GEOLOGICAL SURVEY CIRCULAR 885

Petroleum Geology and Resources of the Volga-Ural Province, U.S.S.R.

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By James A. Peterson and James W. Clarke

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A resource assessment and a brief description of the petroleum geology of the largest petroleum-producing area of the European part of the U.S.S.R.

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ASSESSMENT OF ENERGY RESOURCES

The World Energy Resources Program of the U.S. Geological Survey intends to develop reliable and credible estimates of undiscovered petroleum resources throughout the world. Initial program efforts have focused on the major producing areas of the world in order to gain a broad geological understanding of the characteristics of petroleum occurrence for resource assessment as well as for analysis of production potential. Investigations of production potential are carried out in cooperation with other U.S. Government agencies; specifically, studies of the main exporting nations of the free world, of which this study is a part, are carried out in cooperation with the Foreign Energy Supply Assessment Program of the Department of Energy.

The program seeks to investigate resource potential at the basin level, primarily through analogy with other petroleum regions, and thus does not necessarily require current exploration information commonly held to be proprietary. In conducting the investigations, we intend to build a support base of publicly available data and geologic synthesis against which to measure the progress of exploration and thereby validate the assessment. Most of these investigations will lead directly to quantitative resource assessments; to be effective, resource assessment, like exploration, must be an ongoing process that takes advantage of changing ideas and data availability – the results produced are but progress reports reflecting on a state of knowledge at a point in time. Because the program is coordinated with the Geological Survey's domestic assessment program and uses similar assessment techniques, the user can be assured that a thread of consistency will permit comparisons between the various petroleum basins of the world, including those in the United States, that have been assessed in the overall Survey program.

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Open-File Report 81-986 – Assessment of conventionally recoverable petroleum resources of Persian Gulf basin and Zagros Fold Belt (Arabian-Iranian basin)
Open-File Report 81-1027 – Assessment of conventionally recoverable petroleum resources, Volga-Urals basin, U.S.S.R.
Open-File Report 81-1142 – Assessment of conventionally recoverable petroleum resources of Indonesia
Open-File Report 81-1143 – Assessment of conventionally recoverable petroleum resources of northeastern Mexico
Open-File Report 81-1144 – Assessment of conventionally recoverable petroleum resources of southeastern Mexico, northern Guatemala, and Belize
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Open-File Report 81-1146 – Assessment of conventionally recoverable petroleum resources of Venezuela
Open-File Report 81-1147 – Assessment of conventionally recoverable petroleum resources of the West Siberian basin and Kara Sea basin, U.S.S.R.

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Petroleum Geology and Resources of the Volga-Ural Province, U.S.S.R.

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Abstract

The Volga-Ural petroleum province is, in general, coincident with the Volga-Ural regional high, a broad upwarp of the east-central part of the Russian (East European) Platform. The central part of the province is occupied by the Tatar arch, which contains the major share of the oilfields of the province. The Komi-Perm arch forms the northeastern part of the regional high, and the Zhigulevsko-Pugachev and Orenburg arches make up the southern part. These arches are separated from one another by elongate downwarps.

The platform cover overlies an Archean crystalline basement and consists of seven main sedimentation cycles. (1) Riphean (lower Bavly) continental sandstone, shale, and conglomerate beds, from 500 to 5,000 m thick, were deposited in aulacogens. (2) Vendian (upper Bavly) continental and marine shale and sandstone are up to 3,000 m thick. (3) Middle Devonian–Tournaisian transgressive deposits, which are sandstone, siltstone, and shale in the lower part and carbonates and abundant reefs in the upper part, range from 300 to 1,000 m in thickness. The upper carbonate part includes the Kamsko-Kinel trough system, which consists of narrow, interconnected, deepwater troughs. (4) The Viséan-Namurian-Bashkirian cycle began with deposition of Viséan clastic deposits, which draped over reefs of the previous cycle and filled in an erosional relief that had formed in some places on the sediments of the previous cycle. The Viséan clastic deposits are overlain by marine carbonate beds. The cycle is from 50 to 800 m thick. (5) The lower Moscovian–Lower Permian cycle consists of 1,000 to 3,000 m of terrigenous clastic deposits and marine carbonate beds. (6) The upper Lower Permian–Upper Permian cycle reflects the maximum growth of the Ural Mountains and the associated Ural foredeep. Evaporite deposits were first laid down, followed by marine limestones and dolomites, which intertongue eastward with clastic sediments from the Ural Mountains. (7) Continental red beds of Triassic age and mixed continental and marine clastic beds of Jurassic and Cretaceous age were deposited on the western, southwestern, and northern margins of the Russian Platform; they are generally absent in the Volga-Ural province, however.

Approximately 600 oilfields and gasfields and 2,000 pools have been found in the Volga-Ural province. Nine productive sequences are recognized; these are, in general, the same as the sedimentation cycles, although some subdivisions have been added. The clastic section of Middle and early Late Devonian age contains the major recoverable oil accumulations, including the supergiant Romashkino field.

Cumulative production to 1980 is estimated at 30 to 35 billion barrels of oil equivalent, identified reserves at about 10 billion barrels of oil equivalent, and undiscovered resources at about 7 billion barrels of oil equivalent. Identified reserves of natural gas are estimated at 100 trillion cubic feet and undiscovered resources at 63 trillion cubic feet.

ACKNOWLEDGMENT

The resource assessment for this report was prepared in collaboration with the Resource Appraisal Group of the Branch of Oil and Gas Resources.

INTRODUCTION

INFORMATION SOURCES

Data and information used in preparing this report were compiled primarily from Soviet journals and other publications on the petroleum geology and the general geology of the area. Of particular value were publications by Maksimov and others (1970), the Atlas of Lithological-Paleogeographical Maps of the U.S.S.R. by the Academy of Sciences of the U.S.S.R. (1966), translations of the Soviet journals *Geologiya Nefti i Gaza* and *Neftegazovaya Geologiya i Geofizika* (published in the American journal *Petroleum Geology*), the Robertson Research International, Ltd. (1976) report on the Volga-Ural petroleum province, and the information files of Petroconsultants, S.A.

GEOGRAPHY

The Volga-Ural petroleum province is an area of about 500,000 km² (200,000 mi²) located on the

FIGURE 1.–Volga-Ural basin assessment region (shaded).

Russian Plain between the Volga River on the west, the Ural Mountains on the east, and the Peri-Caspian depression on the south (figs. 1, 2 and 3). The plain is a low erosional surface having elevations of 100 m (325 ft) or less along the Volga and Kama Rivers, but, as it approaches the Ural Moun-

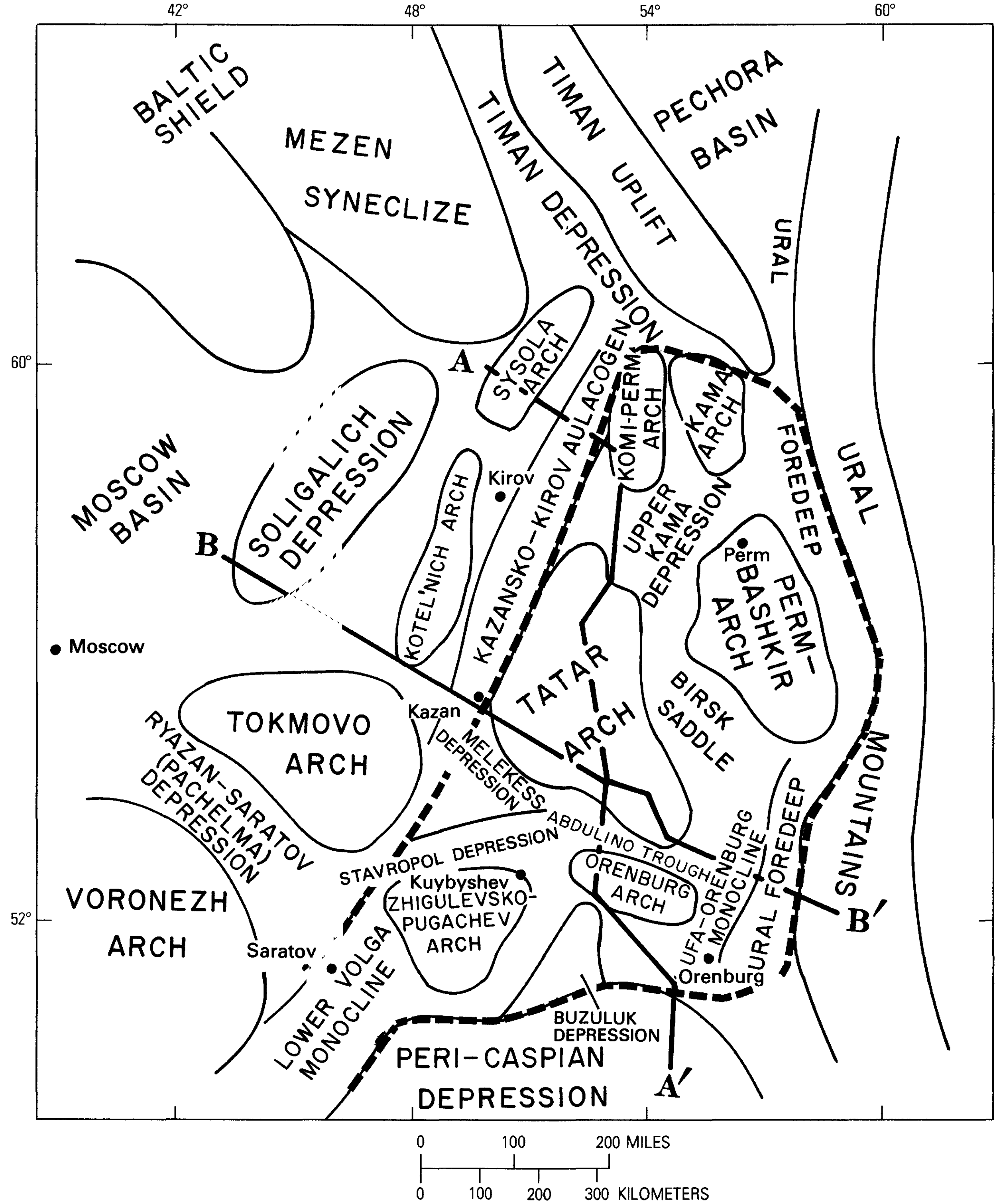

FIGURE 2.—Main structural features of the Russian Platform region and locations of cross sections A–A′ (fig. 6) and B–B′ (fig. 7). Dashed outline encloses Volga-Ural province.

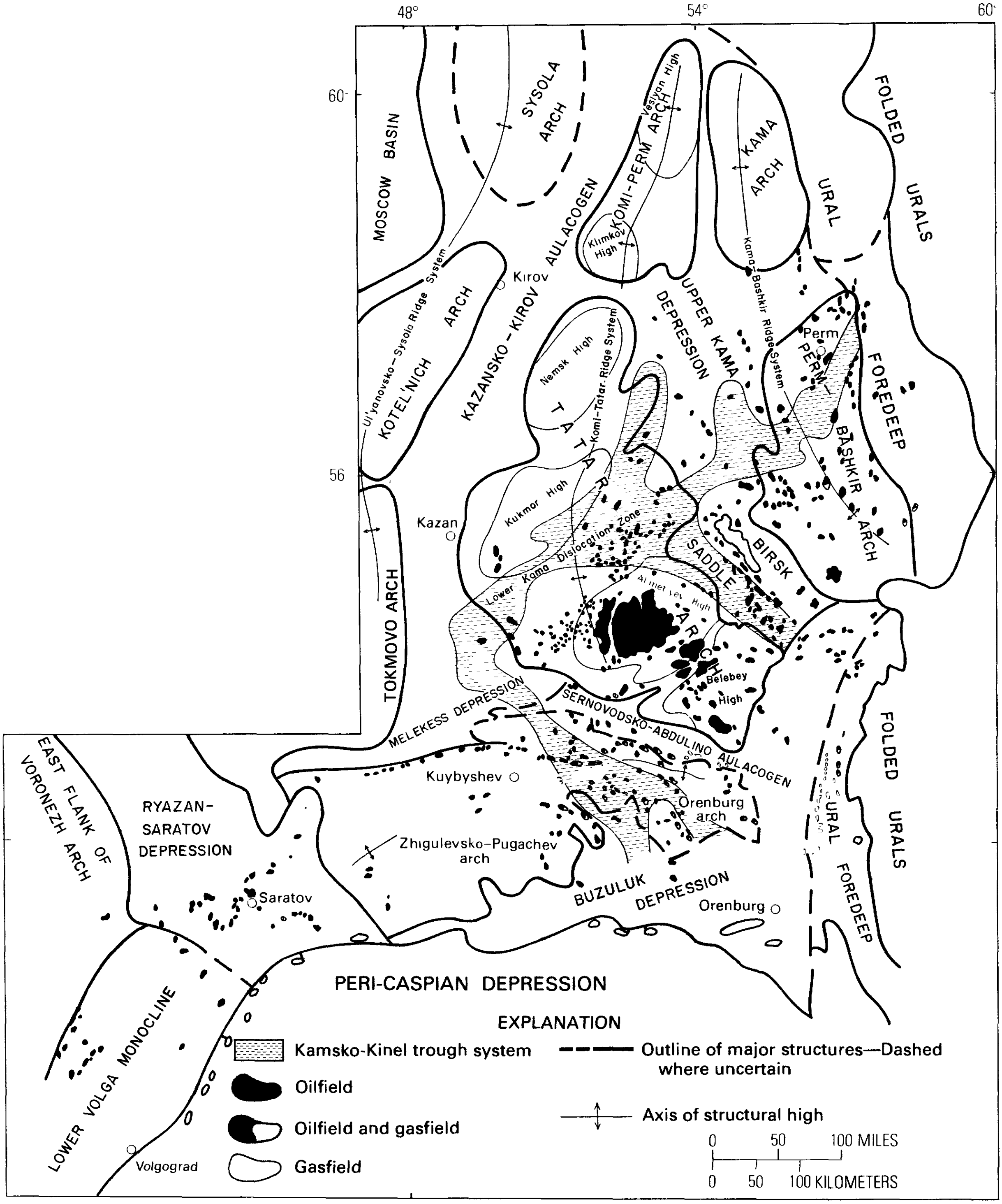

FIGURE 3.—Position of oilfields and gasfields with respect to the main structural features of the Volga-Ural province. The large field in the middle of the map area is Romashkino.

