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Geology of the Volga-Ural Petroleum Province and detailed description of the Romashkino and Arlan oil fields

by

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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 oil fields of the province. The Perm-Bashkir arch forms the northeastern part of the regional high, and the Zhigulevsko-Orenburg arch makes 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 as follows: 1) Riphean (lower Bavly) continental sandstone, shale, and conglomerate beds from 500 to 5,000 m thick deposited in aulacogens. 2) Vendian (upper Bavly) continental and marine shale and sandstone up to 3,000 m thick. 3) Middle Devonian-Tournaisian transgressive deposits, which are sandstone, siltstone, and shale in the lower part and carbonates with abundant reefs in the upper; thickness is 300-1,000 m. In the upper carbonate part is the Kamsko-Kinel trough system, which consists of narrow interconnected deep-water troughs. 4) The Visean-Namurian-Bashkirian cycle, which began with deposition of Visean clastics that 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 Visean clastics are overlain by marine carbonates. Thickness of the cycle is 50-800 m. 5) Early Moscovian-Early Permian terrigenous clastic deposits and marine carbonate beds 1,000-3,000 m thick. 6) The late Early Permian-Late Permian cycle, which reflects maximum growth of the Ural Mountains and associated Ural foredeep. Evaporites were first deposited, then marine limestones and dolomites, which intertongue eastward with clastic sediments from the Ural Mountains. 7) Continental redbeds of Triassic age and mixed continental and marine clastic beds of Jurassic and Cretaceous age, which were deposited on the southern, southwestern, and northern margins of the Russian platform; they are generally absent in the Volga-Ural province, however.

The Volga-Ural oil and gas basin is a single artesian system that contains seven aquifers separated by seals. The areas of greatest hydraulic head are in the eastern parts of the basin near areas where the aquifers crop out on the western slopes of the Ural Mountains. The Peri-Caspian basin is the principal drainage area of the artesian system.

Approximately 600 oil and gas fields and 2,000 pools have been found in the Volga-Ural province. Nine productive sequences are recognized as follows: 1) Upper Proterozoic (Bavly beds), which are promising but not yet commercial. 2) Clastic Devonian, which contains the major reserves and includes the main pays of the super-giant Romashkino field. 3) Carbonate Upper Devonian and lowermost Carboniferous, which is one of the main reef-bearing intervals. 4) Visean (Lower Carboniferous) clastics, which are the main pays in the super-giant Arlan field. 5) Carbonate Lower and Middle Carboniferous. 6) Clastic Middle Carboniferous Moscovian. 7) Carbonate Middle and Upper Carboniferous. 8) Carbonate-evaporite Lower Permian, which contains the major gas reserves and the lower part of the Melekess tar deposits. 9) Clastic-carbonate Upper Permian, which contains the major part of the Melekess tar deposits.

The Volga-Ural province is divided into several productive regions on a basis of differences in structure, distribution of reservoir and source-rock facies, and general composition of the petroleum accumulations. These regions are the Tatar arch, Birsk saddle, Upper Kama depression, Perm-Bashkir arch, Ufa-Orenburg monocline, Melekess-Sernovodsko-Abdulino basin, Zhigulevsko-Orenburg arch, Ural foredeep, and north borders of the Peri-Caspian depression.

Exploration activity has declined in recent years; however, interest remains high in several parts of the province, particularly in the Ural fore-deep, Perm-Bashkir arch, Upper Kama area, and north border of the Peri-Caspian depression.

The super-giant Romashkino oil field is in the middle of an oily belt that extends along the eastern margin of the Russian platform. For twenty years it was the largest producer in the U.S.S.R. The field covers an area of 3,600 sq km, and more than 10,000 wells have been drilled. Although in decline, production in 1981 was still 400 million barrels. The main pay zone is a complex succession of beds and lenses of sandstone, siltstone, and shale in the Middle Devonian Frasnian stage. The trap is a broad, hummocky structural plateau on which the crest of the main pay zone is at -1,435 m and closure is about 60 m. In addition to the Devonian pays, flows of oil have been recovered from five additional pays higher in the Paleozoic section.

Initial formation pressure in the Devonian pools at Romashkino was 175 atm, and saturation pressure was 81-95 atm. The gas-oil ratio ranges from 41 to 54 m^3/m^3, and density is about 0.805. Sulfur content is 1.5-2.1 percent, paraffin is 2.6-5.4 percent, and tar content is 30-48 percent.

The field was divided into 23 independent production sectors and worked by water flood from the very beginning. Facies changes within the pays are so abrupt, however, that three, and in places four, rounds of infill drilling have been necessary.

The giant Arlan field is the second largest producer in the Volga-Ural province. The field is 90 km long and 15-20 km wide. Production in 1981 was 62 million barrels.

The main pay zones at Arlan are Lower Carboniferous Visean clastics that, along with underlying Tournaisian limestones, drape over Upper Devonian reefs. The draping of the Visean pays is enhanced further by their having been deposited on a pre-Visean erosion surface where channels had been cut in the area between the reefs.

Initial formation pressure in the main pays at Arlan was 142 atm, and saturation pressure was 99 atm. Gas-oil ratio was 16-21 m^3 per ton. The oil is very viscous; values range from 15 to 20 cps. Density is 0.874-0.881. Sulfur content is 2.8-3.4 percent. Formation pressure has been maintained by water flood.

INTRODUCTION

Purpose of Study.--As the world economy has become ever increasingly complicated and nations more interdependent, a knowledge of availability of crucial natural resources becomes indispensable for guiding sound economic development. Petroleum availability on a worldwide basis is now central to any economic planning, be it by industry or government.

In order better to estimate future supplies of oil and natural gas for the United States, the World Energy Resources Program of the U.S. Geological Survey is making an ongoing study of the principal producing regions of the world. The fields of the Soviet Union are important in this world picture, because if the Soviets should not be able to meet their own needs by domestic production, then their bid for outside oil and gas could be disruptive to already strained world conditions.

For more than a quarter of a century, the Volga-Ural petroleum province (fig. 1) provided more than half of the oil production of the U.S.S.R.; only recently (1978) was it exceded by West Siberia. The present study analyzes the sedimentary and structural geology of the province and its petroleum geology, including details on the two largest oil fields.

ACKNOWLEDGEMENTS

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HISTORY OF EXPLORATION

A special geological expedition began to explore for oil in the Volga-Ural region in 1919. The basis for the high expectations held for the region was the presence of numerous oil shows such as asphalt, tar, and bitumen in the Permian rocks. The thinking was that the sources of these shows were oil pools in Devonian and Carboniferous sediments, which had a capacity to generate oil on a regional scale (Kachatryan, 1977, p. 162-163).

The first oil flow was from Lower Permian limestones in the Perm Near-Urals near Chusovskiye Gorodki in April of 1929. The well was being drilled for salts; it was extended below the salt, however, as an oil wildcat. In 1932, oil pools were discovered in Lower Permian reef limestones in the Ishimbay region. During this time (the First Five-Year Plan of 1929-33), more than 90 percent of the drilling was on Permian sediments in the Near-Urals and but little in the western regions along the Volga.

In the Second Five-Year Plan of 1934-38, production was largely from fields of the Ishimbay region of the Bashkir ASSR, and the exploration was shifted to the Carboniferous sediments. In 1936, oil pools were discovered in the Verey horizon of the Middle Carboniferous and a year later in the Yasnopolyana horizon of the Lower Carboniferous and in the Kazan sediments of the Upper Permian. The first oil pool in limestones of the Tournaisian stage was discovered in 1938.

As time passed, the new Volga-Ural region was called the Second Baku. In the pre-World War II years, exploration in the then known oil-bearing regions continued to find new fields with oil pools in Carboniferous and Permian sediments. The first gas field was discovered in the Saratov region of the Volga. Devonian sediments were penetrated in many areas. Nevertheless, oil production increased slowly, and its annual level for the Ural-Volga region in 1940 had not reached 2 million tons (14 million barrels).

During World War II, exploration was intensified. Discoveries were made in new regions, particularly in the Tatar ASSR and in the Saratov region. The most significant event was the discovery in 1944 of the first high producing oil pools in sandy-silty strata of the Givetian and lower part of the Frasnian stages of the Devonian. The discovery of Devonian oil was a turning point in the development of the Volga-Ural province.

During the Fourth Five-Year Plan the high evaluation of the Carboniferous, and particularly of the Devonian, was confirmed by the discovery of Romashkino (1948) and other fields in the Tatar ASSR, and additional fields in the Bashkir ASSR. During this period, the Volga-Ural province ranked first in the country in oil reserves, and annual production here was more than 10 million tons (70 million barrels) in 1950.

Oil reserves increased substantially during the Fifth Five-Year Plan (1951-55), due not only to the outlining of known fields but also to the discovery of new oil pools in Devonian and Carboniferous sediments. The oil resource base was strengthened in particular during this time in the Kuybyshev Region by discoveries in Devonian and Carboniferous sediments. Oil production in 1955 in the Volga-Ural province was more than 41 million tons (290 million barrels). This province had then become the leading producer of the country.

Oil reserves increased markedly during the Sixth and Seventh Five Year Plans (1956-60 and 1961-65). Whole zones of oil-gas accumulation were discovered in the Perm Region. Production increased rapidly here. The Arlan-Dyurtyulin and other zones of oil-gas accumulation were found in Bashkiria. Other zones were outlined in the Kuybyshev and Orenburg Regions. The Volga-Ural province produced 104.5 million tons (730 million barrels) in 1960 and 173 million tons (1.2 billion barrels) in 1965.

Oil exploration continued on a broad front during the Eighth and Ninth Five-Year Plans (1966-70 and 1971-75). The main thrust was toward determining systematic distributions of the oil fields. This information was used very effectively in exploration of the Kamsko-Kinel system of troughs. Exploration in those troughs was particularly successful in the Perm and Orenburg Regions and also in Udmurtia, which at the end of the Sixties became one of the new oil-producing regions of the Volga-Ural province. Oil production in the province in 1970 was at more than 208 million tons (1.4 billion barrels) and in 1975 almost 225 million tons (1.6 billion barrels). This last figure was the peak for the province.

On the whole, the Volga-Ural oil-gas province has been studied and explored extensively; there are nonetheless still good possibilities for finding new reserves. The present level of oil production can probably be maintained for a long time (Khachatryan, 1977, p. 162-163).

GEOGRAPHY

The Volga-Ural petroleum province is on the Russian Plain between the Volga River on the west and the Ural Mountains on the east; hence the name Volga-Ural province. This plain is a low erosional surface along the Kama and Volga Rivers; elevations here are less than 100 m (325 ft). The plain then rises to a low erosional plateau as it approaches the Ural Mountains. Elevations here exceed 200 m (650 ft).

The region of the petroleum province is generally designated as the Povolzhye or "Along the Volga." This region extends from the cold, humid tiaga on the north to the hot, dry deserts of the Caspian region on the south (Lyndolph, 1970, p. 67).

The climate and soil belts of European Russia extend generally east-west. The climate of the Volga-Ural region is Atlantic continental, and precipitation ranges from 30 to 40 cm (12-18 inches) per year. Average mean January temperature is -12 to -16°C (10 to 3°F), and that for July is 20-24°C (66 to 75°F). The region is at about the same latitude as the southern half of Canada: 50-60°N. There are 100-150 frost-free days per year; the region is far from any areas of permafrost. The area is almost entirely south of the limit of maximum glaciation.

The region is in a forest-steppe belt of extensive forests and grass lands that are cultivated. Podzols predominate in the northern half; these are produced by the cool, humid climate. Chernozens are present in the south; these developed under steppe conditions. Karst topography is present throughout the region, especially in the eastern part.

The Povolzhye region was long neglected by Soviet planners and held to agricultural production. After World War II and the discovery of extensive oil resources, this area became the most rapidly developing region in the Soviet Union with respect to industrial production.

PALEOGEOGRAPHY AND PALEOSTRUCTURE

The Volga-Ural petroleum province makes up the eastern part of the Russian (East European) Platform, which includes most of European U.S.S.R., extending from the Baltic Sea on the west to the Ural Mountains on the east (figs. 1, 2, 5). Geologically, the platform is part of the craton of the Paleozoic European continent, and the basement consists of Precambrian crystalline rocks. The province has an area of 200,000 square miles (500,000 square kilometers) and extends from the Kama arch on the north to the Lower Volga depression on the southwest. During Paleozoic time, the Ural eugeosyncline lay to the east of the platform and received a great thickness of deep to shallow-water marine clastics, volcanics, fine siliceous carbonates, and isolated reef deposits. The Peri-Caspian depression lay to the south, the Moscow basin to the west, and the Baltic Shield to the northwest. The Baltic Shield was a major source area for early and middle Paleozoic terrigenous clastic deposits. The Ural Mountain uplift, which began active growth in Late Carboniferous time, was the main source for Permian clastic sediments.

During middle and late Paleozoic time, after a long period of early Paleozoic emergence, the Russian Platform became the site of cyclic transgressive-regressive marine deposition of a thick sequence of fossiliferous shelf carbonates and nearshore shallow-water deltaic and interdeltaic marine clastics. During regressive phases, continental and coastal nearshore clastic sediments spread eastward across the platform to intertongue with marine beds. Superimposed on the continental platform or shelf province were several major positive and negative paleostructural features, which strongly influenced the nature and distribution of sedimentary facies in the Volga-Ural province through at least middle to late Paleozoic time. The persistent growth and interrelationship between these paleostructural elements had a profound effect on the development of sedimentary facies, the distribution of petroleum reservoir bodies and source rocks, and the early to late petroleum migration and trapping patterns in the province.

