Petroleum Geology and Resources of the Dnieper-Donets Basin, Ukraine and Russia

By Gregory F. Ulmishek

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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 were ranked according to the discovered oil and gas volumes within each (U.S. Geological Survey World Energy Assessment Team, 2000). Subsequently, 76 "priority" provinces (exclusive of the U.S. and chosen for their high rank) 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 the World Energy Project is to aid in assessing the quantities of oil, gas, and natural gas liquids that have a potential to be added to reserves during the next 30 years. These estimated resources are in undiscovered fields whose sizes exceed the stated minimum-field-size cutoff value for an assessment unit (variable, but at least 1 million barrels of oil equivalent), or they are reserve growth of fields already discovered.

The *petroleum system* is the basic geologic unit of the oil and gas assessment. A total petroleum system includes all genetically related petroleum in shows and accumulations (discovered and undiscovered) that was 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, trap, 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, or it may be divided into two or more assessment units, such that each assessment unit is sufficiently homogeneous in terms of geology, exploration considerations, and risk to be assessed individually.

A numeric code identifies each region, province, total petroleum system, and assessment unit; these codes, uniform throughout the World Energy Project, are:

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 for the Dnieper-Donets basin are 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 the boundaries of the total petroleum system and the assessment unit. The map 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 scale digital coverage (1992), have no political significance, and are displayed for general reference only. Oil and gas field centerpoints shown on the map are reproduced, with permission, from Petroconsultants (1996).

Abstract

The Dnieper-Donets basin is almost entirely in Ukraine, and it is the principal producer of hydrocarbons in that country. A small southeastern part of the basin is in Russia. The basin is bounded by the Voronezh high of the Russian craton to the northeast and by the Ukrainian shield to the southwest. The basin is principally a Late Devonian rift that is overlain by a Carboniferous to Early Permian postrift sag. The Devonian rift structure extends northwestward into the Pripyat basin of Belarus; the two basins are separated by the Bragin-Loev uplift, which is a Devonian volcanic center. Southeastward, the Dnieper-Donets basin has a gradational boundary with the Donbas foldbelt, which is a structurally inverted and deformed part of the basin.

The sedimentary succession of the basin consists of four tectono-stratigraphic sequences. The prerift platform sequence includes Middle Devonian to lower Frasnian, mainly clastic, rocks that were deposited in an extensive intracratonic basin.

The Upper Devonian synrift sequence probably is as thick as 4–5 kilometers. It is composed of marine carbonate, clastic, and volcanic rocks and two salt formations, of Frasnian and Famennian age, that are deformed into salt domes and plugs. The postrift sag sequence consists of Carboniferous and Lower Permian clastic marine and alluvial deltaic rocks that are as thick as 11 kilometers in the southeastern part of the basin. The Lower Permian interval includes a salt formation that is an important regional seal for oil and gas fields. The basin was affected by strong compression in Artinskian (Early Permian) time, when southeastern basin areas were uplifted and deeply eroded and the Donbas foldbelt was formed. The postrift platform sequence includes Triassic through Tertiary rocks that were deposited in a shallow platform depression that extended far beyond the Dnieper-Donets basin boundaries.

A single total petroleum system encompassing the entire sedimentary succession is identified in the Dnieper-Donets basin. Discovered reserves of the system are 1.6 billion barrels of oil and 59 trillion cubic feet of gas. More than one-half of the reserves are in Lower Permian rocks below the salt seal. Most of remaining reserves are in upper Visean-Serpukhovian (Lower Carboniferous) strata. The majority of discovered fields are in salt-cored anticlines or in drapes over Devonian horst blocks; little exploration has been conducted for stratigraphic traps. Synrift Upper Devonian carbonate reservoirs are almost unexplored. Two identified source-rock intervals are the black anoxic shales and carbonates in the lower Visean and Devonian sections. However, additional source rocks possibly are present in the deep central area of the basin. The role of Carboniferous coals as a source rock for gas is uncertain; no coal-related gas has been identified by the limited geochemical studies. The source rocks are in the gas-generation window over most of the basin area; consequently gas dominates over oil in the reserves.

Three assessment units were identified in the Dnieper-Donets Paleozoic total petroleum system. The assessment unit that contains all discovered reserves embraces postrift Carboniferous and younger rocks. This unit also contains the largest portion of undiscovered resources, especially gas. Stratigraphic and combination structural and stratigraphic traps probably will be the prime targets for future exploration. The second assessment unit includes poorly known synrift Devonian rocks. Carbonate reef reservoirs along the basin margins probably will contain most of the undiscovered resources. The third assessment unit is an unconventional, continuous, basin-centered gas accumulation in Carboniferous low-permeability clastic rocks. The entire extent of this accumulation is unknown, but it occupies much of the basin area. Resources of this assessment unit were not estimated quantitatively.

Introduction

This report describes the regional and petroleum geology of the Dnieper-Donets basin (DDB), Province 1009, most of which is in Ukraine; only the extreme southeastern part of the basin is in Russia. The location and boundaries of the basin are shown in figure 1. Discovered petroleum volumes in the basin are slightly more than 11.5 billion barrels of oil equivalent (BOE), of which 86 percent is gas (Petroconsultants, 1996). However, the in-place oil and gas resources reported by Ukrainian geologists suggest that recoverable reserves actually may be larger (Yevdoshchuk and others, 1998). About 30 percent of the gas reserves are in the Shebelinka gas field (fig. 1), the largest field in the basin. The basin is ranked 36th among 102 world provinces that were designated for appraisal of undiscovered oil and gas resources by the U.S. Geological Survey (U.S. Geological Survey World Energy Assessment Team, 2000).

A single total petroleum system (TPS), the Dnieper-Donets Paleozoic TPS (100901), which includes the entire sedimentary section, was defined in the basin. Areally, the TPS boundaries coincide with those of the basin, although the extreme northwestern part of the basin, devoid of discovered fields (fig. 1), possibly is not a part of the TPS. However, data are insufficient to justify a conclusion that no discoveries will be made in that northwestern area in the future. Lower Permian rocks contain the largest portion of the reserves; reservoirs in these rocks are sealed by salt. The principal identified source rocks are in the Visean (Lower Carboniferous) and Upper Devonian stratigraphic units. Additional source rocks, including Carboniferous coals, possibly are present in deep parts of the basin. Over most of the basin, the source rocks are overmature with respect to oil generation; consequently gas dominates over oil in the resource base. Carboniferous–Lower Permian clastic reservoirs contain the great majority of discovered oil and gas reserves.

Structural prospects in Carboniferous and younger rocks of the Dnieper-Donets basin have been extensively explored to depths of 4–5 km, and only smaller structures at great depths remain undrilled. In contrast, little exploration has been conducted in stratigraphic traps and in underlying Devonian rocks. Three assessment units (AU) were identified for resource appraisal. The Carboniferous–Lower Permian Clastics AU (10090101) includes Carboniferous and younger rocks of the basin. The Devonian Synrift AU (10090102) encompasses the synrift Devonian rocks that occur at great depths everywhere except on basin margins. The results of the resource assessment of these two AU are shown in table 1. Definitions of the TPS and AU are given in the Foreword; the assessment technique and procedure are described in U.S. Geological Survey World Energy Assessment Team (2000). The third AU, the Continuous Basin-Centered Gas Accumulation AU, is an unconventional gas accumulation in Carboniferous tight clastic rocks. That AU was not assessed quantitatively.