tains, it becomes a low erosional plateau having elevations of 200 m (650 ft) or more. The region extends from the cold, humid taiga on the north to the hot, dry desert of the Caspian on the south. Climate is Atlantic continental, and precipitation ranges from 30 to 40 cm (12 to 18 in) per year.

Average mean January temperature is −12° to −16°C (10° to 3°F); that for July is 20° to 24°C (66° to 76°F). The region lies at lat 50° to 60° N., about the same as the southern half of Canada. It lies in a forest-steppe belt of forest and grasslands that are extensively cultivated. The region was long neglected by Soviet planners and held to agricultural production. After World War II and the discovery of significant petroleum resources, this area (the "Second Baku") became the most rapidly developing industrial region in the Soviet Union.

REGIONAL GEOLOGY

STRUCTURE

The Volga-Ural petroleum province is, in general, coincident with the Volga-Ural regional high, a broad upwarp of the east-central part of the East European (Russian) Platform. The province is bordered on the east by the Ural foredeep, on the west by the Kazansko-Kirov aulacogen, and on the south by the Peri-Caspian depression (figs. 2 and 3). The central part of the province is occupied by the Tatar arch, an elongate basement uplift that includes the structurally highest part of the regional high and contains the major share of the petroleum deposits in the province. The Komi-Perm arch forms the northeastern part of the regional high, and the Zhigulevsko-Pugachev and Orenburg arches make up the southern part adjacent to the regional Peri-Caspian depression. Subsurface elevation of the Archean crystalline basement ranges from about −1,500 m (−4,900 ft) on the Tatar arch to more than −5,000 m (−16,000 ft) along the eastern border of the province (fig. 4) and more than −8,000 m (−26,000 ft) in the Ural foredeep. Maximum relief on the basement thus exceeds 6,000 m (19,500 ft) in the province. Thickness of the sedimentary cover ranges from 1,500 m (4,900 ft) to more than 8,000 m (26,000 ft).

The relief on the basement surface differs significantly from the structure in the overlying sedimentary rocks because of deformation that occurred during deposition of successive stratigraphic units. These structural differences are the basis for recognizing seven structural stages: Archean crystalline basement, Proterozoic Y and Z, Middle to Upper Devonian, Upper Devonian–Lower Carboniferous, Carboniferous–Lower Permian, Upper Permian, and Mesozoic-Cenozoic. Many of the structural features, particularly the larger arches and downwarps, are inherited from Proterozoic Y and Z–early Paleozoic structural trends. The arches are separated by relatively narrow, elongate basement-fault-bounded troughs or aulacogens (Maksimov and others, 1970; Nalivkin, 1976; Valeyev and others, 1969). The arches form large (regional) uplifts on which more localized but relatively large "highs" are superposed. The internal structure of the major arches consists of polygonal block and interblock linear-zonal structures. The polygonal block structures are characterized by relatively mild deformation of the sedimentary cover, a relatively thinner sedimentary section, and primary development of carbonate facies. The interblock linear-zonal structures are marked by greater deformation and a thicker sedimentary cover.

Both the aulacogens and the interblock linear-zonal structures formed through the action of deep faults in the basement. Movement along these basement faults was certainly associated with the contemporary subsidence in the Ural geosyncline to the east and in the Dnieper-Donets depression farther to the southwest, as well as with the downwarping of the Peri-Caspian depression to the south. The fault zones are characteristically associated with the steep gravity of magnetic gradients.

ARCHEAN CRYSTALLINE BASEMENT STRUCTURAL STAGE

In general, the Volga-Ural regional high is divided into three prominent ridge systems separated by elongate depressions or aulacogens (Maksimov and others, 1970). The Komi-Tatar ridge system is about 700 km (435 mi) long and 200 km (125 mi) wide and includes the Komi-Perm and Tatar arches and their local highs (fig. 3). The Lower Kama dislocation zone, which extends northeast across the central part of the Tatar arch, is a zone of extensive faults of the basement and sedimentary cover related to the Kama abyssal fault, which extends from the Voronezh arch to the Ural foredeep.

The Kama-Bashkir ridge system forms the northeastern part of the Volga-Ural regional high. It is separated from the Komi-Tatar ridge system by the Upper Kama depression and the Birsk saddle; this regional structural low (sometimes called the Birsko–Upper Kama aulacogen) is bordered by faults and is filled by thick Proterozoic Y and Z (Bavly) sedimentary and basic intrusive rocks. The Kama and Perm-Bashkir arches are the main

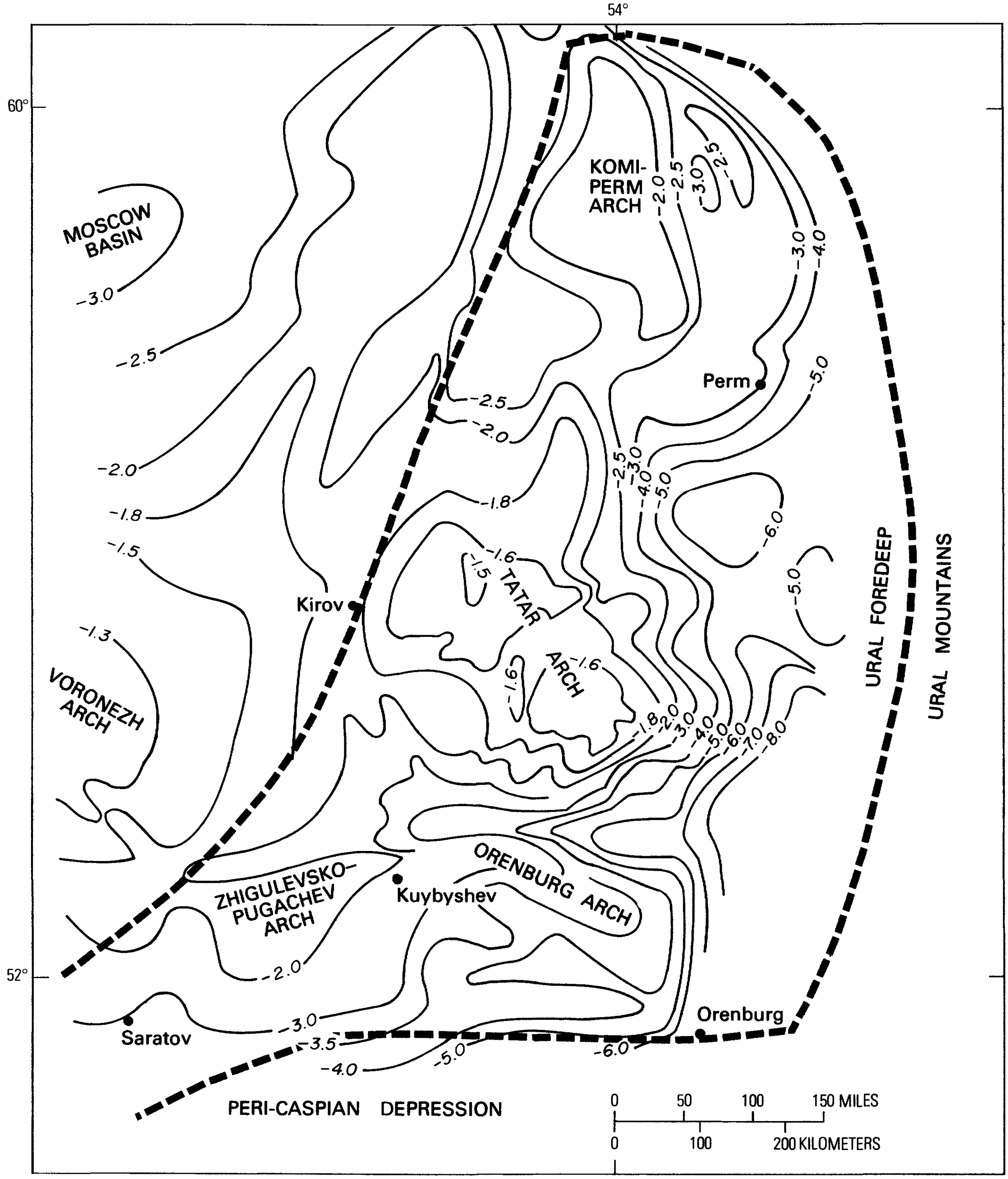

FIGURE 4.–Regional structure of the Archean crystalline basement in the Russian Platform region. Structure contours in kilometers. Dashed outline encloses the Volga-Ural province.

structural highs on the Kama-Bashkir ridge system, which is bounded on the east by the northern segment of the abyssally faulted Ural foredeep.

The Zhigulevsko-Pugachev and Orenburg arch system occupies the southern part of the Volga-Ural regional high and is separated from the Tatar arch by the Melekess depression and the abyssally faulted Sernovodsko-Abdulino aulacogen. The Zhigulevsko-Pugachev and Orenburg arch system is bounded on the south by the northern border of the deep Peri-Caspian depression and the Buzuluk depression. On the east, it is bounded by the Ufa-Orenburg monocline (fig. 2), which is separated from the southern Ural foredeep by an abyssal fault system. On the west, the deep-seated Ryazan-Saratov depression separates the arch system from the lower Volga monocline, which forms the western border of the Peri-Caspian depression.

PROTEROZOIC Y AND Z (RIPHEAN-VENDIAN) STRUCTURAL STAGE

Proterozoic Y and Z sedimentary rocks are as much as 10,000 m (32,500 ft) thick and, to a great extent, infill the deep aulacogen trough system within the basement (Kazansko-Kirov and Sernovodsko-Abdulino aulacogens, Upper Kama, Buzuluk, and Ryazan-Saratov depressions, and the Birsk saddle) (figs. 5 and 6). A regional unconformity is present between the Riphean and Vendian sedimentary rocks; consequently, two independent structural substages are recognized. The dominant regional structures in the Proterozoic Y and Z beds are rounded anticlines, separated by basins or troughs; the outlines of these anticlines are less sharply defined than those of anticlines in the Archean basement.

MIDDLE TO UPPER DEVONIAN (EIFELIAN-FRASNIAN) STRUCTURAL STAGE

The general structure of this Devonian clastic interval does not differ substantially from that of the underlying basement surface. These clastic beds are thinner or absent altogether on some structural highs. Depositional thinning on the Kukmor high of the Tatar arch results in the Al'met'yev high's being structurally higher than the Kukmor high for the Devonian beds; the relationship is reversed for the basement surface. Deposition of a great thickness of Devonian clastic rocks in the Kazansko-Kirov aulacogen led to almost complete infilling of this trough. On the eastern edge of the trough, a lava flow present in the lower Frasnian rocks suggests possible renewed faulting along the borders of the aulacogen. The Tatar arch has a closure of 160 m (520 ft) on the top of the Eifelian-Frasnian structural stage; this closure is 50 to 80 m (163–260 ft) less than that on the surface of the basement. In this structural stage, the Sernovodsko-Abdulino aulacogen and the Orenburg arch become buried structures beneath the monoclinal southeastern flank of the platform.