According to Maksimov and others (1970), Aranova and others (1962), and other Soviet authors, many of the major paleotectonic elements began to develop during late Proterozoic time, and the remainder were in existence early in the Paleozoic. The most persistent paleostructural features were the Tatar, Perm-Bashkir and Zhigulev-Orenburg arches, and the Birsk saddle (fig. 2), which contain the major petroleum deposits of the province, as well as the Komi-Perm arch and the Upper-Kama, Melekess, and Buzuluk depressions. Several other paleostructural-paleogeographic features are located along the margins of the province; some were clastic source areas at times and others were sites of thicker deposition. These include the Voronezh arch crystalline massif, the Tokmovo, Kotel'nich, Sysola, and Onega arches, the Timan uplift, and the Soligalich, Timan, Pechora, and Peri-Caspian depresssions (fig. 5). The Mezen "synclize" underwent subsidence in early Paleozoic time and received a substantial thickness of Lower Cambrian terrigenous sediments, but this area was apparently an emergent clastic source area during all of middle to late Paleozoic time. The Riazan-Saratov depression strongly subsided during at

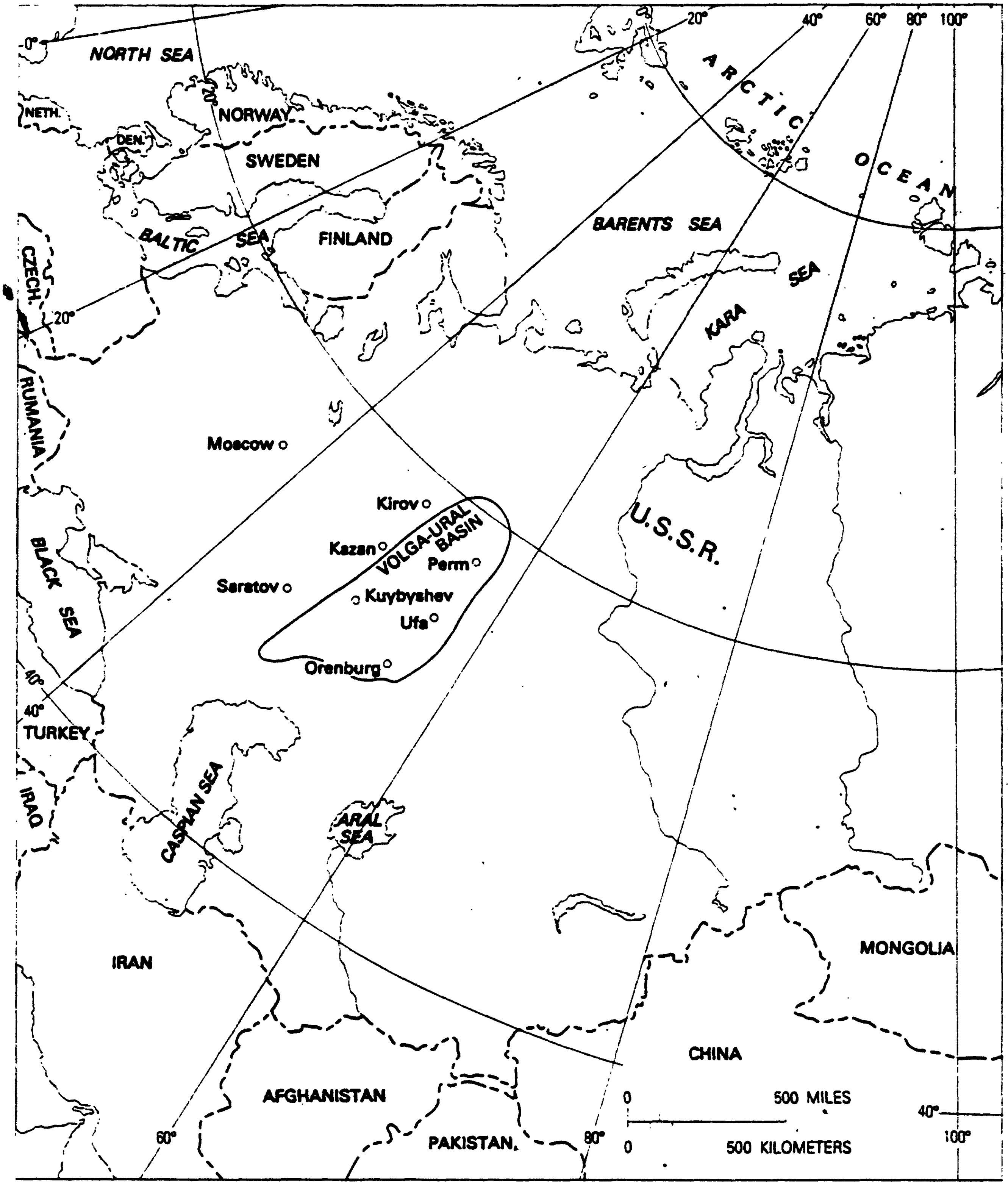


Fig. 1. Location of Volga-Ural province.

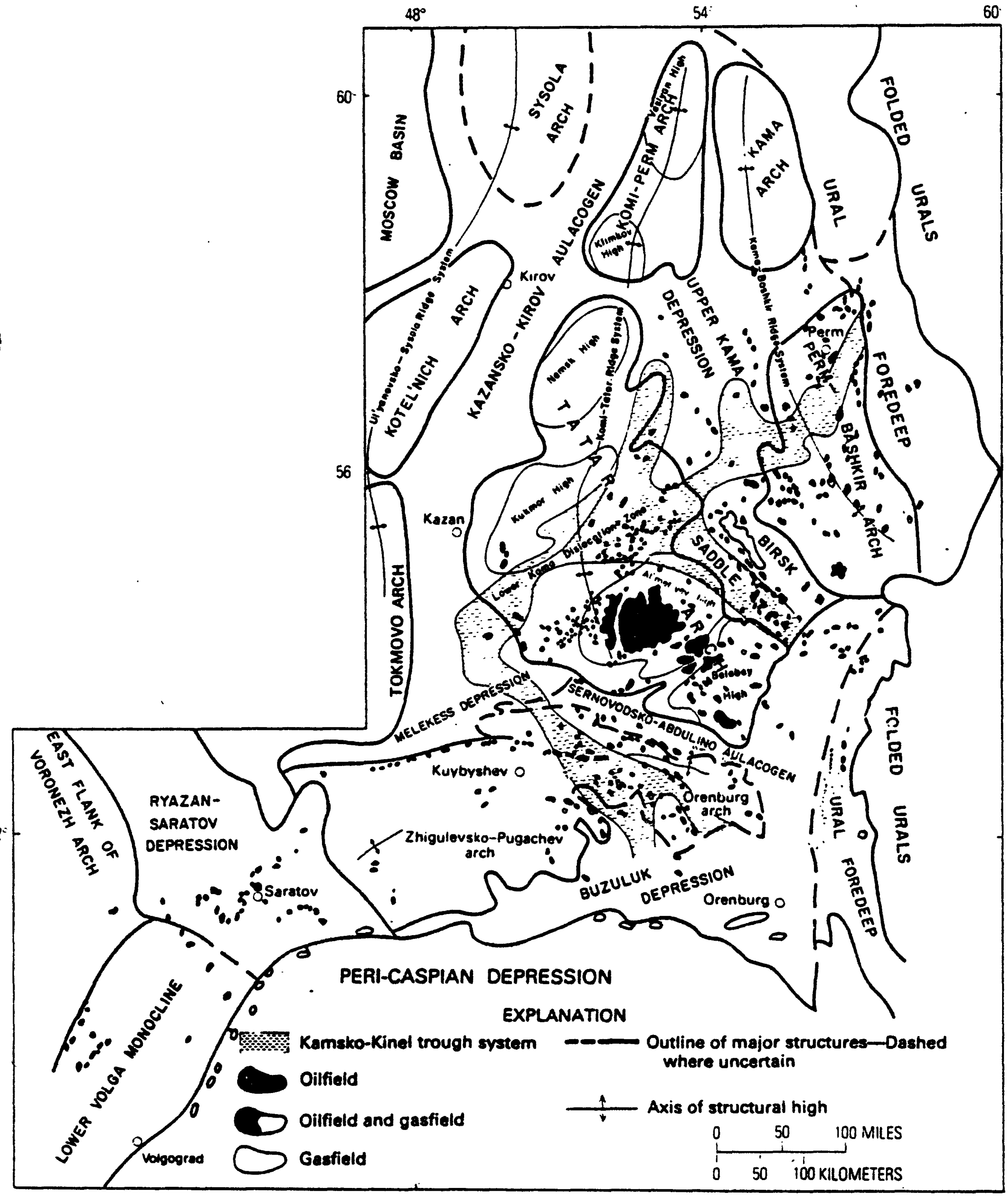


Fig. 2. Volga-Ural regional high.

least part of Paleozoic time, as indicated by greatly thickened Devonian and Lower Carboniferous beds in that area. The Lower Volga monocline also contains a thickened section of middle Paleozoic through Permian rocks, but during most of Paleozoic time it may have been closely merged with the paleo-structural Peri-Caspian depression where the present-day basement is depressed as much as 25 km (15.5 mi) (Garetsky and others, 1972). The Ural foredeep region was the site of both deep- and shallow-water shelf deposition, including reef and other organic carbonate buildups during Devonian, Carboniferous, and Early Permian time, but underwent active uplift and faulting in Middle to Late Permian time during the building of the folded and thrust-faulted Ural Mountain chain. Further details regarding the influence of these paleostructural features on depositional processes in the Volga-Ural province will be discussed later.

STRUCTURAL GEOLOGY

Introduction

The structure of the Volga-Ural oil-gas basin has been synthesized largely on a basis of regional geophysical data, although drilling and conventional geological surveying have made essential contributions. Knowledge is fairly detailed for those areas where oil is recovered commercially; elsewhere, however, the structure is much less well understood.

The relief of the surface of the basement differs sharply from the structure in the overlying sediments, and configurations of marker horizons within the sedimentary section also differ from one another due to deformation that occurred between deposition of the successive markers. Between successive horizons there are changes in degree of deformation and in basic structural trend. These structural differences are a basis for recognizing seven structural stages: crystalline basement, Riphean-Vendian, Eifelian-Frasnian, Famennian-Tournaisian, Carboniferous-Lower Permian, Upper Permian, and Mesozoic-Cenozoic. See figure 8 for stratigraphic section.

Along with the discordances, there are also inherited features that persist throughout all the structural stages. Prominent here are the large structural elements; these are generally associated with faults in the basement.

The Volga-Ural petroleum province is in general coincident with the Volga-Ural regional high, a broad upwarp of the Russian platform bounded on the east by the Ural foredeep, on the northwest and west by the Moscow basin, and on south by the Peri-Caspian depression. See figure 1.

The Volga-Ural regional high consists of arches separated by aulacogens (figs. 2 and 5; see also Maksimov, 1970). In Soviet terminology, two or more arches may be combined into a ridge system. The arches have two main types of structures: polygonal block and interblock linear-zonal structures. The polygonal block structures are characterized by relatively mild deformation of the sedimentary cover and by a relatively thin sedimentary section. The interblock linear-zonal structures are marked by greater deformation as well as by greater thickness of the sediments.

Both the aulacogens and 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 on the east and in the Dnieper-Donets depression farther to the southwest, as well as with the downwarping of the Peri-Caspian depression on the south. The fault zones are characteristically associated with steep gravity or magnetic gradients.

Structural Stages

Of the seven structural stages present in the Volga-Ural petroleum province, the basement and configuration of its surface are described in the greatest detail because the main structural features here persist in some degree throughout the other structural stages. The configuration of the basement surface is indeed an integration of all the tectonic movements that affected the later structural stages. The only major structure that is not reflected on the basement surface is that due to reef buildup and associated uncompensated sedimentary troughs.

Basement surface

On structural highs the basement surface is between -1,500 m (-4,875 ft) and -1,550 m (-5,200 ft). In the aulacogens, basement has been penetrated at the depths of 4,300 m (14,000 ft), and in Bashkiria the drill had not reached basement at -5,000 m (-16,250 ft). Relief of the basement surface thus exceeds 3,500 m (11,375 ft) (fig. 6). Angles of dip of the basement surface are up to 10°. The basement consists of Archean rocks.

The Volga-Ural regional high is cut from north to south by the relatively narrow Kazansko-Kirov graben or aulacogen (fig. 2). This aulacogen lies between the Ul'yanovsko-Sysola ridge system on the west and the Komi-Tatar ridge system on the east. On the south of the Komi-Tatar ridge system, the Sernovodsko-Abdulino graben, or aulacogen, extends in an east-west direction and is, in turn, bordered on the south by the Zhigulayevsko-Orenburg arch.

The Ul'yanovsko-Sysola ridge system extends north-south for more than 700 km (435 mi), and its width is 100-150 km (62-93 mi). Its main components are from north to south the Sysola, Kotel'nich, and Tokmovo arches. This ridge system is bounded on the west by the Moscow basin.

The Kazansko-Kirov aulacogen is a narrow but deep structure at least 480 km (300 mi) long and 25-50 km (16-31 mi) wide. It is bounded along its margins by steep faults and divided into northern and southern segments by a saddle near Kazan. The northern segment is deeper, and within it are preserved Proterozoic Bavly sediments, as well as a thicker section of Devonian clastics. The oldest sediments in the southern sector are lower Frasnian. To the south the aulacogen passes into the Melekess depression.

The Komi-Tatar ridge system (fig. 2) is 690 km (430 mi) long and about 200 km (125 mi) wide. The Komi-Perm arch on the north has two highs, the Veslyan and Klimkov. The Tatar arch on the south has three highs: the Nemsk, Kukmor, and Al'met'yev. Basement surface relief on the Tatar arch is 200-300 m (650-975 m) (fig. 6). The Belebey high to the southeast of the Al'met'yev projection first shows up as a structure beginning with the Devonian clastic section.

The Lower-Kama dislocation zone (fig. 2) extends in a northeast direction between the Kukmor and Al'met'yev highs of the Tatar dome. This is a zone of extensive faulting of the basement and of the entire sedimentary cover related to the Kama abyssal fault, which extends from the Voronezh massif to the Ural foredeep.

East-west trends predominate in the southern part of the Volga-Ural regional high.

The Sernovodsko-Abdulino aulacogen extends east-west, opening on the east into the southeast-dipping monoclinal flank of the platform. On the west it merges with the Melekess depression. Upper Proterozoic (Bavly) sediments are preserved in the eastern part of the aulacogen but not in the western part.

South of the Sernovodsko-Abdulino aulacogen is the Zhigulevsko-Orenburg arch, which consists of the Zhigulevsko-Pugachev and Orenburg raised blocks.

The Buzuluk depression adjoins the Zhigulevsko-Orenburg arch on the south, and it in turn passes on the south into the Peri-Caspian depression.

The Melekess depression is a triangular basin to the southwest of the Tatar arch and is about 300 km (185 mi) by 140 km (87 mi) in size. The basement surface here dips regionally to the south but is complicated by several separate depressions. Some gentle arches are present in the north part of the depression.

On the southwest is the Ryazano-Saratov depression (or Pachelm aulacogen), which separates the Volga-Ural regional high from the Voronezh crystalline massif (arch). It consists of a system of downwarps, trenches, and depressions on the basement surface.

To the east of the Komi-Tatar ridge system is the Upper-Kama depression. This structural low continues south and southeast into the area of the Birsk saddle and finally into the Ural foredeep. This regional structural low is bounded by faults and is filled by thick upper Proterozoic molasse sediments and basic intrusives. It has also been called the Birsko-Upper-Kama aulacogen.

In the northeastern part of the Volga-Ural regional high is the Kama-Bashkir ridge system (fig. 2). Structural highs on this ridge are the Kama and Perm-Bashkir arches.

The Birsk saddle is a narrow structure between the Perm-Bashkir arch and the Al'met'yev high of the Tatar arch.