Province Overview

Province Location and Boundaries

The Dnieper-Donets basin (DDB), Province 1009, is underlain by a segment of the Late Devonian rift graben that extends more than 800 km in a northwest-southeast direction in the southwestern part of the Precambrian Russian craton (fig. 2). The basin is 70–130 km wide; in addition to the rift graben it includes the northeastern rift shoulder that is overlain by thick Carboniferous rocks; it also includes a foredeep along the

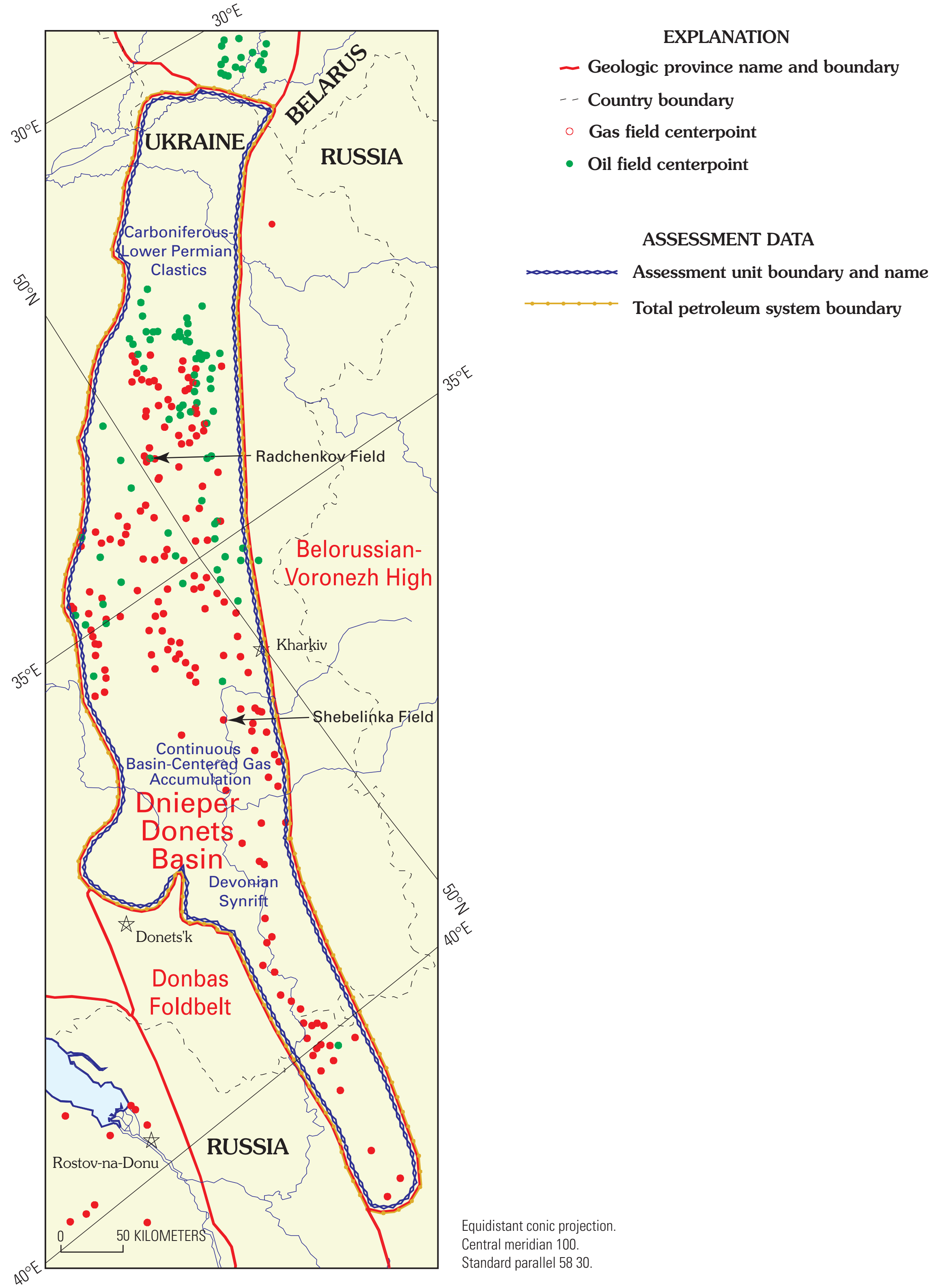

Figure 1. Petroleum systems and assessment units of Dnieper-Donets basin.

northern front of the Donbas foldbelt. Farther northeast, the sedimentary cover thins rapidly on the slope of the regional Voronezh high (fig. 2). On the crest of the high, in places the crystalline basement has been penetrated at depths of only a few tens of meters. Northwest of the DDB, the Pripyat basin is the continuation of the rift structure. The Dnieper-Donets and Pripyat basins are separated by the Bragin-Loev uplift composed mainly of thick Devonian volcanics. To the southeast, the DDB is limited by the Donbas foldbelt, the deformed and structurally inverted portion of the rift. The boundary between the DDB and the Donbas foldbelt is gradational; anticlines of the foldbelt plunge beneath younger rocks of the basin and lose structural