UPPER DEVONIAN–LOWER CARBONIFEROUS (FAMENNIAN-TOURNAISIAN) STRUCTURAL STAGE

Sedimentary processes, mainly carbonate mound or reef buildups, become significant in the development of the structural forms of the Famennian-Tournaisian. The Kamsko-Kinel trough system, which extends about 900 km (560 mi) and is from 20 to 90 km (13–56 mi) wide, formed at this time (fig. 3). The pre-Mendym (Domanik and older) structure generally does not reflect either the troughs or the bordering highs of the Kamsko-Kinel system. However, structural closure increases abruptly at the top of the Devonian owing to draping of the overlying beds, which is related to reef growth near the trough borders and thinner (uncompensated) deposition within the troughs. During the upper part of this structural stage (Tournaisian), draping of beds over the Devonian reef buildups caused a general lessening of relief; this lessening continued into the overlying structural stage and resulted in a tendency to return to structural elements more like those of the earlier Eifelian-Frasnian or Middle to Upper Devonian structural stage.

CARBONIFEROUS–LOWER PERMIAN STRUCTURAL STAGE

Draped structures continue into the lower Viséan clastic beds, but, during middle to late Viséan time, surface evidence of the Kamsko-Kinel trough system and associated carbonate buildups disappeared owing to depositional processes. After this time, the main tectonic elements again became dominant but tended toward greater complexity. The main structural highs on the Tatar, Perm-Bashkir, Zhigulevsko-Pugachev, and Orenburg arches and the Birsk saddle remained clearly defined. During Early Permian time, a thick, narrowly defined belt of reef growth developed along the eastern and southern borders of the Russian Platform, the result being a narrow band of reef structures adjacent to the Ural foredeep and the Peri-Caspian depression.

UPPER PERMIAN AND MESOZOIC-CENOZOIC STRUCTURAL STAGES

During the Upper Permian and Mesozoic-Cenozoic structural stages, a large zone of highs

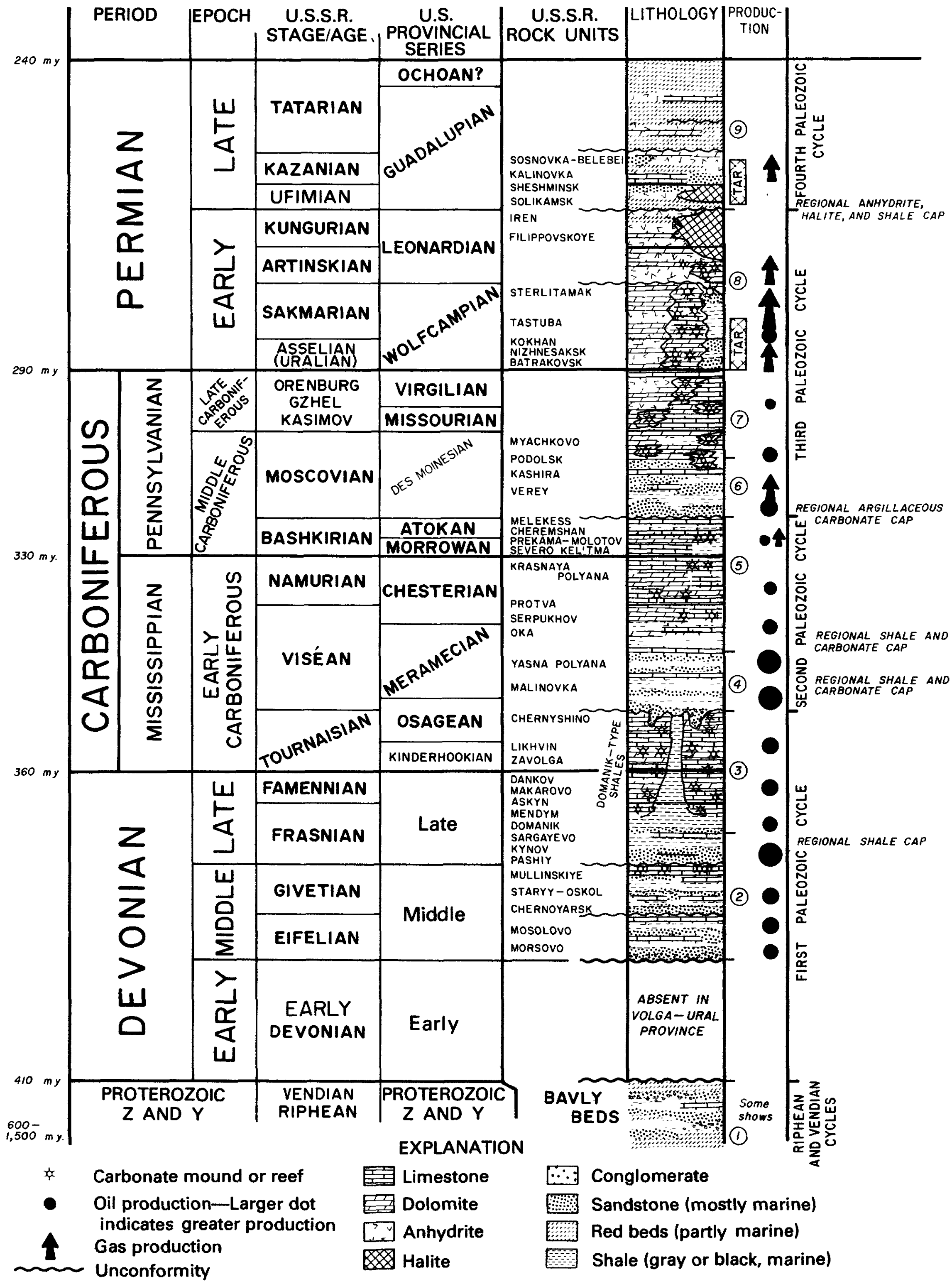

FIGURE 5.–General lithologic facies, productive intervals, and regional sedimentary cycles of the Volga-Ural province.

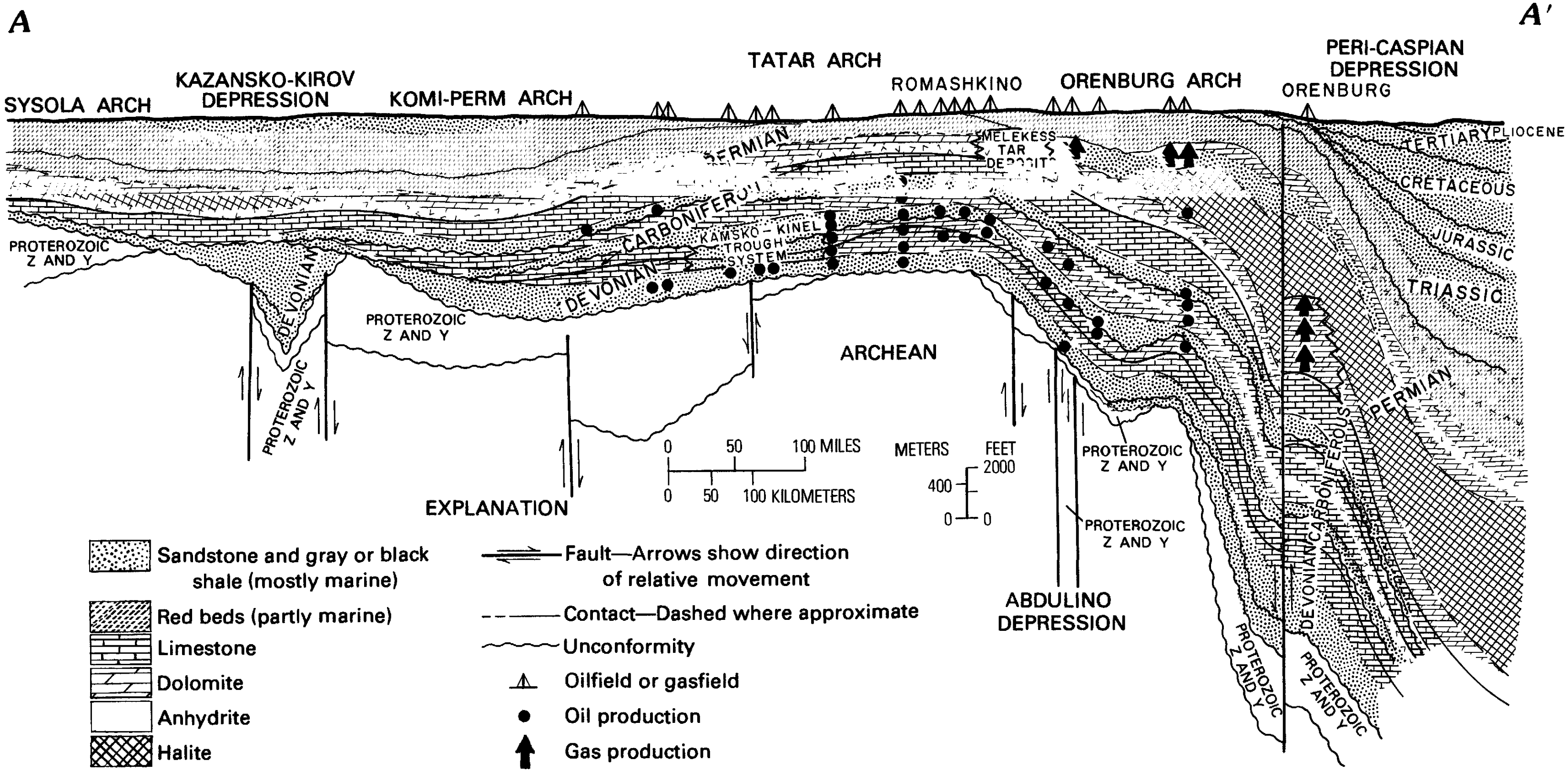

FIGURE 6.—North-south generalized cross section A–A′ from the Sysola arch on the southeastern flank of the Baltic shield to the Peri-Caspian depression. Location of cross section shown on figure 2.

developed along the eastern flank of the Perm-Bashkir arch and extended southwest across the Birsk saddle and the Belebey high of the Tatar arch to merge with a similar zone of highs extending northwest across the Al'met'yev and Kukmor highs of the Tatar arch; within this arcuate system of highs is the Upper Kama depression. During the Mesozoic, the northwestern part of the Volga-Ural regional high subsided and became part of a depositional basin. The Buzuluk depression is particularly well defined in the Mesozoic systems. The Zhigulevsko-Pugachev arch became highly elevated and was eroded down to Middle Carboniferous beds.

STRATIGRAPHY

The sedimentary history of the Russian Platform is closely related to its structural stages. Soviet geologists subdivide the stratigraphic section into a correlation framework of series and stages similar but not identical to those used in North America (fig. 5). Sedimentary rock sequences of Proterozoic Y and Z, Devonian, Carboniferous, Permian, Mesozoic, and Cenozoic age make up the sedimentary cover on the platform (figs. 6, 7, and 8). The total thickness of the post-Proterozoic sedimentary cover ranges from about 1,500 m (4,875 ft) on the Tatar arch to more than 8,000 m (25,000 ft) along the northern border of the Peri-Caspian depression (fig. 8). Cambrian through Silurian rocks are not reported in the Volga-Ural province, although Ordovician and Silurian beds have been recognized in the complexly folded and faulted Ural foredeep a short distance to the east, and Lower Cambrian clastic rocks are present in the western part of the platform. Middle Devonian through Permian strata occur in more or less continuous depositional sequence, interrupted at several horizons by disconformities of variable extent. Upper Permian rocks make up the surface exposures over most of the province, and, except for the southern border of the region adjacent to the Peri-Caspian depression, Mesozoic rocks are absent. Tertiary rocks are present only in a narrow belt along the Volga River valley in the southwestern part of the province, where Pliocene continental beds of conglomerate, sandstone, and shale as thick as about 500 m (1,625 ft) are preserved. Most of the platform was emergent in early Paleozoic time and again during Mesozoic and Cenozoic time.