Riphean-Vendian structural stage

Sediments of the Riphean-Vendian infill to a great extent the deep aulacogens within the basement surface. They fill the northern part of the Kazansko-Kirov aulacogen, the Upper-Kama depression, the Birsk saddle, the eastern part of the Sernovodsko-Abdulino aulacogen, the Buzuluk depression, and the Ryazano-Saratov depression. An unconformity is everywhere present between the Riphean and Vendian sediments; consequently, two independent structural sub-stages are recognized here.

Faulting is widespread; these faults generally do not extend into the overlying Paleozoic sediments.

Eifelian-Frasnian structural stage

The dominant regional structures in the Paleozoic section are rounded anticlinal uplifts of softer outline than in the basement, separated by flattened basins or troughs. The positions of the large structural elements are unchanged.

The general structure of the 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 being structurally higher than the Kukmor high for the Devonian beds; the relationship is opposite for the basement surface.

Deposition of a great thickness of Devonian clastics in the Kazansko-Kirov aulacogen led to almost complete infilling of this trough. Its structural relief remained 275-350 m (900-1,140 ft). On the eastern edge of the trough a lava flow is present in the lower Frasnian rocks, suggesting 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 Eifelien-Frasnian structural stage; this is 50-80 m (163-260 ft) less than on the surface of the basement. The Klimkov high is not expressed in this structural stage nor is the Sysola arch.

The east flanks of the Tokmovo and Kotel'nich arches repeat in subdued form the basement surface. The Tokmovo merges with the Voronezh arch. The Melekess depression, Upper-Kama depression, Perm-Bashkir arch, and Birsk saddle remained well defined.

In this structural stage the Sernovodsko-Abdulino aulacogen and the Orenburg block become buried structures beneath the monoclinal southeast flank of the platform.

Famennian-Tournaisian structure stage

In this structural stage, processes of sedimentation dominate in determining composition and thickness in contrast to basin relief and tectonic movements in the previous two structural stages. Most of the main structural elements that are present on the base of the Paleozoic section are preserved in this structural stage. The Tatar and Perm-Bashkir arches and their highs, the Zhigulevsko-Pugachev block, Kazansko-Kirov aulacogen, Melekess and upper-Kama depressions, Birsk saddle, and south and southeast flanks of the Russian platform are well expressed. During this time, however, the Kamsko-Kinel trough system became delineated on this regional background. The system extends a distance of 900 km and is from 20-40 km (12-25 mi) to 80-90 km (50-56 mi) wide (figs. 2 and 3). The pre-Mendym (Domanik and older) structure does not reflect the troughs. For example, the pre-Mendym sediments in the area of the Aktanysh-Chishmin trough (fig. 3, III) have a gentle monoclinal dip, which is due to post-Devonian tilt (Mkrtchyan, 1965, p. 515).

Organic carbonate buildups are present within and along the borders of the troughs of the Kamsko-Kinel system. Some of these buildups parallel the margins of the troughs, whereas others intersect them at an angle. The Arlan-Dyurtyuli reef on the outer edge of the northeast border of the Aktanysh-Chishmin trough is a parallel feature, as is also the Karacha-Yelgin reef, which lies within the downwarp (fig. 4). The Kueda and Mukhanovo (fig. 3) reefs are at high angles to the borders of the depressions, as are several others.

Draped structures above the reefs that parallel the borders of the depressions are generally not expressed structurally in the pre-Mendym sediments. Those that intersect the troughs are generally persistent throughout the section; however, the closure increases abruptly at the top of the Devonian at the intersection with the borders of the troughs due to growth of reefs (Mkrtchyan, 1965, p. 516). The development of the highs that intersect the borders of the troughs is due probably to recurrent local movements of the basement along zones of weakness.

The Famennian-Tournaisian structural stage is unusual in that in its lower part it is characterized by greater structural relief due to thinner deposition in troughs and on reef buildups on the margins of these troughs. This depositional history is treated in detail in the chapter on Stratigraphy and Depositional Facies of this report. According to Maksimov and others (1970, p. 36), the upper part of the structural stage is marked by a smoothing out of this relief so that at the top of the stage the principal structural elements are not those of the stage itself but are more like those of the earlier Eifelian-Frasnian stage. However, thickness and facies distribution show that the troughs were still strongly expressed at the end of the Tournaisian (fig. 19). The troughs were actually filled during the Visean (fig. 20), and the subsequent Namurian deposition shows little or no indication of their presence (fig. 21).

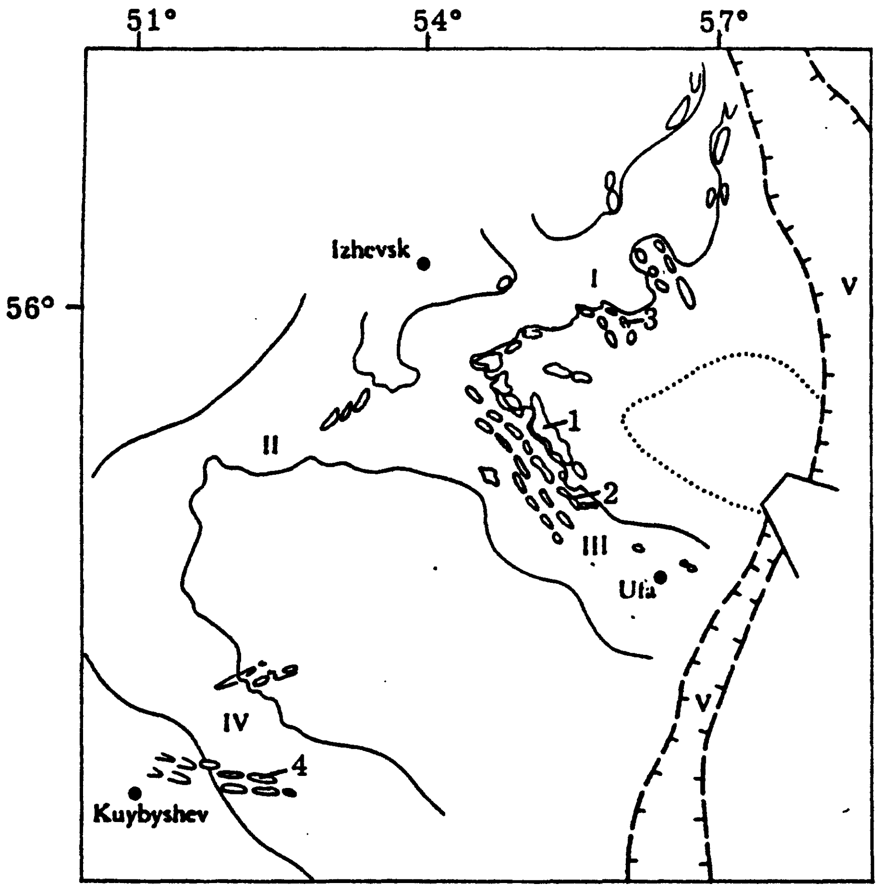


Fig. 3. Troughs of the Kamsko-Kinel system (from Mkrtchyan, 1965).

Troughs: I - Shalym, II - Saraylin, III - Aktanysh-Chishmin,
IV - Mukhanovo-Yerokhov.
V - Ural foredeep.
Reefs: 1 - Arlan-Dyurtyuli, 2 - Karacha-Yelgin, 3 - Kueda, 4 - Mukhanovo.

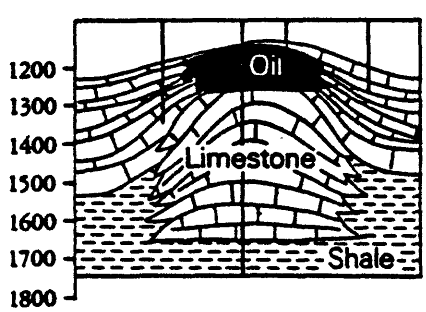


Fig. 4. Section of Karacha-Yelgin reef (from Mkrtchyan, 1965).

Carboniferous-Lower Permian structural stage

The main tectonic elements of this structural stage repeat those of the Devonian clastics and of the basement surface but with a tendency toward greater complexity. An exception is the Kazansko-Kirov aulacogen and adjacent flanks of arches. In the northern part of this structure, the lineal system of the Vyat arches developed on the site of the aulacogen (Vyat arches not shown on Fig. 2). These arches rise 150-300 m (490-953 ft) above adjacent flattened-out sectors of older arches.

The Perm and Bashkir highs of the Perm-Bashkir arch, the Kukmor, Al'met'yev, and Belebey highs of the Tatar arch, the Lower Kama dislocation zone, and the Birsk saddle remain clearly defined. The highest part of the buried Orenburg block has the form of a flattened structural terrace. The crest and flanks of the Zhigulevsko-Pugachev block and the Buzuluk depression are clearly expressed.

Upper Permian and Mesozoic-Cenozoic structural stages

A very large zone of highs developed along the eastern flank of the Perm-Bashkir arch during the Mesozoic and Cenozoic. This zone extended on southwest through the Birsk saddle and Belebey high of the Tatar arch, and then to the northwest through the Al'met'yev and Kukmor highs of the Tatar arch and the Vyat arches. Within this arcuate system of highs is the Upper-Kama depression, which is 260-280 km (160-174 mi) wide. A basin developed during the Mesozoic-Cenozoic on the site of the Kotel'nich arch.

The Buzuluk depression continued its development in these upper structural stages; it is particularly well defined on the Triassic, Jurassic and Cretaceous systems. The gentle north border of the depression extends to the arcuate system of highs mentioned above. On the west, the depression is bounded by the Zhigulevsko-Pugachev block, which became highly uplifted and was eroded to the Middle Carboniferous.

STRATIGRAPHY AND DEPOSITIONAL FACIES

Introduction

Soviet geologists subdivide the stratigraphic section of the Russian Platform into a correlation framework of series and stages, some of which differ from those used in North America (fig. 8). Sedimentary rock sequences of late Precambrian, Devonian, Carboniferous, Permian, Mesozoic, and Cenozoic age make up the sedimentary cover on the platform. 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 (figs. 9, 11). Middle Devonian through Permian strata occur in more or less continuous depositional sequence, interrupted at several horizons by disconformities of variable extent (figs. 8, 9, 10, 11, 12). Upper Permian rocks make up the surface exposures over most of the province (fig. 7), 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 much as about 500 m (1,625 ft) thick are preserved. Most of the platform was emergent in early Paleozoic time and again during Mesozoic and Cenozoic time.

Various aspects of the regional stratigraphy and geologic history of the Volga-Ural province and the Russian Platform have been discussed by several authors including Maksimov and others (1970), Smirnov (1958), Aranova and others (1967), and Vasilyev and others (1963). Maksimov and others (1970) recognize seven main sedimentation cycles in the Volga-Ural province:

1. Riphean - primarily terrigenous coarse clastic continental beds deposited directly on crystalline basement, mainly in elongate, graben-like depressions (aulacogens) with some marine deposits in the upper part (late Proterozoic).

2. Vendian - coarse clastic beds followed by a marine clastic and carbonate sequence (late Proterozoic).

3. First Paleozoic cycle (first Hercynian cycle) - Middle Devonian through Tournaisian time; terrigenous clastics of Middle and early Late Devonian age, followed by marine reef-bearing carbonates of late Late Devonian and Tournaisian age.

4. Second Paleozoic cycle (second Hercynian cycle) - Terrigenous clastic deposits of early and middle Visean age, followed by fossiliferous marine carbonates of late Visean, Namurian, and Bashkirian age.

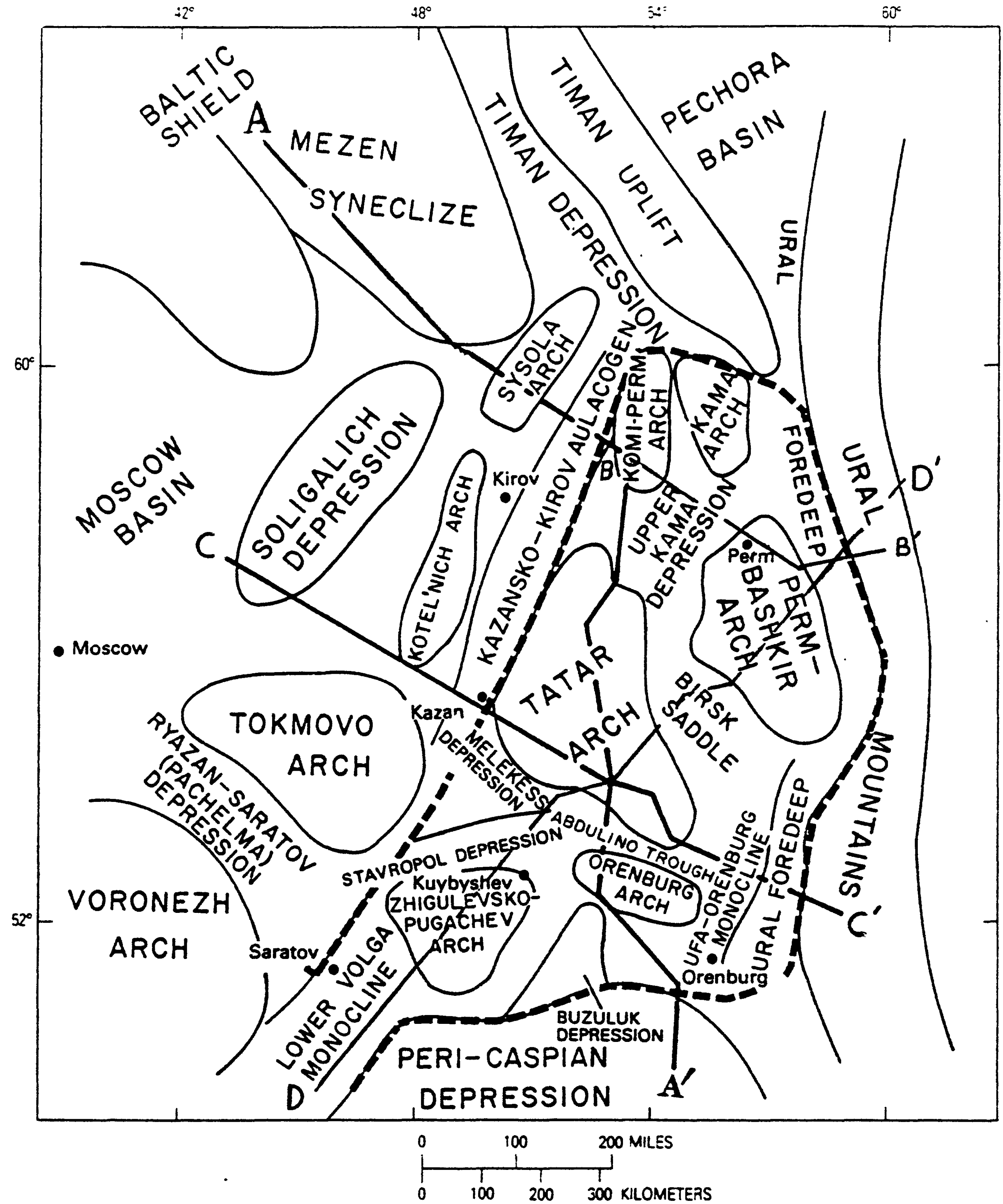


Fig. 5. Index map of Russian Platform region showing main structural features and location of lines of cross-sections.

