maturation of source rocks and was related to faulting and fracturing during middle Miocene to present time. A single assessment unit covers the entire TPS. Largest undiscovered resources of this assessment unit are expected in the largely undrilled offshore portion of the TPS, especially on the western plunge of the Mangyshlak meganticline.



EXPLANATION

- Hydrography
- Shoreline
- Geologic province name and boundary
- Country boundary
- Gas field centerpoint
- Oil field centerpoint

ASSESSMENT DATA

- Assessment units boundary and name
- Total petroleum system boundary and name
- Pod of active source rocks boundary—Ticks indicate side of their presence; Ŧ-Triassic, J-Jurassic

Projection: Equidistant Conic. Central meridian: 100. Standard Parallel: 58 30

Figure 1. Map showing petroleum systems and assessment units of Middle Caspian basin, Province 1109.

The Terek-Caspian TPS occupies the fold-and-thrust belt, foredeep, and adjoining foreland slope. About 50 hydrocarbon fields, primarily oil, have been discovered in the TPS. Almost all hydrocarbon reserves are in faulted structural traps related to thrusting of the foldbelt, and most traps are in frontal edges of the thrust sheets. The traps are further complicated by plastic deformation of Upper Jurassic salt and Maykop series (Oligocene–lower Miocene) shale. Principal reservoirs are fractured Upper Cretaceous carbonates and middle Miocene sandstones. Principal source rocks are organic-rich shales in the lower part of the Maykop series. Source rocks may also be present in the Eocene, Upper Jurassic, and Middle Jurassic sections, but their contribution to discovered reserves is probably small. Three assessment units are delineated in the TPS. One of them encompasses the thrust-and-fold belt of northern Caucasus foothills. This assessment unit contains most of the undiscovered oil resources. The second assessment unit occupies the foredeep and largely undeformed foreland slope. Undiscovered resources of this unit are relatively small and primarily related to stratigraphic traps. The third unit is identified in almost untested subsalt Jurassic rocks occurring at great depths and is speculative. The unit may contain significant amounts of gas under the Upper Jurassic salt seal.

The Stavropol-Prikumsk TPS lies north of the Terek-Caspian TPS and extends offshore into the central Caspian Sea where geologic data are scarce. More than one hundred oil and gas fields have been found onshore. Offshore, only one well was recently drilled, and this well discovered a large oil and gas field. Almost the entire sedimentary section of the TPS is productive; however, the principal oil reserves are in Lower Cretaceous clastic reservoirs in structural traps of the Prikumsk uplift. Most original gas reserves are in Paleogene reservoirs of the Stavropol arch and these reservoirs are largely depleted. At least three source rock formations, in the Lower Triassic, Middle Jurassic, and Oligocene–lower Miocene (Maykop series), are present in the TPS. Geochemical data are inadequate to correlate oils and gases in most reservoirs with particular source rocks, and widespread mixing of hydrocarbons apparently took place. Three assessment units encompassing the onshore area of the TPS, the offshore continuation of the Prikumsk uplift, and the central Caspian area, are identified. The principal portion of undiscovered resources is assigned to the offshore Prikumsk zone where a large discovery was recently made (after this resource assessment had been completed).

The Shakpakhty TPS is small and located east of the South Mangyshlak subbasin. The TPS contains a single gas field, possesses very low potential, and has not been assessed.

Introduction

With 14.4 billion barrels of oil equivalent (BOE) of discovered hydrocarbon reserves, the Middle Caspian basin is ranked 27th among 102 provinces designated for appraisal of undiscovered oil and gas resources by the U.S. Geological Survey (U.S. Geological Survey World Energy Assessment Team, 2000). The location and boundaries of the province are shown in figure 1. This report outlines the principal geologic features of the basin and defines its total petroleum systems (TPS) and assessment units (AU). Definitions of the TPS and AU are given in the Foreword of this report. The assessment technique and procedure are explained in U.S. Geological Survey World Energy Assessment Team (2000).

The first production in the basin was established as early as 1893, when a well discovered oil in shallow middle Miocene sandstones near Groznyi, Russia. However, major discoveries in the basin were made in deeper Cretaceous and Jurassic rocks in the 1950's and 1960. Peak production was reached in 1969–1971, after which a gradual decline in production of both oil and gas began (Dikenshtein and others, 1983). Exploration in the basin has been almost entirely concentrated on land, and only a few wells have been drilled offshore. The first offshore oil and gas field (Inchkhe-more) was found in 1974 in the southeastern nearshore area, but several other prospects drilled in the 1980's failed to discover commercial accumulations. In 2000, Russian company Lukoil announced discovery of a large (potentially more than 2 billlion BOE) oil and gas field in the north-central offshore area (Severny area) of the basin (The Wall Street Journal, 2000). The basin mostly lies in Russia and Kazakhstan; a small southwestern part of the basin is in Azerbaijan.

Province Overview

Province Location and Boundaries

The Middle Caspian basin occupies the eastern North Caucasus region, the central part of the Caspian Sea, and a system of depressions east of the sea (fig. 1). The southern basin boundary is defined by the Great Caucasus foldbelt, Karabogaz arch, and, in offshore areas, by the Apsheron sill (Apsheron-Pribalkhan zone of uplifts) separating the Middle Caspian and South Caspian basins (fig. 2). The northern boundary with the North Caspian basin extends along the Karpinsky Ridge (southeastern continuation of the Donbas foldbelt). Strongly deformed upper Paleozoic rocks of the ridge (foldbelt) are exposed on the surface in its western part and buried under Mesozoic and Tertiary rocks in the eastern part. Offshore, the boundary is defined by the southern limit of salt tectonics, and farther east it is drawn along the Mangyshlak and Central Ustyurt systems of uplifts (fig. 4). On the west, the Stavropol arch and Mineralovod high separate the Middle Caspian basin from the Azov-Kuban basin located farther west. On the Stavropol arch, the basement is overlain by Albian and younger rocks and older stratigraphic units pinch out on the slopes. Most of the basin is located in Russia (west of the Caspian Sea) and Kazakhstan (east of the sea). A small southern part of the western nearshore area is in Azerbaijan.

Tectono-Stratigraphic Sequences

Basement of the Middle Caspian basin is a Hercynian accreted terrane composed of various middle to late Paleozoic deformed rocks. The basement is overlain by the Late Permian–Triassic rift system filled with clastic, carbonate, and volcanic rocks. Various parts of this taphrogenic sequence are unconformably overlain by a platform sequence of Jurassic through Eocene rocks. Lower–Middle Jurassic clastics, commonly enriched by coaly organic matter, occur at the base of this sequence. The

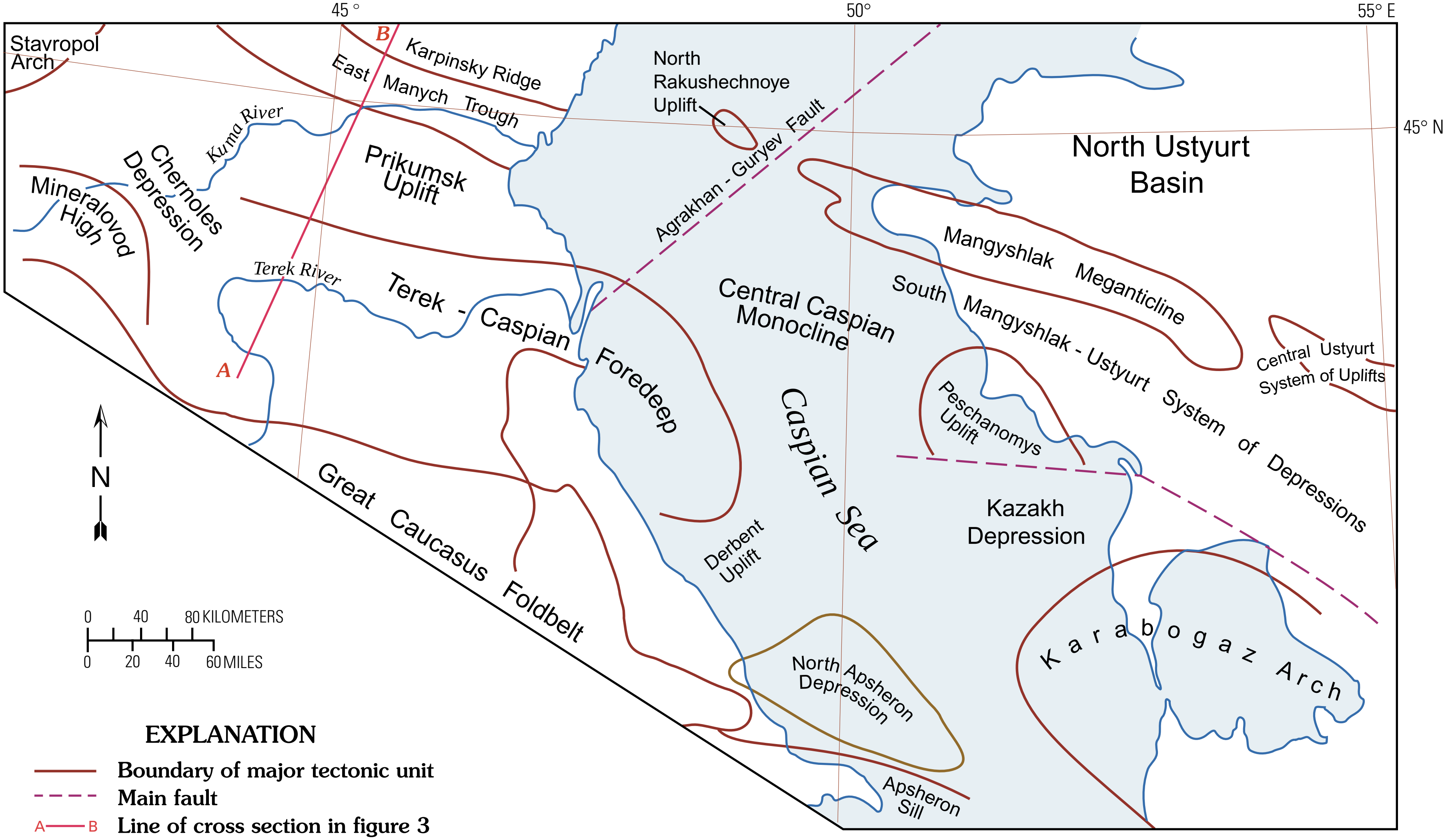


Figure 2. Generalized map showing main structural units of Middle Caspian basin (modified from Ulmishek and Harrison, 1981).

rocks are mainly continental in the lower part (except for a zone along the Great Caucasus), becoming progressively more marine to the top of the section. During the widespread transgression of middle Callovian-Kimmeridgian time, the sea deposited shales and carbonates. The Tithonian interval is represented by a significant unconformity in most areas except for the central Terek-Caspian foredeep where thick salt was deposited in a deep-water lagoon that was separated by reefs from the Tethyan ocean to the south. Cretaceous rocks are dominantly marine and composed of Neocomian carbonates and clastics, a thick Aptian-Albian clastic section, and mostly carbonate Upper Cretaceous rocks. Paleocene-Eocene rocks at the top of the platform sequence are thick shallow-marine clastics on the Stavropol arch and a thin condensed section of deep-marine pelagic carbonates and shales east of the arch.

The orogenic sequence at the top of the sedimentary cover was deposited during formation of a foreland basin north of the growing Great Caucasus foldbelt. The sequence reaches its maximum thickness of 4–6 km in the foredeep along the mountain front. The sequence starts with the Oligocene–lower Miocene Maykop series—a thick shale section, which, in the northeastern areas, contains sandstone beds in its middle and upper parts. Deep-water black shales enriched by type II kerogen are ubiquitous in the lower part of the series and are an important source rock. Major provenance was still to the northeast of the basin, but numerous massive olistostromes (gravity flow deposits) are present along the Caucasus front. The olistostromes that include various chaotically mixed pre-Maykop rocks indicate the initial stage of Caucasus orogenic uplift, although the uplifted structures were still submerged. Clastic turbidites, including sandstones, derived from the south are known in the lower Maykop series in more western areas of North Caucasus, in the Azov-Kuban basin.

An important pre-middle Miocene unconformity at the top of the Maykop series records the beginning of the neotectonic stage. The stage was characterized by continuing compressive stress from the south, which affected the entire basin and extended far to the north into the Russian craton. The stress produced intense structural growth, faulting, and fracturing in many areas. Thick (to 2.5–3.5 km), coarsening-upward orogenic clastics deposited during this stage are limited to the narrow foredeep, and they abruptly thin to a few hundred meters and less across the foreland slope (fig. 3).

Structure

The Middle Caspian basin was formed in Jurassic-Cenozoic time on the epi-Hercynian late Paleozoic basement, which was cut by a number of near latitudinal Late Permian–Triassic rifts. The basin is tectonically heterogeneous; its western part is a typical foreland basin whereas formation of the eastern part is related to post-Triassic subsidence of a crustal block between two Permian-Triassic rifts (Ulmishek and Harrison, 1981). The northern rift was structurally inverted and strongly deformed in pre-Jurassic time. It is expressed as the Mangyshlak foldbelt (meganticline) in the present structure (fig. 2).

The main structural units of the basinal sedimentary cover are shown in figure 2. The principal structural grain parallels the Great Caucasus foldbelt, which was formed in post-Eocene time due to closing of the marginal sea in the northern Tethys. The deepest part of the basin is in the foredeep where depth to the basement reaches 10–12 km (fig. 3). From the foredeep, basement rises northward to the Stavropol arch and Karpinsky Ridge where it occurs at 1.5–2 km.

Available data on the structure of the central Caspian Sea are scarce because, until recently, few seismic surveys had been conducted there. During the last few years, a consortium of international oil companies shot a number of regional profiles across the northern and central parts of the sea, but results of this work are not in the public domain. Structures on both shores of the sea plunge offshore and lose expression. Apparently, eastern and western structural units (including Triassic rifts) are not continuous across the sea and are separated by the regional Agrakhan-Guryev fault, which can be interpreted as a pre-Jurassic strike-slip fault (fig. 2).

Petroleum Systems

The Middle Caspian basin contains at least four known total petroleum systems (TPS): (1) South Mangyshlak, (2) Terek-Caspian, (3) Stavropol-Prikumsk, and (4) Shakpakhty systems (fig. 1). Three of the four TPS of the basin extend into the Caspian Sea, where their dimensions are conjectural because only a few wells have been drilled offshore and only two potentially commercial discoveries have been made on the southern Dagestan shelf and in the north-central part of the sea. Assessed undiscovered oil and gas resources of three principal petroleum systems are shown in table 1.

The dominant petroleum reserves of the rich South Mangyshlak TPS are in Middle Jurassic sandstones in structural traps. Minor reserves are in Triassic carbonates and clastics in fields that are controlled by zones of fracturing. A few accumulations are known in Lower Cretaceous sandstones and in fractured basement granites. Source rocks are certainly present in the Triassic section, but their areal extent has not been mapped. Some hydrocarbons could have been generated from Lower–Middle Jurassic clastics, but their endowment in reserves, if any, is probably small.

The Terek-Caspian TPS is also rich in hydrocarbons, mainly oil. The principal reserves are in Upper Cretaceous fractured carbonates and middle Miocene sandstones. The fields are controlled by high-amplitude anticlines, which are related to thrusts and are complicated by deformation of Upper Jurassic salt and Oligocene–lower Miocene Maykop shales. The main source rocks are probably Maykop shales (Ulmishek and Harrison, 1981). An analogy with the geologically similar, neighboring Azov-Kuban and Amu-Darya basins suggests that source rocks may also be present in the subsalt Jurassic section.

The Stavropol-Prikumsk TPS contains large gas reserves in lower Maykop (Khadum Horizon) sandstones on the Stavropol arch and moderate oil and gas reserves mainly in Lower Cretaceous sandstones in anticlinal traps of the Prikumsk uplift and

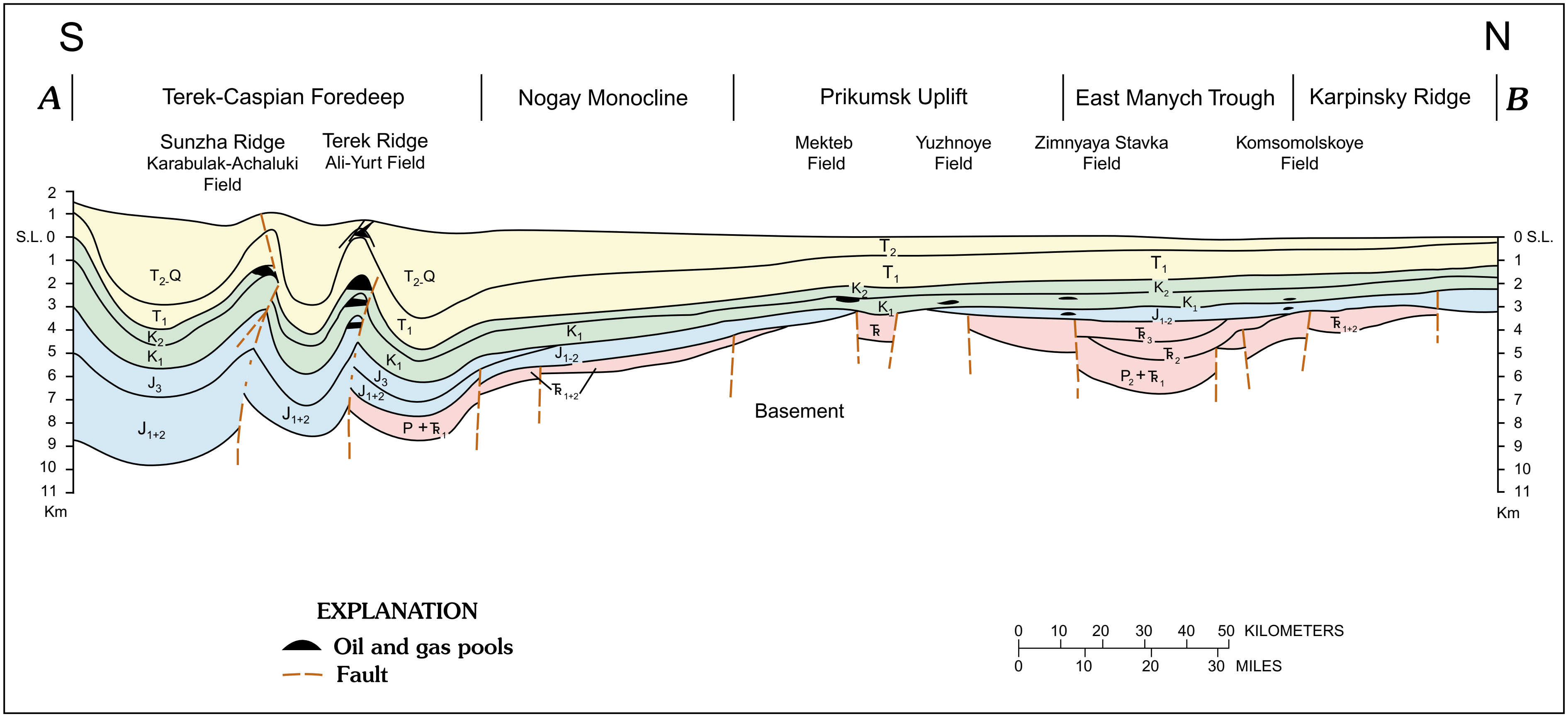


Figure 3. Cross section through Middle Caspian basin (modified from Dikenshtein and others, 1983). Location shown in figure 2. Although this figure shows otherwise, Terek and Sunzha anticlines are related to thrusts with decollement in Upper Jurassic evaporites. (See fig. 10.) P, Permian; ₮, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary; Q, Quaternary. Subscripts 1, 2, and 3 denote lower, middle, and upper respectively.

adjacent structures. Minor reserves have been discovered in Jurassic clastics, Lower Triassic carbonates, and in self-sourced fractured shale reservoirs in the lower part of the Maykop series. Principal source rocks are difficult to identify. Probably they are Bajocian marine shales moderately rich in organic matter. Source rocks are also present in Lower Triassic and lower Maykop sections. When more geochemical data are available, two or three overlapping petroleum systems can probably be identified in the sedimentary section.