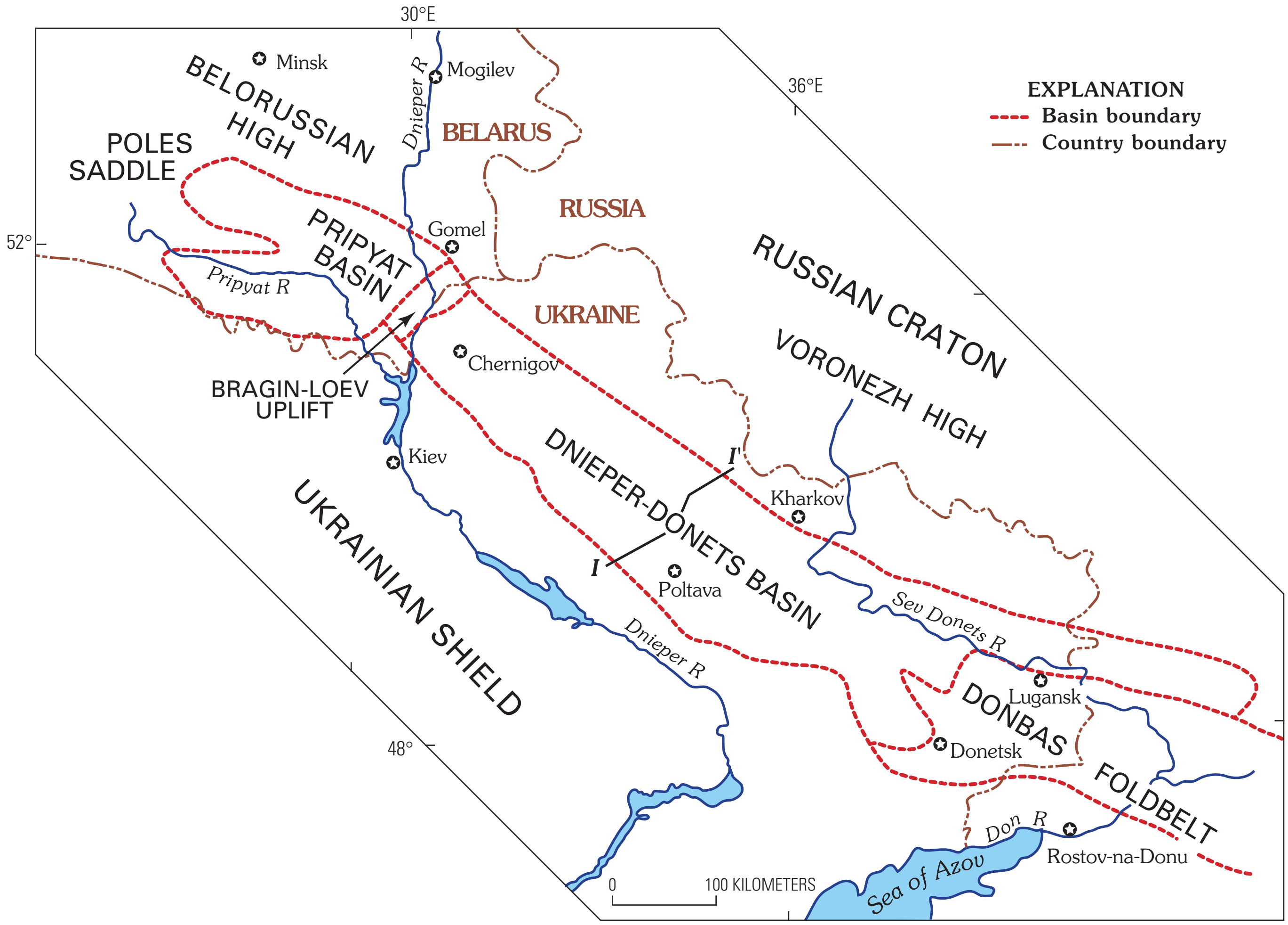

Figure 2. Location of Dnieper-Donets basin. Modified from Ulmishek and others (1994).

expression. This boundary commonly is drawn along the outcrop of Tournaisian–lower Visean rocks. The Pripyat and Dnieper-Donets basins and the Donbas foldbelt separate the Ukrainian shield from the main body of the Russian craton (fig. 2). The basin area is almost entirely in Ukraine; only its extreme southeastern part, north of the Donbas foldbelt, is in the Rostov Administrative Region of Russia.

Tectono-Stratigraphic Development

Devonian and younger sedimentary rocks of the DDB overlie the crystalline basement of the Russian craton; the basement rocks crop out on the Ukrainian shield. The exposed internal basement structure consists of Archean massifs and Lower Proterozoic deformed belts. The structural grain has a north to northeast orientation, transverse to the strike of the Devonian rift. Gravity and magnetic data indicate that this orientation is continuous across the basin. North-south-trending basement faults generally are assumed to have played an important role in structural development of the basin; supposedly they controlled abrupt changes of rock unit thicknesses (for example, Gavrish, 1989; Kabyshev, 1987). However, those assumptions are poorly substantiated by structural data (Ulmishek and others, 1994). On the basis of interpretation of refraction seismic data, it also was inferred that the southeastern part of the Devonian rift and the Donbas foldbelt are underlain by an older, Riphean (Late Proterozoic), rift structure (Gavrish, 1987; Chekunov and others, 1993). More recent reflection seismic data do not support the hypothesized existence of this older rift (Stovba and others, 1995).

The sedimentary succession of the DDB consists of four sequences that reflect major stages in tectonic development of the basin (fig. 3). The pre-rift platform sequence is poorly known in much of the DDB because of great burial depths, but different parts of this sequence have been penetrated by wells in the marginal zones of the basin. From these data and on the basis of analogy with the adjacent Pripyat basin, the sequence includes Middle Devonian–lower Frasnian clastic and carbonate rocks. The rocks were deposited in platform conditions similar to those of the central and eastern Russian craton. Judging from the absence of marginal facies, the platform originally extended far beyond the present limits of the rocks.

Formation of the rift began in middle Frasnian time and continued until the end of the Devonian period. Apparently, the rifting was caused by clockwise rotation of the Ukrainian shield relative to the rest of the Russian craton. The width of the rift increased eastward, resulting in the opening of oceanic crust in