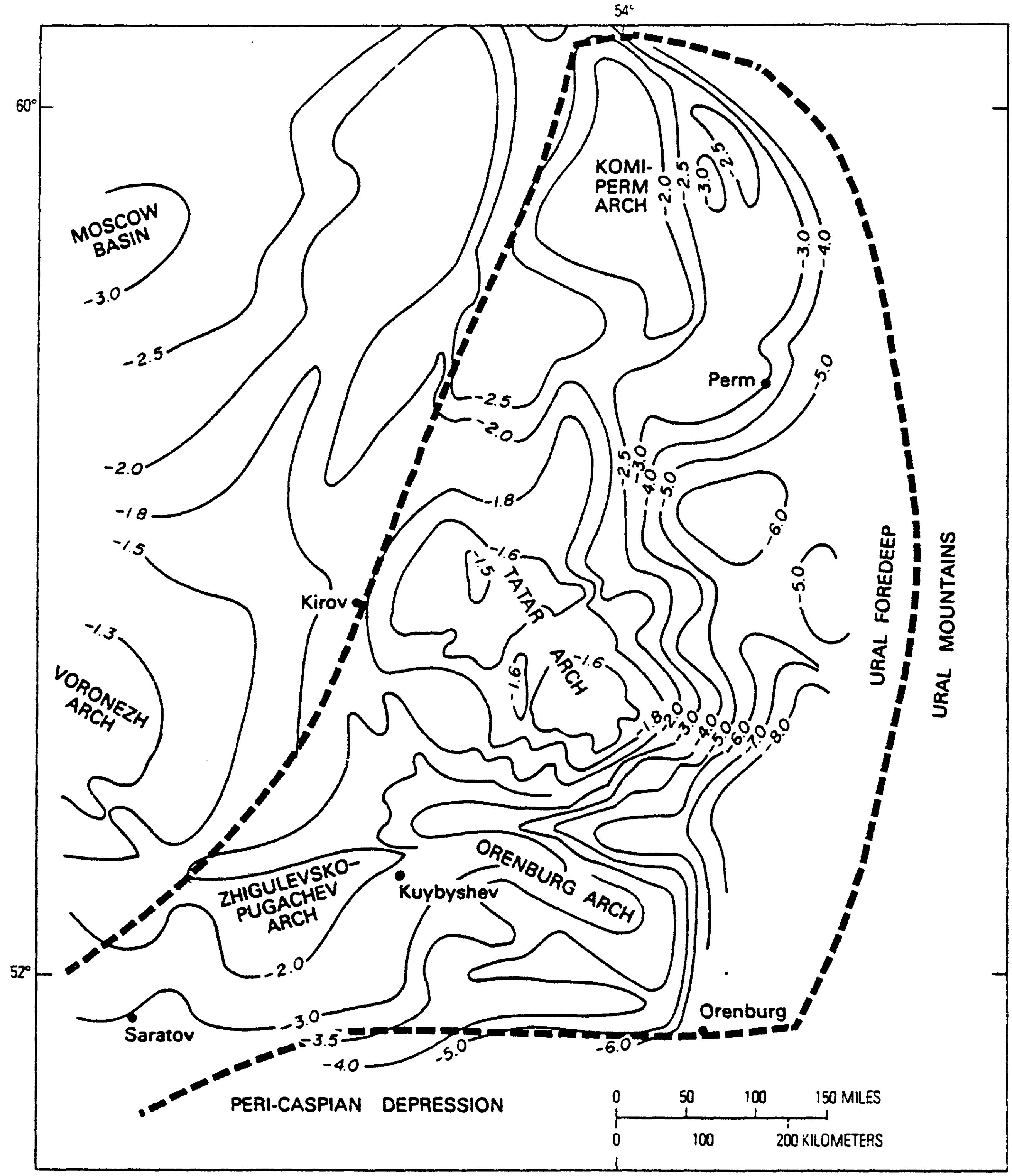


Fig. 6. Regional structure map on Precambrian crystalline basement, Russian Platform region. Contours in kilometers.

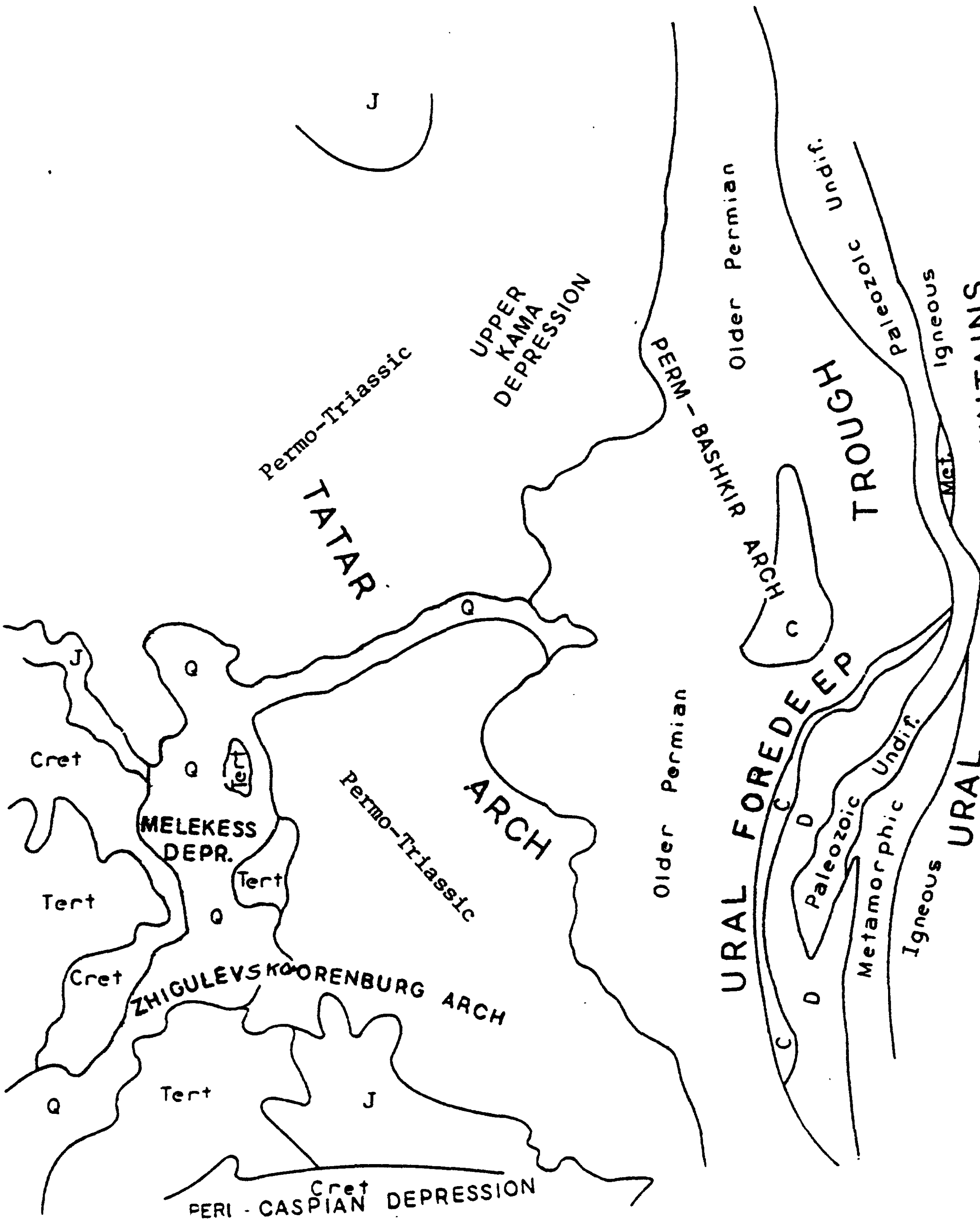


Fig. 7 Generalized geologic map of the Volga-Ural province.
Q - Quaternary, Tert - Tretiary, Cret - Cretaceous, J - Jurassic, C - Carboniferous, D - Devonian.

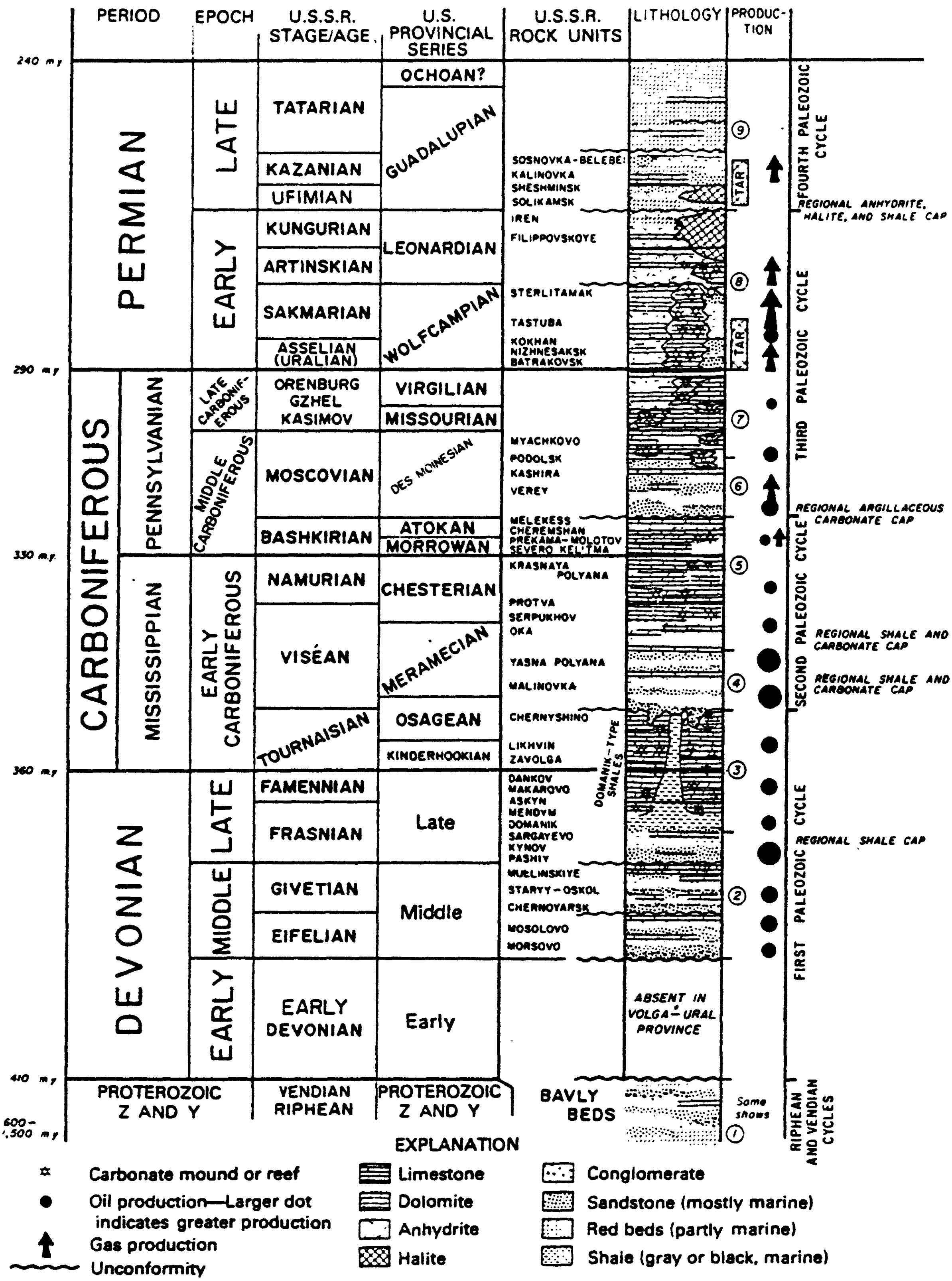


Fig. 8. Stratigraphic column, Ural-Volga province.

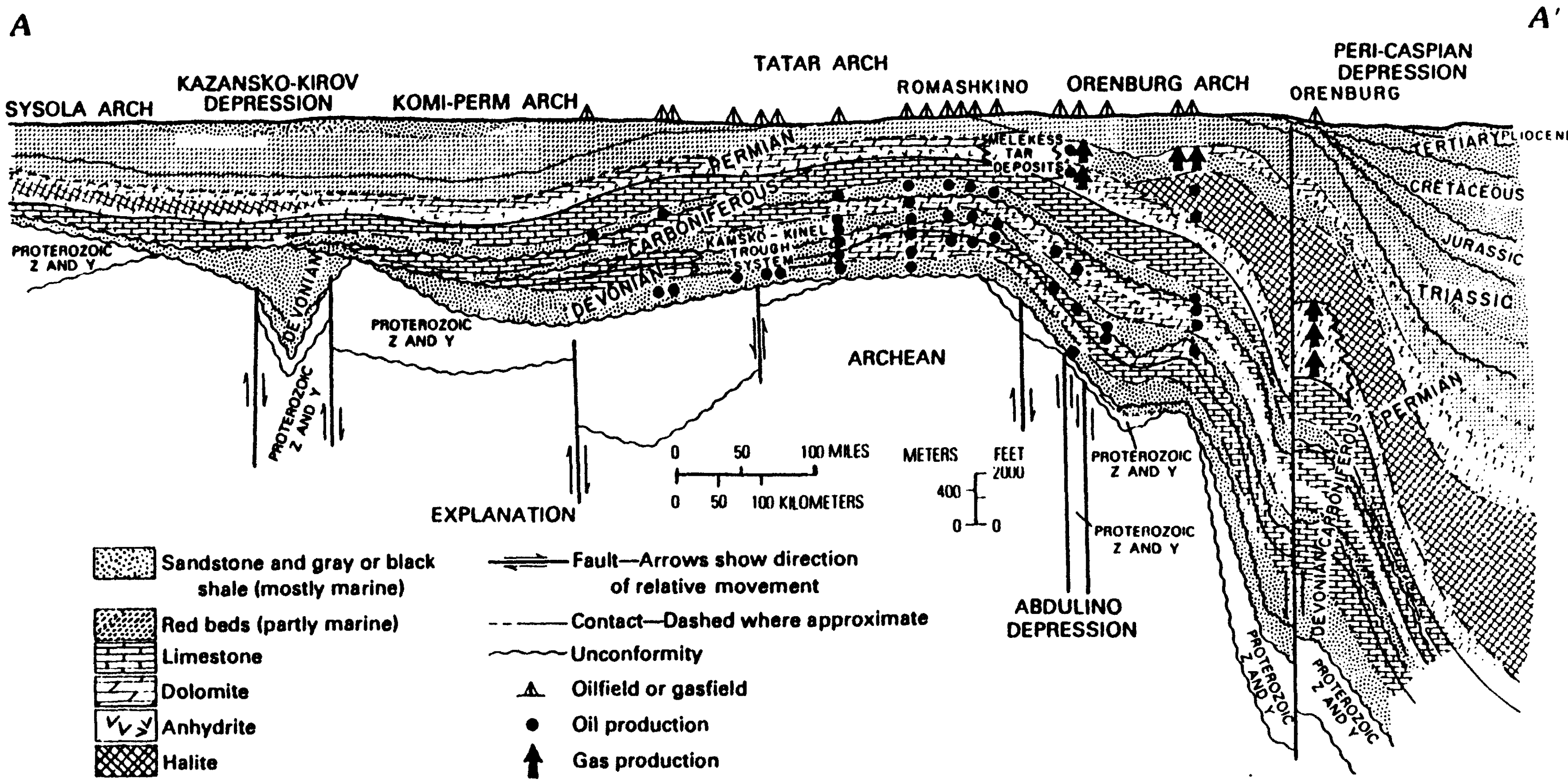


Fig. 9. North-south generalized structural-stratigraphic cross-section A-A', southeastern flank of Baltic Shield to Caspian Depression.