The Shakpakhty TPS is identified by the Shakpakhty gas field where three gas pools are reservoired in Middle Jurassic clastic rocks. Source rocks for the gas are unknown. A number of other structural prospects have been drilled in the area, but no commercial accumulations or even significant shows have been found. The petroleum potential of the system is low, and it is not assessed or further described in this report.

South Mangyshlak Total Petroleum System (110902), Middle Caspian Basin, Kazakhstan

Introduction

The South Mangyshlak total petroleum system (TPS) is located in the eastern part of the Middle Caspian basin, east of the Caspian Sea (fig. 1). On the north and northeast, the system is bounded by the Mangyshlak foldbelt, which is a structurally inverted and deformed axial zone of the Triassic rift. On the south, the TPS borders the Karabogaz arch where thin Cretaceous and Tertiary rocks overlie the basement. To the west, the TPS extends into the central Caspian Sea where its dimension is unknown. Possibly, it extends to the Agrakhan-Guryev strike-slip(?) fault separating structures of the western and eastern Caspian Sea (fig. 2).

Proved hydrocarbon reserves of the system exceed 6 billion barrels of oil equivalent (BOE), most of which (84 percent) is oil. Most hydrocarbons are in Middle Jurassic clastic reservoirs on the Zhetybay step (structural terrace) south of the Mangyshlak foldbelt (fig. 4). Fields in the area include two giant (Uzen and Zhetybay) and a number of medium and small fields. Several small accumulations have been discovered in carbonate and clastic Triassic reservoirs on the Zhetybay step, on the slope of the Karabogaz arch, and on the Peschanomys uplift. Despite significant exploration efforts, no fields have been found in the deep South Mangyshlak (Zhazgurly and Segendyk) depressions. Source rocks have not been geochemically identified; however, spatial distribution of hydrocarbon accumulations indicates that major source rocks occur in the Lower–Middle Triassic section. Lower–Middle Jurassic coaly, continental to marine rocks could have been a secondary source, but probably of limited importance.

Discovery History

Shallow core drilling for delineation of surface structures on the Zhetybay step started in 1957. In 1960, one of the wells penetrated a shallow gas pool in Cretaceous rocks of the Uzen field. Deep drilling began shortly thereafter, and in 1961 two giant fields, Uzen and Zhetybay, in Lower–Middle Jurassic clastic rocks, were discovered. Exploration in the following years was targeted at this section, and a series of smaller discoveries were made. By the end of the 1960's, structural prospects of the Zhetybay step had been largely exhausted, and attempts to explore structures in the South Mangyshlak depressions had failed. The first gas and condensate flow from the Triassic section was obtained in 1972 in the South Zhetybay field, opening a new play in the petroleum system. Exploration efforts then were extended to the Peschanomys uplift and the slope of the Karabogaz arch where a number of medium and small size fields in Triassic rocks were found. Several wells were also drilled offshore, but only noncommercial hydrocarbon flows were obtained.

Petroleum Occurrence

Most oil and gas fields of the system and the great majority of discovered reserves are found on the Zhetybay step, which is a gently southward dipping structural terrace between the Bekebashkuduk anticline of the Mangyshlak foldbelt and the deep depressions farther south (fig. 4). Except for a few small gas accumulations in Cretaceous rocks of the Uzen field and several oil and gas condensate accumulations in Triassic rocks, all pools occur in the Lower–Middle Jurassic clastics below the Upper Jurassic regional seal. On the Bekebashkuduk anticline, deformed Triassic rocks are overlain by a thin Jurassic-Cretaceous section, and the regional seal is truncated by a pre-Cretaceous unconformity. Several heavy oil accumulations, including the very large Karasyaz-Taspas pool at depths of 400–500 m, are known in Lower Cretaceous rocks. These rocks also contain a few pools on the western plunge of the Bekebashkuduk and more northern anticlines of the Mangyshlak foldbelt.

Several oil and gas condensate fields of small to medium size have been discovered south of the South Mangyshlak depressions. The fields are located on the Peschanomys uplift and on the northern slope of the Karabogaz arch, above or near the Kara-Audan buried rift of Late Permian(?)-Triassic age (fig. 5; Murzagaliev, 1996). Most reserves of these fields are in the Middle Triassic carbonate formation although a few pools are present in other parts of the Mesozoic section. A medium-size oil pool has been discovered in a fractured granite batholith of the basement in the Oymasha field.

Few wells have been drilled offshore, but all failed to make commercial discoveries. Only one well in the Rakushechnaya-more prospect on the offshore extension of the Peschanomys uplift (fig. 2) recorded a significant gas condensate show from Triassic rocks, but apparently the show was considered noncommercial. Despite significant exploration efforts, no discoveries have been made in either the Segendyk or Zhazgurly depressions (fig. 4), although structural traps, Lower–Middle Jurassic reservoir rocks, and a thick Upper Jurassic seal are present there.

All oils of the petroleum system have common chemical characteristics. They are of medium gravity (31°–38° API in most pools) and have very high paraffin (to 30 percent) and resin (10–20 percent) contents and low sulfur content (0.1–0.25

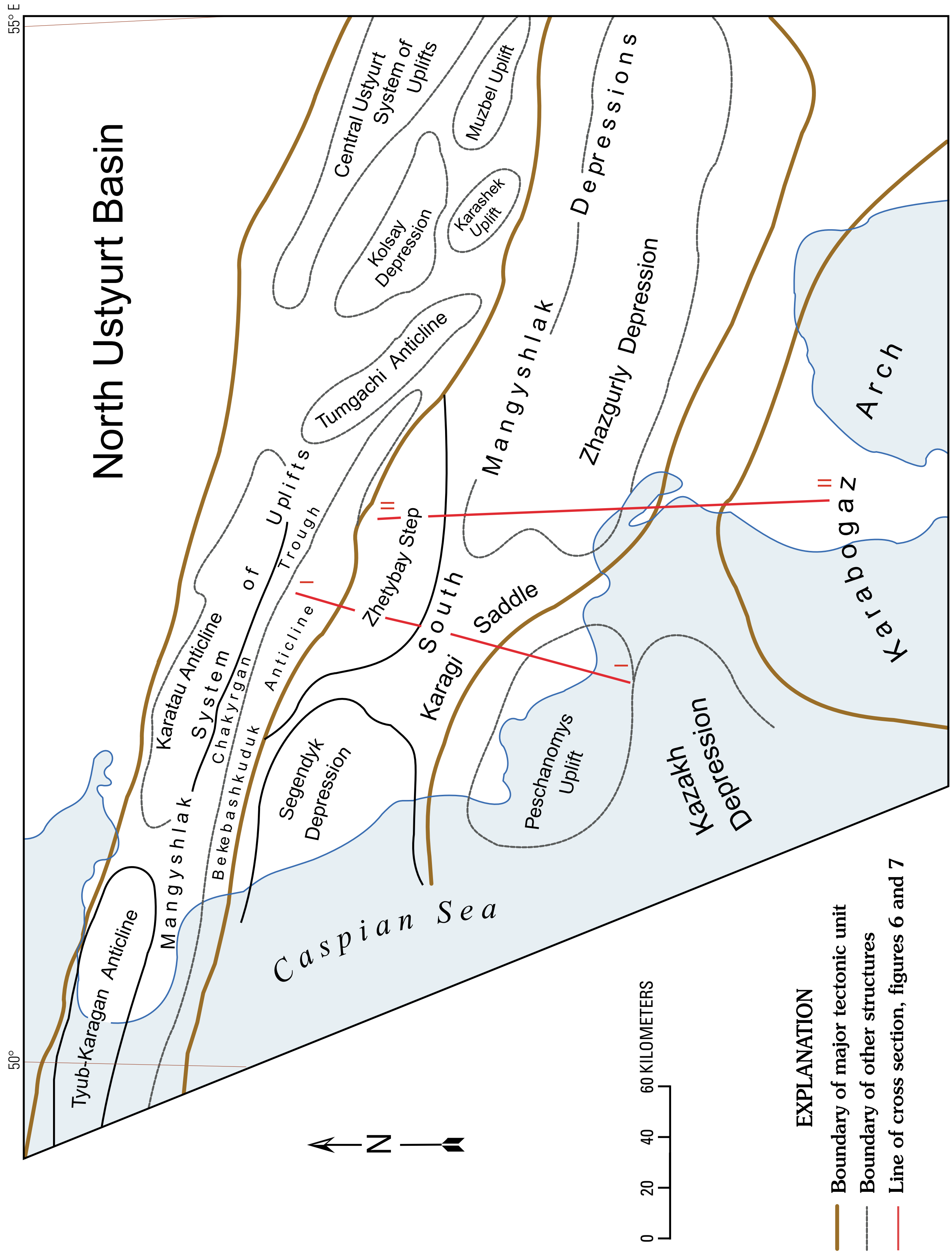


Figure 4. Generalized map showing structural units of South Mangyshlak petroleum system (modified from Krylov, 1971). Cross sections are shown in figures 6 and 7.

percent). No significant changes in chemical properties of oils from different depths are noticeable. None of the South Mangyshlak oils have been studied by modern geochemical methods. However, group compositions of Jurassic and Triassic oils are similar, and both oil groups are highly mature and are characterized by similar distribution of normal alkanes (Timurziev, 1986). These characteristics and other geologic data suggest that the oils were probably generated from the same source rock.

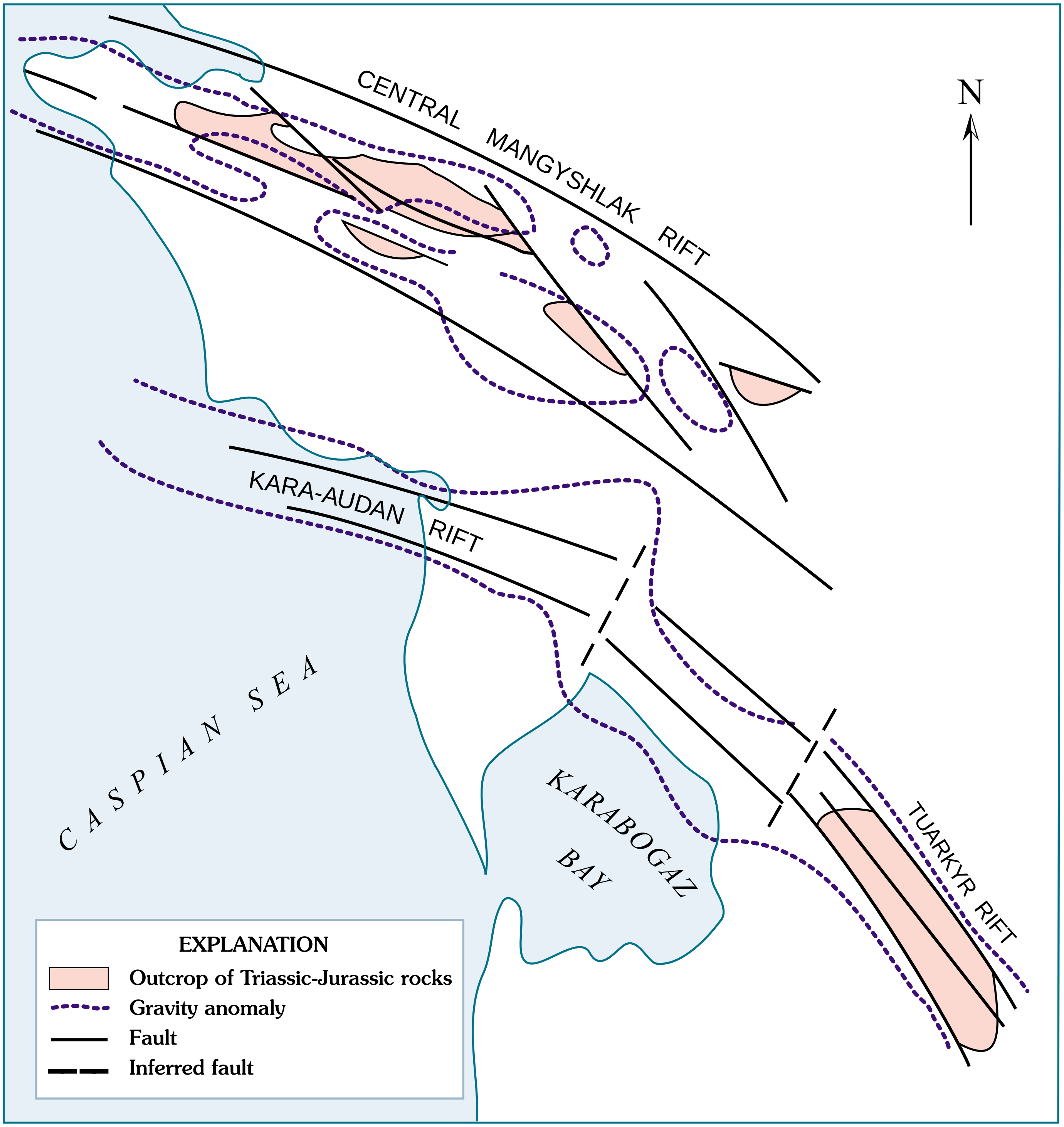


Figure 5. Sketch map showing Triassic rift systems of South Mangyshlak (modified from Murzagaliev, 1996). No scale.

Gases of the petroleum system are typical thermogenic gases. They contain 8–15 percent ethane and heavier homologues, small amounts of carbon dioxide (0.4–1.7 percent), and varying amounts of nitrogen (1–10 percent).

Stratigraphic Section

The upper Olenekian–Middle Triassic carbonate formation, which includes the main source rocks, overlies lower Olenekian marine variegated clastics and Induan red beds, which are more than 1,500 m thick on the Zhetybay step. These rocks thin and pinch out on the Peschanomys uplift. Older, Upper Permian, gray clastic rocks are present only in the Mangyshlak and, probably, in the Kara-Audan rifts. Upper Triassic marine clastics, directly overlying the upper Olenekian–Middle Triassic carbonate formation, are preserved chiefly in the South Mangyshlak depressions where they are up to 600 m thick. On the Zhetybay step and slopes of the Karabogaz arch, the rocks were eroded in pre-Jurassic time (figs. 6, 7).

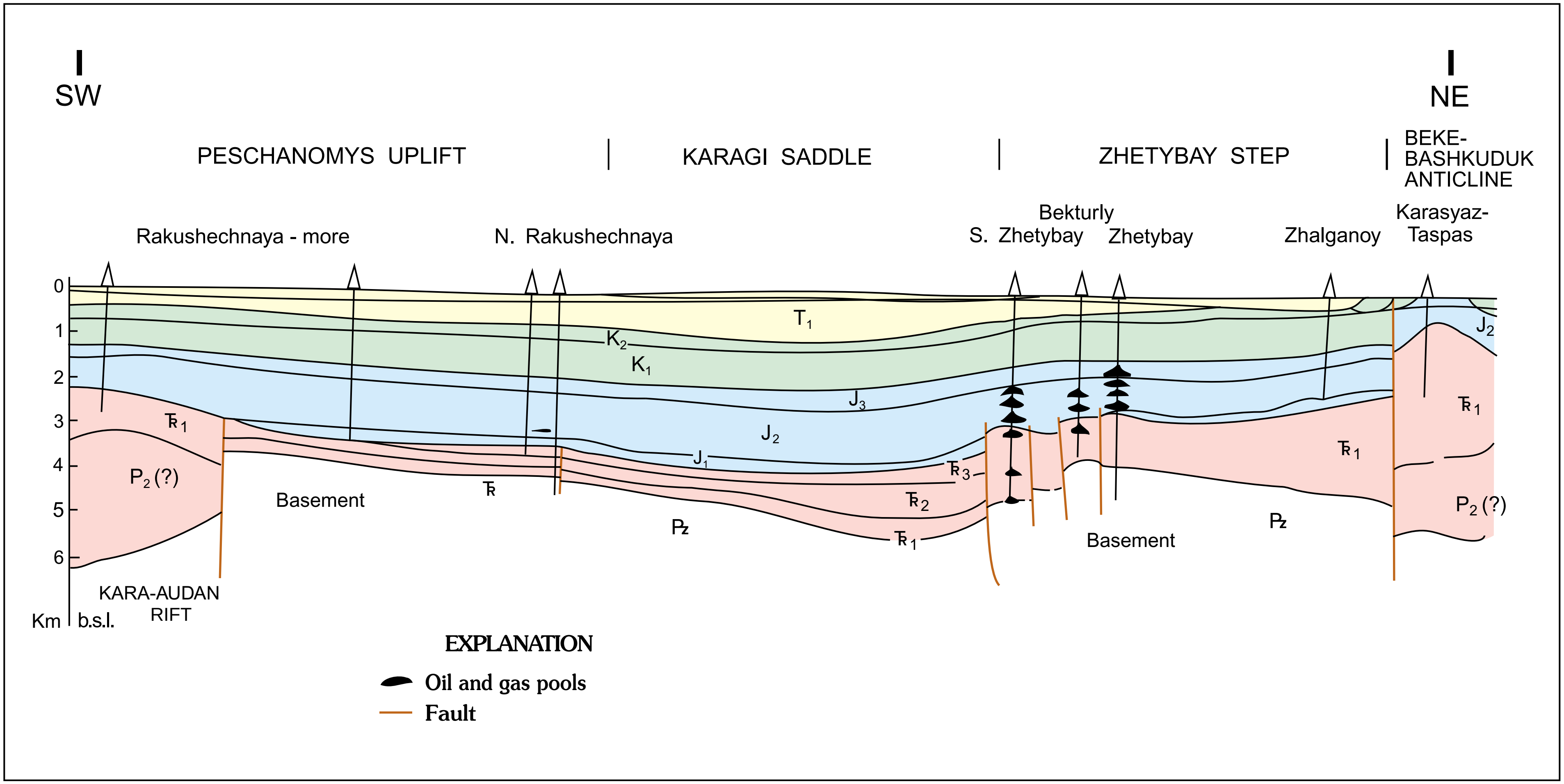


Figure 6. Cross section through South Mangyshlak petroleum system (modified from Orudzheva and others, 1985). Location shown in figure 4. Pz, Paleozoic; P, Permian;, TR, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary. Subscripts 1, 2, and 3 denote lower, middle, and upper, respectively.