Maksimov and others (1970) recognize seven main sedimentation cycles in the Volga-Ural province: Riphean, Vendian, first Paleozoic, second Paleozoic, third Paleozoic, fourth Paleozoic, and Alpine (figs. 5, 6, and 7 show the elements of this subdivision). The general lithologic characteristics and thickness variations of the Paleozoic cycles are shown on regional cross sections (figs. 6 and 7) compiled from numerous Soviet literature sources, including regional thickness and facies maps, geologic analyses of local areas, and oilfield data. In general, the cycles are separated by unconformities of regional extent and are related to transgressive-regressive episodes of the Paleozoic seaway. The lower part of each cycle consists mainly of near-shore marine sandstone and shale, which grade upward to predominantly marine carbonate beds commonly containing reef or organic mound buildups. Evaporites in varying amounts are present in each cycle and are particularly prominent at the close of the third Paleozoic cycle (Kungur halite beds). Continental and marine red beds, evaporites, dolomite, and alluvial conglomerate beds dominate the uppermost cycle.

RIPHEAN (LOWER BAVLY) CYCLE

Riphean beds are from 500 to more than 5,000 m (1,625 to more than 16,250 ft) thick and consist primarily of terrigenous, coarse, clastic continental sandstone, shale, and conglomerate beds deposited directly on crystalline basement, mainly in elongate grabenlike depressions (aulacogens), and some marine deposits in the upper part.

VENDIAN (UPPER BAVLY) CYCLE

Vendian beds are as much as 3,000 m (9,750 ft) thick and are much more widespread than the underlying Riphean sedimentary rocks. Basal Vendian beds are coarse continental and marine clastic sediments that unconformably overlie Riphean beds. The lower Vendian grades upward to a sequence of marine shallow-water shale and sandstone that contains some carbonate and phosphorite beds.

PALEOZOIC CYCLES

FIRST (MIDDLE DEVONIAN-TOURNAISIAN)

Rocks of the first Paleozoic cycle are 300 to more than 1,000 m (975 to more than 3,250 ft) thick and represent a major transgressive marine cycle that spread westward from the Ural eugeosyncline and,

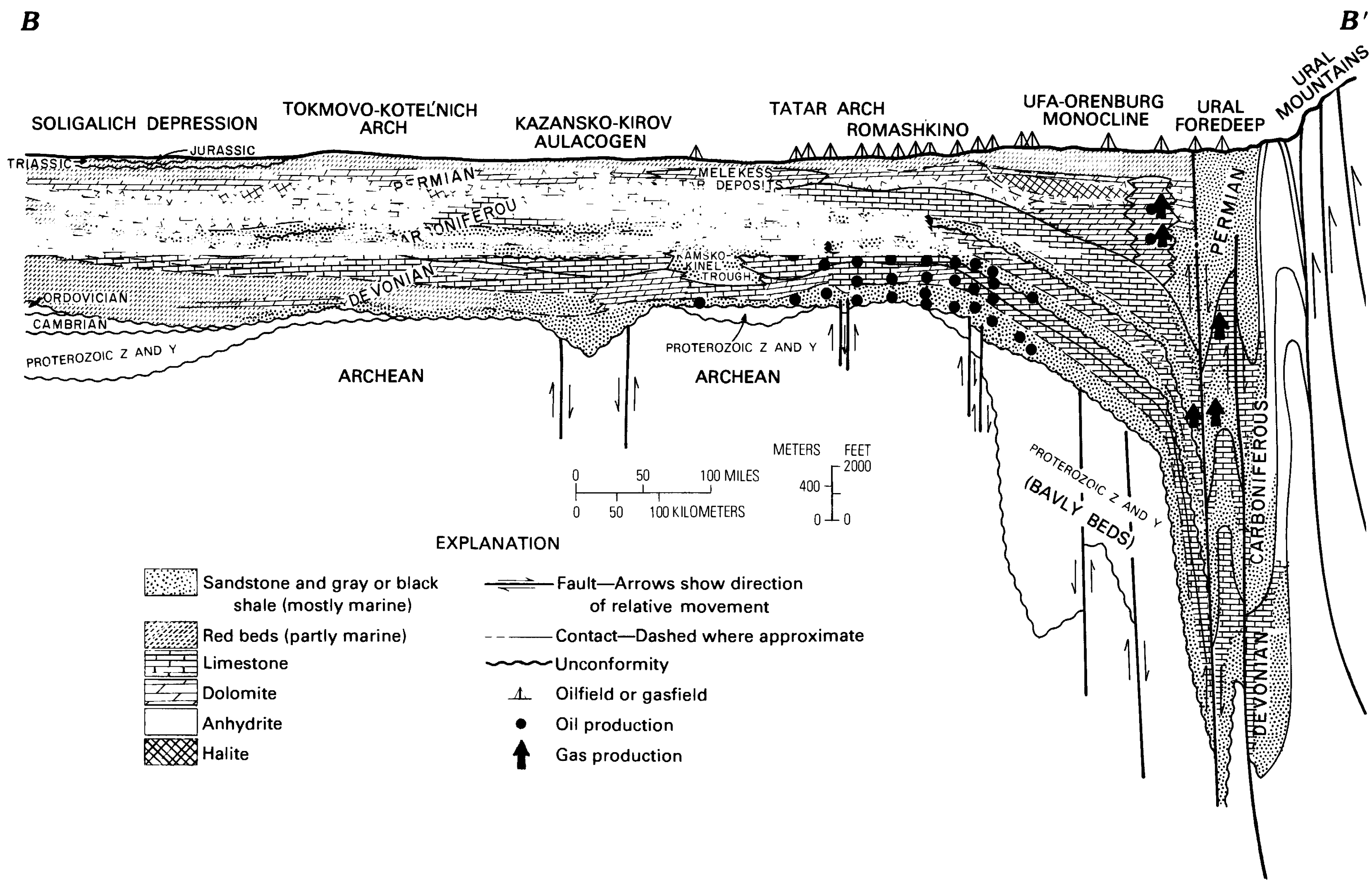

FIGURE 7.—Northwest-southeast generalized cross section B–B′ from the Soligalich depression to the Ural Mountains. Location of cross section shown on figure 2.

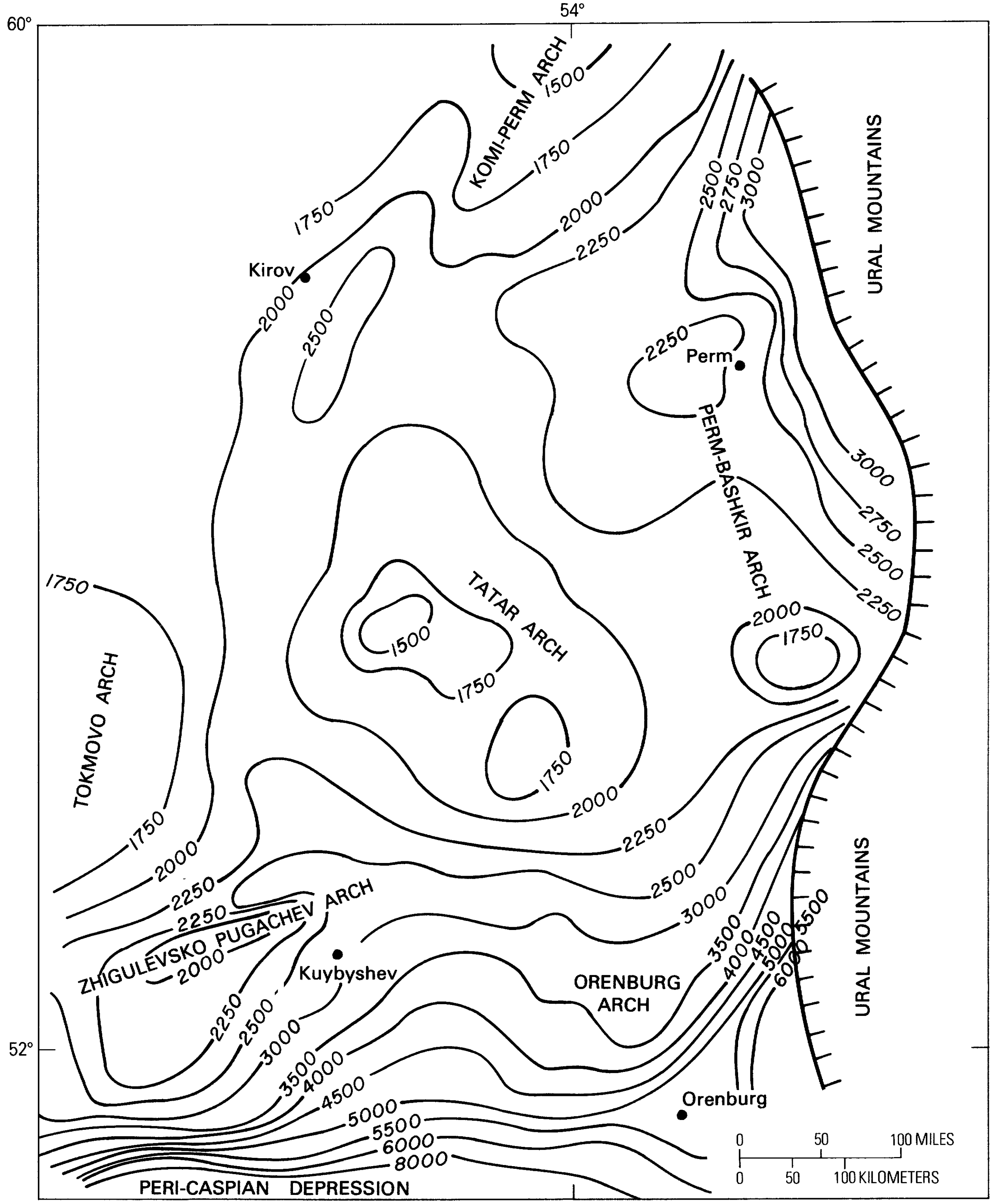

FIGURE 8.—Isopach map of post-Proterozoic sedimentary cover. Thickness contours in meters.

by the end of the cycle, had covered the entire Russian Platform. The lower part represents the Devonian clastic beds of Middle and earliest Late Devonian age. These beds, which contain the major petroleum deposits of the province, grade upward to a predominantly reef and mound carbonate section of latest Devonian (Famennian) and earliest Carboniferous (Tournaisian) age. The cycle closed with a marine regression and the emergence of the platform when erosion, karstification, and probably early dolomitization of the carbonate beds occurred prior to deposition of the lower Viséan clastic beds of the succeeding cycle.

The middle and upper parts of this cycle contain the highly bituminous Domanik facies, a restricted marine black shale, marl, and argillaceous limestone facies that was deposited primarily in the deeper water Kamsko-Kinel troughs of the shelf. The unique Kamsko-Kinel trough system comprises a grouping of narrow, interconnected, deeper water troughs that persisted between late Frasnian and Tournaisian time. The origin of the trough system is thought to be related to a combination of structural and sedimentary processes involving block faulting of the platform basement followed by deposition of an extensive shelf carbonate reef and mound facies that reached its greatest development along the trough borders.

SECOND (VISÉAN, NAMURIAN, AND BASHKIRIAN)

The second Paleozoic cycle comprises a 50- to about 800-m (160 to 2,600 ft) sequence of terrigenous clastic deposits of early and middle Viséan Age, followed by fossiliferous marine carbonate rocks of late Viséan, Namurian, and Bashkirian Age. The basal Viséan beds are continental and near-shore marine sandstone and shale that represent the initial transgressive deposits of the depositional cycle. These deposits fill the Kamsko-Kinel troughs and the irregularities of the underlying channeled and karstified erosion surface on the Tournaisian carbonate beds. Viséan clastic beds grade upward to marine carbonate and shale units and finally to widespread fossiliferous marine carbonate beds of Namurian and Bashkirian Age that covered the entire platform.

THIRD (LOWER MOSCOVIAN THROUGH LOWER PERMIAN)

The third Paleozoic cycle comprises a 1,000- to more than 3,000-m (3,250 to 9,750 ft) sequence of terrigenous clastic deposits of early Moscovian Age followed by fossiliferous marine carbonate beds of late Moscovian, Late Carboniferous, and Early Permian age. Lower Moscovian sandstones are generally fine grained and primarily of marine origin and grade to a relatively narrow band of deltaic and interdeltaic facies west and northwest of the Volga-Ural province. This sequence grades upward to upper Moscovian marine limestone, dolomite, and intertonguing shale beds, which contain porous carbonate mound buildups in places. Rocks of Late Carboniferous age form a blanketlike carbonate deposit 150 to 200 m (490 to 650 ft) thick over much of the Volga-Ural province and mark the maximum transgressive stage of the cycle. These beds are overlain conformably by shallow-water carbonate rocks of earliest Permian (Asselian) age. Permian reef growth was initiated at this time in a relatively continuous belt along the eastern and southern borders of the platform, adjacent to the deepwater Ural foredeep and the Peri-Caspian depression. Reef growth continued along this band during the remainder of the third Paleozoic cycle of deposition, and the main part of the Volga-Ural province was covered by back-reef carbonate, evaporite, and fine clastic beds. The reef bodies are primarily limestone, dolomitized to varying degrees and ranging up to several hundred meters thick. More than 2,000 m (6,500 ft) of deepwater clastic bituminous shale, sandstone, and siltstone are deposited in the Ural foredeep, which was actively subsiding at this time during the early growth stages of the Ural Mountains chain.