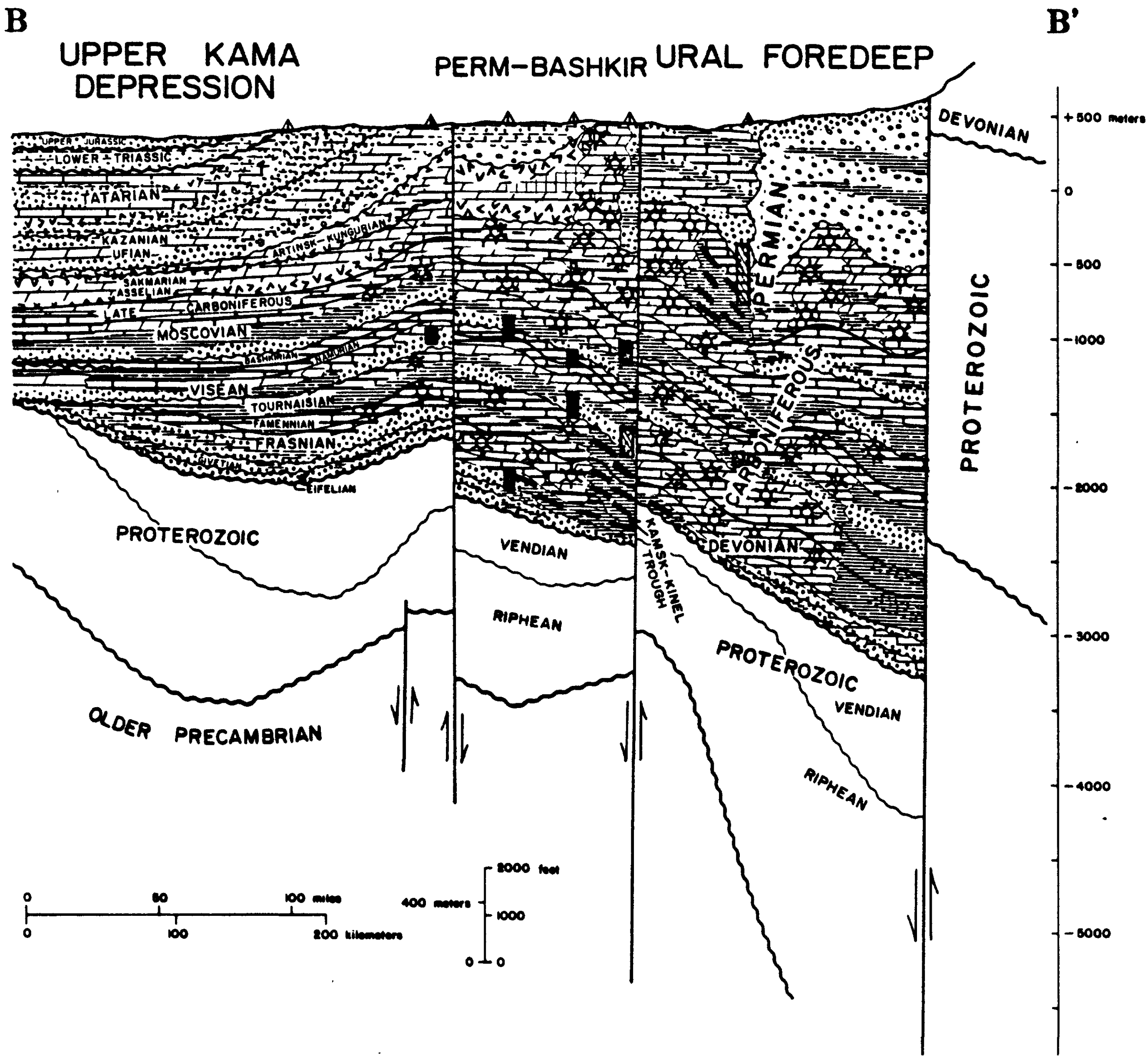


Fig. 10. Northwest-southeast generalized structural-stratigraphic cross-section B-B', Komi-Perm arch to Ural Mountains. See explanation on fig. 9.

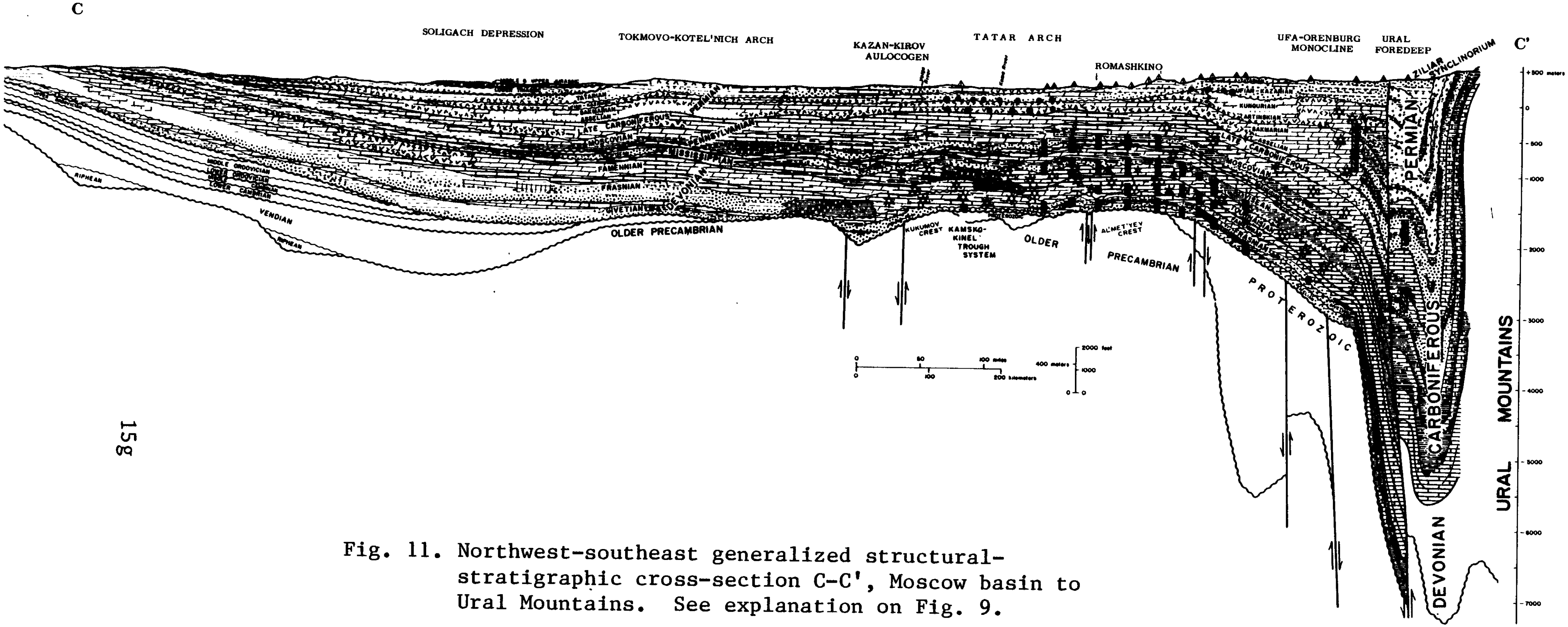


Fig. 11. Northwest-southeast generalized structural-stratigraphic cross-section C-C', Moscow basin to Ural Mountains. See explanation on Fig. 9.

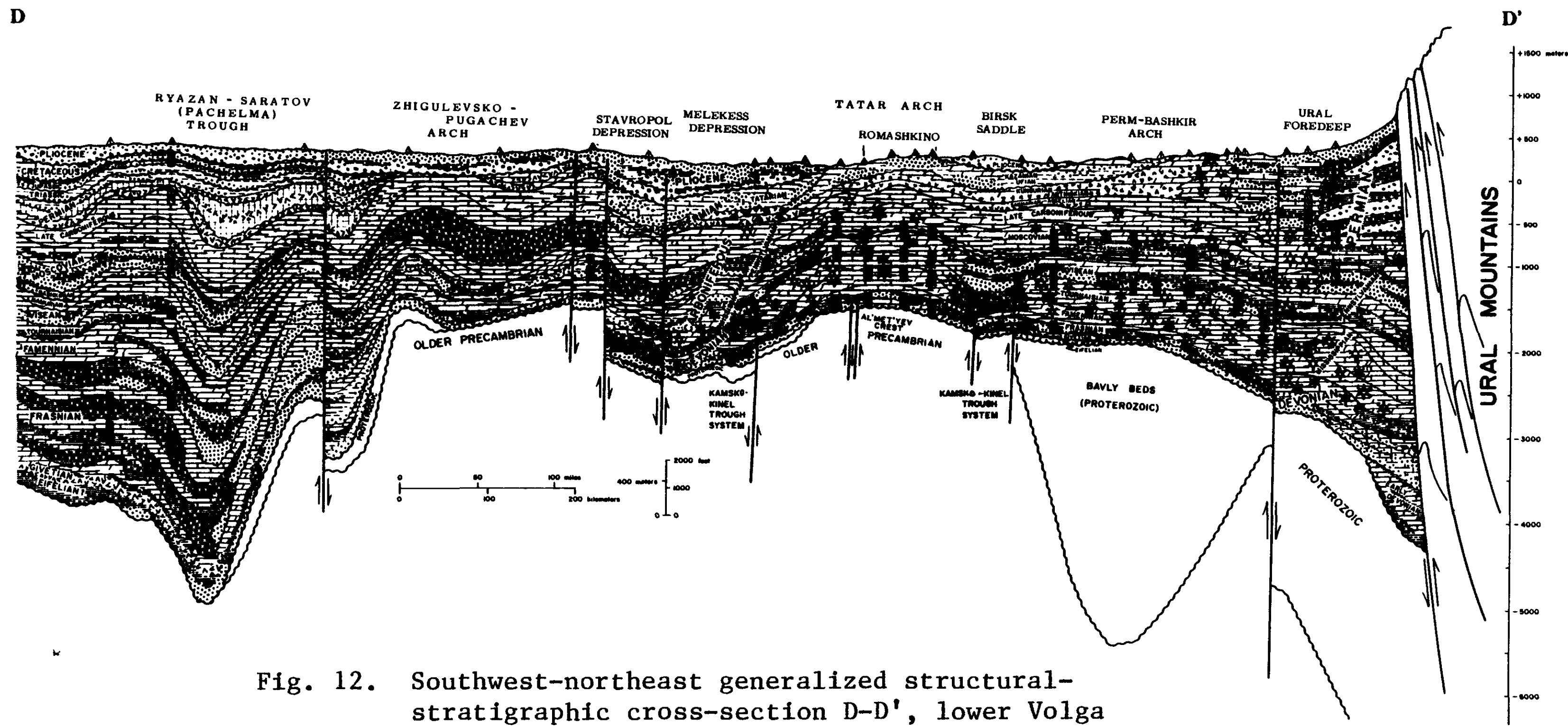


Fig. 12. Southwest-northeast generalized structural-stratigraphic cross-section D-D', lower Volga region to Ural Mountains. See explanation on fig. 9.

5. Third Paleozoic cycle (third Hercynian cycle) - Terrigenous clastic deposits of early Moscovian age, followed by fossiliferous marine carbonates of late Moscovian, Late Carboniferous, and Early Permian (Wolfcampian-early Leonardian) age.

6. Fourth Paleozoic cycle (fourth Hercynian cycle) - clay and carbonate deposits of late Leonardian age followed by carbonate and evaporite deposits of late Leonardian and early Guadelupian age and continental beds of Permian (late Guadelupian and Ochoan) age.

7. Alpine cycle - continental redbeds of Triassic age followed by marine sandstone and shale of Jurassic and Cretaceous age, deposited on the southern and western borders of the province.

The stratigraphic position of these cycles is shown on figure 8, which was compiled from several Soviet literature sources. For convenience, the age subdivisions used by Soviet geologists are compared with equivalent American chronologic subdivisions. Regional stratigraphic facies cross-sections apparently are not readily available in Soviet publications, but the general lithologic characteristics, facies changes, and thickness variations of the Paleozoic cycles are shown on the regional cross-sections of figure 9, 10, 11, and 12. These are "synthetic" cross-sections compiled from numerous Soviet literature sources, primarily regional thickness and facies maps, geologic analyses of local areas, and oil field data. Each of the sedimentary cycles is related to a transgressive-regressive episode of the Paleozoic seaway, and the main cycles are separated by unconformities of regional extent. The lower part of each cycle consists mainly of nearshore marine sandstone and shale; these grade upward into predominantly marine carbonate beds, which commonly contain 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 redbeds, evaporites, dolomite, and alluvial conglomerate beds predominate in the upper part of each cycle. All of the sedimentary cycles are closely related to the structural stages, and the depositional processes were strongly influenced by the paleostructural history of the major tectonic elements of the region.