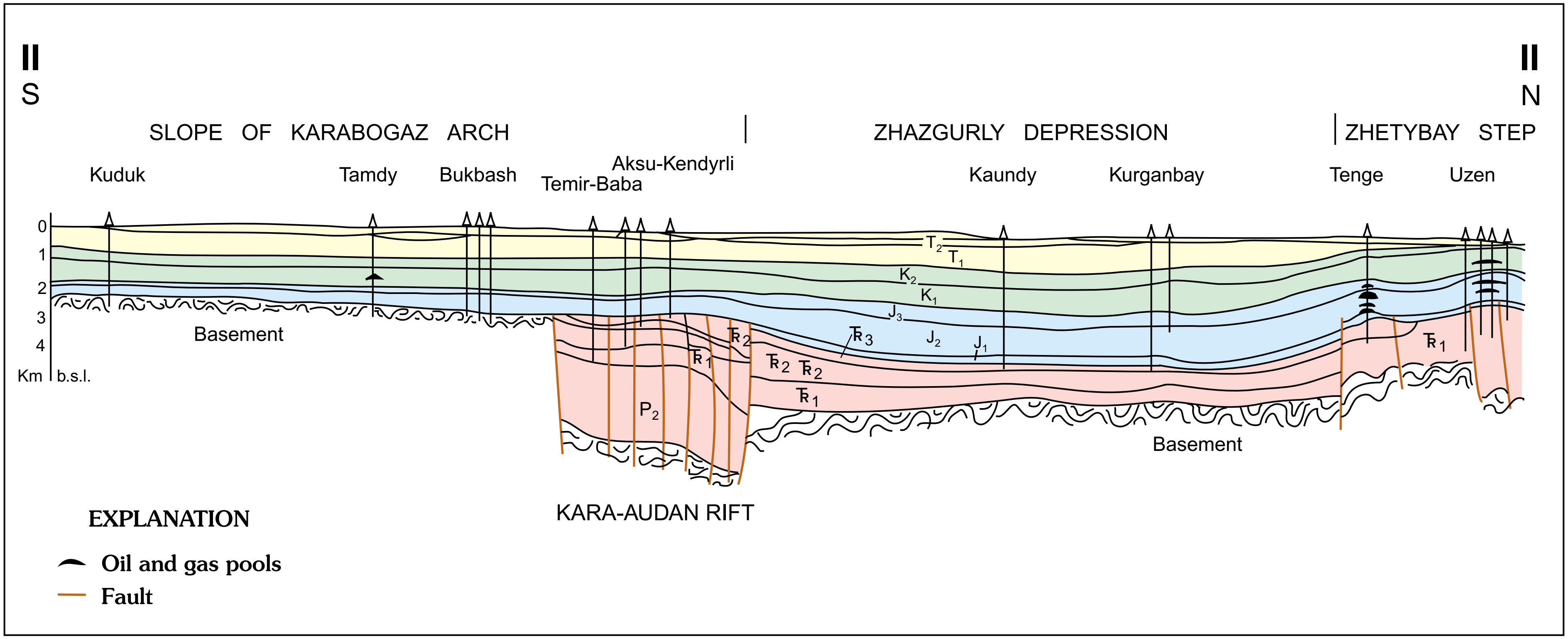


Figure 7. Cross section through South Mangyshlak petroleum system (modified from Orudzheva and others, 1985). Location shown in figure 4. P, Permian; TR, Triassic; J, Jurassic; K, Cretaceous; T, Tertiary. Subscripts 1, 2, and 3 denote lower, middle, and upper, respectively.

The Lower–Middle Jurassic (to top of the lower Callovian) section includes the principal producing pays of the petroleum system. The lower part of the section (through the Bajocian) is composed of various coal-bearing continental clastics. Marine interbeds are more common in the Bathonian. Thickness of the section reaches 1,300–1,400 m in central parts of the South Mangyshlak depressions and thins to 800–1,000 m on the Zhetybay step. An overlying marine transgressive section of middle Callovian–Kimmeridgian age consists of shales and carbonates and is a regional seal. The section is 500–700 m thick in central areas of the South Mangyshlak depressions and thins northward and southward. The Volgian Stage is absent.

The Lower Cretaceous section is 1,100–1,200 m thick in the depressions and 700–900 m thick on the Zhetybay step. The section is composed of Valanginian-Hauterivian carbonates, Barremian continental clastics, and thick Aptian-Albian marine shales with beds of sandstone. The Upper Cretaceous is 300–600 m thick in the depressions and thins to 100–200 m toward the Mangyshlak foldbelt. It includes Cenomanian–lower Turonian marine clastics and upper Turonian–Maastrichtian carbonates. Paleocene-Eocene rocks are chiefly carbonates, 50–200 m thick, unconformably overlying Upper Cretaceous rocks. The Maykop series (Oligocene–lower Miocene) is composed of marine shales up to 800 m thick in the depressions and 100–200 m thick on the Zhetybay step and Peschanomys uplift (figs. 6, 7). Middle Miocene and younger rocks lie unconformably on various parts of the Maykop series. They are present only in the South Mangyshlak depressions and are not more than 250 m thick.

Source Rocks

Source rocks for the petroleum system have not been positively identified. Two opposing points of view suggest that (1) source rocks for Triassic-reservoired oils are in the Lower–Middle Triassic marine section, whereas Jurassic and Cretaceous oils were generated from largely continental Lower–Middle Jurassic rocks with mainly type III kerogen (Kabanova and Braslavskaya, 1979; Florensky and others, 1975) and (2) all oils were generated from Triassic source rocks and migrated into overlying strata (Timurziev, 1986). Although convincing geochemical data are absent, geologic considerations suggest that the principal source rocks of the petroleum system are stratigraphically confined to the upper Olenekian–Middle Triassic section composed of alternating shales, carbonates, and tuffs. Thickness of the section is about 750 m in the southern part of the Zhetybay step and 250–300 m on the Peschanomys uplift. Measured TOC contents in shales reach 9.8 percent and organic matter is dominated by type II kerogen (Shablinskaya and others, 1990). An interval of black bituminous shales (“oily shale”) is present on the Zhetybay step in the Karadzhatyk Formation of the upper Olenekian Stage (Florensky and others, 1975). The generative potential of Induan and Upper Triassic rocks is substantially lower (Tverdova and others, 1982; Tverdova, 1988). Source rock quality of Lower–Middle Jurassic rocks is poor. Kerogen is dominantly of type III, and TOC content in shales commonly ranges from 0.5 to 1 percent reaching 1.5 percent only in the central part of the Segendyk depression (Polyakova, 1977).

In central areas of the South Mangyshlak depressions, Lower–Middle Jurassic rocks are thicker, buried at greater depths, and contain higher TOC. Structural traps, reservoir rocks, and seals are present; however, despite a significant amount of drilling, no discoveries have been made. Most probably, the lack of discoveries is related to insufficient generative potential of these rocks. Probable Triassic source rocks have been deposited in different geologic environments. Major areas of subsidence and best conditions for source rock deposition were confined to grabens of the Mangyshlak and Kara-Audan rifts and their shoulders where deeper-water anoxic basins probably existed (fig. 5). In the central zone of the former, Lower–Middle Triassic source rocks are strongly overmature and were deformed during rift inversion and folding. The source rocks were truncated by pre-Jurassic erosion in the northern part of the Zhetybay step where the giant Uzen field is located. However, Lower Triassic rocks that subcrop at the pre-Jurassic unconformity in this area may belong to the upper thrust sheet and may be underlain by younger Triassic source rocks. The Lower–Middle Triassic source rocks are certainly present in the southern part of the Zhetybay step and in the Kara-Audan rift (Orudzheva and others, 1985). Areas of the present-day South Mangyshlak depressions are between the two rifts and, in Triassic time, probably were a shallow-water platform devoid of organic-rich rocks. Another model that seems improbable, but cannot be excluded, is that Lower–Middle Triassic source rocks do extend from the Zhetybay step into the South Mangyshlak depressions, but hydrocarbons could not migrate upward into Jurassic reservoirs because of the lack of significant faults and the presence of the Upper Triassic seal.

The preceding considerations indicate that the principal source rocks of the South Mangyshlak petroleum system are basinal facies of parts of the upper Olenekian–Middle Triassic carbonate formation, probably its upper Olenekian part (Karadzhatyk Formation). The expected main areas of source rock development are the southern zone of the Zhetybay step, possibly the Bekebashkuduk anticline, and the Kara-Audan rift (figs. 4, 5). All discovered fields of the TPS are found either in these areas or updip in close proximity to them. The generative potential of Lower–Middle Jurassic rocks that contain most of petroleum reserves is low. Possibly, these rocks generated some gas, which is mixed with hydrocarbons migrated from the principal source.

Time of the beginning of oil generation by Triassic source rocks is uncertain. The present-day geothermal gradient varies from 38° to 41°C/km in most wells; however, it was probably substantially higher during the Triassic rifting event. Following this event, large volumes of Triassic rocks were denuded in pre-Jurassic time. A leap in vitrinite reflectance values between uppermost Triassic and basal Jurassic rocks has been reported in some wells (Bobylev and Grechishnikov, 1983). These uncertainties hamper modeling of oil generation history. Oil generation probably started during deposition of thick Cretaceous rocks and continued through deposition of the Oligocene–lower Miocene Maykop series (fig. 8). Pre-middle Miocene uplift resulted in deep and extensive erosion of older sediments, and little or no hydrocarbon generation could have occurred afterwards.

Reservoir Rocks

Principal reservoir rocks of the TPS, which contain the dominant part of oil and gas reserves, are confined to the Lower–Middle Jurassic section. They are sandstones interbedded with shales and mudstones. Thirteen productive intervals are present. Gross thickness of each interval ranges from 35 to 65 m, and net thickness ranges from 10 to 30 m. Significant lateral discontinuity and lens-like geometry greatly complicate the production (Ulmishek, 1990). The sandstones are fine to medium grained, polymictic, commonly poorly rounded, poorly to moderately sorted, with argillaceous and calcareous cement. Clay content varies widely from several to 40–50 percent, but is commonly high. On the Zhetybay step, porosities decrease from 18–23 percent at depths of 1,050–1,300 m (Uzen field) to 14–18 percent at depths of 1,950–2,650 m (South Zhetybay field). Permeability is highly variable (from several to 1,200 mD) and, unlike porosity, depends on clay content. Best reservoir properties are within channel sandstones (braided-stream deposits) that are present in several reservoirs.

Most hydrocarbons in the Triassic sequence are found in Middle Triassic carbonate reservoirs, and noncommercial oil flows have been obtained from the other parts of this sequence. Reservoir rocks are fractured carbonates with dominant vuggy porosity. Best reservoir rocks are in a bed 30–180 m thick (Bed B of local nomenclature), consisting of alternating tuffs and leached oolitic dolomites with porosities exceeding 20 percent and permeabilities to 200–300 mD (Cherbyanova and others, 1984). Reservoir properties are enhanced by vugs and fractures; matrix porosity of dolomites does not exceed 3–4 percent and permeability is near zero. The leaching has developed along neotectonic (post-early Miocene) fracture systems (Timurziev, 1984).

A significant oil pool in the Oymasha field is reservoired in fractured and weathered basement granites directly overlain by Triassic carbonates. Productivity of the granites extends 300 m below the basement surface. Data on reservoir properties are not available, but oil flow rates ranged from several to as much as more than 2,000 b/d (barrels per day) during well tests.

Several hydrocarbon pools have been discovered in Cretaceous rocks in areas where the Upper Jurassic seal is eroded (western plunge of the Mangyshlak foldbelt). Most hydrocarbons are reservoired in Aptian and Albian marine sandstones that have porosities of 16–21 percent and permeabilities of a few tens of millidarcies.

Seal Rocks

Only one regional seal of high quality that is present in the stratigraphic section consists of Upper Jurassic (upper Callovian–Kimmeridgian) transgressive marine shale and carbonate beds. Carbonates become more common and compose a large part of the seal in the southern areas of the TPS. The regional seal controls the principal oil and gas reserves in Lower–Middle Jurassic rocks, although separate pools may be directly capped by shale and mudstone beds alternating with reservoir sandstones. The Upper Jurassic seal is more than 500 m thick in deepest parts of the South Mangyshlak depressions but thins to 100–300 m on the Zhetybay step. The seal is highly effective; it is less than 100 m thick in the Uzen field, but nevertheless traps a giant oil accumulation with the oil column more than 300 m high.

The Triassic sequence does not contain regional seals. Hydrocarbon accumulations in this sequence are apparently sealed by dense carbonates and tuffs that have not developed secondary porosity and permeability.

Traps

Almost all hydrocarbon reserves in the principal producing Lower–Middle Jurassic section are in structural traps of the Zhetybay step. These traps are elongated anticlines grouped in three lines approximately parallel to the Mangyshlak foldbelt. Length of the anticlines varies from a few to 45 km (Uzen field), and closures range from a few tens to more than 300 m. Dips on the southern flanks of the anticlines substantially exceed those on the northern flanks, and the southern flanks are commonly faulted. The morphology of the anticlinal traps indicates that they were formed by compression in the direction normal to the Mangyshlak foldbelt. Interpretation of seismic data suggests that Jurassic-Tertiary anticlines are underlain by leading edges of thrust sheets in Triassic rocks (Popkov, 1991). Southward thrusts in Triassic rocks have been mapped in the Mangyshlak foldbelt, and thrusting evidently extends across the entire Zhetybay step.

Although principal thrusting of Triassic rocks took place in pre-Jurassic time, some compression and movements along thrust planes continued during late Mesozoic and Tertiary time. The movements occurred mainly during regional uplifts in pre-Cretaceous, pre-Tertiary, and post-early Miocene times (Popkov, 1991). The latest period was most important; about 70 percent of structural growth took place between the middle Miocene and the present (fig. 8).

Known stratigraphic traps in Jurassic rocks are few. Only one small oil accumulation in the Burmasha field has been found in Middle Jurassic fluvial channel sandstone, but no exploration was specifically targeted at stratigraphic traps. Because of significant lateral discontinuity of Jurassic lithologies in alluvial and nearshore depositional environments, potential for stratigraphic traps is probably high (Dmitriev and others, 1982).

Oil and gas accumulations in Triassic and basement rocks of the Peschanomys uplift and northern slope of the Karabogaz arch are in traps different from those of the Zhetybay step. Although exploration was targeted at structural uplifts, hydrocarbon accumulations are actually controlled by zones of fracturing and related leaching of carbonates (Makhutov, 1989). The zones have northeastern and northwestern trends. The northeastern zones are connected with faults having a significant strike-slip component, and the northwestern zones are interpreted as tear fractures (Timurziev, 1986). Both systems of fractures were formed in post-early Miocene time (Larichev, 1988).

Preceding data suggest that oil and gas fields of the South Mangyshlak TPS were mainly, and perhaps exclusively, formed in the post-early Miocene (neotectonic) stage of development. Generation of hydrocarbons during this stage did not take place. Thin (maximum 250 m) sediments were deposited only in central areas of the Segendyk and Zhazgurly depressions where the

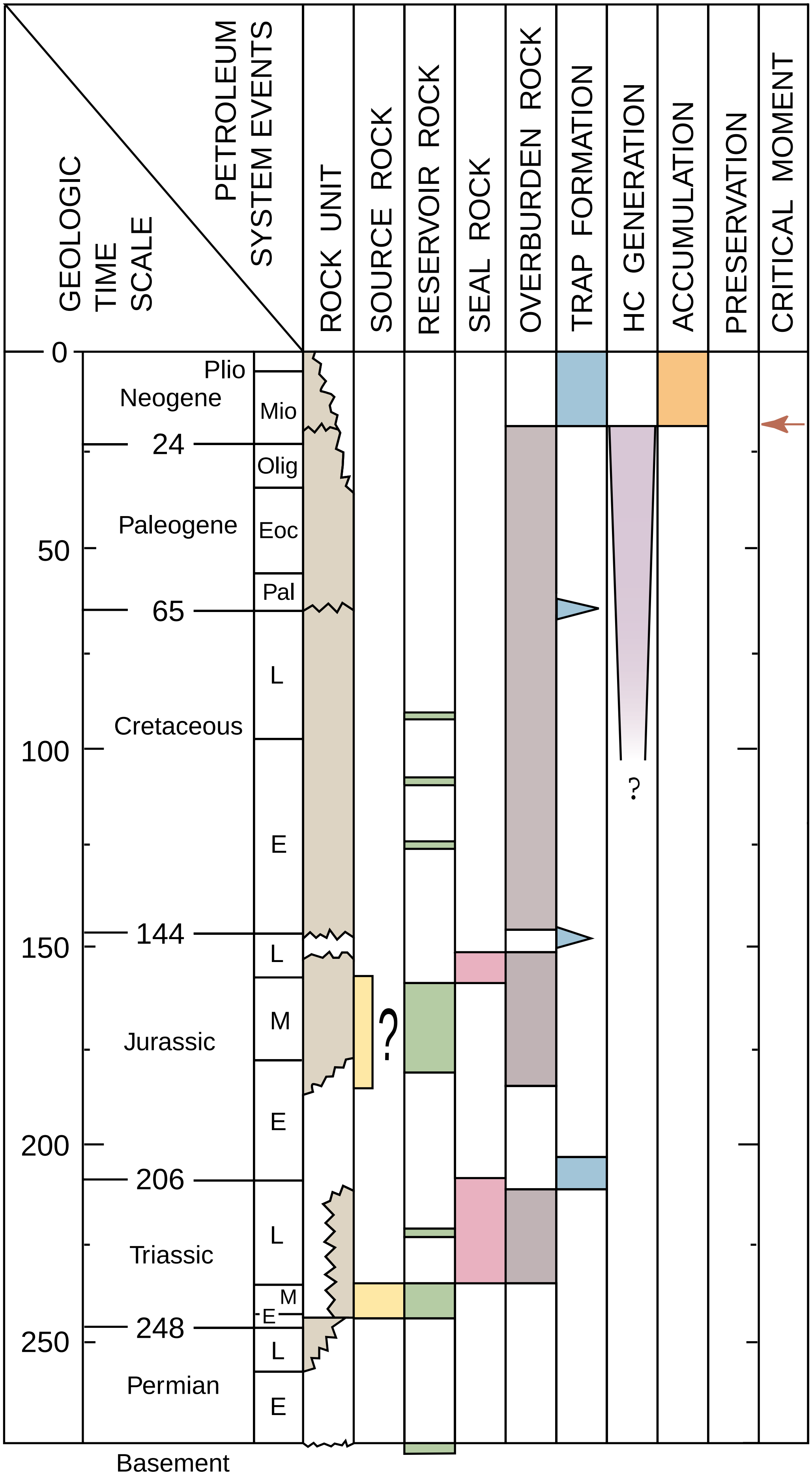


Figure 8. South Mangyshlak petroleum system events chart. Question marks indicate uncertainty.

principal Triassic source rocks are probably absent. Productive areas of the system and Triassic rifts that contain source rocks experienced uplift and erosion during this stage. Migration of oil and gas into traps postdated maturation and hydrocarbon generation (fig. 8). The inception of migration was probably caused by faulting and fracturing of overpressured mature source rocks and overlying beds, which created migration paths.

Assessment Units

Assessment Unit 11090201, South Mangyshlak (Entire)

In this report, the South Mangyshlak TPS is considered a single assessment unit although parts of the system have different potential. Assessed undiscovered oil and gas resources of the TPS are shown in table 1. Complete statistical data on the assessment of this and other units can be found in U.S. Geological Survey World Energy Assessment Team (2000). Offshore area of the western plunge of the Mangyshlak foldbelt and Bekebashkuduk anticline (fig. 4) possesses the best potential. Triassic source rocks responsible for large hydrocarbon reserves of the Zhetybay step extend into the area. The intensity of folding decreases westward, and seismic surveys indicate the presence of structural traps (Lebedev and others, 1987). Good preservation conditions can be expected because of increasing depths to potential targets. Large oil and gas condensate pools may be primarily reservoired in Jurassic and Cretaceous rocks. The Zhetybay step itself is maturely explored and has limited future potential for small fields in Triassic structural traps and in Jurassic stratigraphic traps.

No oil or gas has been found in the South Mangyshlak depressions, probably because of the absence of Triassic source rocks and the low efficiency of possible Jurassic source rocks. Even if Triassic source rocks extend from the Zhetybay step into the depression under the Upper Triassic seal, only small pools at great depths (greater than 4–5 km) can be expected. The potential of this structure and its offshore continuation is low.

The productivity of the Peschanomys uplift and the northern slope of the Karabogaz arch is related to Triassic source rocks of the Kara-Audan rift (fig. 5). Unlike on the Zhetybay step, hydrocarbons are contained only in Triassic fractured reservoirs of inferior quality, and drilled wells indicate no signs of migration into overlying Jurassic sandstones. Only structural prospects have been drilled. However, reservoirs in zones of fracturing are probably present outside local uplifts, and many small to medium-size fields may be found. Regional updip pinch-out zones of Mesozoic rocks on the slope of the Karabogaz arch are potential for discoveries in stratigraphic traps. The offshore continuation of the Peschanomys uplift also has significant potential, although a few drilled structural prospects there have not been commercial discoveries. Productivity of Jurassic rocks in this part of the system depends on the presence of migration paths between Triassic source rocks and Jurassic reservoirs and, although not proven, is possible, especially in the offshore area.