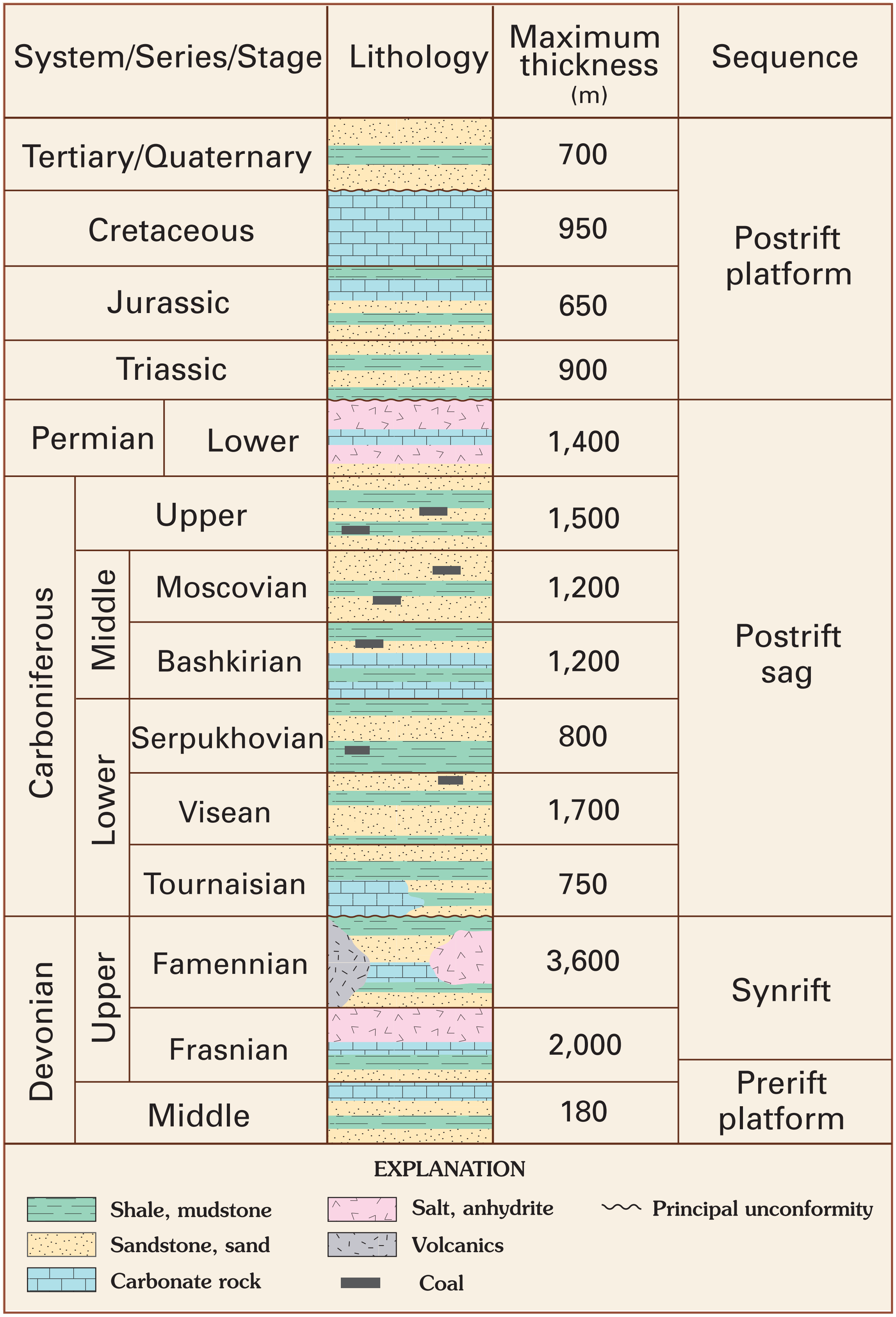

Figure 3. Columnar stratigraphic section of Dnieper-Donets basin. Modified from Law and others (1998).

the easternmost DDB and in the Donbas foldbelt. The synrift stratigraphic sequence is stratigraphically complex and poorly understood. It includes two thick salt formations of late Frasnian and late Famennian age that are deformed into domes and plugs. Famennian salt is believed to be present only in local grabens along the rift boundaries, and its presence in the axial zone of the rift is uncertain (Kurilyuk and others, 1991). Analogy with the Pripyat basin indicates that both salt formations probably filled deep-water basins, in which organic-rich anoxic shales and carbonates were deposited prior to evaporite sedimentation. Shallow-shelf and reef carbonates correlative with this deep-water facies have been drilled on the basin margins and within internal uplifts (synsedimentary horsts).

During rift development, the Ukrainian shield was uplifted; it became a major source of terrigenous clastic material that formed fans in proximal areas along the southern rift margin. Extensive volcanism accompanied rifting. Dikes, lava flows, and tuffs are thick near volcanic centers that were located along the marginal faults of the rift, especially along the western half of the northern basin margin. Volcanic rocks are of basic and intermediate compositions; they interfinger with and laterally replace carbonates and salt. Seismic data show that by the end of Devonian time the sea depth in the DDB was not less than 3 km. Uppermost Devonian rocks form large subaqueous clastic fans on the southern margin; the fans have clinoform shapes in cross section. The clinoforms are composed of flyschoid interbedding of shale and coarser clastics. The clastic sequence is as thick as 3 km on the basin slope; the sequence thins rapidly both toward the Ukrainian shield and basinward. Most of the flyschoid clastic sequence was deposited during the time interval represented by the pre-Carboniferous unconformity outside the deep-water basin. The total thickness of the synrift sequence is estimated to be 4–5 km.

The post-rift sag sequence is bounded by the pre-Carboniferous and pre-Triassic unconformities (fig. 3). The tectonic regime and paleogeographic conditions of deposition of this sequence differ markedly from those that existed earlier in Devonian time. Termination of rifting was accompanied by cessation of uplift of the Ukrainian shield. The shield probably was covered by a thin veneer of Carboniferous sediments. A large volume of fluvial clastic material was transported by a river from the northwest along the basin strike. The river delta prograded into the deep-water basin that existed from Devonian time. The basin probably was filled by middle Visean time; late Visean and younger sediments were deposited on the previously existing rift shoulders. Serpukhovian and younger Carboniferous sediments commonly consist of cyclothems of marine limestone or shale at the bottom to coal and paleosol beds at the top.

During Carboniferous and much of Early Permian time, the Dnieper-Donets basin, with heavy oceanic or transitional crust, subsided isostatically and under the sediment load. The rate of subsidence was high; the thickness of the Carboniferous–Lower Permian strata increases from 2–3 km in the northwest to about 11 km in the southeast and in the Donbas foldbelt. The rocks are dominantly clastics; some limestones were deposited on the northern margin, and occasionally also in the basin center during transgressions and retreat of the delta. Increased aridity during Asselian-Sakmarian (Early Permian) time resulted in deposition of red beds, carbonates, and evaporites (including salt).

The post-rift sag stage was terminated in Artinskian (Early Permian) time by compression related to Hercynian collision of continental blocks with the southern margin of the Russian craton. Shortening of the crust increased southeastward, and in the Donbas foldbelt the shortening resulted in thrusting, folding, and partial inversion of the basin. A shallow foredeep formed along the northern boundary of the foldbelt. In the DDB, the intensity of uplift and erosion increased southeastward along the basin strike and from the northern to the southern basin margins. The depth of erosion varies from zero in the basin center to almost 2 km in the east part of the southern basin margin (Goncharenko and others, 1984; Yevdoshchuk and others, 1998).

Sedimentation in the basin resumed in Triassic time, when continental red and variegated gypsiferous shales and some fresh-water carbonates were deposited on the truncated surface of older strata. Triassic through Tertiary rocks compose the post-rift platform sequence, which is 2–2.5 km thick in the basin center. Rocks of the sequence are Triassic, lower-Middle Jurassic, and Tertiary marine and continental clastics and Cretaceous and Upper Jurassic carbonates. The sediments were deposited in a gentle platform-type depression that extended far beyond the boundaries of the Paleozoic basin. Several pulses of rejuvenated compression from the south produced uplifts and erosion. The largest pulse of uplift took place in earliest Tertiary time. The uplift affected approximately the same areas as in pre-Triassic time and resulted in erosion of as much as several hundred meters of sediments.

Present-Day Structure

The basement is at great depths along the axial trough of the DDB, and only general characteristics of its structure are known from refraction and limited deep reflection seismic surveys. The Devonian rift structure, also known as the Dnieper graben, is bordered by two major faults. Depths to the Precambrian crystalline basement are 3–4 km on the southern rift shoulder and 4–5 km on the northern shoulder. Vertical displacement across the boundary faults ranges from several hundred meters to 2–3 km (fig. 4). Inside the graben, the basement surface is at depths of 4–5 km in the northwestern area, and the depth increases to more than 18 km near the boundary with the Donbas foldbelt. The core of the basement structure is a series of axial depressions that are separated by structural saddles (fig. 5). Basement structures also include narrow depressions that are stretched along the boundary faults and also two chains of uplifted blocks that separate the marginal and axial depressions. On some of these blocks, post-rift upper Visean rocks directly overlie the basement. This horst and graben structure is inherited from the rifting stage; however, it was modified significantly during subsequent sag development, when maximum subsidence occurred along the basin axis.

The structure of the subsalt Devonian rocks is poorly known, owing to poor resolution of seismic data at these depths. Where mapped, these rocks generally are conformable with the basement surface. Tilted fault blocks that commonly dip toward the marginal faults of the rift have been mapped along the basin margins (Gavrish, 1989).