Late Proterozoic

Rocks of late Proterozoic age (Bavly beds) in the Volga-Ural province were deposited in two transgressive-regressive depositional cycles, the Riphean (1,600 to 675 m.y.) and the Vendian (675 to 570 m.y.), separated by a regional unconformity and erosion surface. Early Riphean rocks (Kaltesin Series) are present in narrow trough-like depressions in the eastern part of the province, mainly the southern Ural foredeep (2,000-5,000 m or 6,500-16,250 ft. thick), the Sernovodsko-Abdulin aulacogen (as much as 900 m or 2,930 ft. thick), Birsk saddle and Upper-Kama depression

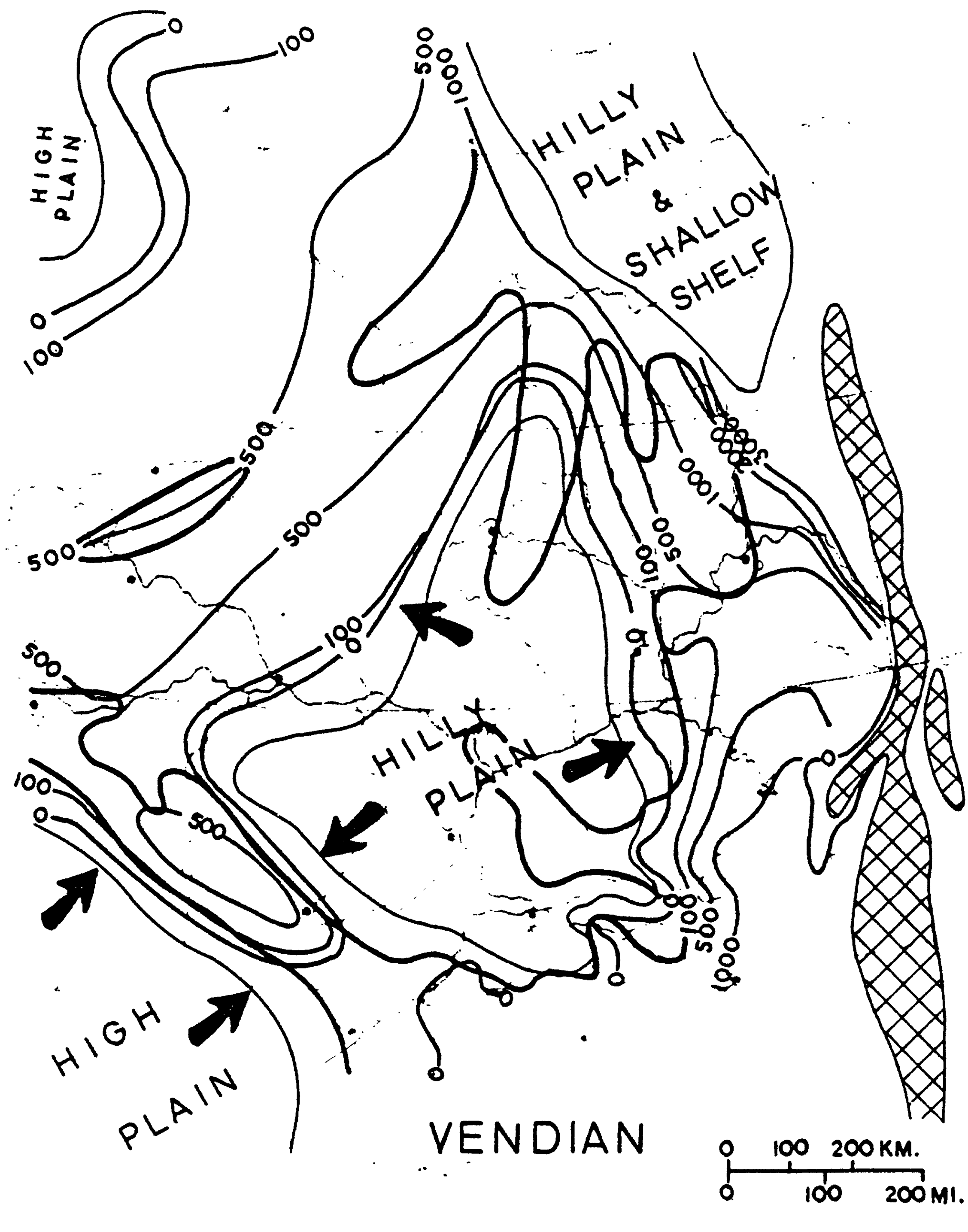
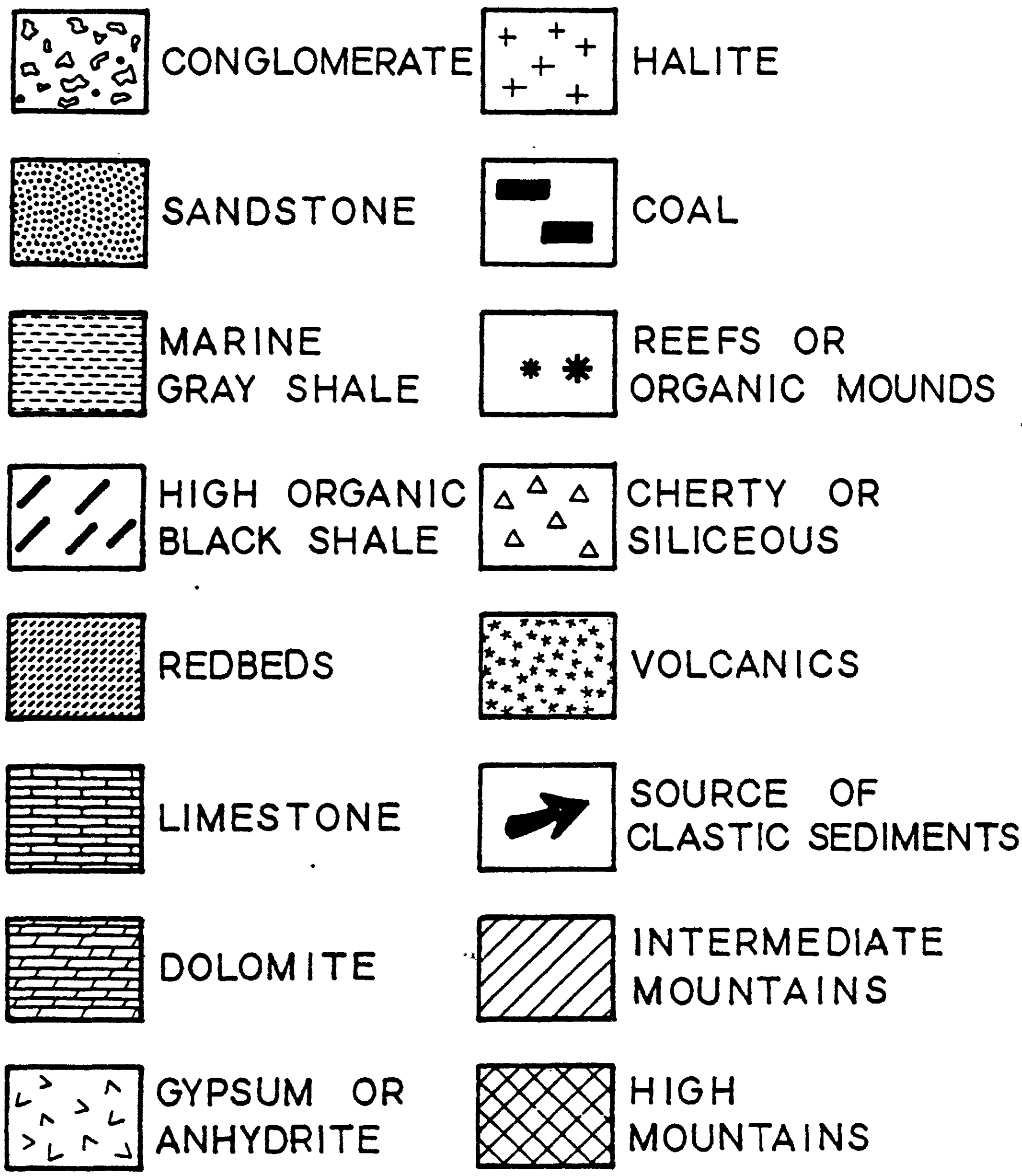


Fig. 13. Thickness in meters, Vendian (upper Proterozoic).



Explanation for figures 13-28.
M = Moscow; I = Ishimbay; O = Orenburg; P = Perm; S = Saratov;
K = Kuybyshev, Kazan, or Kirov.

Figures 13-28 are modified from Atlas litologo-paleogeograficheskikh kart SSSR, 1968, A. P. Vinogradov, ed.

(more than 650 m or 2,120 ft. thick), and the northern part of the Kazansko-Kirov aulacogen. These beds consist mainly of a lower sequence of continental coarse clastic and minor marine deposits that overlie the Precambrian crystalline surface and grade upward into and are overlapped by marine carbonate (dolomite and some limestone), shale, and partly glauconitic sandstone (upper Kaltesin Series). The Kaltesin Series is overlain conformably by the middle Riphean Serafin Series of varicolored and green-gray, primarily marine sandstone and shale with some carbonate beds in the upper part. According to Maksimov and others (1970), regional uplift of the platform occurred in late Riphean time, and previously deposited upper Precambrian beds were eroded. Deposition at this time consisted mainly of continental and minor marine clastics (Leonidov Series), restricted to the main subsiding troughs or aulacogens (Sernovodsko-Abdulino, Kazansko-Kirov, Ryazano-Saratov, and Timan troughs) and the Ural and Peri-Caspian depressions. Regional uplift was accompanied by volcanic activity in some places.

Vendian (upper Bavly) deposition was much more widespread than that of the Riphean. During this time active subsidence of the aulacogens diminished, and much of the Russian platform was inundated by shallow seas. The central part of the Volga-Ural province was emergent, and low-lying land areas were present to the west, southwest, and northeast (fig. 13). The Vendian sequence was deposited in more gently sloping and more extensive basins, in contrast to the aulacogen trough-like depressions of the Riphean. Basal lower Vendian beds (Kanov Series) consist of coarse clastics that unconformably overlie the Riphean, in some places with angular discordance. These beds grade upward into the upper Vendian (Shakpovo Series) sequence of mostly shallow-water marine shale and sandstone that contains some carbonate and phosphorite. The Shakpavo Series is as much as 800 m (2,600 ft) thick in the Sernovodsko-Abdulino aulacogen and Upper Kama depression.

In general, late Proterozoic sedimentary rocks of the Volga-Ural area are relatively unmetamorphosed, contain a great thickness (6-12 km or 3.7-7.5 mi) of normal marine as well as continental sandstone, shale and carbonate, and in many places have not been buried to great depths. Good reservoir rocks and moderate source rock quality are reported, and according to Yarullin and Romanov (1974), the Vendian and upper Riphean beds have good potential for oil and gas production, especially along the eastern border of the Cis-Urals belt (Ural foredeep) and the western part of the folded Ural Mountains. The most favorable areas are within the Alatau anticlinorium, a part of the southern Urals foredeep, particularly the western part which is only mildly disturbed by faulting. Indications of oil and gas are also found in the upper Riphean and Vendian beds in other parts of the province (Sulaymanov and Bazev, 1974; Stankevich and others, 1977; Chizh, 1977).

Several of the persistent Paleozoic paleostructures of the Volga-Ural province were active areas of subsidence or uplift during the late Proterozoic. These include the Sernovodsko-Abdulino, Kazansko-Kirov, Birsk-Upper-Kama, and Ryazano-Saratov depressions and the Tatar, Voronezh, Timan, Komi-Perm, Zhigulevsko-Orenburg, and Baltic arches, which were persistent clastic source areas for both Proterozoic and Paleozoic terrigenous deposits. Active uplift and mountain building occurred in many places near the close of the Vendian

Period, and the presence of tillites indicates the occurrence of continental and mountain glaciation, particularly in Scandinavia and the Ural Mountains (Keller and others, 1968). Regional uplifting, which began with the close of the Vendian, continued through the Caledonian (early Paleozoic) orogenic period, when most of the Russian Platform was emergent. According to Maksimov and others (1970), rocks of Cambrian, Ordovician, Silurian and Lower Devonian age are not present in the Volga-Ural province; conditions of erosion or nondeposition apparently prevailed throughout this time.

First Paleozoic Cycle (Middle Devonian-Tournaisian)

Rocks of Middle and Late Devonian age ranging form 200 m (650 ft) to more than 800 m (2,600 ft) thick (figs. 15-19) are present in all of the Volga-Ural province, deposited as part of a major transgressive marine cycle (first Paleozoic, or first Hercynian cycle) that spread westward from the Ural eugeosyncline across the Russian Platform. The "clastic Devonian" beds of Middle and earliest Late Devonian age form the lower part of the sequence (figs. 16, 17); these grade upward into carbonate beds, which reached a maximum thickness in Late Devonian (Famennian) and Early Carboniferous (Tournaisian) time when reef and organic carbonate deposition was dominant across the entire Volga-Ural region (figs. 18, 19). The cycle closed with regression of the seaway and emergence of the platform in Early Carboniferous time when erosion, karstification, and probably dolomitization of the carbonate section occurred prior to deposition of the lower Visean clastic beds of the succeeding cycle.

Numerous papers have been published on the Devonian rocks of the Russian platform and the Volga-Ural region (e.g. Aranova and others, 1967; Ovanesov and others, 1972; Krebs and others, 1972; Tikhy, 1967; Rzhonsnilskaya, 1967; Maksimov and others, 1970).

Early Devonian (fig. 14)

Rocks of Early Devonian age are absent on the Volga-Ural regional high where Middle Devonian sandstone and shale beds rest on late Proterozoic sedimentary rocks or older Precambrian crystallines. During this time, the early Paleozoic seas were restricted to the Ural geosyncline, where a thick section of Lower Devonian water-laid volcanics, deep and shallow water cherty muds, and thick carbonate reef bodies were deposited. According to Kondiain and others (1967), the greatest thickness of Lower Devonian clastics (more than 2,000 m or 6,500 ft.) was deposited in a system of transverse fault-bounded troughs that occupied the elongate north-south Ural geosynclinal province. Reefs of Early and Middle Devonian age, which are as much as 1,500 m (4,900 ft.) thick, grew mainly on uplifted fault blocks along the borders of the transverse troughs (Tikhy, 1967; Varentsov and others, 1976) and probably on the flanks of volcanic cones (Shadrina, 1977). Lower Devonian rocks are probably present in the deep subsurface of the Peri-Caspian depression, and varicolored beds as much as 600 m (1,950 ft.) thick of this age are reported in the Lower Volga region (Maksimov and others, 1970).