In the Kazakh depression (figs. 2, 4), potential Jurassic and Triassic targets occur at depths of 3–4 km and more. Triassic source rocks are probably absent. No significant structural prospects have been identified (Lebedev and others, 1987), and no wells have been drilled. Petroleum potential of the depression is probably low.

Terek-Caspian Total Petroleum System (110901), Middle Caspian Basin, Russia

Introduction

The Terek-Caspian total petroleum system (TPS) lies in the eastern North Caucasus region and occupies the foredeep of the same name (figs. 1, 2). On the south, the system is bounded by the Great Caucasus foldbelt. The boundary with the Stavropol-Prikumsk TPS to the north is along the Nogay monocline, which is the northernmost structural unit of the foredeep (fig. 9). To the west, the TPS terminates along the slopes of the Mineralovod high and Stavropol arch, an uplifted structural trend transverse to the Caucasus strike that separates the eastern and western branches of the North Caucasus foredeep troughs. On the southeast, the system extends into the poorly known North Apsheron depression offshore in the Caspian Sea (fig. 2).

Original oil reserves of the TPS amount to 3.4 billion barrels whereas non-associated gas reserves are small (0.2 TCF). Almost all fields are controlled by structural traps related to thrusting of the Great Caucasus foldbelt onto the Mesozoic-Cenozoic epi-Hercynian platform. Oil and gas pools occur in reservoirs ranging in age from Late Jurassic to Miocene. Most original reserves (55 percent) are in Upper Cretaceous fractured limestone reservoirs of the Terek-Sunzha zone (fig. 9), but substantial reserves (30 percent) are also in middle Miocene sandstones. Reserves in Upper Jurassic and Lower Cretaceous carbonate and sandstone reservoirs are much smaller. The most important source rocks are probably shales of the Oligocene–lower Miocene Maykop series, but some endowment of hydrocarbons from older potential source rocks in the upper Eocene, Upper Jurassic, and Lower–Middle Jurassic sections is possible.

Discovery History

Surface oil seeps in the Terek-Sunzha anticlinal zone near Groznyi (fig. 9) have been known for a long time, and oil was produced there from hand-dug wells starting in the early 1800’s. The first producing well was drilled into middle Miocene sandstones of the Starogroznen field in 1893 by an Englishman, Alfred Stuart. The Berekey field in the South Dagestan area (western zone of the South Dagestan projection in fig. 9) was discovered in 1899. Oil production increased rapidly and reached a total of 8.8 million barrels by 1910.

After revolution in Russia, exploration resumed in the 1930’s, and several significant fields were discovered in shallow middle Miocene sandstones. However, major discoveries were made after World War II, in the 1950’s, when a number of large and highly productive pools were found in Upper Cretaceous rocks. Maximum production was reached in 1970–1971, after which production started to decline, as new discoveries were much smaller.

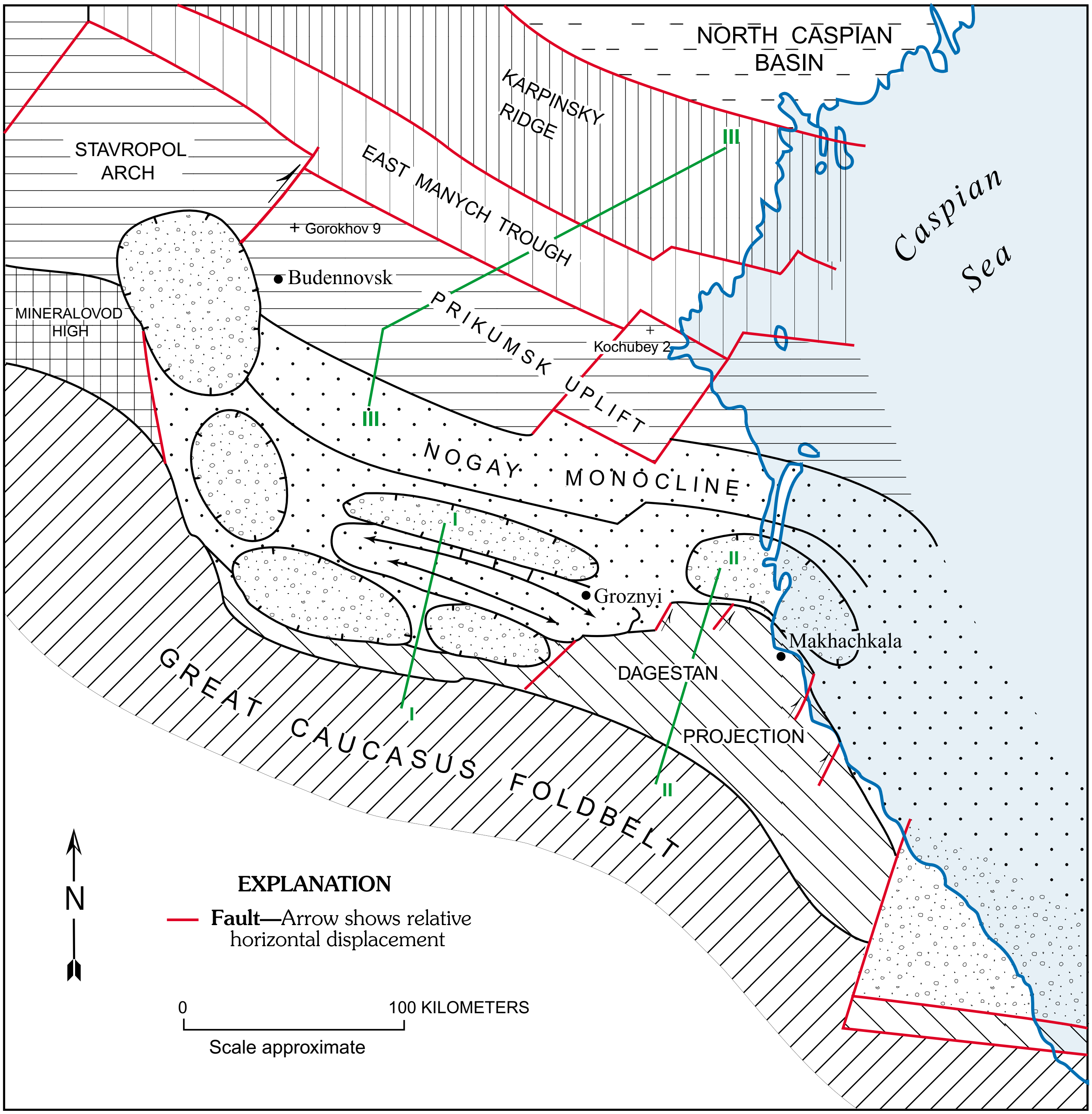


Figure 9. Structural map of eastern North Caucasus region (modified from Sokolov and others, 1990). Dot pattern, Terek-Caspian foredeep; dot-circle pattern, deepest depressions of the foredeep (outlines hachured to indicate closed low). Arrows in Groznyi area show Terek and Sunzha anticlines. Lines I-I, II-II, and III-III are approximate locations of cross sections in figures 10 and 16. Kochubey 2 and Gorokhov 9 are locations of wells in figures 17 and 18.

Petroleum Occurrence

The largest fields of the petroleum system and the main hydrocarbon reserves are concentrated in the Terek-Sunzha anticlinal zone (figs. 9, 10A). The zone consists of two principal anticlines (Terek and Sunzha anticlines) and two subordinate deeper lines of folds. The anticlines are related to thrust sheets with decollement along Tithonian (Upper Jurassic) salt (fig. 10*A*). Largest and most productive pools are in the Upper Cretaceous–Eocene fractured carbonate formation at depths of 1,650–5,200 m (fig. 11). Also large, but presently substantially depleted reserves are present in middle Miocene sandstones at shallow depths. Smaller pools have been discovered in Lower Cretaceous sandstone and carbonate and in Tithonian suprasalt carbonate reservoirs. Most reserves are oil, but several gas condensate pools are also present.

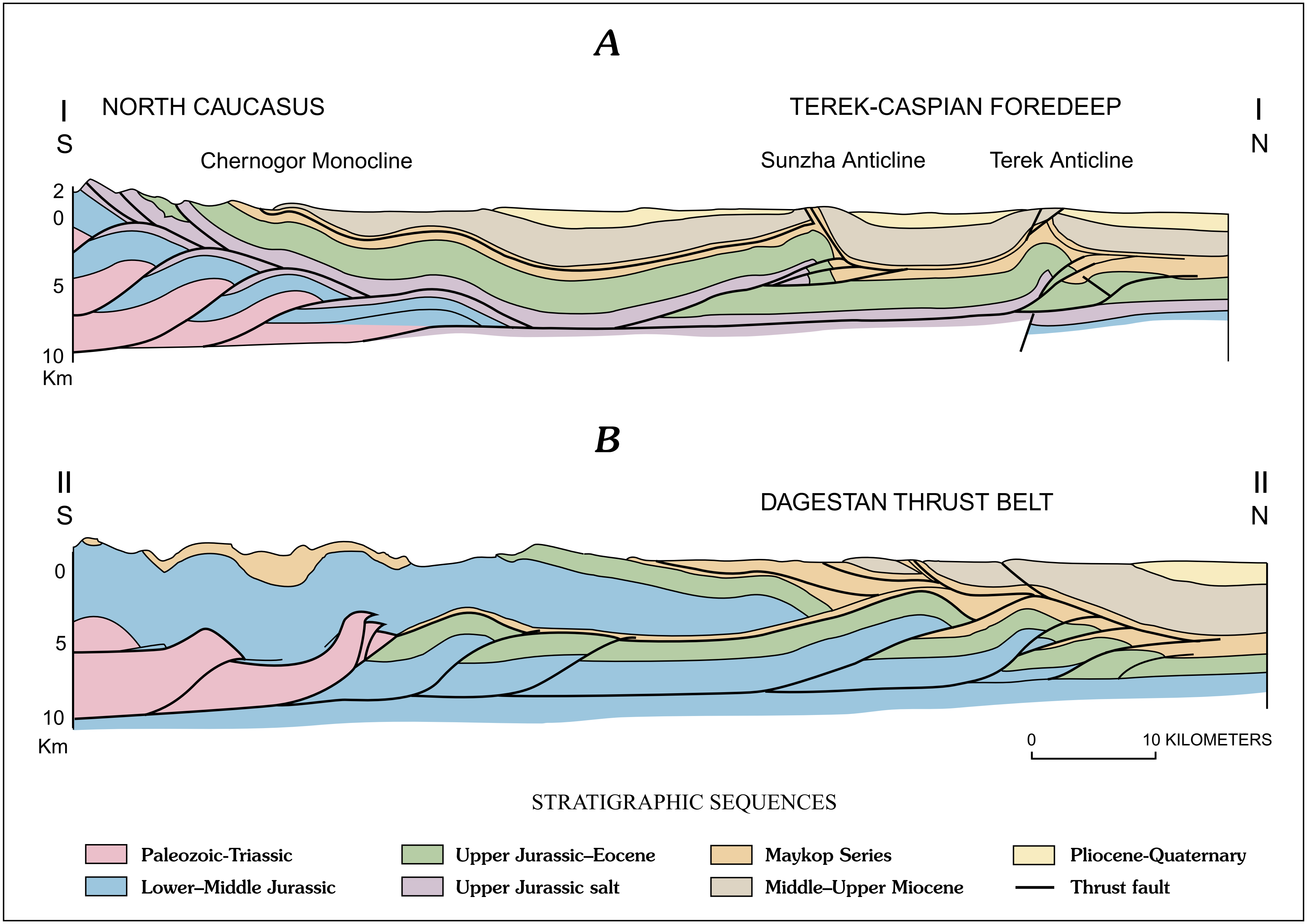


Figure 10. Cross sections through Terek-Sunzha (*A*) and Dagestan (*B*) thrust belts (modified from Sobornov, 1995). Wedge-shaped frontal parts of thrust are intruded in Upper Jurassic salt (*A*) and Maykop plastic shales (*A* & *B*). Location of cross sections shown in figure 9.

South of the Terek-Sunzha zone, two small fields (Datykh and Benoy) have been discovered in thrust-related folds of the Caucasus foothills. Farther east and southeast, several oil and gas fields are found in the continuation of the thrust system where most reserves are also in Upper Cretaceous carbonate and Miocene sandstone reservoirs. Only one prospect has been drilled in the offshore portion of the thrust belt, and a gas condensate flow was obtained from middle Miocene sandstones of the Inchkhe-more field.

North of the North Caucasus thrust system, a few noncommercial discoveries have been made on the Nogay monocline (fig. 9). Oil and gas were tested from Cretaceous rocks, largely from Upper Cretaceous carbonates. The traps are platform-type basement-related anticlinal uplifts different from traps of the thrust belt. In the absence of geochemical data, it is uncertain whether these fields constitute a part of the Terek-Caspian TPS, as inferred in this report, or whether they should be attributed to the Stavropol-Prikumsk TPS to the north.

Oils in Cretaceous and Mesozoic reservoirs are of low viscosity and gravity (mostly 37°–41° API). They have low sulfur and resin contents and a moderately high (5–10 percent) content of solid paraffin. GOR is typically high, varying in most pools from 1,400 to 2,600 ft^3/bbl. Pools in Miocene rocks are largely less than 1,200 m deep and contain heavy, biodegraded oils with high (to 25 percent) resins content and low paraffin and sulfur contents. The oils are significantly devoid of paraffinic hydrocarbons and largely consist of naphthenes and aromatics. Limited geochemical chromatography data suggest similarity of Miocene oils of the Terek-Sunzha zone to Mesozoic and Miocene oils of the Dagestan thrust belt (Sokolov and others, 1990). Data indicate that the oils were sourced from low to moderately mature source rock, probably from Maykop series shales. The data are inadequate to determine the affinity of Mesozoic oils of the Terek-Sunzha zone to the same group.

Stratigraphic Section

The basement of the Middle Caspian basin is a Hercynian accreted terrane, which includes several microcontinents. One of them, the North Caucasus microcontinent, crops out in the northern range of the foldbelt. The Paleozoic sedimentary cover of the microcontinent extends into the western area of the Terek-Caspian TPS, but its dimension is unknown. Triassic rocks, which fill rifts to the north of the area, may be present in the foredeep at great depths.

Basement or Triassic rocks are overlain by a thick Lower–Middle Jurassic clastic formation (fig. 11). North of the Caucasus Range, most of the formation is composed of Bajocian-Bathonian marine shales up to 2 km thick that include some sandstone beds. Thickness decreases northward, and the formation pinches out on slopes of the Stavropol arch. Upper Jurassic-Neocomian rocks unconformably overlie the Middle Jurassic. The rocks were deposited in arid climatic conditions. The section consists of carbonates and includes thick (to 1,000 m) lower Tithonian salt in the western half of the TPS area. Thick Oxfordian-Tithonian reefs are exposed in the northern zone of the Caucasus, along the southern margin of the salt basin. To the north and west, the salt grades into red continental clastics. The Aptian-Albian section is 500–700 m thick and is composed of marine shales with beds of glauconitic sandstones. Upper Cretaceous rocks are carbonates and marlstones 300–600 m thick. Thickness increases to 1,400 m in a local depocenter just northwestward of the Dagestan projection (Bayrak, 1982). Paleocene-Eocene rocks are carbonates and marls of a condensed section only 50–100 m thick. The rocks were deposited in deep-water conditions; by the end of the Eocene the water depth could have exceeded 1,000 m (Berlin and Ulmishek, 1978).

The Upper Cretaceous–Eocene carbonate formation is overlain by the Maykop series of Oligocene–early Miocene age. In the TPS area, the series almost exclusively consists of shales and is up to 1,600 m thick. Shales in the lower part of the series were deposited in a deep-water basin inherited from Eocene time. The basin became progressively shallower by the end of Maykop deposition. The shales are undercompacted and overpressured, and experienced plastic flow in zones of tectonic stress. The principal provenance areas were to the northeast; however, large olistostromes, which include huge blocks of underlying carbonates, reaching a cubic kilometer in volume, are present along the Caucasus and indicate the beginning of orogenic uplift.

The middle Miocene through Quaternary sequence consists of coarsening-upward clastic rocks, which include some upper Miocene carbonate beds. This orogenic sequence fills a foredeep formed along the Caucasus front. Thickness of the rocks in the foredeep axial zone can exceed 5 km. To the north, the sequence rapidly thins onto the foreland slope.

Jurassic through Eocene rocks of the Terek-Caspian TPS were deposited on the southern continental margin of Eurasia. Sedimentation was characterized by a passive-margin regime because the TPS area was separated from the active Tethyan margin by the Transcaucasus microcontinent and the marginal sea of Great Caucasus. Provenance for clastic material was far to the north, on the Russian craton. First signs of Caucasus orogenic uplift appeared in Oligocene time and progressively increased afterwards. However, not until late Miocene-Pliocene time did the orogen became the dominant source of clastic material and the present-day foredeep come into existence.

Source Rocks

Geologic and limited geochemical data indicate that the most important source rocks of the Terek-Caspian TPS occur within the thick Maykop series (Oligocene–lower Miocene). The lower part of the series was deposited in a deep anoxic marine basin, which was gradually filled with clastic sediments of the upper part of the series (Ulmishek and Harrison, 1981). Lower Maykop shales and marlstones are characterized by variable, but commonly high (to 4.4 percent) TOC content and dominant type II kerogen. Hydrogen index in the lower to middle part of the oil window reaches 250–260 mg HC/g TOC. Toward the top of the Maykop series, TOC decreases to 1–2 percent, and organic matter contains much more terrigenous constituents. In the depressions of the foredeep, the lower Maykop series occurs in the lower part of the oil window and into the gas window (fig. 12*D*).