The structure of Carboniferous to Lower Permian rocks composing the post-rift sag sequence is different from that of the basement. This structure was formed by basin sagging, tilting of the basin floor southeastward along the strike, and plastic deformation of Devonian salt. Only in the northwestern part of

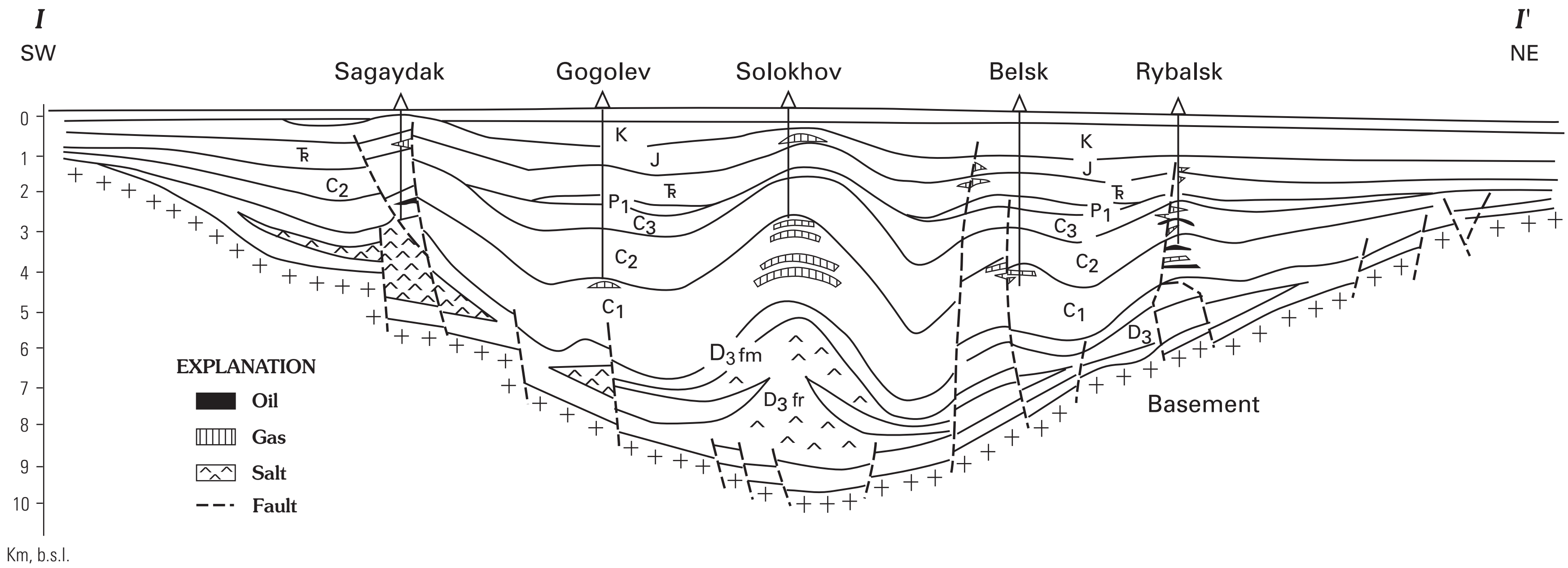

Figure 4. Cross section of Dnieper-Donets basin. Location is shown in figure 2. D_3fr and D_3fm are Frasnian and Famennian Stages, respectively, of the Upper Devonian; C_1, C_2, and C_3 are Lower, Middle, and Upper Carboniferous, respectively; P_1, Lower Permian; TR, Triassic; J, Jurassic; K, Cretaceous. Scale is not available. Approximate length of section is 160 km.

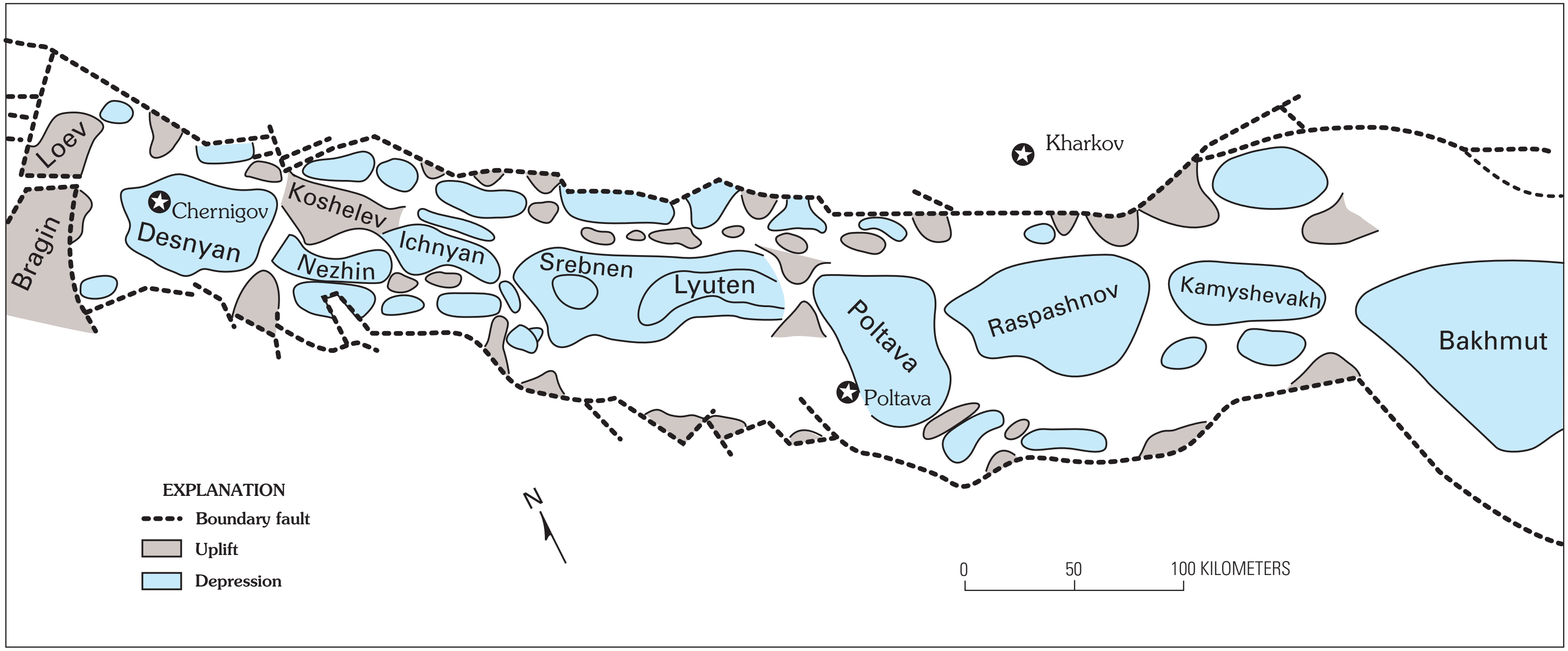

Figure 5. Generalized structure of Dnieper-Donets basin showing major depressions and uplifts of basement. Modified from Ulmishek and others (1994).

the basin and on its margins, where Devonian salt is thin or absent, are some structures related to draping of Carboniferous rocks over basement horsts. Faulting of Carboniferous–Lower Permian rocks is related to salt tectonics, and most of the faults do not penetrate the basement. Regionally, all rocks dip southeastward along the basin strike, and dip angles increase in progressively older rocks. Linear anticlines that are mostly parallel to the basin strike, isometric local uplifts, and gentle depressions dominate the structural pattern. Most of the anticlinal uplifts have buried salt cores. Structural closures of the uplifts decrease upward in the section, and the uplifts are only gently expressed in the structure of Lower Permian rocks. On a regional scale, the intensity of deformation decreased further in Mesozoic and Tertiary time, but local uplifts and depressions reflect continuous salt movements in some of the domes.