FOURTH (UPPER LOWER PERMIAN AND UPPER PERMIAN)

The fourth Paleozoic cycle reflects the maximum growth of the Ural Mountains and the associated Ural foredeep. At the close of the third Paleozoic cycle, evaporite deposits consisting of gypsum or anhydrite and some dolomite formed on the main platform, and thick deposits of halite accumulated in the Peri-Caspian depression and the southern part of the Ural foredeep. This event was followed by marine transgression and deposition on the platform of limestone and dolomite interbedded with some gypsum (Ufimian beds). These strata intertongue eastward with clastic sedimentary rocks from the Ural Mountains, which began to uplift vigorously near the close of the third Paleozoic cycle. During the remainder of the fourth Paleozoic cycle, continental coarse-grained clastic deposits from the Ural Mountain chain became increasingly dominant and continued until complete withdrawal of marine conditions in latest Permian time. Parts of the Upper Permian beds are removed by post-Permian erosion. The total thickness of the fourth Paleozoic cycle sequence ranges from less than 500 m (1,625 ft) on the Tatar arch to more than 1,500 m (4,875 ft) in the southern part of the Ural foredeep and the Peri-Caspian depression.

ALPINE CYCLE (MESOZOIC)

The Alpine cycle was apparently a time of emergence of the platform area. Mesozoic rocks are not present in the main area of the Volga-Ural province and, according to most Soviet authors, were never deposited there. Continental red beds of Triassic age and mixed continental and marine clastic beds of Jurassic and Cretaceous age are present in the Peri-Caspian depression and in the southwestern, western, and northern parts of the Russian Platform. Rocks of this age, however, are generally absent in the Volga-Ural province (figs. 6 and 7).

Lower and middle Tertiary rocks are not reported in the Volga-Ural province, and there is no evidence to show that they were ever deposited there. Continental clastic beds of Pliocene age 100 to 400 m (325 to 1,300 ft) thick are present along the Volga River valley in the southwestern part of the province.

PETROLEUM GEOLOGY

INTRODUCTION

Maksimov and others (1970) list 525 fields in the Volga-Ural province (480 oil or oil and gas and 45 gas) and 1,450 recognized oil and gas pools (425 in Devonian rocks, 890 in Carboniferous, and 135 in Permian). Since the publication of the Maksimov report, a large number of additional fields or pools have been discovered, notably in the Ural foredeep and on the northern border of the Peri-Caspian depression. Bol'shakov (1975) reports a total of 1,900 oil and gas pools in the province. Many of the fields are small, but several are giants. Halbouty (1970) lists seven giant oilfields (more than 500 million barrels of ultimately recoverable oil), totaling about 28 billion barrels of recoverable oil, and two giant gasfields, of which Orenburg (now reported as about 70 trillion cubic feet) is the largest. Most of the fields are located on anticlinal structures (either tectonic or draping over reef buildups), but, according to Shaykhutdinov (1975), almost half the pools on the Tatar arch are stratigraphic traps. Many of the fields contain multiple pays, and some produce from all the main productive intervals of the province, particularly in the Kuybyshev-Orenburg area. The province is in a mature stage of exploration and production, and increasing emphasis is being placed on exploring for both clastic and carbonate stratigraphic trap prospects, which were not emphasized during the structural stage of exploration drilling. These efforts, aided by refined methods of seismic interpretation, have resulted in the discovery of many fields of both the stratigraphic and the structural type in recent years. A large percentage of the known reserves of the province is depleted, but Soviet geologists have identified a significant number of deeper, more complex prospects that promise to add continuing reserves for some time.

PRODUCTIVE SEQUENCES

Maksimov and others (1970) divide the petroleum-bearing and prospective strata into nine productive sequences (fig. 5) on the basis of stratigraphic characteristics, the nature of the oil and gas occurrence, hydrologic conditions, and the geochemical character of the oil and gas. These productive units fit well with natural stratigraphic facies divisions within the geologic column of the province and are considered separately in the following discussion.

PROTEROZOIC Y AND Z (BAVLY BEDS) SECTION

Soviet geologists report that the Bavly beds are not highly metamorphosed and contain a significant thickness of porous marine and continental sandstone beds that have good reservoir qualities (Stankevich and others, 1977; Suleymanov and Bazev, 1974). The Bavly beds are also highly fractured in some areas. Carbonaceous and bituminous beds, as well as algal carbonate bodies, are also reported. These factors indicate that accumulations of indigenous gas and nonindigenous oil and gas may be found, particularly as deep drilling progresses.

DEVONIAN CLASTIC SECTION

The Devonian clastic section of Middle and earliest Late Devonian age has been the main oil objective in the Volga-Ural province. These beds contain the major recoverable oil accumulations on the Tatar arch, which includes the Romashkino, Novoyelkhov-Aktash, Tuymazy, Shkapovo, Mukhanovo, and Yarino-Kenennyy oilfields, among the largest in the province. Significant production from these beds (mainly oil) is also present in all other parts of the province as well. More than 200 oilfields produce from the Devonian clastic reservoirs, and 9 main productive sandstone or siltstone horizons are reported. The main pays occur in the uppermost Givetian and lower Frasnian sequence; almost half of the Devonian pools of the Volga-Ural province are in the lower Frasnian clastic section. The Devonian clastic sandstone, shale, and minor limestone interval occurs in a north-south belt extending across the central part of the province. The greatest thickness is in the northern and southern parts of the region (fig. 9).

The reservoirs are marine near-shore sandstone and siltstone derived from a west-to-northwest source area. Net sandstone content is highest to the north and northwest–175 to 300 m (570 to 975 ft). A belt of sandstone facies also extends from north to south across the southern crest of the Tatar arch. Sandstone intervals pinch out to the west along the eastern flank of the northern crest of the Tatar arch and the Komi-Perm arch and also to the east along the border of the platform. Porosity and permeability are highly variable in the clastic Devonian reservoirs, ranging from very low in siltstone reservoirs to as much as 25 to 30 percent and 3 to 4 darcies in the cleaner and better sorted quartz sandstone reservoirs. Fracturing is important in increasing reservoir quality in many fields, particularly those controlled partly by fault traps.

The sandstone beds of the Devonian clastic section are interbedded with dark near-shore marine and lagoonal dark shale beds, which have variable contents of organic carbon. The organic carbon content increases upward in the section, reaching an overall maximum source-rock quality in the uppermost Givetian and lower Frasnian when the Domanik facies began to be deposited in the more depressed areas of the shelf (Ronov, 1958). Intertonguing and interbedding of the dark organic shale beds with individual sandstone reservoir bodies, many of which are lensing in nature, have provided an efficient interrelationship for the generation and preservation of petroleum accumulations.

Most of the important Devonian clastic oilfields are located on structural closures, mainly anticlinal, but some are also partly fault controlled. Numerous "lithologic" (stratigraphic) accumulations have been found during field development drilling, mainly on the flanks of the larger structures (Bol'shakov, 1975). More than 300 pools of this type are reported. The lower Frasnian shale and lensing sandstone interval provides a regional impermeable seal for most structural accumulations, and individual dark shale units of lesser extent provide local cap rock beds for stratigraphic and structural pools.

Possible analogs to the Devonian clastic section of the Volga-Ural province include the productive Chesterian (Upper Mississippian) sandstone and shale sequence of the northern Midwestern United States (Illinois basin and adjacent area), the Upper Devonian clastic section of the northern Appalachians ("Bradford" and other sands), and beds of the Simpson Group (Middle Ordovician) of the midcontinent region. Of these three, the Chesterian sequence is probably the best analog with respect to paleogeography, the nature of the sandstone facies and its source, and the interrelation with indigenous source-rock facies.

UPPER DEVONIAN AND LOWERMOST CARBONIFEROUS CARBONATE SECTION

The Upper Devonian and lowermost Carboniferous carbonate interval contains the Volga-Ural province's most widespread and fully developed reef and organic carbonate facies, which attains a thickness of more than 500 m (1,625 ft) in all the paleostructurally high areas of the province. At least 150 fields and 10 or more reservoir intervals from these beds are productive, although the total amount of oil discovered is considerably less than that found in the Devonian clastic section. Most of the oil pools of this interval are in the Tournaisian reefal and organic mound carbonate section, especially its upper part, which, in most places, is considerably thicker than the underlying Upper Devonian carbonate beds (Ovanesov and others, 1972). Most pools found thusfar are in structural traps in reservoirs where primary intercrystalline and skeletal porosity is accompanied by fracture and vuggy porosity. Porosity, generally not high, averages about 8 to 10 percent. Excellent source-rock beds of the Domanik facies are present in the Kamsko-Kinel trough system that surrounds all of the main carbonate buildup belts (figs. 3, 6, and 7). These beds are highly bituminous and have an organic carbon content of as much as 5 percent or more. The Domanik facies beds, however, generally do not intertongue widely with the car-

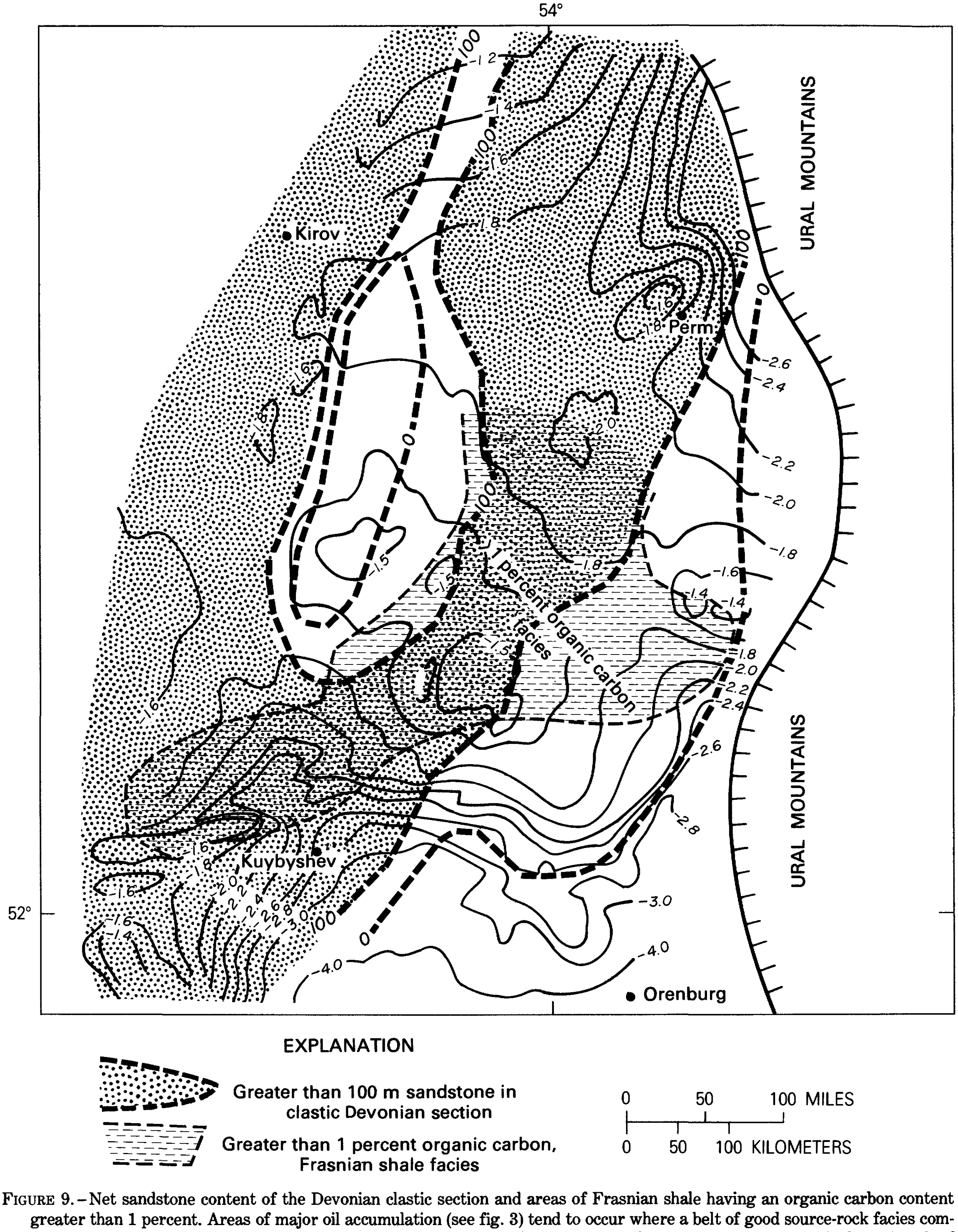

FIGURE 9.–Net sandstone content of the Devonian clastic section and areas of Frasnian shale having an organic carbon content greater than 1 percent. Areas of major oil accumulation (see fig. 3) tend to occur where a belt of good source-rock facies combines with a higher sandstone content. A western area having a sandstone content of more than 100 m is outside the main belt of good source rocks and contains no oilfields. The structurally highest area of the northwestern side of the Tatar arch has low sandstone and source-rock contents and contains no oilfields. Contours in kilometers.

bonate buildup facies and thus may not be as effective a source-rock facies for these carbonate reservoirs as they are for the underlying clastic beds.