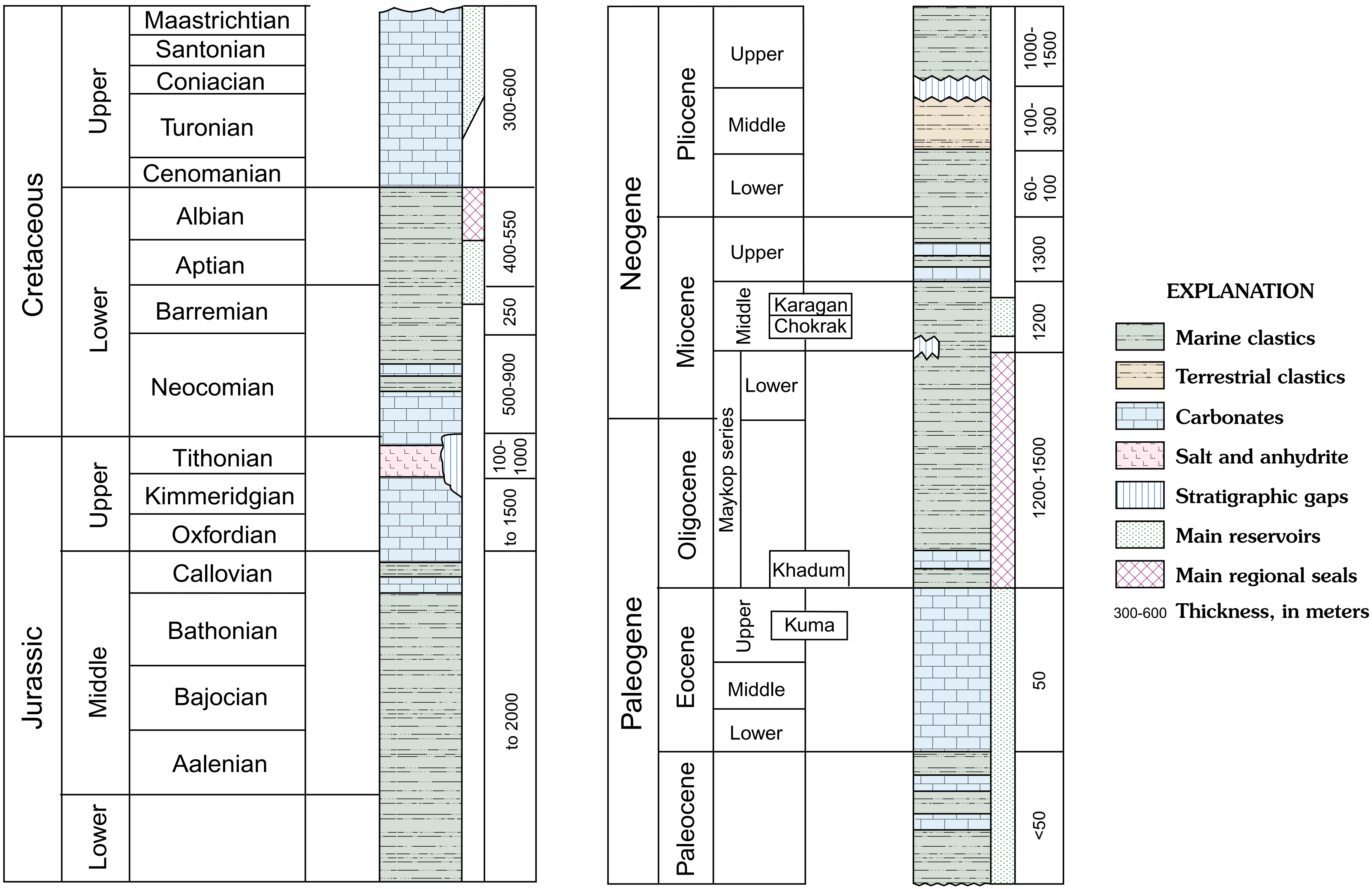


Figure 11. Columnar stratigraphic section of Mesozoic-Tertiary rocks of Terek-Caspian petroleum system (modified from Ulmishek and Harrison, 1981).

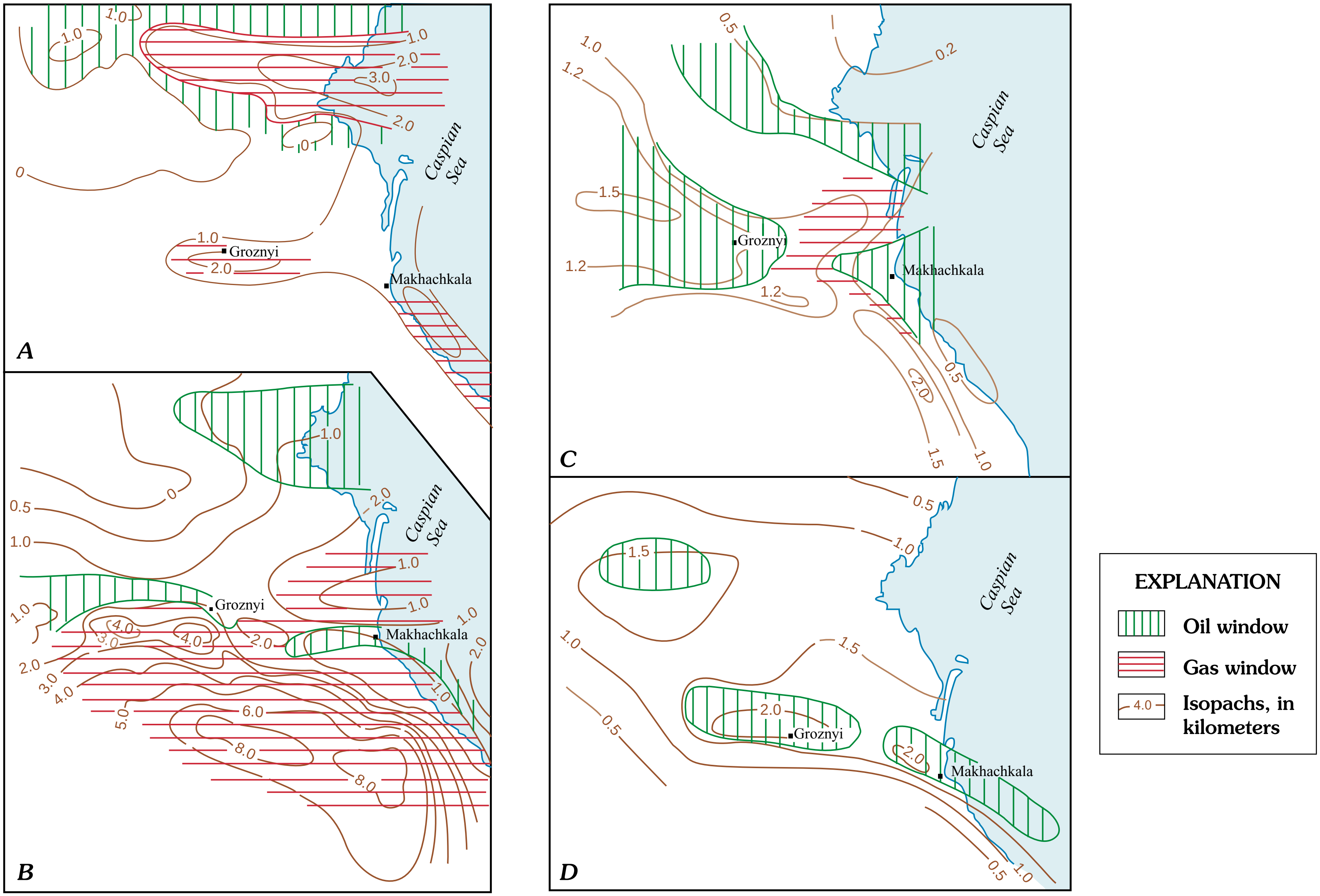


Figure 12. Maturity zones in stratigraphic units of eastern North Caucasus region: *A*, in Triassic rocks; *B*, in Middle Jurassic rocks; *C*, in Aptian-Albian rocks; *D*, in upper part of Maykop series (modified from Sokolov and others, 1990). Mature source rocks at bottom of Maykop series occupy significantly larger area.

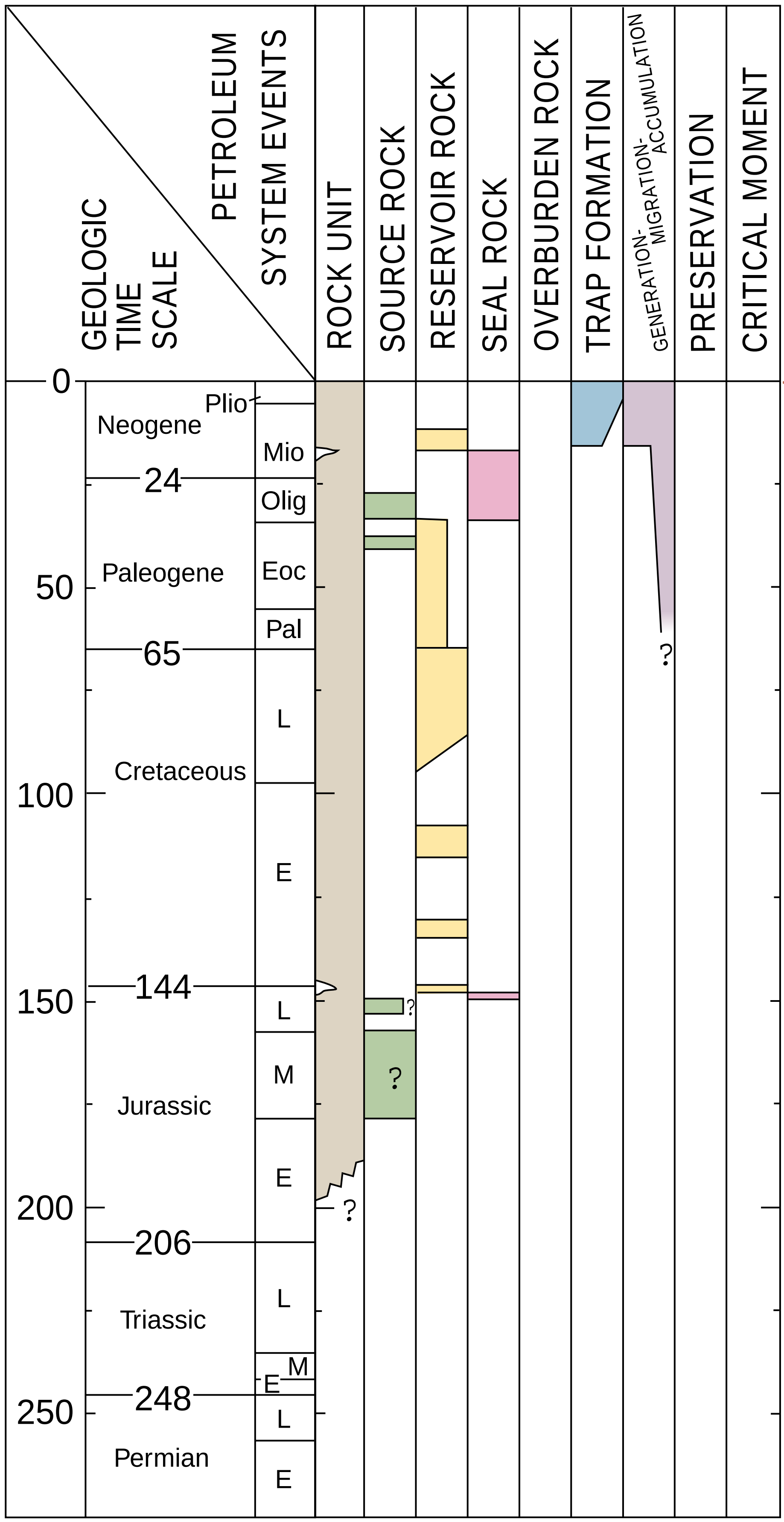


Figure 13. Terek-Caspian petroleum system events chart. Question marks indicate uncertainty.

Information on the presence of older source rocks in the TPS is uncertain because of limited geochemical data. Probable source rocks are argillaceous bituminous limestones of the upper Eocene Kuma Formation (fig. 11), which is 20–30 m thick and is separated from the base of the Maykop series by a 20-m bed of light foraminiferal limestone. TOC in rocks of the Kuma Formation averages 2–2.5 percent. The formation was deposited in conditions similar to that of the Maykop series, but with lower input of clastic material (Berlin and Ulmishek, 1978).

North of the Caucasus Range, Middle Jurassic marine rocks include shale beds in which TOC averages 1.15 percent and reaches as much as 5–10 percent. Terrigenous organic matter dominates. The rocks are in the gas window over most of the area (fig. 12*B*) and could be a gas source for the petroleum system. Source rocks may also be present in the subsalt Upper Jurassic section. Rocks of this section have been erratically sampled only in a few wells drilled below the salt on the basin margins, but the presence of source rocks may be inferred by analogy with the stratigraphically similar Amu-Darya basin. In both basins, salt was deposited in deep lagoons separated by reefs from the Tethyan ocean. Significant oil shows from subsalt carbonates in the marginal areas of the salt basin (Kosarev, 1982) and a gas flow of 9 MMCFD in the Datykh field support this supposition.

Although hydrocarbon generation from Jurassic source rocks could have started in Cretaceous time, generated hydrocarbons were probably lost because of the absence of traps. The principal stage of maturation of younger source rocks took place after deposition of the Maykop series, during middle Miocene through Quaternary time, contemporaneously with thrusting and formation of traps (fig. 13).

Reservoir Rocks

Most oil and gas reserves of the TPS are in Upper Cretaceous–Eocene carbonate reservoirs. Matrix porosity of Upper Cretaceous carbonates is low and commonly varies from a few to 10 percent; it is even lower in Paleocene-Eocene marlstones. Matrix permeability is negligible. Reservoir properties are enhanced by the presence of fractures and related vugs. Fracturing resulted from tectonic stress in thrust-related anticlines. Most pools are overpressured, and characteristic initial oil flow rates are in thousands of barrels per day.

The second important group of reservoirs is confined to sandstone beds of the middle Miocene Karagan and Chokrak Horizons (fig. 11). Seventeen to twenty-three sandstone beds occur much shallower than the Upper Cretaceous and possess excellent reservoir properties, although separate sandstone beds are laterally discontinuous and commonly pinch out. Thickness of each sandstone bed is usually less than 10 m. Lateral discontinuity and significant faulting result in a large number of hydrodynamically isolated pools in many fields (for example, 65 pools in the Malgobek-Gorskaya field). Sandstone porosity varies from 15 to more than 30 percent, and permeability is commonly measured in hundreds of millidarcies.

Aptian-Albian sandstones and Neocomian and Upper Jurassic carbonates contain only a few petroleum accumulations. Reservoir properties of both sandstones and carbonates at great depths are poor and mainly depend on fracturing.

Seal Rocks

The principal regional seal that controls hydrocarbon accumulations in the Mesozoic sequence is Maykop series shales. The shales are undercompacted and overpressured and are characterized by high plasticity in the subsurface. The series is from 750 to nearly 1,600 m thick and overlies most of the TPS area except for the Great Caucasus foothills, where it has been eroded. The seal directly overlies the principal reservoirs in the Upper Cretaceous–Eocene carbonate formation. Seals for pools in underlying Lower Cretaceous and Upper Jurassic rocks are dense shales and carbonates that probably would not be effective in the absence of Maykop shales.

Hydrocarbon accumulations in middle Miocene sandstones are sealed by alternating shale beds that range up to several tens of meters thick. In most uplifted anticlines, upper sandstone beds are exposed and either flushed by water or leak oil to the surface. An additional high-quality seal of potential importance is the Upper Jurassic (Tithonian) salt formation that is only locally deformed and is present west and northwest of the Dagestan projection. A number of shows and a gas flow have been obtained from subsalt Jurassic carbonates, but this play remains unexplored. Because of the presence of a perfect salt seal above these shows, they may represent a separate petroleum system charged by Upper Jurassic and (or) Lower–Middle Jurassic source rocks.

Traps

Structural traps control all oil and gas fields of the TPS, although many particular pools are outlined by pinchouts of middle Miocene sandstones and by limits of fracturing in Upper Cretaceous–Eocene carbonates. Almost all discovered reserves are in anticlines related to leading edges of thrust sheets (fig. 10*A*), and only a few apparently noncommercial fields are known on the Nogay monocline in structural uplifts of the platform type. In the Terek-Sunzha zone, where the principal reserves of the petroleum system are concentrated, most discovered fields are in traps which form two east-to-west anticlinal lines, the Sunzha anticline on the south and the Terek anticline on the north (fig. 10*A*). The anticlines are expressed on the surface as two ridges. Deformation of Quaternary sediments and present-day seismicity indicate their continuing growth. Two less pronounced and much deeper structural lines containing several smaller fields are present to the north and south. The main detachment surface probably is in the Upper Jurassic salt formation. The salt itself is deformed by plastic flow and composes cores of the anticlines. It is interpreted from seismic data that thrust sheets of competent rocks intruded like wedges into undercompacted, plastic Maykop series shales. This intrusion caused antithetic reverse faults and thrusts of southern vergence to form in the upper part of the sedimentary section (Sobornov, 1995). Plastic deformation of Maykop shales resulted in additional faulting and folding of post-Maykop rocks, and the structure of the latter is substantially different from that of Upper Cretaceous rocks. Traps of the main structural lines are long and narrow anticlinal folds with closures reaching 1,500 m on Upper Cretaceous rocks.

Traps on the northeastern periphery of the Dagestan projection are also thrust-related anticlines that are arranged in three structural lines. Progressively younger rocks crop out on consecutively northeastward anticlinal lines. The easternmost line is located offshore where only one prospect has been drilled. In this part of the TPS area, Jurassic salt is absent, and the main detachment occurs in Lower–Middle Jurassic shales (fig. 10*B*). In other respects, these traps are similar to traps of the Terek-Sunzha zone, although the regional structure of the Dagestan zone is characterized by more intense deformation.

Assessment Units

Three assessment units are identified in the Terek-Caspian TPS (fig. 1). Assessed undiscovered oil and gas resources of these units are listed in table 1.

Assessment Unit 11090101, Foldbelt-Foothills

This unit occupies the front thrust system of the Caucasus foldbelt (fig. 1). Almost all discovered hydrocarbon reserves belong to this unit. Principal characteristics of undiscovered fields are probably similar to that of known fields. Along the foldbelt, the prospective area is limited by truncation of the Maykop series seal. Presently, the Terek-Sunzha zone contains the dominant reserves of the assessment unit. However, productive suprasalt Upper Jurassic through Tertiary rocks of this zone are substantially explored to depths of 5–5.5 km, and only smaller fields in deep satellite structures can be found. The deeper subsalt Jurassic section occurs below the main detachment surface. Probably, it has different structural characteristics and is therefore placed in a separate assessment unit (11090102, Terek-Sunzha Subsalt Jurassic). The area between the Terek-Sunzha zone and exposed Caucasus folds is only sparsely explored. However, Cretaceous and younger rocks of this area are almost undeformed, and structural prospects have been identified only in its southern part (Chernogor monocline; fig. 10*A*) where two discoveries have been made. Potential of the area is modest at best.

To the east of the Terek-Sunzha zone, the thrust belt is sparsely explored north of the Dagestan projection. Deformation is complex there (fig. 10*B*), and both leading edges and rear parts of the thrust sheets contain structural prospects. Until recently the quality of seismic data was inadequate for prospect mapping. The potential of the area is good. Light oil and gas condensate fields in both Cretaceous and middle Miocene reservoirs can be expected.

Farther to the southeast, the onshore area has been thoroughly explored because structures are expressed in the surface geology. Two onshore anticlinal lines have been densely drilled. The anticlines are strongly faulted, and the sealing conditions are poor. Therefore, the fields are relatively small. The third, less deformed anticlinal line has been mapped offshore. One of the anticlinal folds, the Inchkhe-more prospect, was drilled, and a gas condensate and oil discovery of medium size was made in middle Miocene rocks. The field has not been developed, probably because of relatively deep water. The potential of the offshore area is high, and large to medium-size light oil and gas fields with high condensate content can be expected.

Assessment Unit 11090103, Foreland Slope and Foredeep

This assessment unit covers the central, deepest part of the foredeep (except for the Terek-Sunzha zone) and the adjacent foreland slope north and northeast of the thrust belt (fig. 1). The area is virtually unexplored. Only a limited number of wells have been drilled with a few small discoveries in the western part of the unit. In the foredeep, depths to the potential targets are great and exceed 6 to 7 km in the deepest nearshore area and in the North Apsheron depression. Depths on the foreland slope are shallower, but the slope is significantly undeformed and large structural prospects have not been identified. Smaller, low-amplitude anticlinal structures are open to the north and northeast because of the regional dip of rocks toward the foredeep. The Tertiary section abruptly thins across the slope. Therefore, stratigraphic traps in the middle Miocene and possibly the lower part of upper Miocene rocks are likely to be present, but exploration for these traps in a frontier area at great depths is highly risky. Younger and shallower rocks are dominantly orogenic coarse clastics devoid of seals. The potential of the assessment unit is low.