Petroleum System

At least two, and possibly more, stratigraphic units that contain petroleum source rocks are present in the Paleozoic succession of the DDB. However, as is typical for rift basins, the DDB is characterized by the dominance of vertical over lateral migration of oil and gas and by a large stratigraphic range of productive reservoirs. Therefore, only one composite total petroleum system (TPS)—the Dnieper-Donets Paleozoic TPS (100901)—is identified in the basin. This TPS is substantially gas-prone, apparently because of the high maturity of source rocks; oil fields are present only in the shallower western area and on basin margins. Almost all of the reserves are in Carboniferous and Lower Permian reservoirs. All known source rocks are in the Visean and Devonian intervals; however, additional marine and deltaic source rocks possibly are present in the basin at great depths. It is not known whether some gas was sourced from Carboniferous coals.

Dnieper-Donets Paleozoic Total Petroleum System

The Dnieper-Donets Paleozoic TPS (100901) includes the entire sedimentary section of the DDB. Areally, the TPS boundaries coincide with those of the basin, although the extreme northwestern area of the basin, devoid of discovered fields, possibly should not be included in the TPS (fig. 1). However, the data are insufficient to permit a conclusion that no discoveries will be made in that area in the future. According to Petroconsultants (1996), discovered hydrocarbon reserves of the TPS exceed 11.5 billion BOE, of which 86 percent is gas. Ukrainian geologists report in-place resources of oil and gas, and the stated amounts indicate that recoverable reserves may be somewhat larger (Yebdoshchuk and others, 1998). Reserves of the largest gas field, the Shebelinka field (fig. 1), are slightly more than 18 trillion cubic feet (TCF). Lower Permian rocks contain the greatest portion of the reserves; reservoirs in these rocks are sealed by salt. Most of the hydrocarbons were sourced from Devonian and Lower Carboniferous marine rocks. Estimated undiscovered resources of oil and gas in this TPS are shown in table 1.

Discovery History

Oil shows in the Dnieper-Donets basin were first recorded in 1936 in the caprock of a salt dome. The first significant commercial discovery was in 1950, when the giant Shebelinka gas field was discovered in Lower Permian rocks at a depth of 1,300 m. The first oil discovery was made during the same year, in Carboniferous rocks of the Radchenkov field (fig. 1). A number of other significant oil and gas fields were found during the following 10–15 years. Starting in the middle 1960’s, the efficiency of exploration decreased, as progressively smaller fields dominated the new discoveries and drilling depths increased. At least 25 fields in the basin produce from depths greater than 5 km (Kabyshev and Shpak, 1988). At present, more than 200 oil and gas fields have been discovered; however, the majority of the reserves are heavily concentrated in three gas fields and three oil fields, the latest of which was found in 1965. In the 1990’s, U.S. Geological Survey studies identified the presence of a large unconventional basin-centered gas accumulation that encompasses much of the TPS area and extends into the Donbas foldbelt (Law and others, 1998).

Petroleum Occurrence

Oil and gas fields are present over the entire Dnieper-Donets Paleozoic TPS area, except its extreme northwestern part (fig. 1). The majority of oil fields and most of the oil reserves are concentrated in the northwestern part of the productive area. Southeastward, gas fields predominate and only a few, relatively small, oil fields are known on basin margins. This spatial separation of oil and gas fields is clearly related to the level of maturity of potential source rocks (Shpak, 1989). Among the more than 200 discovered fields, 23 are large, each with in-place resources of more than 220 million BOE. These 23 fields contain more than 75 percent of the resources in the basin (Yevdoshchuk and others, 1998). Lower Permian salt plays an important role in the distribution of giant and large fields. This salt seal is present in the central areas of the TPS, and it directly caps many of the largest accumulations.

The greatest portion (about 55 percent) of discovered reserves is in Upper Carboniferous–Lower Permian rocks, which presently contain only 24 fields (Shpak, 1989). The second richest interval is the Lower Carboniferous section with 37 percent of reserves in more than 120 fields. The Devonian, Middle Carboniferous, and Mesozoic productive complexes are much poorer in hydrocarbons. Most fields have multiple reservoirs; the maximum number of productive reservoirs in a single field is 27.

Oils of the TPS are of light to medium gravity, low in sulfur (0.1–0.4 percent), with variable content of paraffin (0.4–8 percent). Gas composition changes with depth; shallow pools in Upper Carboniferous–Lower Permian and Mesozoic rocks contain dry gas, dominantly composed of methane, whereas the contents of heavier hydrocarbon gases and condensate increase significantly in deeply buried Lower Carboniferous reservoirs.

Source Rocks

Geologic data and limited geochemical data indicate that the principal petroleum source rocks in the TPS are in the Lower Carboniferous and Devonian intervals. However, in a large part of the basin, these rocks are at great depths, not yet reached by drilling. Therefore, the stratigraphic position of source rocks is deduced from paleogeographic models and by comparison with the adjacent Pripyat basin.

An unpublished U.S. Geological Survey study of the geochemistry of oil, gases, and source rocks of the DDB identified two families of oils (J.L. Clayton, written commun., 1998). One of the families is correlative with Lower Carboniferous marine shales. The most prominent of these rocks is a black-shale interval (Rudov Bed) at the top of the lower Visean section. The Rudov Bed, 8–70 m thick, contains 2 to 6 percent total organic carbon (TOC) with type II kerogen. It is composed of siliceous shales with a variable content of carbonate material (Gavrish and others, 1994). The shales are a deep-water basinal facies that is stratigraphically correlative with shallow-shelf and reefal carbonates developed on the surrounding shelf (Lukin and others, 1994). These source rocks were drilled in the western Srebnen depression (fig. 5); they probably extend farther southeast, where they are at depths not yet reached by wells.

Source rocks for the second oil family have been sampled only in a few wells, and they are inadequately known. The geographic and stratigraphic locations of fields and hydrocarbon shows indicate that the source rocks are in the Devonian synrift sequence. The suspected source rocks were sampled in a few wells; they are Frasnian and lower Famennian dark siliceous shales and carbonates with a TOC content as high as 4–5 percent (Shpak and Lukin, 1986). Similar source rocks have been studied in the Pripyat basin, where they are present among basinal facies developed in grabens and are correlative with productive reef carbonates on horst blocks (Ulmishek and others, 1994).