In general, Upper Devonian–Tournaisian carbonate beds have not yet been of primary importance as petroleum reservoirs in the province. However, in the poststructural phase of exploration, greater attention is being paid to the isolated nature of some reefal porosity; some success is apparent in infill drilling on larger structures (Shikhov and others, 1976; Yarullin and Yunusov, 1976.)

VISÉAN CLASTIC SECTION

At least 10 or 12 regionally productive sandstone intervals are present in the lower Viséan section (Malinovka and Yasna Polyana beds) of the Volga-Ural province. More than 250 fields produce from Viséan sandstone and siltstone reservoirs distributed across all of the region; according to Maksimov and others (1970), this interval contains the greatest number of economically extractable oil and gas deposits in the province. The Viséan clastic section ranges from 100 to more than 400 m (325 to more than 1,300 ft) thick; the thickest section is present within the Kamsko-Kinel trough system, which, in its final phase of development, was filled with Viséan clastic deposits.

Viséan clastic reservoirs, in general, are highly lensing, discontinuous, elongate quartzose sandstone bodies of highly variable thickness and extent. Many are sinuous channel sandstones, particularly well developed within the Kamsko-Kinel trough areas, which contain many of the oilfields producing from these beds (Tsotsur, 1974). Many of the reservoirs are classed as "stray sands," and well density is important for adequate exploration (Baymukhametov, 1976). Porosity and permeability characteristics are highly variable, ranging from very low in siltstone reservoirs to as much as 35 to 40 percent and 4 to 5 darcies, respectively, in coarser sandstone reservoirs. Lower Viséan sandstone reservoirs in the Kuybyshev region have average porosities of about 22 percent and average permeabilities of about 650 millidarcies (Aleksin and others, 1974).

Dark bituminous shales of good source-rock quality are present in the Viséan clastic section; total thickness generally increases from west to east across the Volga-Ural province. The organic carbon content of these beds, however, is highest within a northeast-southwest belt that passes approximately across the central part of the Volga-Ural province. The Viséan oilfields are concentrated in this northeast-southwest belt.

Many of the oilfields producing from the Viséan clastic section were discovered on structural closures, mostly anticlines or domes, mapped on Permian strata at the surface or on shallow seismic horizons. Traps formed by draping over Upper Devonian–Tournaisian reefs are widespread. The Arlan field, the second largest field in the province, is of this type. Lithologic or stratigraphic trapping is involved in most accumulations, and, because of the consistent lensing nature of almost all the sand bodies, many primarily stratigraphic trap fields have been found. Many are relatively small, but, according to Soviet geologists, significant reserves are now being added by the current emphasis on delineating isolated sandstone reservoir bodies on the flanks of large structures or along sand trends within the Kamsko-Kinel troughs. The clay and dense carbonate beds of the uppermost Viséan clastic section form a regional impermeable seal that extends across all of the province.

The Viséan clastic section is comparable to the productive Chesterian sandstone section of the north-central United States, which contains numerous petroleum accumulations in the deltaic and near-shore marine lensing and sinuate sandstone bodies interbedded with dark marine shale facies. Source areas for the Viséan clastic and the Chesterian quartzose sandstones are comparable; both cases involve reworking and redeposition of previously deposited sands by streams flowing off the margins of a cratonic continental mass into an advancing marine seaway.

LOWER AND MIDDLE CARBONIFEROUS CARBONATE SECTION

The carbonate Lower and Middle Carboniferous section is about 100 m (325 ft) thick in the western part of the Volga-Ural province and thickens uniformly eastward to about 500 m (1,625 ft) on the borders of the Ural foredeep and the Peri-Caspian depression.

The upper Viséan and Namurian carbonate beds are mainly low-porosity limestones; few significant productive horizons have been delineated. The Bashkirian carbonate beds, however, are more porous and are characterized by a much more variable facies or by organic carbonate buildups and dolomitized sectors. Potential source rocks are not reported in this section, however, and, thusfar, the section has been of secondary importance in number of oilfields (about 100) and volume of oil reserves found.

MOSCOVIAN CLASTIC SECTION

The Moscovian clastic section is thickest (200 to 400 m or 650 to 1,300 ft) in the western and southwestern parts of the Volga-Ural province, generally outside the area of petroleum occurrence. These beds thin uniformly eastward to less than 50 m (160 ft) along the eastern border of the province where the section grades into a dark marine shale facies. About 100 oilfields produce from these sandstone and siltstone reservoirs, which are scattered throughout the province. Most of the oil accumulations occur in the eastern part of the clastic facies belt, where the sandstone beds are generally thin, fine grained, and low in porosity. For this reason, the Moscovian clastic section is of secondary importance as an exploratory objective.

The dark-gray marine shale beds, which enclose the Moscovian quartzose sandstone reservoirs, are the most likely petroleum source beds for this section, if burial depth is sufficient. Specific source-rock data, however, are lacking.

Most of the fields are on structures, but the lensing and spotty distribution of the sandstone reservoir bodies necessitate a strong stratigraphic trap approach in exploration procedures. The relatively thick, impermeable shale section enclosing the sandstone bodies forms a natural seal for hydrocarbons.

MIDDLE AND UPPER CARBONIFEROUS CARBONATE SECTION

Only a few scattered fields produce from Middle and Upper Carboniferous carbonate beds. Upper Moscovian reservoirs are porous (in places cavernous) fossiliferous limestones and some dolomite intervals. Except for the underlying gray marine shale and argillaceous carbonate beds of the Moscovian clastic section, rocks of suitable source-rock quality apparently are not present in association with these beds and may not have been buried deeply enough for organic matter to have matured. These factors, plus the absence of suitable cap rocks within or above the section, may account for the lack of significant hydrocarbon production from these beds.

LOWER PERMIAN CARBONATE-EVAPORITE SECTION

Oil and gas production from the Lower Permian carbonate-evaporite unit is entirely from reefal and other carbonate reservoirs that are developed along the southeastern and southern margins of the Volga-Ural province. More than 100 gasfields or gas-condensate fields and a few oilfields have been discovered, mainly in reefs along the eastern edge of the platform and in dolomite reservoirs of the Zhigulevsko-Pugachev and Orenburg arches.

Porosity and permeability in Lower Permian carbonate reservoirs are highly variable, ranging from very low to as much as 30 to 35 percent and 1 to 2 darcies, respectively. Some of the reef reservoirs along the platform edge are dolomite beds characterized by very low porosity and permeability, but the net productive section is often high (as much as 600 m or 2,000 ft), and fracture permeability is very important. Reservoirs in the Zhigulevsko-Pugachev arch area are mainly fine-to medium-grained crystalline dolomites in which porosity and permeability are variable. The lower part of the Melekess tar deposits occurs in similar dolomite reservoirs and appears to have accumulated in pinchout or permeability traps over a paleostructural thinning trend that passes southwest-northeast across the area (figs. 6, 7, and 10).

Permian beds of good source-rock quality apparently are not present on the platform, but a thick section (several hundred meters) of bituminous marine shale is present in the Ural foredeep east of the Lower Permian reef belt (fig. 10). These beds, which also may be present at depth in the Peri-Caspian depression, appear to be the most likely indigenous source-rock facies for Permian hydrocarbons. According to Svetlakova and Kopytchenko (1978), however, most hydrocarbon accumulations in Permian reservoirs probably originated by upward migration from Devonian or Carboniferous source-rock beds.

Most of the Permian oilfields and gasfields on the Orenburg arch are on local structures mapped in shallow Permian beds. Those along the platform edge are mainly in reef structures, some of which are associated with post-reef vertical faulting and some of which are thrust faulted. The Orenburg gasfield, the largest in the province (70 trillion cubic feet) and clearly one of the world's supergiants, is located on a large faulted anticlinal fold. The Kungurian halite and gypsum-anhydrite facies regionally overlies the productive carbonate

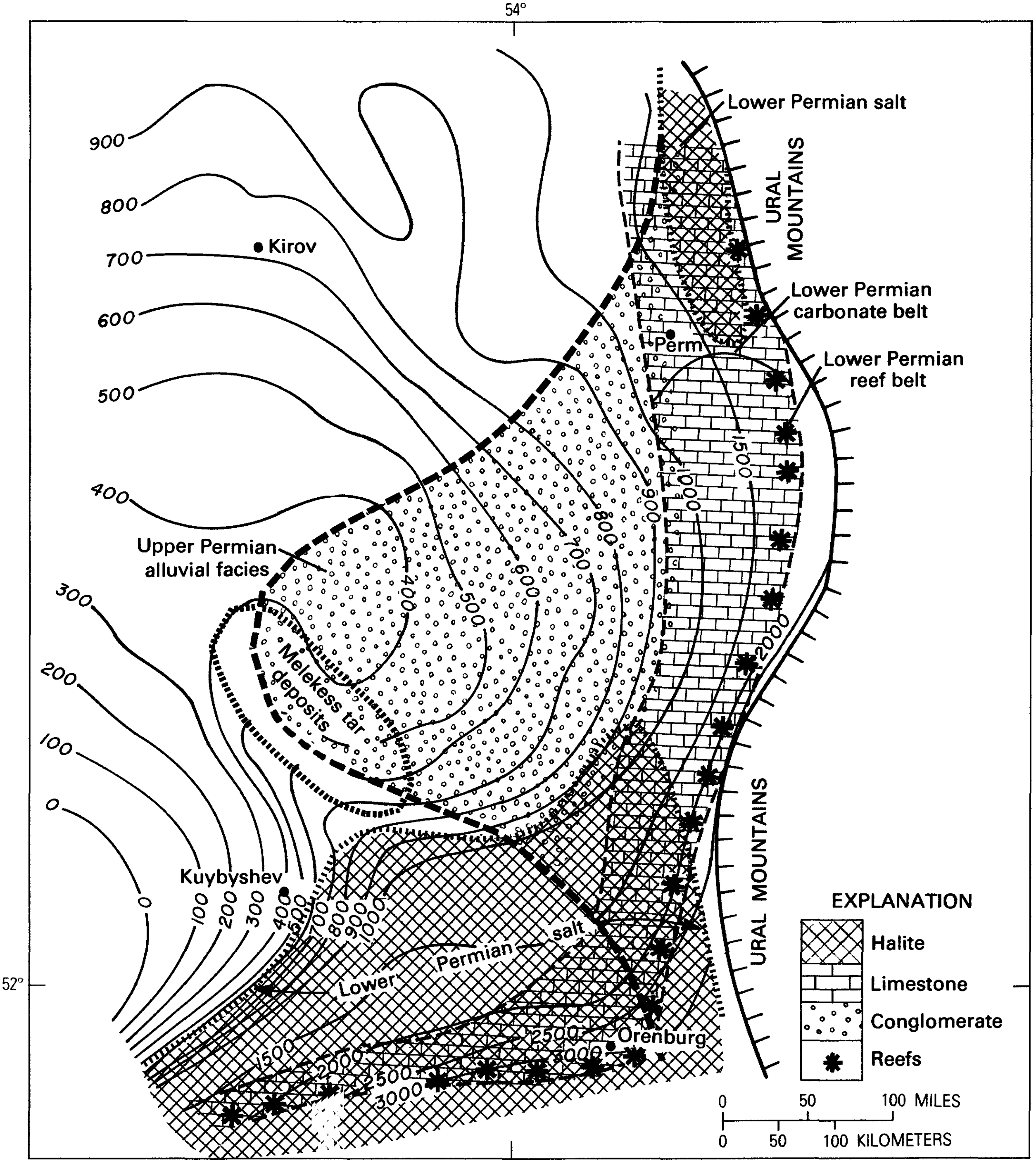

FIGURE 10.—Isopach map showing marine facies patterns in Permian beds in the Volga-Ural province. Thickness contours in meters.

and carbonate reef section to form an impermeable cap rock facies over most of the province.