Assessment Unit 11090102, Terek-Sunzha Subsalt Jurassic

This third assessment unit of the petroleum system includes subsalt Jurassic rocks of the Terek-Sunzha zone and surrounding areas (fig. 1). The area of the unit is defined by the pinchout boundary of the salt. Several attempts to drill into subsalt rocks on structures of the Terek-Sunzha zone, where these rocks occur at depths of about 6 km, did not succeed because of technical difficulties. The rocks have been penetrated in marginal areas of the salt basin. Shows were recorded and a gas flow was obtained from Oxfordian-Kimmeridgian carbonates in the Datykh field, which proves the presence of source rocks. The salt provides an excellent seal. Structure of subsalt rocks is poorly known, but some deformation related to stress from the Caucasus is probable. Reef buildups may be present on margins of the salt basin. High productivity of Jurassic subsalt carbonates is known in the tectonically and stratigraphically similar Amu-Darya basin east of the Caspian Sea where large oil and gas reserves have been found in structural traps and Oxfordian reefs. Productivity of Upper Jurassic subsalt carbonates and underlying Middle Jurassic clastics has been established in the East Kuban depression, which is located just west of the Mineralovod high (fig. 9), in the Azov-Kuban basin. Potential of the assessment unit may be significant. Sour gas with a high condensate content and light oil in shallower peripheral areas of the unit are the most likely hydrocarbons. Potential of the unit is assessed based on analogy with the Amu-Darya basin.

Table 1. Middle Caspian basin, Province 1109—Assessment results summary—allocated resources.

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of naural gas liquids. MFS, minimum field size assessed (MMBO) or BCFG). Prob., probability (including both geologic and accessibility probabilities) of at least one field equal to or greater than the MFS. Results shown are fully risked estimates. For gas fields, all liquids are included under the NGL (natural gas liquids) category. F95 represents a 95 percent change of at least the amount tabulated. Other fractiles are defined similarly. Fractiles are additive under the assumption of perfect positive correlation. Shading indicates not applicable]

MFS	Prob. (0-1)	Undiscovered Resources: Oil (MMBO) F95	Oil F50	Oil F5	Oil Mean	Gas (BCFG) F95	Gas F50	Gas F5	Gas Mean	NGL (MMBNGL) F95	NGL F50	NGL F5	NGL Mean
Total: Assessed onshore portions of Middle Caspian Basin Province													
	1.00	1,005	2,053	3,677	2,159	2,020	5,129	10,273	5,503	117	299	606	322
						4,646	19,192	33,101	19,139	121	858	1,569	855
	1.00	1,005	2,053	3,677	2,159	6,666	24,321	43,374	24,641	238	1,158	2,175	1,177
Total: Assessed offshore portions of Middle Caspian Basin Province													
	1.00	822	2,683	4,793	2,728	1,689	5,527	10,726	5,766	95	320	625	334
						1,457	9,552	17,811	9,278	38	149	318	158
	1.00	822	2,683	4,793	2,728	3,146	15,079	28,537	15,044	133	469	943	492
Grand Total: Assessed portions of Middle Caspian Basin Province													
	1.00	1,828	4,737	8,470	4,887	3,708	10,656	20,999	11,269	212	619	1,231	656
						6,103	28,744	50,913	28,417	159	1,007	1,887	1,014
	1.00	1,828	4,737	8,470	4,887	9,812	39,400	71,911	39,685	371	1,626	3,118	1,670

MFS	Prob. (0-1)	Undiscovered Resources: Oil (MMBO) F95	Oil F50	Oil F5	Oil Mean	Gas (BCFG) F95	Gas F50	Gas F5	Gas Mean	NGL (MMBNGL) F95	NGL F50	NGL F5	NGL Mean
Terek-Caspian Total Petroleum System													
Foldbelt-Foothills Assessment Unit (50.6% of undiscovered oil fields and 80% of undiscovered gas fields allocated to ONSHORE province 1109)													
7	1.00	556	1,012	1,728	1,060	1,359	2,555	4,560	2,707	80	153	277	162
42						3,775	7,048	11,874	7,329	107	209	370	220
	1.00	556	1,012	1,728	1,060	5,134	9,603	16,435	10,036	188	362	647	382
Foldbelt-Foothills Assessment Unit (49.4% of undiscovered oil fields and 20% of undiscovered gas fields allocated to OFFSHORE province 1109)													
7	1.00	543	988	1,687	1,034	1,327	2,495	4,452	2,643	79	149	270	159
42						944	1,762	2,969	1,832	27	52	93	55
	1.00	543	988	1,687	1,034	2,271	4,257	7,421	4,475	105	201	363	214
Terek-Sunzha Subsalt Jurassic Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to ONSHORE province)													
20	0.85	0	264	633	283	0	1,291	3,270	1,413	0	77	198	85
120						0	10,488	18,245	10,051	0	620	1,139	603
	0.85	0	264	633	283	0	11,779	21,516	11,464	0	697	1,337	688
Foreland Slope and Foredeep Assessment Unit (59.5% of undiscovered oil fields and 59.5% of undiscovered gas fields allocated to ONSHORE province)													
7	1.00	142	254	445	269	201	377	693	403	12	23	42	24
42						295	623	1,201	670	6	13	26	14
	1.00	142	254	445	269	496	1,000	1,894	1,073	18	35	68	38

Table 1—Continued. Assessment results summary—allocated resources.

MFS	Prob. (0-1)	Undiscovered Resources: Oil (MMBO) F95	Oil F50	Oil F5	Oil Mean	Gas (BCFG) F95	Gas F50	Gas F5	Gas Mean	NGL (MMBNGL) F95	NGL F50	NGL F5	NGL Mean
Foreland Slope and Foredeep Assessment Unit (40.5% of undiscovered oil fields and 40.5% of undiscovered gas fields allocated to OFFSHORE province)													
7	1.00	97	173	303	183	137	257	472	274	8	15	29	16
42						201	424	817	456	4	9	18	9
	1.00	97	173	303	183	337	680	1,289	731	12	24	46	26
South Mangyshlak Total Petroleum System													
South Mangyshlak (Entire) Assessment Unit (40% of undiscovered oil fields and 40% of undiscovered gas fields allocated to ONSHORE province 1109)													
3	1.00	122	246	449	261	150	359	821	406	6	14	33	16
18						208	466	899	499	5	11	23	12
	1.00	122	246	449	261	359	825	1,720	905	11	26	57	29
South Mangyshlak (Entire) Assessment Unit (60% of undiscovered oil fields and 60% of undiscovered gas fields allocated to OFFSHORE province 1109)													
3	1.00	182	369	673	391	225	539	1,232	609	9	21	50	24
18						313	700	1,348	749	7	17	35	19
	1.00	182	369	673	391	538	1,238	2,580	1,357	16	39	85	43
Stavropol-Prikumsk Total Petroleum System													
Offshore Prikumsk Zone Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to OFFSHORE province 1109)													
10	0.90	0	794	1,419	789	0	1,545	3,048	1,580	0	92	184	95
60						0	2,215	4,708	2,330	0	43	100	47
	0.90	0	794	1,419	789	0	3,760	7,755	3,910	0	135	284	141
Onshore Stavropol-Prikumsk Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to ONSHORE province 1109)													
3	1.00	185	277	421	287	310	547	929	574	18	33	56	34
18						368	567	882	589	3	6	10	6
	1.00	185	277	421	287	678	1,114	1,811	1,163	21	38	66	40
Central Caspian Offshore Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to OFFSHORE province 1109)													
10	0.72	0	360	711	331	0	693	1,523	661	0	41	92	40
60						0	4,451	7,969	3,911	0	28	73	29
	0.72	0	360	711	331	0	5,144	9,492	4,572	0	69	165	69

Stavropol-Prikumsk Total Petroleum System (110903), Middle Caspian Basin, Russia

Introduction

The Stavropol-Prikumsk TPS is located in the northern part of the eastern North Caucasus region, just north of the Terek-Caspian TPS (fig. 1). On the west, the petroleum system area includes the eastern slope and top of the Stavropol arch (fig. 9), whereas the western slope of the arch belongs to the neighboring Azov-Kuban basin. On the north, the system area is bounded by the uplift of the Karpinsky Ridge (fig. 2). The ridge is a late Paleozoic foldbelt covered by thin Mesozoic rocks. Closer to the Caspian Sea, thickness of the Mesozoic on the southern slope of the ridge increases and a number of hydrocarbon accumulations are present. This slope is included in the Stavropol-Prikumsk TPS. To the east, the TPS extends into the northwestern area of the central Caspian Sea and farther southeast into its central area. Only one prospect was recently drilled offshore and oil was tested; however, no detailed data are available. Limited seismic data of inferior quality are described in literature. Results of seismic surveys along regional profiles that were obtained by a consortium of Western companies in recent years are not publicly available. Therefore, the TPS boundaries offshore are conjectural. The inclusion of the central Caspian Sea area into the TPS is conditional and is based on supposed similarity of stratigraphic and, to a lesser extent, structural characteristics with the onshore TPS areas.

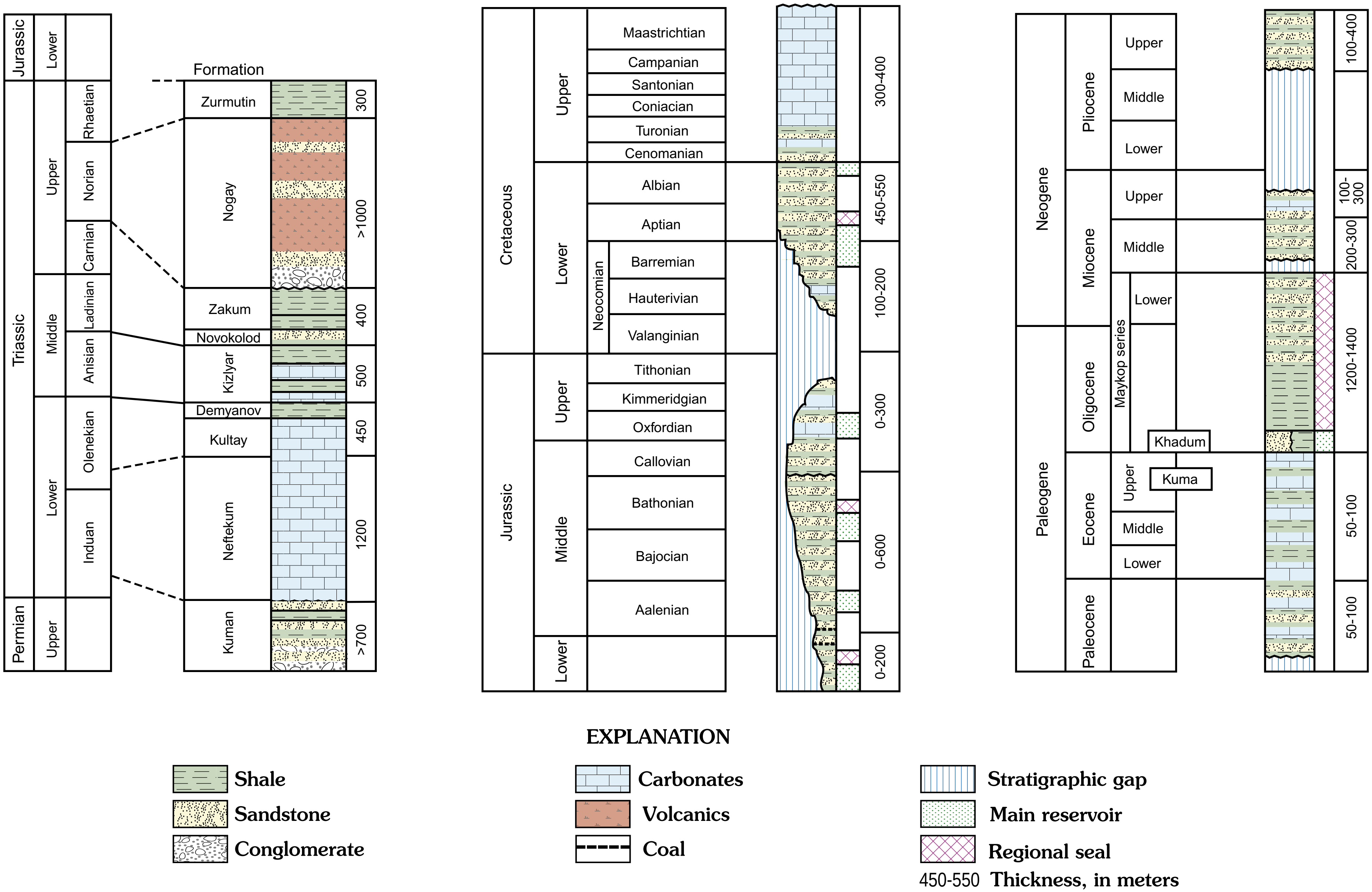


Figure 14. Columnar stratigraphic section of Mesozoic-Tertiary rocks of Stavropol-Prikumsk petroleum system (modified from Ulmishek and Harrison, 1981).

Original hydrocarbon reserves of the TPS are approximately 1.8 billion barrels of oil and 14 TCF of gas. Productivity has been established in a wide stratigraphic range, from the Triassic to the Miocene. The largest gas reserves are found in lower Maykop (Oligocene) sandstones in structural traps on the Stavropol arch and its slope. Discovered oil reserves are mostly in Triassic, Jurassic, and Cretaceous reservoirs in structural traps of the Prikumsk uplift (figs. 2, 9). The largest part of original reserves is in Aptian-Albian sandstone pays, but Triassic, Neocomian, and Upper Cretaceous carbonates and Middle Jurassic sandstones also contain many oil and gas condensate pools. Source rocks are present in the Triassic, Middle Jurassic, and Paleogene sections, but they are geochemically poorly characterized, and their relative endowment in hydrocarbon reserves is largely unknown.

Discovery History

Deep drilling in the petroleum system area began after World War II. The giant (nearly 8 TCF) North Stavropol–Pelagiada gas field in the central part of the Stavropol arch was discovered in 1951, followed by discoveries of several gas fields in the same area in the late 1950's. In the 1960's and 1970's, the main exploration efforts shifted to the east of the Stavropol arch, and several tens of oil and gas condensate fields of large to small size were discovered in Jurassic and Cretaceous reservoirs in structural traps of the Prikumsk uplift and Karpinsky Ridge. All sizable structures mapped in Jurassic and Cretaceous rocks were drilled during this time period, and attempts to explore for stratigraphic traps were largely unsuccessful. In the late 1970's and later, deeper Triassic rocks became the principal exploration objective, and more than a dozen oil fields were found in structural and paleogeomorphic traps. Several oil fields were also found in self-sourced fractured shales in the lower part of the Maykop series. The first offshore prospect was recently drilled in the Severny area located close to the boundary between the Stavropol-Prikumsk and South Mangyshlak TPS (fig. 1), and a large oil and gas discovery was reported (The Wall Street Journal, 2000).

Oil and gas production in the area reached its peak in 1969–1971, after which the decline in production started and continued until present.

Petroleum Occurrence

The principal gas reserves of the Stavropol-Prikumsk TPS are in structural traps on the Stavropol arch and in the westernmost part of the Prikumsk uplift. More than 90 percent of the reserves are in sandstone reservoirs of the lower Maykop Khadum Horizon (fig. 14). A few pools have been found in Aptian-Albian sandstones. The gas is dry. Presently, gas reserves are essentially depleted.

The main oil-productive area is the Prikumsk uplift, which contains numerous isometric and variously elongated local structures. Nearly all structures are productive, but most fields are not large. Each field contains from one to six pays. Almost the entire sedimentary succession from the Triassic to the Miocene is productive. In Triassic rocks, larger pools are in carbonates of the Neftekum Formation (fig. 14), mainly in the zone of reef facies along the southern border of the East Manych trough (figs. 2, 9). A few small pools have been found in carbonates of the Middle Triassic Kizlyar Formation. Most reservoirs contain oil.

The Middle Jurassic section contains about 20 pools in sandstone reservoirs. A few small pools have been found in the Lower Jurassic. Oil pools dominate in the more western areas, whereas gas condensate pools are found to the east. Similar areal distribution of oil and gas condensate is characteristic of Upper Jurassic and Lower Cretaceous rocks. The Upper Jurassic and Neocomian contain both sandstone and carbonate reservoirs. The Aptian-Albian clastic section contains the largest portion of TPS reserves. Most productive are lower Aptian sandstones, in which original daily yields of wells reached 2,000 barrels. The upper Aptian shale is a regional seal. In the northern areas, the seal becomes sandy, and leaks hydrocarbons, and younger Albian rocks are most productive (Klubov and Blokhina, 1988; Krylov, 1987). A few small oil pools have been found in Upper Cretaceous carbonate reservoirs.

Established productivity of Tertiary rocks of the Prikumsk uplift is limited. In the 1980's, several oil pools were found in unconventional reservoirs. These pools are located in the western part of the Prikumsk uplift and the adjacent slope of the Stavropol arch. Reservoir rocks are organic-rich shales in the lower part of the Maykop series. Oil pools are substantially overpressured and controlled by zones of fracturing that are not related to local structures. Productivity of wells is highly variable and ranges from several to 800 b/d (Bochkarev and Ilchenko, 1986). Identification of prospects of this type is difficult because the reservoirs cannot be mapped by seismic surveys. Higher in the section, only a few small dry gas fields are found in sandstone beds of the middle Maykop series of the Prikumsk uplift.

About 20 gas condensate and oil fields are known north of the Prikumsk uplift. Most of these fields are on the southern slope of the eastern Karpinsky Ridge. All fields are small to medium in size. Almost entire reserves are found in Aptian-Albian clastic reservoirs in structural traps. A few pools are present in Jurassic sandstones and Upper Cretaceous carbonates. Most fields are depleted.

An apparently large oil and gas discovery made offshore in the summer of 2000 is in a large structural trap. Productive are Middle Jurassic sandstones. Reported reserves are 2.2 billion barrels of oil equivalent of which 60 percent is oil (The Wall Street Journal, 2000). No further data on the discovery are available at this time.

Composition of oils and condensates of the Stavropol-Prikumsk TPS is diverse. Modern geochemical data that would allow correlation of oils with potential source rocks are lacking, and only data on group composition of oils and condensates and some gas chromatography data are available. From these data, Russian geologists identified two (Sokolov and others, 1990) or three (Vinogradova and others, 1985; Dzhabrailov and others, 1991) families of oils.