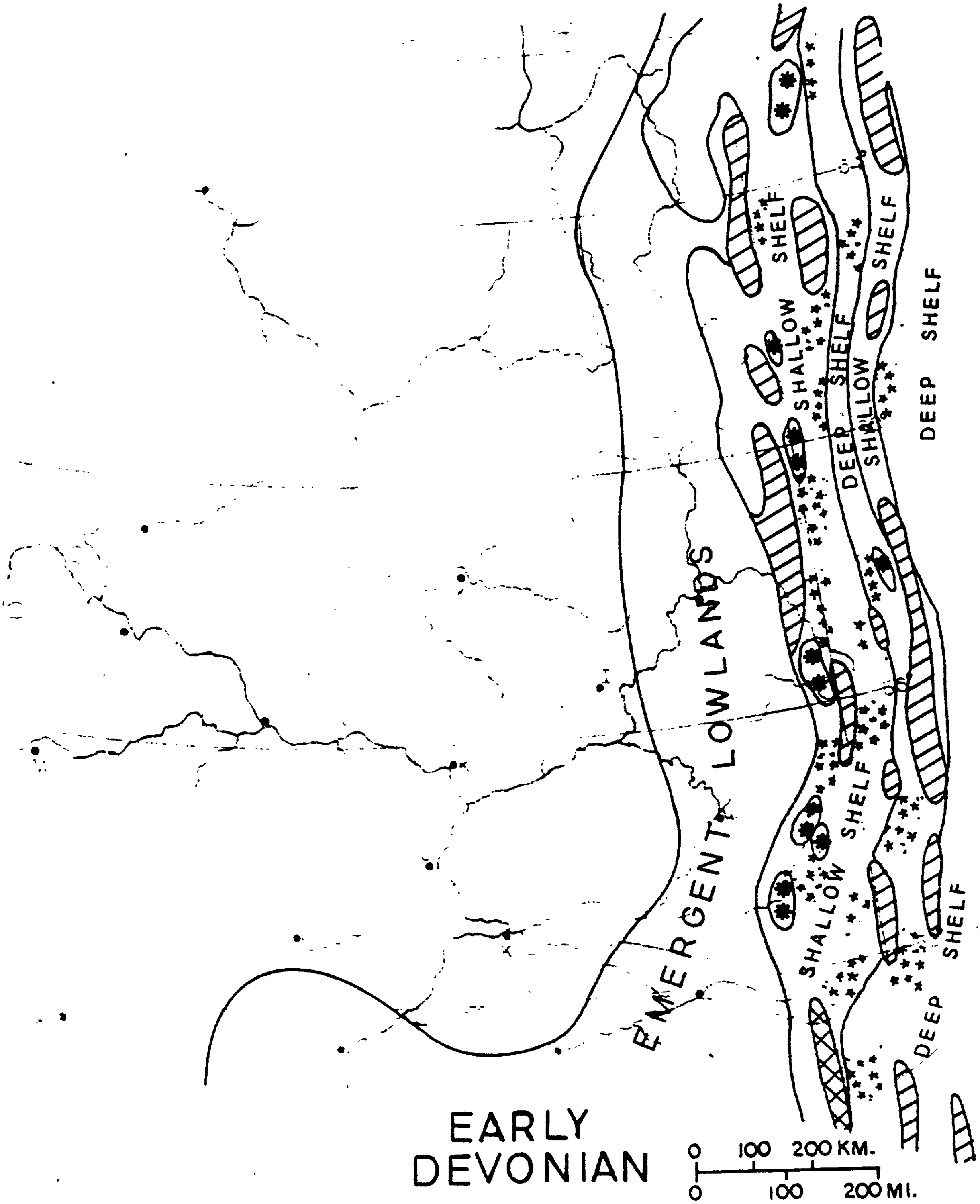


Fig. 14. Thickness in meters and facies map, Early Devonian. See explanation on fig. 13.

Middle Devonian (Eifelian and Givetian) (figs. 15, 16)

Eifelian (lower Middle Devonian) rocks are a sequence of coastal plain and shallow-water marine shelf sandstone, gray shale, and carbonate rocks that represent the initial deposits of the Middle Devonian-Tournaisian regional transgression. At this time, the eastern part of the platform was separated from the western part by a chain of emergent clastic source areas, which were ancestral elements of the Voronezh, Tokmovo, Kotel'nich, north Tatar, and Sysola arches (fig. 15, 16). Continental beds grading upward to restricted marine clastics and evaporites (with some halite) were deposited in a broad shallow water basin (the ancestral expression of the Soligalich depression) west of the emergent belt. Eifelian marine clastics overlap westward from the Ural geosyncline and pinch out on the eastern flanks of the emergent belt, on the border of the Perm-Bashkir arch, and along the east flanks of the Tatar, Zhigulevsko-Orenburg, and Komi-Perm arches, all of which were well-defined structures in Devonian time. Middle Devonian sandstone reservoirs were deposited mainly as deltaic and longshore marine discontinuous bodies of quartzose detritus derived partly from the low-lying land areas immediately to the west. The major source for these clastic sediments at this time was the continental mass in the Baltic Shield area to the northwest. Along the eastern and southern borders of the platform, Eifelian strata contain substantial amounts of dark gray shale beds and fossiliferous carbonate beds, some with an abundant fauna of reef builders (Aranova and others, 1967). These beds are thickest (more than 500 m or 1,625 ft.) on the southeast slope of the platform (figs. 9, 15). General emergence of the platform and erosion of the underlying beds occurred at the close of the Eifelian cycle, except for the southeastern slope of the platform which remained submerged by the Ural geosynclinal sea.

The Givetian transgression was much more widespread than that of the Eifelian, and marine waters eventually covered all of the Russian platform at this time, except for parts of the major positive paleostructures (Voronezh, Tokmovo, Kotel'nich-Sysola, north Tatar, Komi-Perm, Zhigulevsko-Orenburg, and Perm-Bashkir arches). Givetian rocks are thickest (100 to 500 m or 325 to 1,625 ft) in the northeast part of the platform where they are clastics, and along the south slope of the platform, where marine carbonate and dark gray shale beds dominate the section (fig. 16) (Aranova and others, 1972; Maksimov and others, 1970). These beds change northward to gray shale and siltstone facies and finally to predominately sandstone and siltstone farther north and northwest toward the Baltic Shield clastic source area. Redbed and evaporite deposits are present to the west in the ancestral Moscow basin. The Kazansko-Kirov aulocogen began active subsidence again at this time, receiving more than 200 m (650 ft.) of marine terrigenous and carbonate sediments. Givetian marine sandstone reservoirs were deposited under deltaic and longshore marine conditions similar to those of the Eifelian, but the quartzose sand supply was much greater at this time, and in overall geometry the individual sandstone bodies are much thicker and of greater lateral extent.

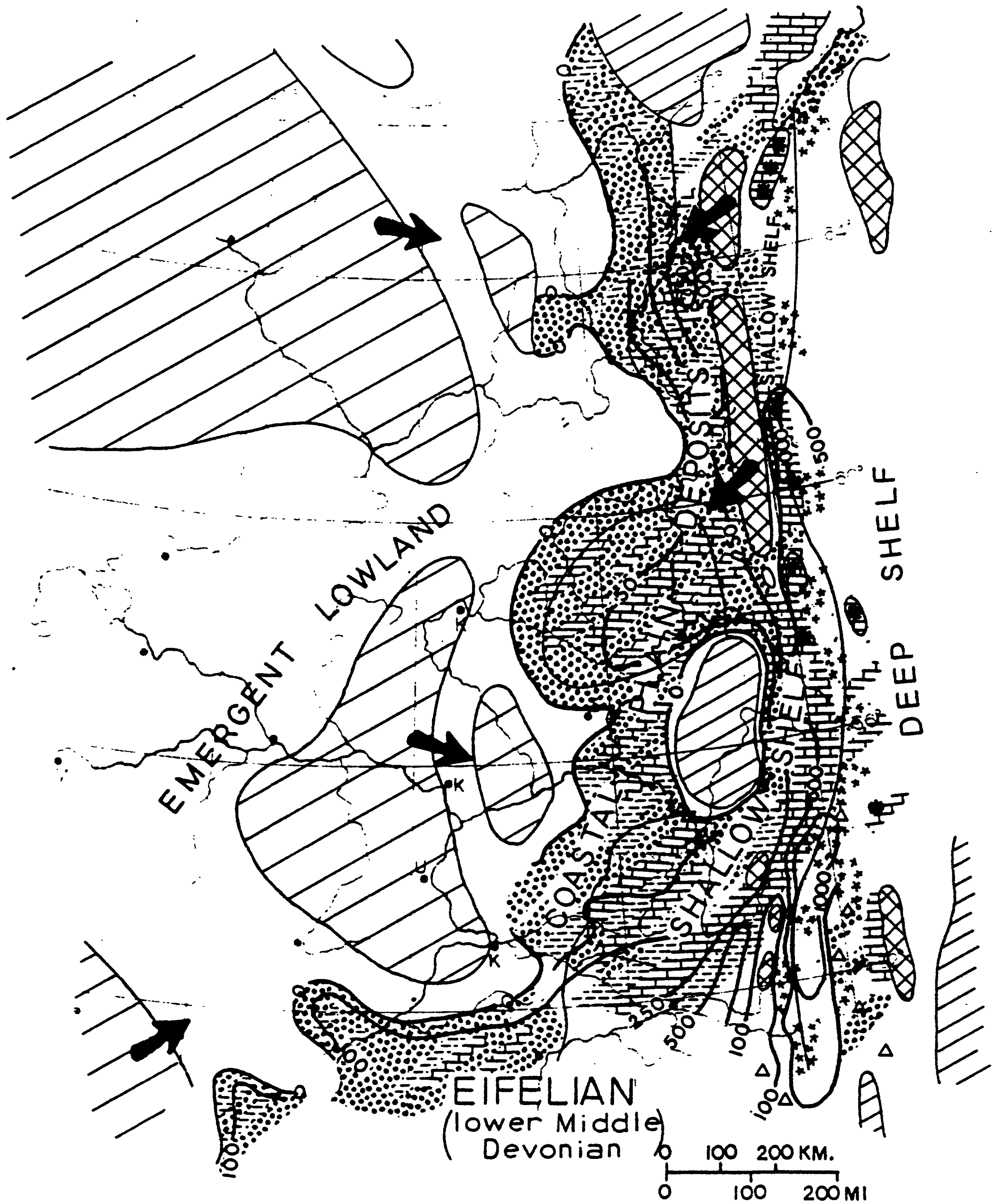


Fig. 15. Thickness in meters and facies map, Eifelian (lower Middle Devonian). See explanation on fig. 13.

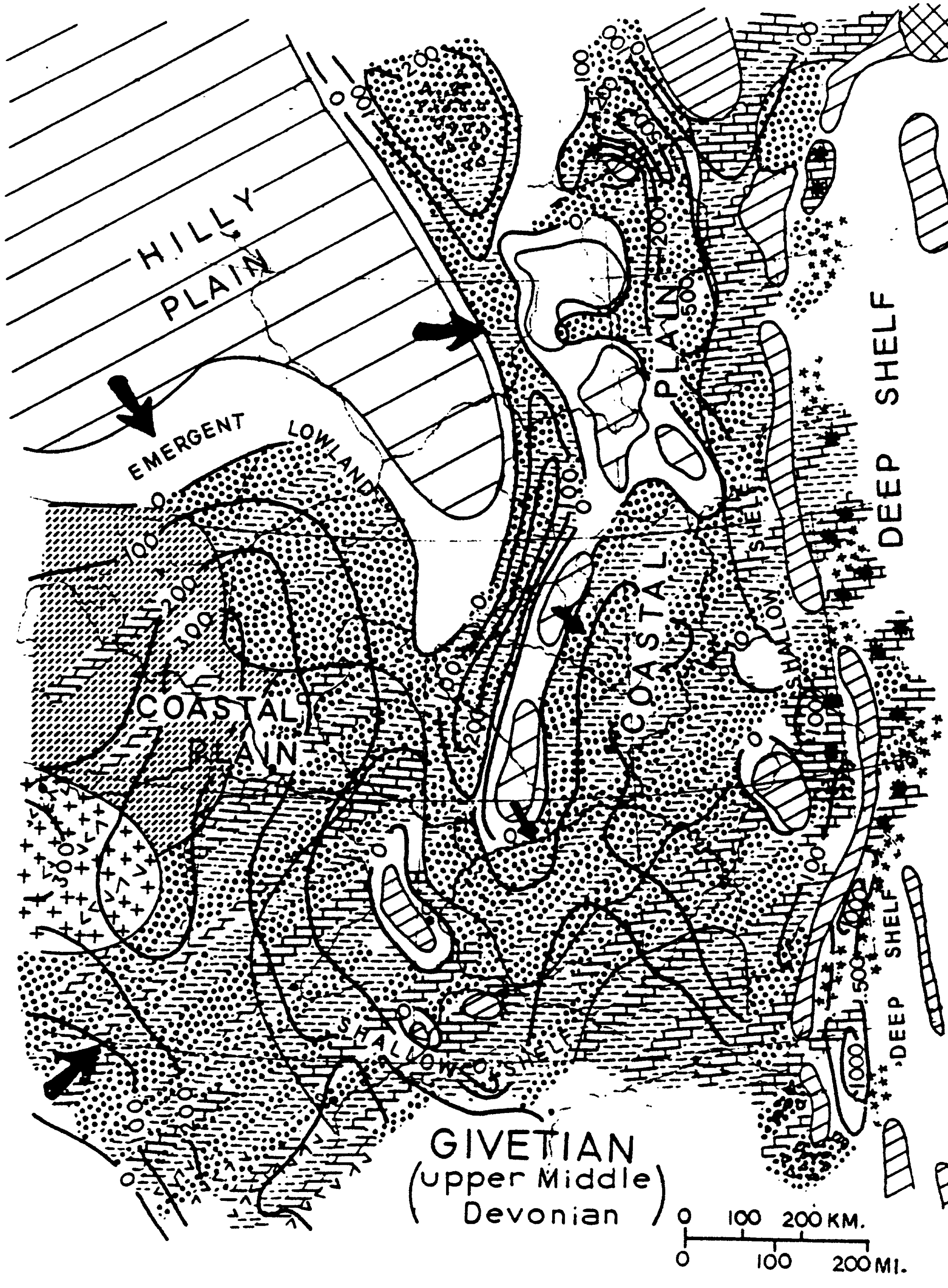


Fig. 16. Thickness in meters and facies map, Givetian (upper Middle Devonian). See explanation on fig. 13.

At the close of Givetian time, volcanic activity occurred to the north and south of the platform, and general emergence and minor erosion took place over most of the Volga-Ural regional high, except for its southern part (Maksimov and others, 1970).

Late Devonian (Frasnian and Famennian) (figs. 17 and 18)

Early Frasnian deposition was similar to that of the Givetian, but the overall Frasnian transgression was more extensive. In early Frasnian time, parts of the Kotel'nich and Perm-Bashkir arches, and the Zhigulvsko-Pugachev block remained emergent, but by the end of the Frasnian time all of the positive paleostructural elements were covered with at least some marine sediments of Frasnian age. The western part of the platform received mainly coastal plain and interbedded nearshore marine deposits that grade into continental redbeds farther west. Deposition in the eastern part of the platform began with large accumulations of shallow-water marine and lagoonal sandstone and dark shale beds similar to those of the lower Givetian. The lower Frasnian clastics are relatively thin, however, and rapidly grade upward into predominantly fossilifereous carbonate beds of the upper Frasnian, when reef and organic carbonate mound buildups developed in many of the shallower water areas of the platform.