The Lower Permian productive carbonate section of the Volga-Ural province is closely similar to the productive Upper Permian reef section of the West Texas–New Mexico Permian basin. Both areas contain thick, narrowly defined shelf-margin reef buildups of similar organic content as much as several hundred meters thick. An important difference is that the West Texas–New Mexico Permian basin reefs are closely associated with a marine source-rock facies that probably contains much more organic carbon than the corresponding facies in the Volga-Ural province. Probably for this reason and because the Lower Permian beds have been buried to greater depths in much of the Volga-Ural province, gas and gas-condensate accumulations dominate there, whereas oil accumulations dominate in the West Texas–New Mexico Permian basin.

UPPER PERMIAN CLASTIC-CARBONATE SECTION

Production (mainly of gas and minor oil or condensate) from this interval is confined to the southern part of the province, mainly the Zhigulevsko-Pugachev and Orenburg arches and the Sernovodsko-Abdulino aulacogen. According to Maksimov and others (1970), three productive intervals are present in the Upper Permian section. The two lower intervals contain sandstone and siltstone (and minor dolomite) reservoirs of Ufimian Age, and the upper, more widespread interval contains dolomite reservoirs of early Kazanian Age. The upper part of the Melekess tar deposits is present a short distance west of the productive area, mainly in clastic reservoirs of this age (Akishev and others, 1974). These accumulations, which make up the greater part of the Melekess deposits, appear to be related to an updip pinchout of porous sandstones, siltstones, and some dolomite beds along the southwestern flank of the Tatar arch. The reservoirs are on the margin of a major Upper Permian deltaic complex (figs. 6, 7, and 10). Comments on the origin of these deposits are also given by Demaison (1977).

Evidence for the presence of petroleum source rocks is lacking in this interval, which is dominated by evaporite deposits and red beds. Some marine shales of possible source-rock quality may be present in the Peri-Caspian depression or in the southern Ural foredeep. The presence of petroleum in Upper Permian beds also may be related to vertical migration of deeper accumulations along fault or fracture systems, as suggested by Svetlakova and Kopytchenko (1978).

GIANT FIELDS

Halbouty (1970) lists seven giant oilfields (more than 0.5 billion barrels ultimate recovery) and two giant gasfields (more than 3.1 trillion cubic feet ultimate recovery) in the Volga-Ural petroleum province (table 1). St. John (1980) lists nine giant oilfields and one giant gasfield (table 1).

TABLE 1.—*Estimated ultimate recoveries from 11 giant oilfields and gasfields in the Volga-Ural petroleum province*

[?, date unknown; –, no data]

Field	Discovery date	Estimated ultimate recovery	
		Halbouty (1970)	St. John (1980)
Oil recovery, in billion barrels			
Romashkino	1948	14.3	12.4
Arlan	1955	4.1	2.8
Aktash-Novoyelkov	1955	3.2	1.3
Tuymazy	1937	2.2	1.9
Shkapovo	1944	1.25	1.25
Kuleshovka	1958	.76	.76
Yarino-Kamennyy	1954	.5	.8
Mukhanovo	?	–	1.55
Kotur-Tepe	?	–	1.46
Gas recovery, in trillion cubic feet			
Orenburg	1966	26.5	26.5
Korobki	1949	3.1	–

Romashkino is a supergiant oilfield almost in the middle of the oily belt that extends along the eastern part of the Russian Platform (fig. 2). The domal structure was first detected by geologic mapping in 1934, and oil was discovered in 1948. For 20 years, between the mid-1950's and the mid-1970's, Romashkino, the largest producing field in the Soviet Union, provided a significant portion of total Soviet production. The field covers an area of 3,600 km^2 (1,400 mi^2), and more than 10,000 wells have been drilled. Cumulative production as of January 1, 1979, was 11.25 billion barrels. Although the field is now in decline, production during 1979 was still 500 million barrels (International Petroleum Encyclopedia, 1980, p. 248).

The stratigraphic section at the Romashkino oilfield is about 2,000 m (6,500 ft) thick. Except for minor unconformities, the section is continuous from Middle Devonian through Permian age (table 2).

The crystalline basement in the area of Romashkino oilfield is a broad, hummocky structural plateau 80 to 90 km (49–56 mi) in diameter and outlined by the −1,640-m (−5,330 ft) structure contour on the basement surface. The highest points on this surface are at about −1,535 m (−4,990 ft), and the lowest are at −1,650 m (−5,360 ft). Closure does not exceed 110 m (360 ft). The Al'met'yev basement high (fig. 3) is the core of the structure. The structure on the top of the Pashiy horizon, which is the main pay zone, has one very broad high, which conforms in position and size to the Al'met'yev basement high. The surface

TABLE 2.—*Stratigraphic section of the Romashkino oilfield in the Volga-Ural petroleum province*

Unit	Thickness, in m (ft)	Lithology	Pay zones	Porosity and permeability	Remarks
		Permian			
Kazan-Tatar	170 (550)	Marine and continental sandstone, clay, marl, and limestone.			
Ufu	40–90 (130–290)	Marine and continental red beds.	Melekess tar deposits.		
Kungur	Absent over field area.				
Sakmar-Artinsk	90–120 (290–390)	Marine dolomite, gypsum, anhydrite, and limestone.	Melekess tar deposits.		
		Middle and Upper Carboniferous			
	350–560 (1,100–1,800)	Marine dolomite and limestone. Marine sandstone, siltstone, and shale.	Carbonate beds		0.902 g/cmffl; 2.11 percent sulfur.
		Lower Carboniferous			
Namurian	80–100 (260–325)	Marine dolomite and limestone	Bashkirian-Namurian limestone (one large pool).		
Visean	175–240 (570–780)	Upper part, marine limestone and dolomite.			
		Lower part, marine sandstone, siltstone, dark-gray shale; coal bearing at base.	Tula B–1 and Bobrikov B–2 (70 pools).		0.876 g/cmffl; gas-oil ratio 11–19.3; formation temperature 20°C.
		Unconformity			
Tournaisian	60–75 (95–245)	Marine limestone, dolomite, and dark-gray shale.	Carbonate beds (72 small pools).		0.870 g/cmffl; formation temperature 20°-25°C.
		Upper Devonian			
Famennian	240–285 (780–930)	Marine limestone, dolomite, and black shale.	Upper Famennian carbonate beds (oil shows).		
Frasnian:					
Upper	75–140 (245–460)	Marine dark-gray limestone			
Middle	55–110 (180–360)	Marine dark-gray to black bituminous limestone, marl, and shale.	Domanik carbonate beds.		
Lower	45–135 (145–490)	Marine sandstone, siltstone, dark-gray shale, and bituminous limestone.	D–0 (many pools).	10–22 percent; 100–800 millidarcies.	
			D–I (many pools). (10–15 m net pay); (as many as 14 reservoir sands).	18–24 percent; 40–2,000 millidarcies.	0.805 g/cmffl Gas-oil ratio 41–54 mffl/mffl; formation temperature 48°C.
		Middle Devonian			
Givetian	55–125 (180–400)	Marine sandstone, gray shale, and minerals.	D–II (8 pools)	20 percent	
			D–III (7 pools)	10–24 percent; 400–1,100 millidarcies.	
			D–IV (3 pools)	21 percent average	
		Unconformity			
		Precambrian			
		Gneisses and migmatites			

of this broad high is differentiated into several smaller highs and lows, which were used as a basis for dividing the field into producing sectors. Closure on the top of the Pashiy is about 60 m (197 ft); the highest point is at −1,435 m (−4,660 ft). Although the structure on the top of the Pashiy corresponds with that on the top of the crystalline basement in form and dimensions, the smaller structures on these surfaces do not seem to correspond. Most of the basement closures are only structural noses on the Pashiy horizon (fig. 11). Also, the basement highs on the cross section (fig. 12) are not directly beneath the highs on the top of the Pashiy horizon. The thicker net pays beneath highs on the top of the Pashiy, as shown on the cross section, suggest that sandstone is thicker at these sites. Consequently, the Pashiy highs may be due in part to differential compaction within the sandstone and shale section.

On the base of the coal-bearing (Bobrikov) formation (lower Viséan), the Romashkino structure is a broad, gentle high complicated by warps having

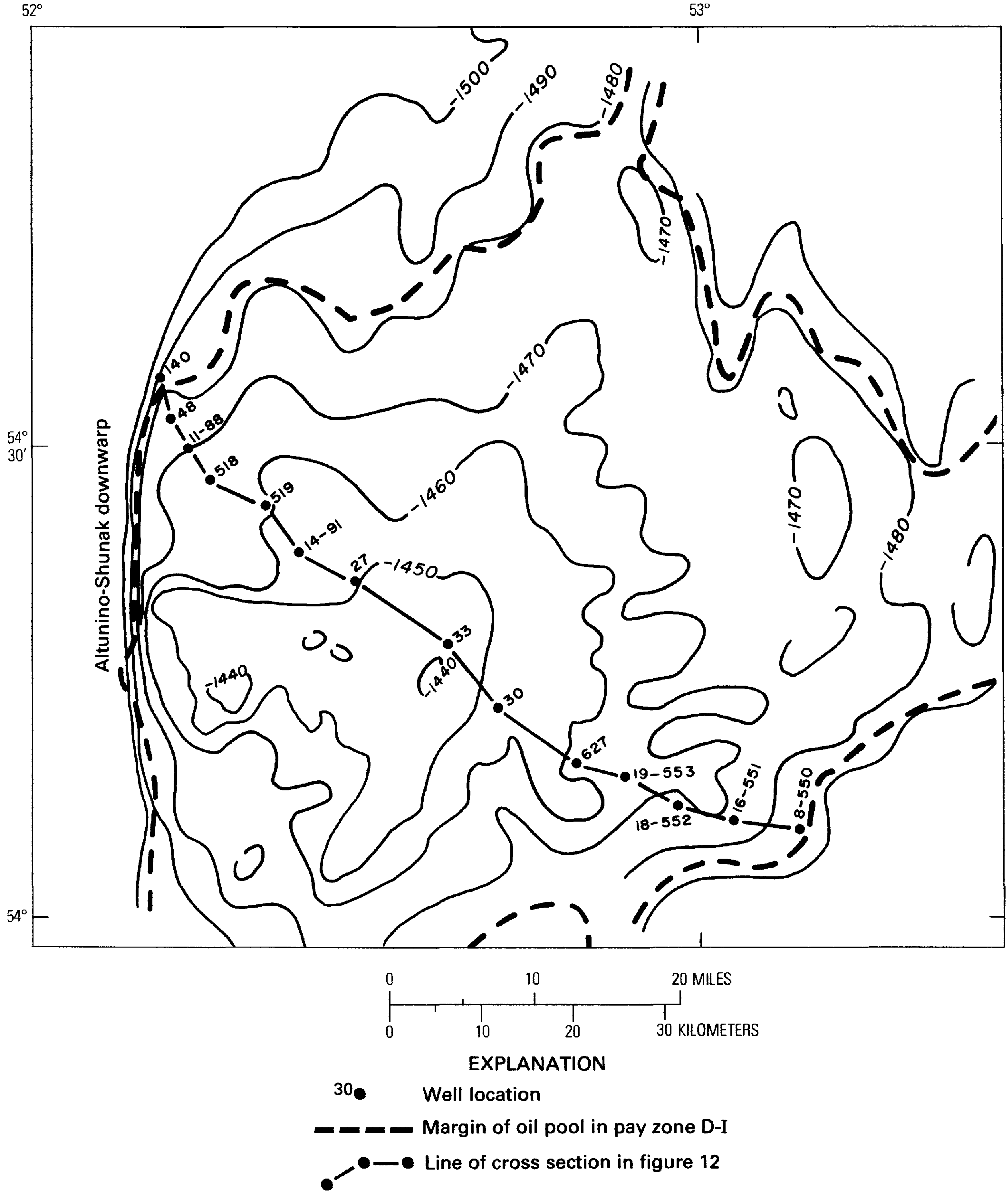

FIGURE 11.–Structural contour map on top of the Pashiy horizon (pay zone D–I) in the Romashkino oilfield. Numbers correspond to those used on the cross section in figure 12.

long dimensions of 1 to 15 km (0.6–8 mi). Although the trends of these small warps are diverse, southeast-northwest trends are predominant. The structures within the coal-bearing formation here