Oils of the first family occur in lower Maykop, Upper Cretaceous, and uppermost Albian reservoirs at depths of 2,300–2,900 m where reservoir temperatures are 115°–120° C. The oils

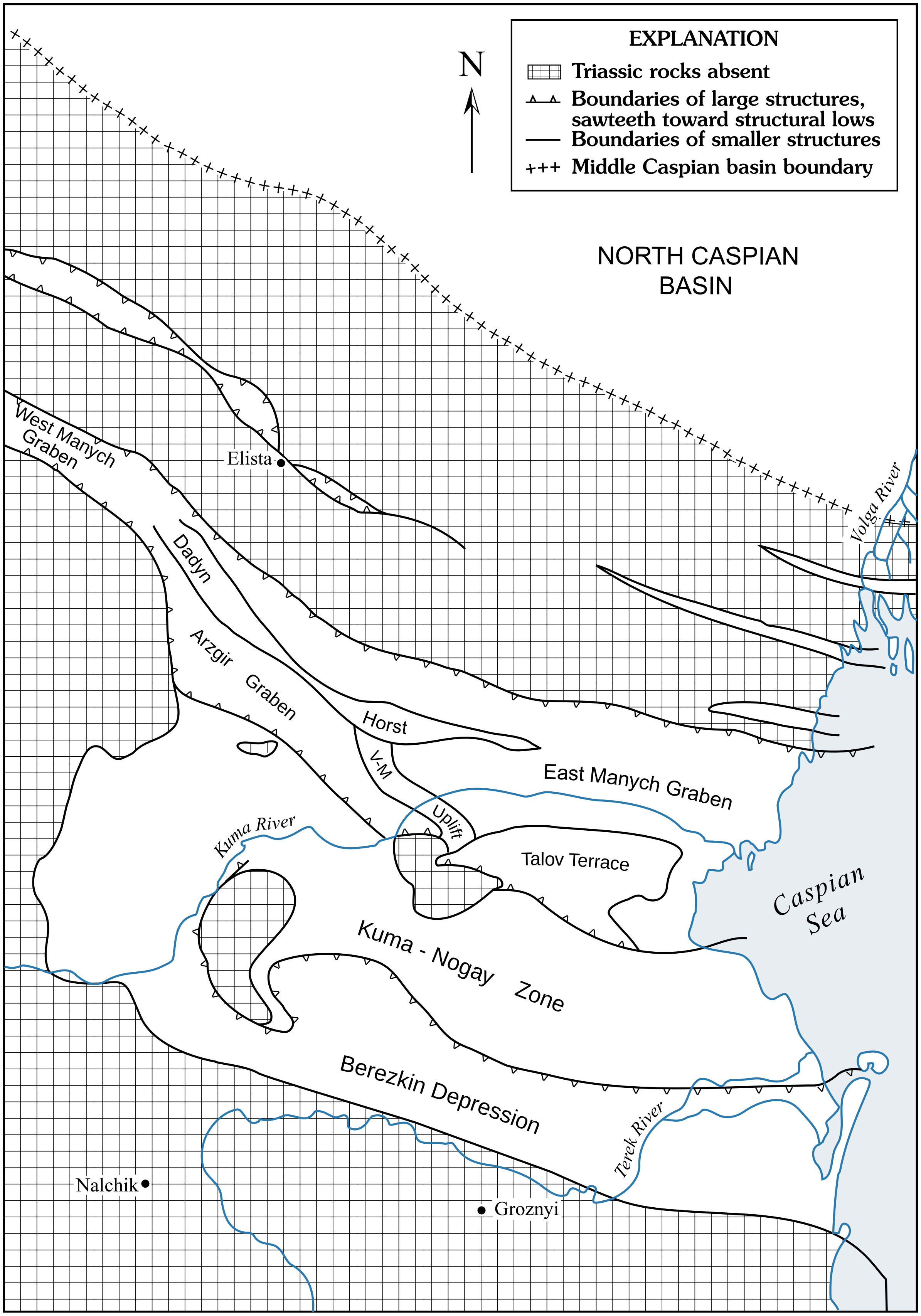


Figure 15. Structural map of Triassic taphrogenic sequence of eastern North Caucasus region (modified from Letavin, 1978). V-M, Velichaev-Maksimokum uplift. No scale.

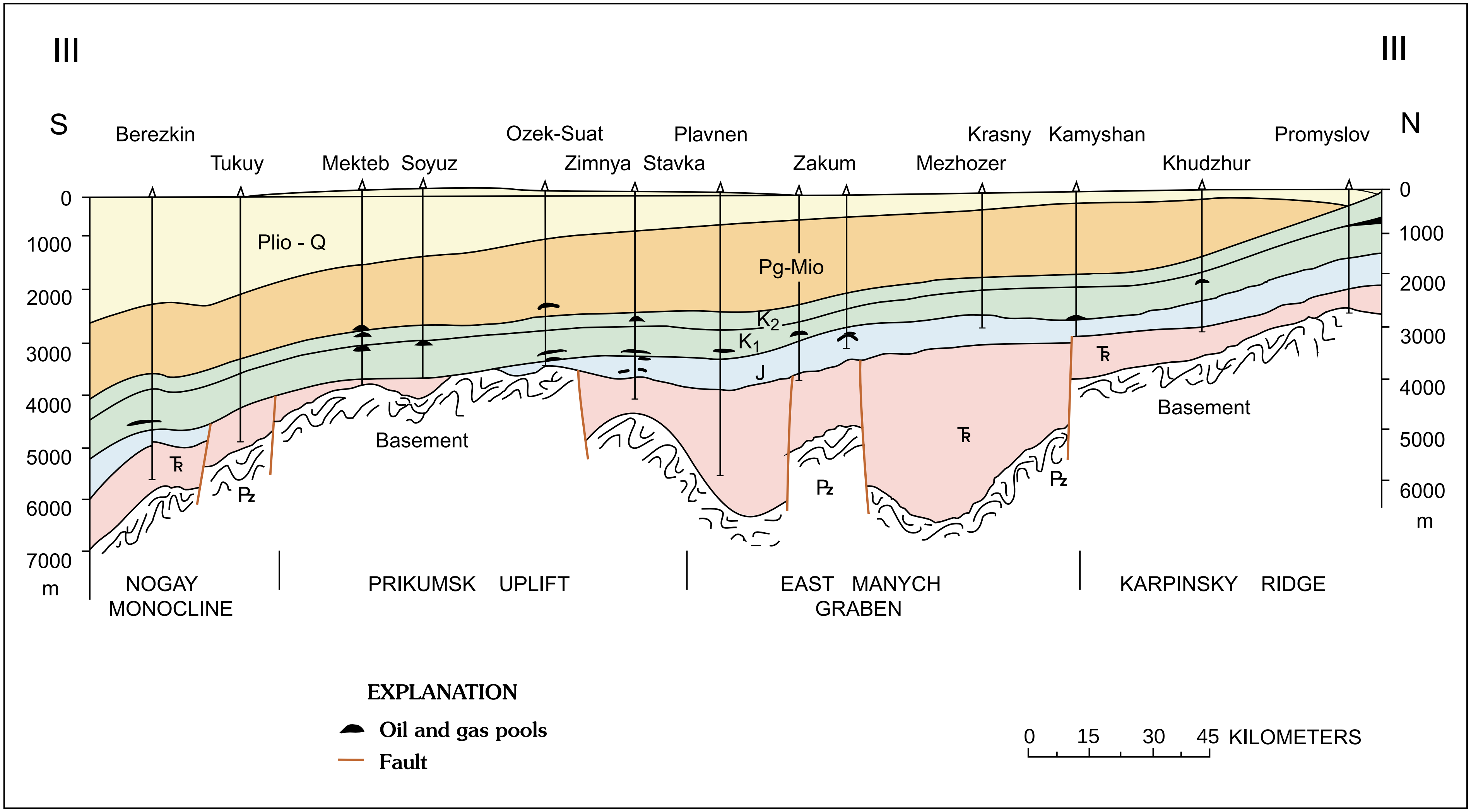


Figure 16. Cross section through Stavropol-Prikumsk petroleum system (modified from Sokolov and others, 1990). Location of cross section shown in figure 9. Pz, Paleozoic; TR, Triassic; J, Jurassic; K_1, Lower Cretaceous; K_2, Upper Cretaceous; Pg, Paleogene; Mio, Miocene; Plio, Pliocene; Q, Quaternary.

are relatively heavy (30°–38° API) and contain up to 0.3 percent sulfur and 7 percent asphaltenes. Solid paraffin content does not exceed 12 percent. The second family of oils occurs in Jurassic and Lower Cretaceous rocks. Most oils are found at depths of 3,070–3,750 m under temperatures of 130°–150°C. These oils are lighter (37°–45° API) and less sulfurous, and they contain only 0.3–3.3 percent asphaltenes. The oils are highly paraffinic (to 30 percent) and are characterized by a pristane/phytane ratio greater than 2 and a cyclohexanes/cyclopentanes ratio of 0.4–0.6. The third family includes oils reservoired in Triassic rocks. Most of the oils occur at depths of 3,400–5,000 m under temperatures of 140°–170° C. They are light, low-sulfur oils with high concentrations of solid paraffins (30–50 percent) and low resin and asphaltene contents. Pristane to phytane ratio ranges from 1.1 to 1.5, and cyclohexanes are more abundant than cyclopentanes (average ratio 1.5). However, mixing of different oil types is common. In several fields, oils of the Triassic type occur in Jurassic and Cretaceous reservoirs, and some Triassic pools contain oils more similar to the Jurassic-Cretaceous type. Many compostional differences between oil types seem likely to have no genetic significance, and more data are needed to identify genetic oil families.

Stratigraphic Section

Maximum thicknesses of the Triassic sequence, which overlies the Paleozoic folded basement, are limited to grabens of the rift system (figs. 15, 16). The Upper Permian(?)–lower Induan Kuman Formation occurs at the base of the sequence (fig. 14). The formation comprises continental coarse red clastics in the lower part and marine gray clastics with thin carbonate beds in the upper part. The rest of the Lower Triassic is mostly a carbonate section on the Prikumsk uplift and basinal calcareous shales in the East Manych and Arzgir grabens. Middle Triassic through Carnian rocks are marine clastics with carbonate beds. The Norian-Rhaetian is unconformable over various older rocks, including the basement, and was formed after cessation of rifting. The section is mainly composed of calc-alkalic volcanics, including thick lava flows. The volcanics constitute a part of the extensive (about 4,000 km) Cimmerian volcanic arc related to a subduction zone on the southern active margin of Eurasia (Zonenshain and others, 1990). Maximum thicknesses of the volcanics (more than 1,000 m) are found in the Berezkin depression where older Triassic rocks are absent (fig. 15). To the north, the section is much thinner or absent because of pre-Jurassic erosion. On the Prikumsk uplift, various Triassic rocks subcrop at the pre-Jurassic unconformity.

The Lower Jurassic section is present chiefly on the Karpinsky Ridge and is formed by continental coaly clastics. Marine clastic rocks dominate in the Middle Jurassic. Lower–Middle Jurassic and overlying Upper Jurassic and Neocomian rocks onlap the slope of the Stavropol arch and successively pinch out. Thin Aptian-Albian clastic rocks directly overlie the basement on the top of the arch. Upper Jurassic rocks are present only in the eastern areas of the TPS. They are mainly dolomites with increasing amounts of clastics to the west and anhydrites in the upper part of the section to the east. Unconformities are present at the bottom of the carbonate formation and at the top of the Kimmeridgian. Tithonian rocks are absent.

The Neocomian is composed of calcareous clastic rocks with carbonate beds in the Valanginian and Hauterivian. The section thins to the west and pinches out on the slope of the Stavropol arch. Aptian and Albian rocks are thick clastics. These rocks gradually become more shaly eastward. The Upper Cretaceous is about 200 m thick on the Stavropol arch and thickens to 400 m eastward and southeastward. It comprises various carbonate rocks, including limestone, marlstone, and chalk, with subordinate shale beds.

Paleocene-Eocene and Maykop series (Oligocene–lower Miocene) rocks unconformably overlie the Upper Cretaceous and are represented by two types of sections (Berlin and Ulmishek, 1978). The first type is developed on the Stavropol arch and is more similar to the sections of the adjacent Azov-Kuban basin west of the arch. The Paleocene-Eocene is thick (800-900 m) and is composed of shallow-water shales, siltstones, and sandstones. The overlying Maykop series is, on the contrary, relatively thin (600–700 m). It consists of basal sandstones of the Khadum Horizon (100–150 m thick) and overlying shales with thin sandstone and siltstone beds. The rest of the TPS area, including offshore, has the second type of section. The Paleocene-Eocene is a thin (50–100 m) condensed section of greenish-gray clayey limestones and calcareous shales deposited in a deep-water basin uncompensated by sediments (Berlin and Ulmishek, 1978). The section includes the upper Eocene Kuma Formation, a 20-m-thick bed of black organic-rich marlstone accumulated in anoxic environments (fig. 14). The deep-water basin was filled by the Maykop series, which is 1,200–1,400 m thick. The lower part of the series, including the Khadum Horizon, is composed of deep-water, organic-rich, anoxic black shales. Upward in the section, clastics are progressively more shallow-water in origin. Sandstone beds are present in the middle and upper part of the series in northeastern areas proximal to the provenance of coarse clastic material. The sandstones and interbedded shales form a series of prograding clastic wedges (clinoforms). Nine major clinoforms and corresponding sedimentary cycles are identified (Kunin and others, 1987). To the west and southwest, sandstones pinch out, and the section is almost exclusively composed of gray and black shales.

Middle–upper Miocene rocks unconformably overlie the Maykop series. The rocks are marine clastics with beds of coquina. Maximum thicknesses are in southeastern areas, and the section thins to the north and west. Upper Pliocene sediments occur at the top of the sedimentary cover.

Source Rocks

No modern geochemical data exist for source rocks of the TPS. However, indirect geologic and some geochemical data suggest that probable source rocks are present in several stratigraphic intervals. Distribution of oil and gas condensate fields in Triassic reservoir rocks of the Prikumsk uplift clearly indicates the presence of indigenous source rocks. Almost all wells were targeted at Neftekum Formation reef and back-reef carbonate reservoirs (fig. 14) of the Prikumsk uplift (Kuma-Nogay zone, and Velichaev-Maksimokum uplift in fig. 15). These shallow-water facies are commonly poor in organic matter; rare

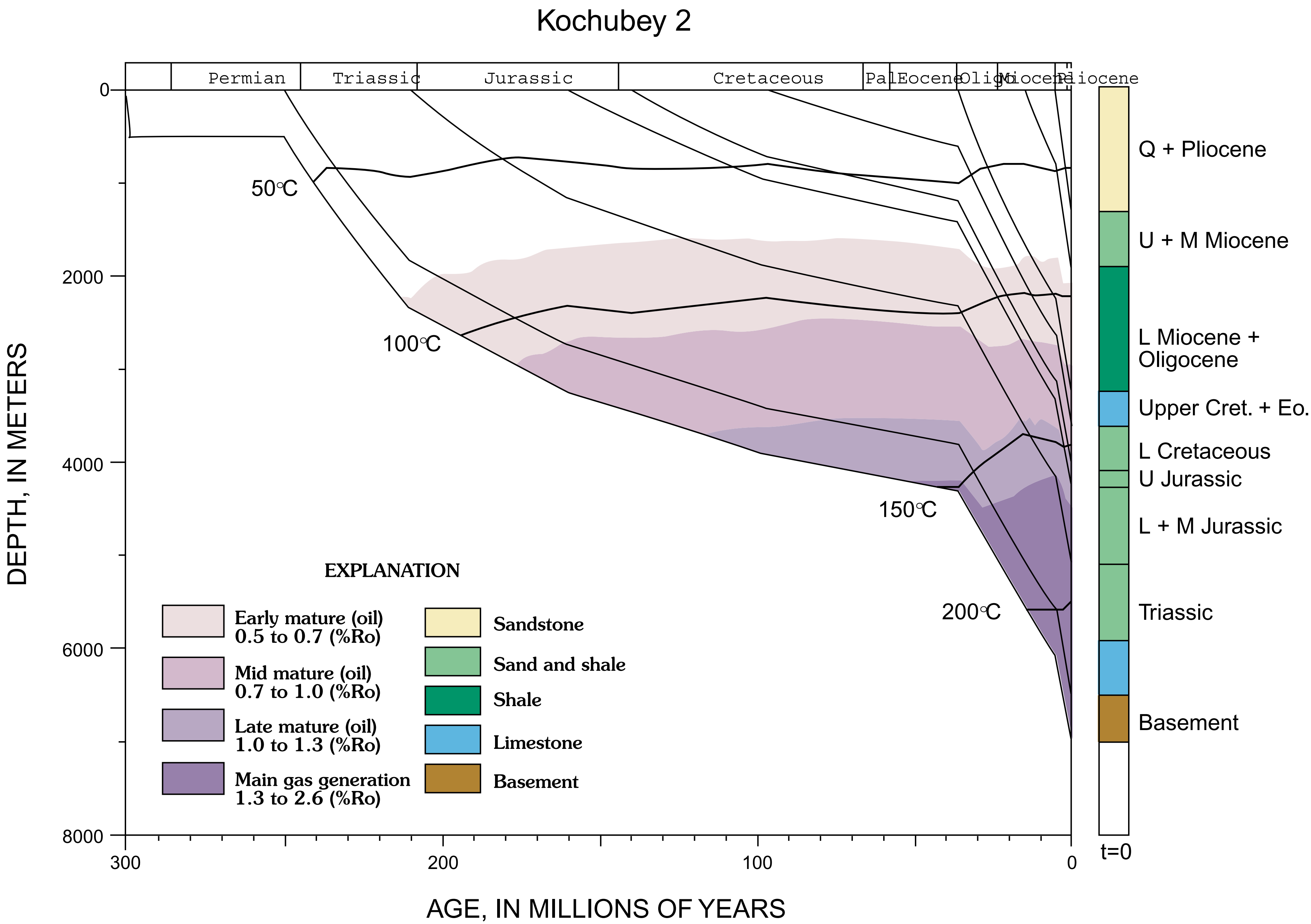


Figure 17. Maturation model for Kochubey 2 well, eastern part of Stavropol-Prikumsk total petroleum system. Approximate location of well shown in figure 9.

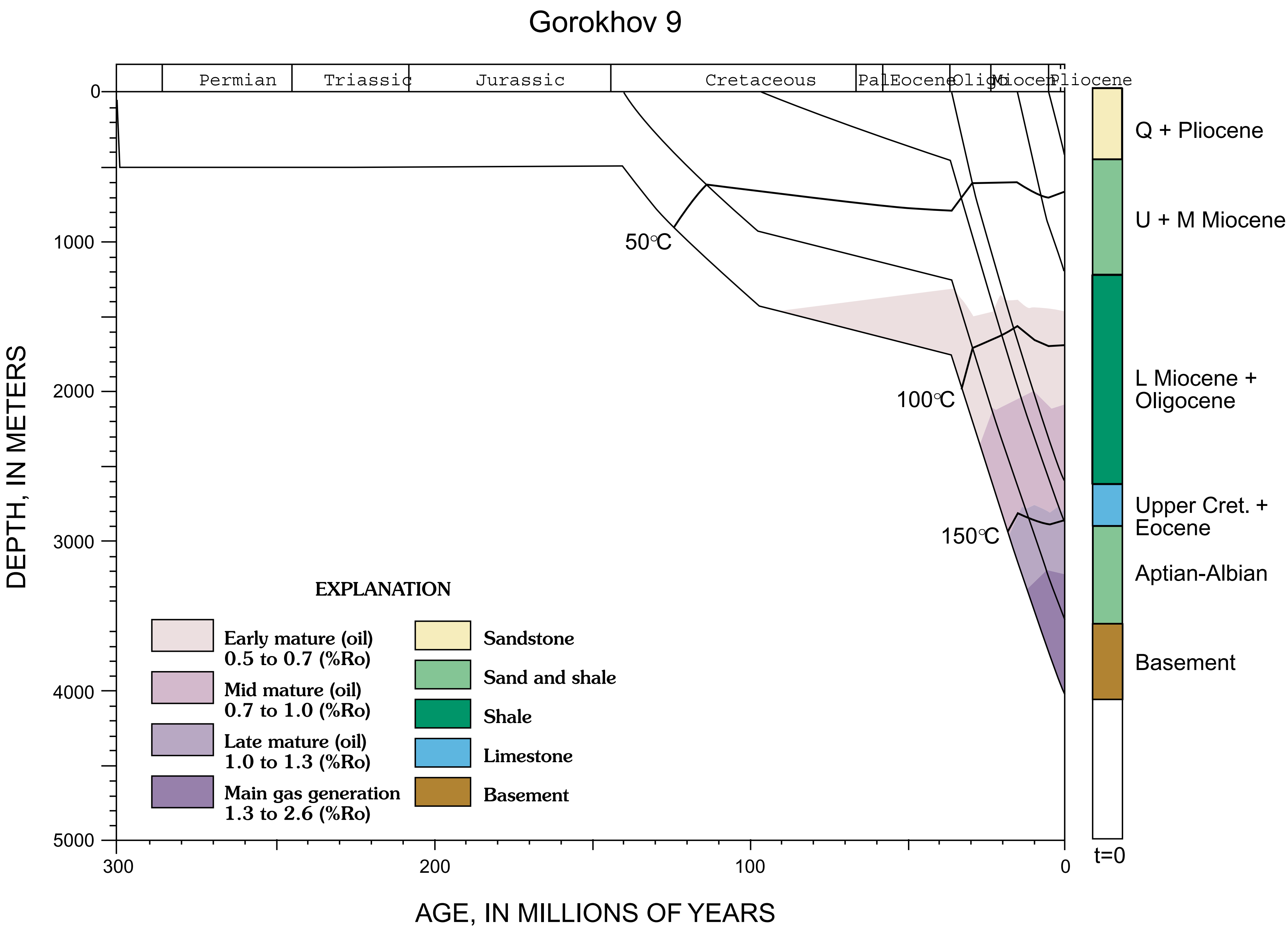


Figure 18. Maturation model for Gorokhov 9 well, central part of Stavropol-Prikumsk total petroleum system. Approximate location of well shown in figure 9.

shale beds have TOC not exceeding 3.5 percent (Mirzoev and Dzhaparidze, 1979). In the East Manych and Arzgir grabens, shallow-water carbonates of the Neftekum and Kultay Formations grade into thin-bedded, dark-colored, deep-water clayey limestones and shales (Letavin, 1988; Bochkarev and others, 1992). Few wells have been drilled in the grabens, and cores are scarce. The principal Triassic source rocks are probably present among these deep-water facies (Klubov and Blokhina, 1988; fig. 1). In the eastern part of the East Manych graben and farther east offshore, Triassic source rocks occur at depths of about 5 km and more. They reached the main oil-generation stage in Cretaceous time and entered the gas window during deposition of the Oligocene–lower Miocene Maykop series (fig. 17). Gas condensate pools are present in adjacent areas of the Prikumsk uplift. To the west, the source rocks occur at depths of 3.5–4 km and are presently in the oil window. Triassic reservoirs contain light oils there. Triassic source rocks are probably absent in the central Caspian area.