Additional source rocks possibly are present in the eastern half of the Dnieper-Donets basin. These possible source rocks are prodeltaic facies of the Tournaisian–early Visean delta that prograded along the basin strike. The black shales, commonly with flyschoid textures, crop out in the Donbas foldbelt, where they are partially metamorphosed. In addition, Serpukhovian–Middle Carboniferous coals that are in the gas generation window in the central and eastern basin areas could have generated some gas. However, USGS analytical data for about 25 gas samples indicate that the gases are thermogenic and were generated from marine source rocks (J.L. Clayton, personal commun.,1998).

Vitrinite reflectance data demonstrate that at a depth of 5 km the maturity of rocks varies from the lower part of the oil window to the upper part of the gas window (Shpak, 1989). These data indicate that both Visean and Devonian source rocks are in the oil window in the western basin area and on its margins, but they are overmature with respect to oil generation elsewhere. Maturation of source rocks could have begun as early as latest Devonian or earliest Carboniferous time (fig. 6). Over most of the basin, maximum burial and maturation were achieved by the beginning of the Artinskian compressional event and associated uplift. Only locally, subsidence during Mesozoic-Tertiary time could have resulted in slight additional heating and maturation (Ivanova, 1991).

Reservoir Rocks

Clastic rocks are the dominant reservoir lithologies in the Dnieper-Donets Paleozoic TPS, and they contain almost entire oil and gas reserves. Comparatively small quantities of hydrocarbons are present in Lower Carboniferous carbonates on the basin margins and also in Lower Permian carbonates and fractured anhydrites near the top of the Paleozoic sequence. Only noncommercial accumulations have been found in Devonian carbonate rocks in the DDB, although these rocks contain the entire oil reserves of the adjacent Pripyat basin. Several oil and gas accumulations have been discovered in fractured metamorphic rocks at the top of the basement complex. These fields are on the northern rift shoulder, where the basement is overlain by upper Visean strata that also contain hydrocarbon pools.

Several tens of sandstone beds, separated by shales, coals, and carbonates and assigned local nomenclature, are present in the Carboniferous section. The thickness of reservoir beds ranges from several meters to 65 m. Reservoir properties of sandstones vary significantly, depending on facies composition and diagenetic changes. Higher primary intergranular porosity is present in better sorted, significantly quartzose, bar, delta-front, and channel sandstones (Samarskaya and Polyak, 1990). During burial, these sandstones retained good porosity (10–17 percent) and permeability (to 300 millidarcies) through the oil window to depths of 4–5 km. Deeper, in the wet-gas window to depths of 6–7 km, secondary porosity and fracturing control the reservoir properties. Porosity and permeability in other alluvial and turbidite reservoir facies deteriorate at much shallower depths (3–4 km).

Traps

Most of the discovered reserves of the Dnieper-Donets Paleozoic TPS are in structural traps, although stratigraphic pinchouts and faults commonly control outlines of individual pools. Prolific oil and gas fields in Upper Carboniferous–Lower Permian reservoirs, covered by the Permian salt seal, are in faulted anticlinal uplifts that are cored by Devonian salt domes. The tops of the salt domes are at depths from 1.5 km to 6–7 km. Structural closures are as large as hundreds of meters. Much of structural growth in these uplifts occurred during Mesozoic and Tertiary time. The oil and gas fields in Lower Carboniferous rocks are either in salt-assisted structural traps in deep, central basin areas, or they are in drape structures over basement blocks in shallower western and marginal areas. Most of the reserves (96 percent) in these rocks are in structures that were formed primarily prior to the Late Permian compression and partial basin inversion (Kabyshev and others, 1998). Several gas fields have

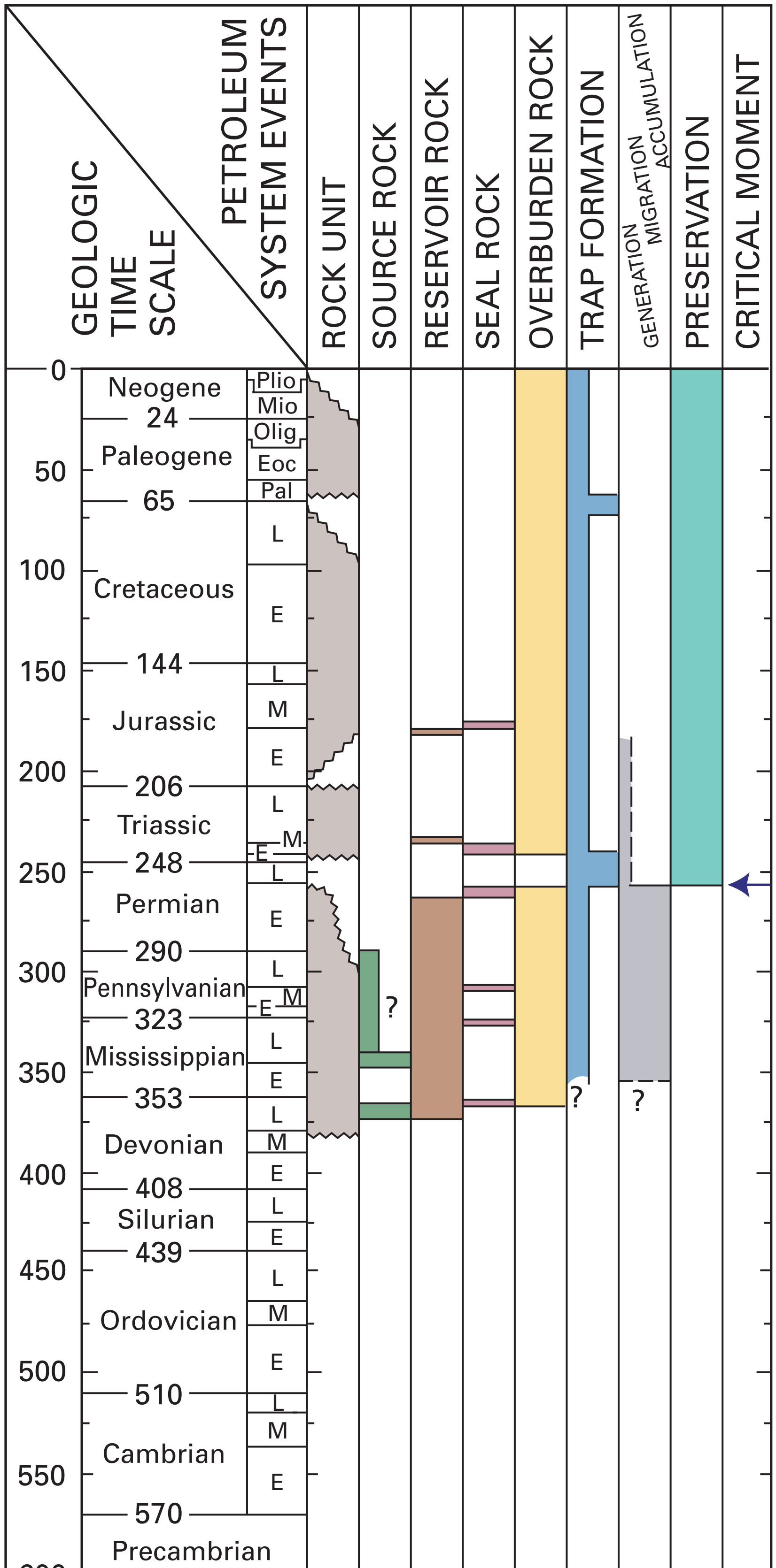

Figure 6. Total petroleum system events chart. Queries indicate uncertainty in extent or identification.

been discovered in stratigraphic pinchouts, chiefly on margins of the Srebnen depression (fig. 5). Presently, stratigraphic traps, Lower Carboniferous pinnacle reefs, and synrift Devonian fault blocks are known to contain only minor hydrocarbon reserves. However, they probably contain a significant portion of the undiscovered resources of the basin.