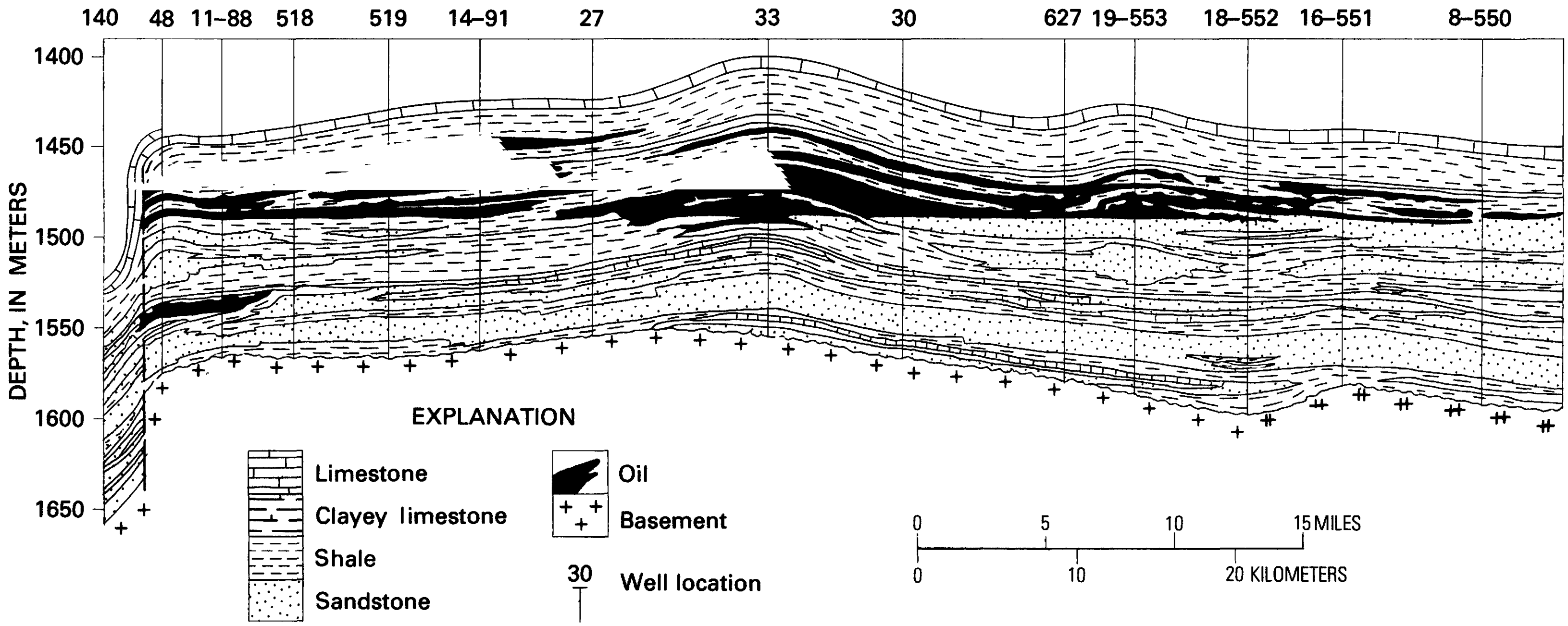

FIGURE 12.—Profile of the Devonian clastic section of Romashkino oilfield (after Maksimov and others, 1970, p. 122).

are due largely to deposition on an irregular erosional surface of the underlying upper Tournaisian beds.

The Romashkino oilfield is bounded on the west by the long, narrow Altunino-Shunak downwarp, which separates the field from the anticlinal structure of the Aktash-Novoyelkov oilfields. Maximum amplitude of this downwarp is more than 100 m (325 ft) on the basement surface. It is less well expressed on the Carboniferous and is barely noticeable on the Permian beds.

In the Devonian clastic section at Romashkino are five pay zones: D–IV, D–III, and D–II in the Givetian Stage, D–I in the Pashiy, and D–0 in the Kynov beds, the last two units being in the Frasnian Stage. The D–I zone produces about 90 percent of the oil at Romashkino. In addition, flows of oil have been recovered from limestones of the Domanik beds, upper Famennian carbonate beds, Tournaisian carbonate beds, clastic rocks of the Tula and Bobrikov horizons of the Lower Carboniferous, and carbonate beds at the base of the Middle Carboniferous.

The oil-water contact of the D–I zone is inclined from −1,480 m (−4,810 ft) on the north to −1,490 m (−4,840 ft) on the south. This inclination has been attributed generally to hydrodynamic pressure of southward-moving formation water. There is no abrupt separation of oil and water in the oil-bearing beds in the majority of the wells. The oil-water transition as seen in well logs is generally a zone in which the resistivity gradually decreases until formation water appears. The transition zone is probably caused by rapid alternation of sandy-silty and clayey beds.

The field was placed on water flood early in its history and divided into 23 sectors separated by water injection wells generally located in structural lows between domal highs. Water flooding results have been highly variable. Facies changes result in abrupt termination of permeable beds throughout the field, yet there is a remarkable hydrodynamic interconnection within individual reservoir bodies over great distances. Gerasimov (1964) reports variations in the water levels of hydrogeologic observation wells in response to water injection at distances of as much as 60 km (37 mi). However, some wells only a short distance apart show no hydrodynamic interconnection. As a result, the more permeable beds have been flushed, whereas less permeable beds have remained virtually undisturbed by the water flooding operations. To induce flow from low-permeability intervals, high pressures (as much as 500 atm or 7,350 psi) are maintained in the injection wells.

Production goals for the individual sectors at Romashkino were seldom met during the first decade of operation. Goals for the field as a whole were attained, however, by bringing on stream new parts of the field having high-flowing wells (Mirchink, 1964).

PRESENT EXPLORATION AND FUTURE PROSPECTS

Exploration activity in the Volga-Ural province has declined significantly in recent years, partly because of the greatly increased Soviet emphasis on the West Siberian basin, which has monopolized a major share of available drilling equipment. However, reports in Soviet geological journals and other publications indicate that exploration interest remains high in several parts of the Volga-Ural province, particularly the Ural foredeep, the Perm-Bashkir arch, the Upper Kama area, and the northern border of the Peri-Caspian depression. At least 125 discoveries have been made in these areas in the past 10 years. Soviet exploration geologists also express considerable interest in infill drilling and stratigraphic exploration for Carboniferous and Upper Devonian reefs and other carbonate buildups and for Devonian and Viséan discontinuous sandstone reservoirs in the areas of the main oilfields (Muslimov and others, 1976).

The thrust belt that makes up the western flank of the Ural Mountains is also of major interest, as are the graben and other fault structures in the Ural foredeep (Klyuchnikov and Kazantsev, 1974). Most of these structures are gas or gas-condensate prospects; however, infill drilling is being done on known structures and in the Kamsko-Kinel trough areas, which are primarily oil prospects. Interest continues in the Permian reef belt and Carboniferous carbonate mound belt along the western border of the Ural foredeep and the northern border of the Peri-Caspian depression, where gasfields have been discovered in recent years (Kuznetsov and Proshlyakov, 1976). These prospects are deep, and their potential is primarily for gas and gas condensate, but the reserves may be significant. The pre-Devonian Bavly beds are of interest, primarily because of their good reservoir quality and thickness. These reservoirs appear to be promising for oil in faulted areas of major uplifts, particularly the Perm-Bashkir arch, and for gas in the western Urals thrust belt.

ASSESSMENT OF UNDISCOVERED CONVENTIONALLY RECOVERABLE PETROLEUM RESOURCES

The location of the Volga-Ural basin and assessment region is shown in figure 1. USGS estimates of oil and gas resources in this basin are given in table 3 and figures 13 and 14. Data supplementary to these estimates are shown in table 4.

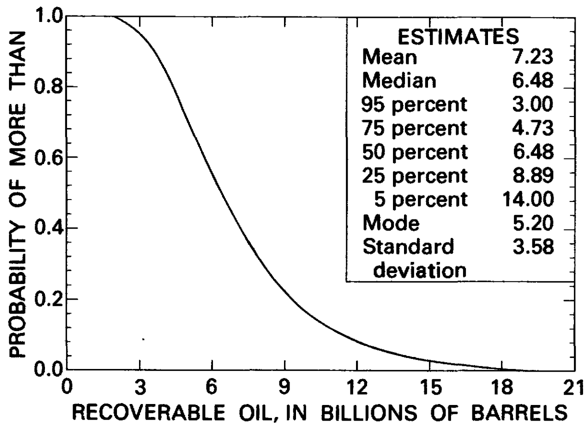

FIGURE 13.–Probability distribution of Volga-Ural recoverable oil as of April 2, 1981. The number of significant figures reflects the precision of the statistical process rather than the accuracy of an estimate.

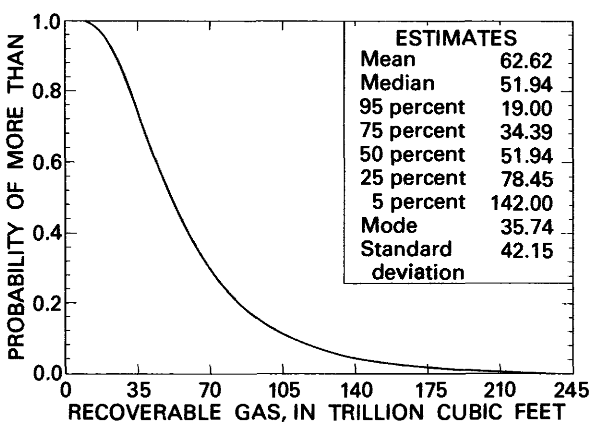

FIGURE 14.–Probability distribution of Volga-Ural recoverable gas as of April 2, 1981. The number of significant figures reflects the precision of the statistical process rather than the accuracy of an estimate.

TABLE 3.–*Assessment of undiscovered conventionally recoverable petroleum resources in the Volga-Ural petroleum province*

[Resource assessment by USGS as of April 2, 1981. F_n denotes the *n*th fractile; the probability that more than the amount F_n is present is *n* percent]

Crude oil, in billions of barrels			Natural gas, in trillions of cubic feet (billions of barrels of oil equivalent)[1]		
Low (F_{95})	High (F_5)	Mean	Low (F_{95})	High (F_5)	Mean
3	14	7	19 (3)	142 (24)	63 (10)

[1]1 barrel of oil equivalent to 6,000 ft³ of gas.

TABLE 4.–*Supplementary and comparative data supporting the petroleum resource assessment of the Volga-Ural petroleum province*

[Average depth of undiscovered resources: 9,500 ft for oil and 14,000 ft for gas. Analogs: Midcontinent, United States; Permian basin, United States; Paleozoic, western Canada basin; Arctic coastal plain, Canada. Cumulative production and reserves are composited estimates based on various sources. +, quantity positive but no data available]

	Crude oil, in billions of barrels of oil equivalent	Natural gas, in trillions of cubic feet
Cumulative production to Jan. 1, 1980	30–35	+
Identified reserves[1] to Jan. 1. 1980:		
Demonstrated	5	75
Inferred	5	25
Total	10	100[2]
Original recoverable resources (ultimate):		
Cumulative	35	+
Identified reserves	10	100
Undiscovered resources (mean)	7	63
Total	52	163+[3]

[1]Follows terminology outlined by U.S. Bureau of Mines and U.S. Geological Survey (1980). "Demonstrated" is equivalent to American Petroleum Institute's "Proved and Indicated Additional." "Inferred" represents anticipated field growth in existing fields.
[2]17 billion barrels of oil equivalent.
[3]27+ billion barrels of oil equivalent.

COMMENTS

Assessment does not include Permian Melekess tar sands, which have approximately 100 billion barrels of oil in place.

Assessment does not include the Peri-Caspian depression or the lower Volga area but does include the Orenburg area.

Cumulative production and reserve estimates are approximate.

Significant new plays in the area are not likely. Additional reserve delineation probably will involve small fields proximal to existing production and from the same part of the stratigraphic section.

Exact areas and amounts of exploration are not well known, but indirect evidence based on the location of subsurface data points suggests a highly mature exploration province.

Extension of production to the northwest is limited by the lack of maturation of the Domanik and Domanik-type source-rock facies.

Major oil occurs in the Devonian and Lower Carboniferous. The Upper Carboniferous and Permian have many pools, but reserves are small.

Permian reef play along the Ural foredeep may have been well tested already.

The Orenburg gasfield in the southeastern part of the area is included in the assessment and contains estimated current reserves of about 70 trillion cubic feet.

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