Higher in the section, source rocks are present in the Lower–Middle Jurassic section, but their geochemical characterization is insufficient for precise identification of specific favorable layers. Judging from lithologic descriptions, most probable source rocks occur in the lower Bajocian strata, which are composed of dark-gray and black marine shales containing ammonites and foraminifers (Letavin, 1988). The strata are about 200 m thick in the eastern areas and pinch out to the west toward the Stavropol arch (fig. 1). Measured TOC in shales averages 1.15 percent and reaches 3.2 percent in separate layers (Sokolov and others, 1990; Mirzoev and Dzhaparidze, 1979). Kerogen is of mixed types II and III; the latter is more abundant. The source rock section extends offshore and probably is present in the central Caspian part of the TPS, although the kerogen may be more coaly there. Bajocian source rocks are in the oil window over most of the onshore area. On the east of this area and probably offshore, the rocks the entered gas window in late Miocene time (fig. 17).

Many geologists believe that shale beds of the thick Aptian-Albian marine clastic section have generated oil found in interbedded sandstone reservoirs. However, the source characteristics of the shales seem to be poor. The shales were deposited in suboxic environments; they are of dark-gray and greenish-gray color and include lenses and thin layers of siltstone. TOC in the shales averages 0.4–0.6 percent, and only in separate thin beds does it reach 1.5–2 percent. The kerogen is of mixed types II and III; type II is more abundant. The rocks reached early maturity in Oligocene–early Miocene time, during deposition of the Maykop series (figs. 17, 18). Presently they occur in the oil window over the entire area (Sokolov and others, 1990; Nazarevich and others, 1983). The contribution of Aptian-Albian source rocks in oil and gas reserves is probably insignificant, as also indicated by the apparent similarity of oils found in Jurassic and Cretaceous reservoirs.

Source rocks in the lower part of the Maykop series and underlying thin Paleocene-Eocene section (primarily the Kuma Formation—see fig. 14), which are so important in the Terek-Caspian TPS, are also present in the Stavropol-Prikumsk TPS. The best source rocks are located in the upper part of the Khadum Horizon and directly overlying shale beds and are 30–40 m thick. This section is formed by thin (1 mm–3 cm) alternation of black and gray shale layers. The rocks were deposited in a deep-water basin in strongly anoxic environments (Berlin and Ulmishek, 1978; Burlakov and others, 1987). TOC in black layers varies from 5 to 8 percent; in gray layers it does not exceed 2 percent (Bochkarev and Ilchenko, 1986). Type II kerogen dominates in the source rocks. On the eastern slope of the Stavropol arch and western Prikumsk uplift, this section contains self-sourced overpressured oil pools in fractured shales. Fractures are oriented along sedimentary planes and are genetically related to hydrocarbon generation. Despite high reservoir temperatures (120°–130° C) the organic matter is at early stages of maturity corresponding to the upper and middle parts of the oil window (figs. 17, 18). Oils in these shales are highly naphthenic. They contain abundant isoprenoids, 6–11 percent waxes, and 7–9 percent resins, and are characterized by odd/even n-alkanes predominance (Vinogradova and others, 1989).

On the Stavropol arch, the Khadum Horizon is composed of gas-bearing sandstones, and overlying and underlying organic-rich shales are immature. They are also immature on the Karpinsky Ridge. Offshore, the source rocks extend over the entire petroleum system area. However, in the northern part of the offshore area, which is located toward the main provenance of clastic material (Onischenko, 1986), low source rock quality may be expected.

The role of Paleogene source rocks in productivity of older reservoirs is not clear because of scarcity of data. Compositional differences of Upper Cretaceous and uppermost Albian oils compared to oils in older Lower Cretaceous and Jurassic reservoirs may be related to different source rocks of the Paleogene and Middle Jurassic sections, respectively. Mixing of oils in these younger reservoirs from both sources is also probable.

In conclusion, the principal oil and gas condensate reserves of the TPS, which are concentrated on the Prikumsk uplift, were generated by at least three source rock formations in the Lower Triassic, Middle Jurassic, and Maykop series (fig. 19). Oil and gas condensate fields on the Karpinsky Ridge probably result from lateral migration of hydrocarbons from the Triassic and possibly Middle Jurassic sources of the East Manych trough. Large gas fields of the Stavropol arch were charged by long-range lateral migration from adjacent depressions, including those located in the Azov-Kuban basin. The principal stage of formation for all oil and gas fields of the TPS was during and after deposition of the thick Maykop series.

Reservoir Rocks

Productive reservoir beds are present through most of the TPS sedimentary section, from the Triassic to the Miocene. Several of these beds contain the bulk of oil and gas reserves; others only sporadically contain small pools. The principal Triassic pay that is productive in more than 10 fields consists of carbonate rocks of the Neftekum Formation (fig. 14). Most of these fields are located along the southern border of the East Manych trough (fig. 15) where the formation is largely composed of reef facies. Reservoir rocks are fractured vuggy limestones and dolomites.

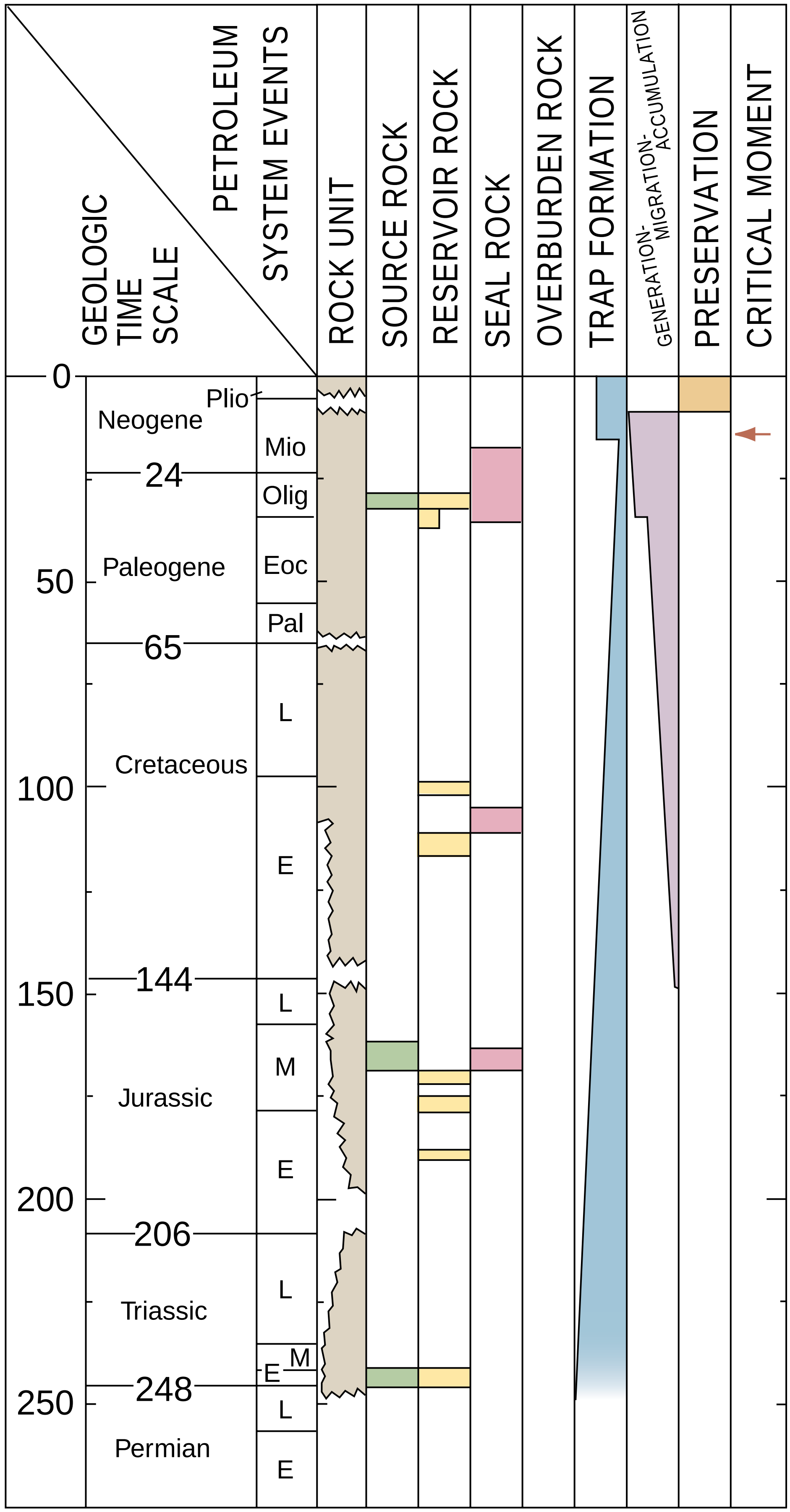


Figure 19. Stavropol-Prikumsk petroleum system events chart.

Measured porosities reach 10 percent; permeability is completely controlled by fracturing (Stasenkov and others, 1983). Best reservoir rocks occur at the top of the formation under the unconformity surface; the rocks are commonly too friable to be cored.

In the Jurassic section, major oil and gas pays are Bajocian sandstones that have porosities of 12–16 percent and permeabilities to 100–150 mD. Eastward, the amount of clay material increases, and reservoir properties of the sandstones deteriorate. The Lower Cretaceous section contains 12 pays productive in different fields; most of the pays are sandstones. The principal reserves are concentrated in uppermost Barremian and lower Aptian sandstone beds. Another important producer is a sandstone bed at the top of the Albian. Porosity of the sandstones varies widely in different fields from 12 to 24 percent; permeability ranges from tens to hundreds of millidarcies.

Fractured shale reservoirs in the lower part of the Maykop series are poorly characterized by laboratory measurements. In situ porosity is evaluated at 10–12 percent (Klubova, 1988), and permeability is highly variable, as indicated by a wide range of initial oil flow rates. Sandstones and siltstones of the Oligocene Khadum Horizon, containing large gas accumulations on the Stavropol arch, possess excellent reservoir properties. Porosity reaches 40 percent, and permeability ranges from hundreds of millidarcies to several darcies.

Seal Rocks

The principal regional seal of the Stavropol-Prikumsk TPS, similarly to that of the Terek-Caspian TPS, is thick overpressured Maykop series shales. Above this seal, only a few small pools of dry gas, possibly of biogenic origin, are present. Although Maykop shales provide hydrodynamic isolation of the entire underlying sequence, they directly seal only gas pools on the Stavropol arch. Oil and gas pools in Mesozoic strata are sealed by various shale beds. Most important among them are thick and areally extensive shale beds in the upper Bajocian and upper Aptian, which seal most oil and gas reserves of the Prikumsk uplift.

Traps

The bulk of oil and gas reserves of the Stavropol-Prikumsk petroleum system are found in structural traps, although outlines of particular pools are often affected by lithologic changes of reservoir rocks. The number and characteristics of structural traps vary over the TPS area. Structural traps on the Stavropol arch that contain large gas accumulations are gentle, irregularly shaped uplifts underlain by basement highs. These traps were probably formed during Pliocene-Quaternary time when the arch was uplifted about 500 m (Shardanov and Romanov, 1988).

The Prikumsk uplift contains a large number of small to medium-size local structures. The structures are isometric or slightly elongated in various directions. Their closures are largest in Jurassic horizons and gradually decrease upward. In the western part of the uplift, the structures are traced upward to the bottom and locally to the top of the Maykop series. Toward the east, structural closures disappear in progressively older rocks. In areas adjacent to the Caspian Sea, the structures are present only in Jurassic rocks, whereas Cretaceous and younger rocks are undeformed. This situation may be expected to extend some distance offshore; however, large structural uplifts have been identified farther east, close to the eastern boundary of the petroleum system where recent discovery in the Severny area is located. Most local structures on the Prikumsk uplift are basement-related, but apparently some are underlain by erosional highs at the top of the Triassic. The morphological characteristics of the traps suggest that they are old and were formed as drape structures, although slight posthumous structural growth could have occurred locally. Traps on the Karpinsky Ridge are similar to those on the Prikumsk uplift. Rocks filling the East Manych and Arzgir grabens are almost undeformed and few local structures are known there. The character of traps in Triassic rocks is poorly understood. Apparently, basement-related structural traps, reefs, and erosional highs under the pre-Jurassic unconformity, and combinations of those are present.

Despite significant facies variability of clastic rocks, only several small pools have been found in stratigraphic traps related to up-dip pinchout of sandstone beds. Most of these pools occur in the Albian (Chepak, 1987). Probably, very little if any exploration specifically targeted at stratigraphic traps has taken place. Finally, traps for oil pools in shale reservoirs of the lower Maykop series are related to fracture zones. Discovered traps are located in depressions and on slopes of local uplifts. Fracturing was caused by hydrocarbon generation and associated increase of pore pressure. Some geologists believe that the location of the fracture zones is related to basement faults (Klubova, 1988), but little evidence exists.

Assessment Units

Three assessment units are identified in the Stavropol-Prikumsk TPS. Undiscovered oil and gas resources of these units are listed in table 1.

Assessment Unit 11090302, Onshore Stavropol-Prikumsk

This unit covers the entire onshore area of the system (fig. 1). The Stavropol arch on the west of the unit area (fig. 2) contains large, presently almost depleted gas fields. The arch is thoroughly explored, and the potential for new somewhat significant discoveries in structural traps is negligible. The Neocomian and lower Aptian sections onlap and thin updip on the eastern slope of the arch. Gas discoveries in stratigraphic traps are possible there, but the fields will probably be small. The rest of the assessment unit is also significantly explored. All known local uplifts in Jurassic and Cretaceous rocks have been drilled, and only small additional structural prospects can be found. However, there was little or no exploration specifically targeted at stratigraphic traps. Considering significant lithologic variability of many Jurassic and Cretaceous reservoir beds, a potential for stratigraphic hydrocarbon accumulations exists. However, mostly small fields can be expected.

Underlying Triassic rocks are significantly less explored and their geology is not well understood. Seismic resolution is poor, and only high-amplitude basement-related uplifts, which are also expressed in Jurassic and Cretaceous rocks, and Triassic erosional highs can be mapped. The presence of Lower Triassic reefs, basinal rocks, and associated facies suggests additional petroleum potential. On analogy with discovered fields, mainly oil accumulations will be found.

All discovered oil accumulations in fractured shales of the lower Maykop series were found accidentally in wells targeted at deeper horizons. The potential distribution of pools of this type is not clear, and seismic methods are inadequate to map prospects. However, relatively shallow depths and high oil quality can make exploration attractive. Mostly small size fields will be found, but their number may be significant. The exploration efficiency will increase as more data on distribution of fracture zones become available.

Assessment Unit 11090301, Offshore Prikumsk Zone

This unit includes the offshore area into which the known onshore structures likely extend (fig. 1). Only one prospect has been drilled in the unit; therefore, risk related to possible changes in geologic characteristics should be included in resource assessment. The southeastern boundary of the unit is the inferred Agrakhan-Guryev strike-slip(?) fault (fig. 2). It is likely that the Triassic East Manych graben was connected with the Central Mangyshlak rift system of the same age and was offset along the strike-slip fault during the post-rift compressional stage. Thus, Lower Triassic source rocks and associated reef facies of the East Manych graben probably extend across the entire southern part of the assessment unit. The Lower–Middle Jurassic section that contains Bajocian source rocks onshore is certainly present over the entire assessment unit and is mature at least in its southern part. However, the quality of source rocks is likely to deteriorate eastward because the presence of source rocks, especially for oil, in this interval in the adjacent South Mangyshlak TPS is doubtful. Maykop source rocks might also be of poorer quality because of closer proximity to provenance for coarse clastic material. In the northern half of the assessment unit, the Maykop series is thin and certainly devoid of source rocks. Thus, the presence of source rocks can be expected only in the southern areas of the assessment unit. Updip migration of hydrocarbons into the more northern areas of the unit is possible, based on analogy with fields on the Karpinsky Ridge onshore. However, the exploration risk is higher.

Results of seismic work conducted offshore in recent years are not available, and information on the presence of structural traps is sparse. The Prikumsk uplift, which contains most of structural traps and major hydrocarbon reserves onshore, loses its structural expression in the nearshore area. In addition, basement-related local structures in the eastern part of the uplift are expressed only in Jurassic rocks, whereas younger beds are undeformed. Russian maps show several large structures in the eastern part of the assessment unit, but more detailed data are not available. Apparently, one of these structures in the Severny area that is located close to the boundary with the South Mangyshlak TPS produced the recent large discovery. This discovery was made after resource assessment of the Middle Caspian basin had been completed. If the size of the new field is confirmed, it raises chances for further significant discoveries, upgrades potential of the assessment unit, and eliminates risks that were included in the resource assessment.

Assessment Unit 11090303, Central Caspian Offshore

This assessment unit occupies the central part of the Caspian Sea and is included in the Stavropol-Prikumsk TPS conditionally (fig. 1). No wells have been drilled, and data on only a few regional seismic profiles crossing the area are available. Based on these profiles, the unit area is occupied by a structural monocline descending southwestward to the Terek-Caspian foredeep. Depth to the basement varies from 3 to 6 km (Lebedev and others, 1987). To the southeast, the basement becomes shallower toward the Karabogaz arch. Comparison of the Jurassic through Tertiary rocks east and west of the Caspian Sea suggests that the stratigraphy of these rocks in the assessment unit is similar to that of the eastern Prikumsk uplift.

A risk involved in resource assessment of this unit is substantially higher than that for assessment unit 11090301. The risk is primarily related to the presence and quality of source rocks and traps. Unlike in the previous assessment unit, Triassic rifts and associated source rocks almost certainly do not extend into the area. The quality of Jurassic source rocks is uncertain. In general, the rocks become more continental and gas-prone eastward. Source rocks at the bottom of the Maykop series are present, but they are probably immature in the southeastern part of the unit. In the rest of the unit area, the feasibility of migration of hydrocarbons from Maykop source rocks to the principal Jurassic and Lower Cretaceous reservoirs is doubtful because mostly gentle, platform-type structures can be expected. Many of these structures might be open updip on the monocline. Larger structural traps have been mapped in the southeastern part of the unit, on the flank of the Karabogaz arch, but source rocks in this area are absent, and exploration should rely upon possible long-range lateral migration. Gas is more likely hydrocarbons in these traps. Stratigraphic traps updip of the monocline in Jurassic–Lower Cretaceous and possibly middle Miocene rocks are probable, but most fields will be small. In conclusion, petroleum potential of the assessment unit is probably rather low.

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