Assessment Units

Three assessment units (AU) have been identified in the Dnieper-Donets Paleozoic TPS; however, only two were quantitatively assessed. The two assessed AU are stratigraphically stacked, and both occupy the entire basin area. One AU includes pre-rift and synrift Devonian rocks; the other includes Carboniferous–Lower Permian post-rift sag and Mesozoic-Tertiary post-rift platform sequences. The estimated petroleum resources of each AU are shown in table 1. Complete statistical data on the assessment are given in U.S. Geological Survey World Energy Assessment Team (2000). The third AU is an unconventional, basin-centered gas accumulation, the resources of which were not assessed quantitatively.

Carboniferous–Lower Permian Clastics, Assessment Unit 10090101

This AU primarily comprises Carboniferous–Lower Permian clastic reservoirs, but it also includes minor hydrocarbons in carbonate rocks of this sequence and in overlying Mesozoic-Tertiary clastic rocks. The AU contains the entire discovered reserves of the TPS and much of its undiscovered resources. The majority of known structural traps of the unit have been drilled, many of them to depths of 4–5 km or more. The remaining structural prospects are chiefly small and are deeply buried. Although discoveries of new fields continue, in general the size of the discoveries decreases progressively with time (Yevdoshchuk and others, 1998). Only a few new medium-size fields in structural traps are expected to be discovered in the future.

The exploration maturity for stratigraphic and combination structural and stratigraphic traps is much lower. Until recently, little effort was devoted to exploration for these traps, and a relatively small number of pools were found. However, deltaic to paralic conditions of sedimentation and intensive synsedimentary tectonics, including salt tectonics, resulted in the formation of numerous and diverse non-anticlinal traps. The application of better seismic technologies in recent years facilitated mapping of these traps. In the late 1990’s, more than half of the mapped prospects were stratigraphic and fault-sealed (Yevdoshchuk and others, 1998). Although few large fields in these traps are expected to be found, the total number of discoveries probably will be significant.

Devonian Synrift, Assessment Unit 10090102

The Devonian Synrift AU includes poorly known Devonian rocks that contain primarily carbonate potential reservoirs. Over much of the TPS area, these rocks are at depths not yet reached by exploratory drilling (deeper than 6–7 km), and future potential is related primarily to marginal zones of the basin. Several oil and gas fields have been discovered, but apparently none of them is commercial. The inferior quality of drilled reservoir rocks and poor seismic resolution, inadequate for prospect identification, probably are major problems. However, the high productivity of Devonian carbonate reservoirs in the adjacent Pripyat basin indicates that undiscovered resources of the AU possibly will be substantial (table 1). Better understanding of the depositional model of the Devonian synrift sequence and improvement of seismic data quality that will ensure reliable mapping of prospects, especially reefs on basin margins, are necessary for future exploration success.

Continuous Basin-Centered Gas Accumulation, Assessment Unit 10090103

This AU includes an unconventional, basin-centered gas accumulation in Carboniferous tight clastic reservoir rocks. The accumulation was identified by cooperative studies of the U.S. Geological Survey and Ukrainian geologists (Law and others, 1998). The boundaries of the accumulation have not been mapped; they are shown conditionally in figure 1 as coinciding with the basin boundaries. At present, the commercial significance of the accumulation over most of its area is uncertain because of the deep occurrence of the gas (mostly deeper than 4.5 km). However, in eastern basin areas, where thick rock sections were removed by pre-Triassic and pre-Tertiary erosion, the top of the gas-saturated, low-permeability, clastic rocks is at much shallower depths. The accumulation extends outside the province boundary into the Donbas foldbelt. In the foldbelt, where younger rocks were largely truncated by erosion, the continuous gas accumulation in Carboniferous coal-bearing clastics is at depths of only several hundred meters, and it may be a viable commercial prospect. The available data are insufficient to allow a quantitative resource assessment of the basin-centered gas accumulation.

Table 1. Dnieper-Donets Basin, Province 1009 Assessment Results Summary—Allocated Resources.

[MMBO, million barrels of oil. BCFG, billion cubic feet of gas. MMBNGL, million barrels of natural 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 chance 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]

Code and Field Type	MFS	Prob. (0-1)	Undiscovered Resources											
			Oil (MMBO)				Gas (BCFG)				NGL (MMBNGL)			
			F95	F50	F5	Mean	F95	F50	F5	Mean	F95	F50	F5	Mean
1009	**Total: Assessed onshore portions of Dnieper-Donets Basin Province**													
Oil Fields		1.00	86	1,019	2,353	1,098	158	1,970	4,954	2,195	9	115	311	132
Gas Fields							6,828	21,233	38,416	21,856	168	681	1,450	731
Total		1.00	86	1,019	2,353	1,098	6,986	23,203	43,370	24,051	177	796	1,760	862
1009	**Total: Assessed offshore portions of Dnieper-Donets Basin Province**													
Oil Fields		0.00	0	0	0	0	0	0	0	0	0	0	0	0
Gas Fields							0	0	0	0	0	0	0	0
Total		0.00	0	0	0	0	0	0	0	0	0	0	0	0
1009	**Grand Total: Assessed portions of Dnieper-Donets Basin Province**													
Oil Fields		1.00	86	1,019	2,353	1,098	158	1,970	4,954	2,195	9	115	311	132
Gas Fields							6,828	21,233	38,416	21,856	168	681	1,450	731
Total		1.00	86	1,019	2,353	1,098	6,986	23,203	43,370	24,051	177	796	1,760	862
100901	**Dnieper-Donets Paleozoic Total Petroleum System**													
10090101	Carboniferous-Lower Permian Clastics Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to ONSHORE province 1009)													
Oil Fields	3	1.00	86	235	466	251	158	457	997	502	9	27	63	30
Gas Fields	18						6,828	13,981	22,375	14,233	168	402	773	427
Total		1.00	86	235	466	251	6,986	14,438	23,372	14,735	177	428	836	457
10090102	Devonian Synrift Assessment Unit (100% of undiscovered oil fields and 100% of undiscovered gas fields allocated to ONSHORE province 1009)													
Oil Fields	7	0.90	0	784	1,886	848	0	1,513	3,957	1,694	0	88	248	102
Gas Fields	42						0	7,252	16,041	7,623	0	280	677	304
Total		0.90	0	784	1,886	848	0	8,765	19,998	9,317	0	368	924	405

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