In the middle Frasnian, the bituminous Domanik facies began to form as a prelude to the development of the Kamsko-Kinel trough system (figs. 3, 5, 18, 19, 34), which comprises a grouping of narrow, interconnected deeper water troughs that persisted into Early Carboniferous time. The Domanik beds are a restricted marine, relatively deep-water, dark gray and black bituminous shale, marl, and argillaceous limestone facies, rich in organic matter, often siliceous, containing goniatite ammonites, coniconches, radiolarians, and thin-walled pelecypods (Aranova and others, 1967). These beds are believed to be the source rocks for much of the oil accumulated in the Volga-Ural province. The lower Frasnian part of the Domanik sequence is present in the Kazansko-Kirov, Melekess, and Buzuluk depressions, and on the south-eastern slope of the platform. During middle Frasnian time, the Domanik facies extended across most of the Volga-Ural province and was thickest in the Sernovodsko-Abdulino and Melekess depressions, the Upper-Kama depression, and along the eastern border of the platform. These beds were named the Domanik Formation by Murchison and others (1845) from outcrops east of Perm. By late Frasnian time, the Domanik facies was reduced in lateral extent as reef and organic mound limestone deposits began to build up along the borders of the Kamsko-Kinel troughs. As the carbonate deposits built vertically and spread laterally, the deeper water troughs were further narrowed, and the true Kamsko-Kinel trough system became fully developed and merged northward with the Ural foredeep north of the Perm-Bashkir arch. By the close of the Frasnian, carbonate deposits had built up to considerable thickness on several of the high areas of the platform, particularly on those of the Tatar and Perm-Bashkir arches, and in several areas along the edges of the Kamsko-Kinel troughs (fig. 3). According to Maksimov and others (1970), tectonic subsidence of several of the main negative

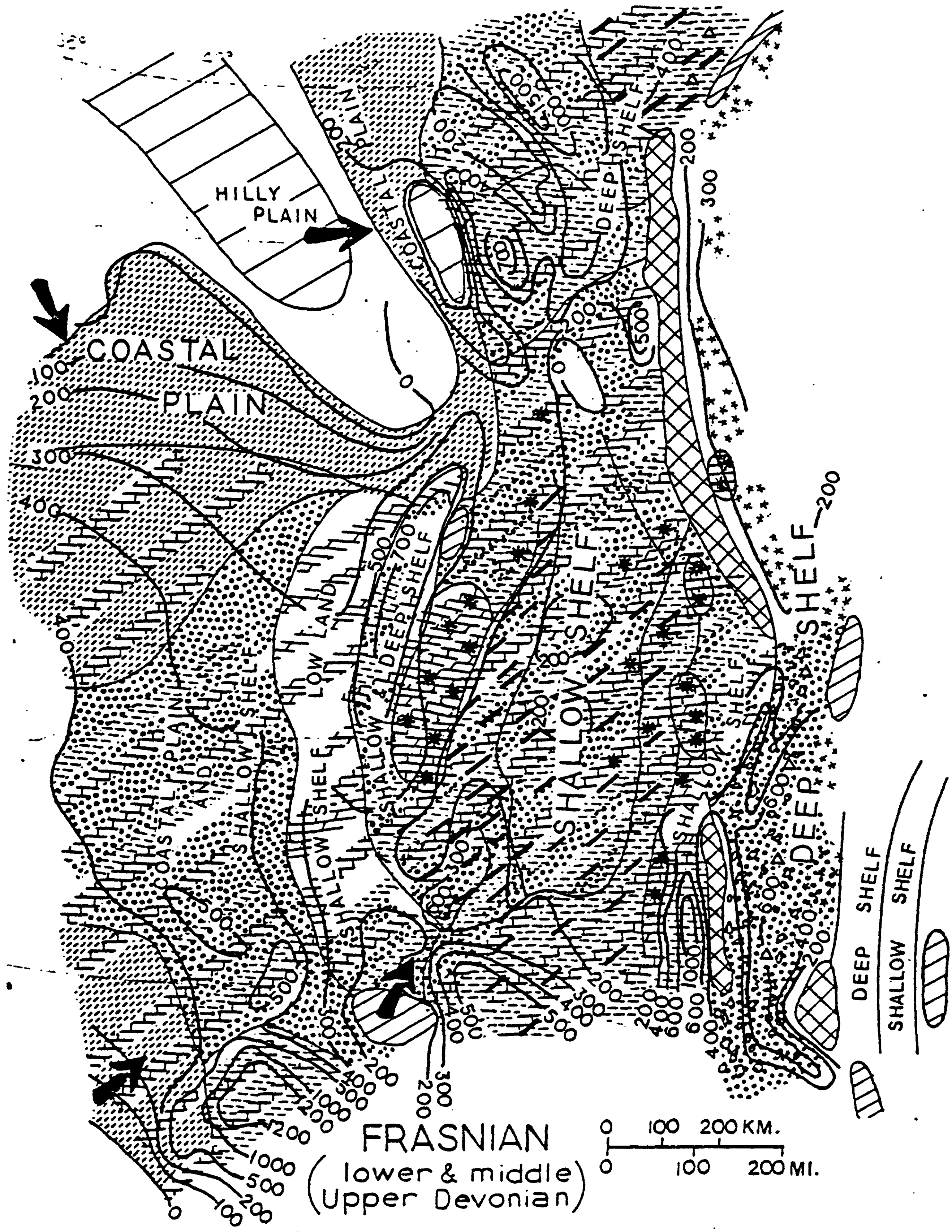


Fig. 17. Thickness in meters and facies map, Frasnian (lower and middle Upper Devonian. See explanation on fig. 13.

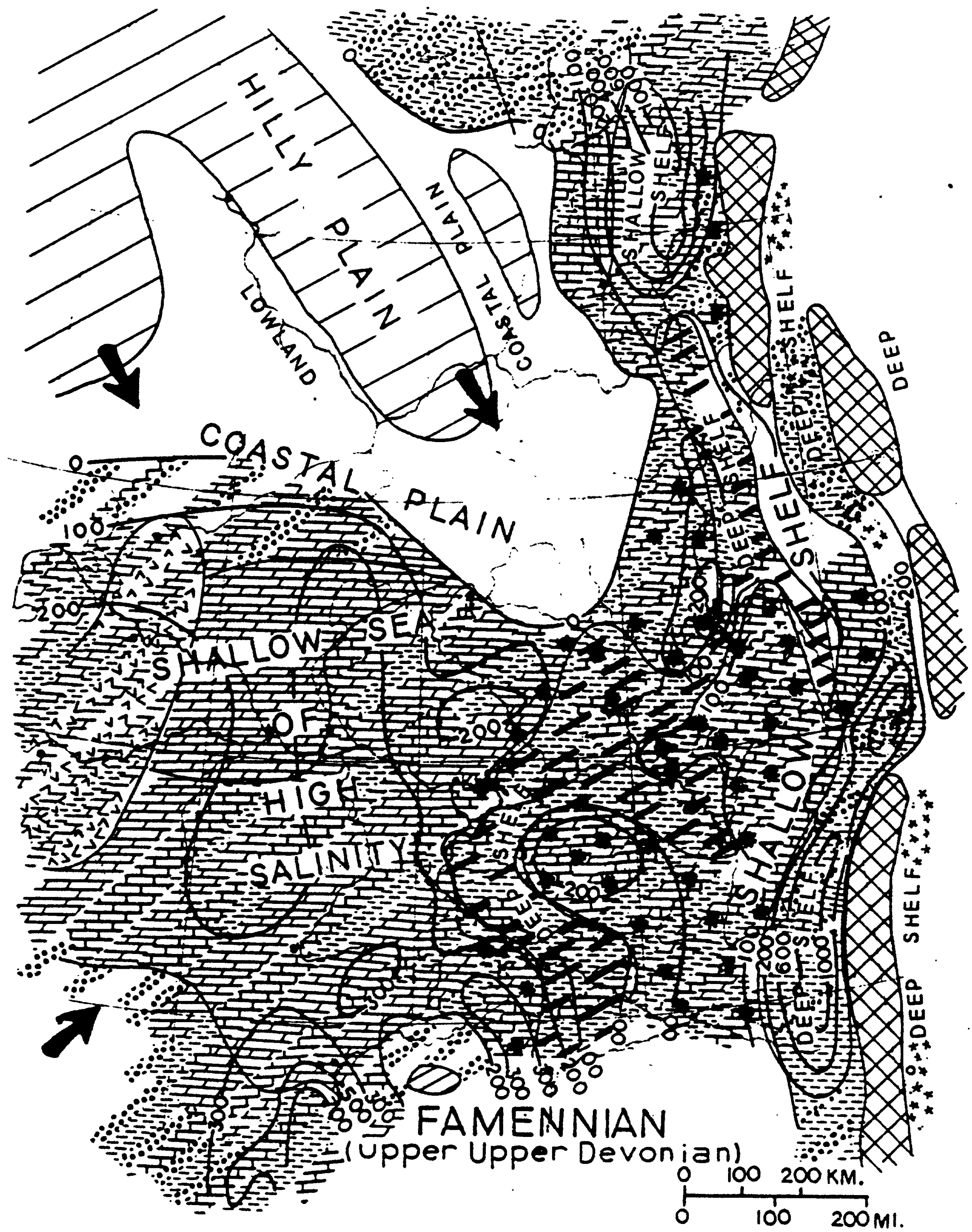


Fig. 18. Thickness in meters and facies map, Famennian (upper Upper Devonian). See explanation on fig. 13.

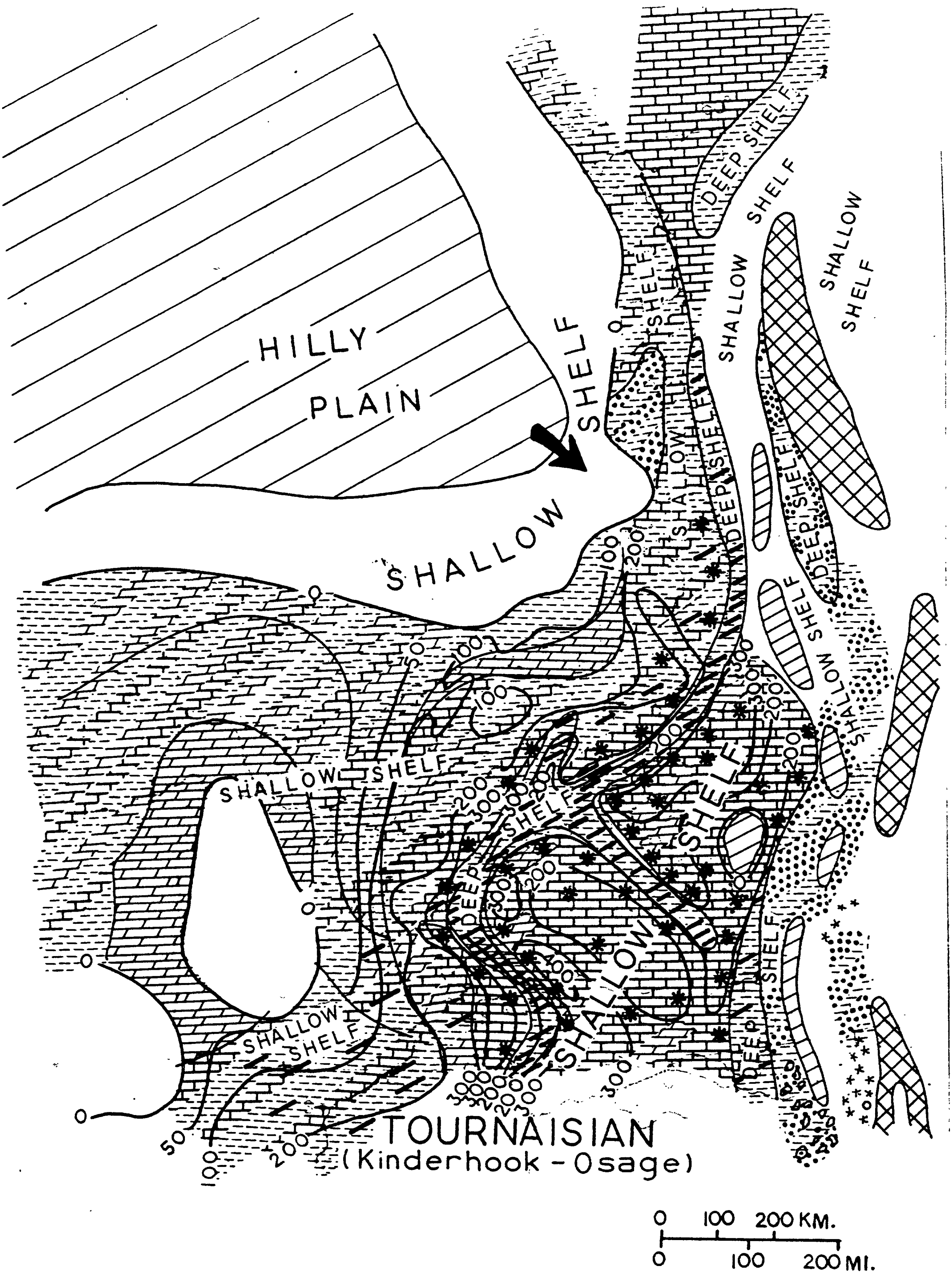


Fig. 19. Thickness in meters and facies map, Tournaisian (Kinderhookian-Osagean). See explanation on fig. 13.

paleostructures of the eastern part of the platform formed the foundation for the Kamsko-Kinel trough system. These include the Buzuluk, Melekess, and Upper-Kama depressions and the Birsk saddle.

Strong subsidence and deposition of greater thicknesses of Frasnian sediments occurred in several other paleostructurally depressed parts of the platform, including the Kazansko-Kirov aulacogen (more than 1,000 m or 3,250 ft), Lower Volga monocline (more than 1,200 m or 3,900 ft), and the southern Ural foredeep (more than 1,500 m or 4,900 ft).

Carbonate deposition increased markedly during the Famennian, and except for the deeper water Kamsko-Kinel troughs, reef and organic carbonate mound deposits covered most of the Volga-Ural province at this time. The Kamsko-Kinel trough system was further narrowed as biohermal carbonate beds grew upward and prograded laterally into the trough borders, across the flanks of previously deposited reefs. The highly bituminous Domanik facies continued to be deposited in the troughs but in general was thinner and less silty than that of the Frasnian. The Famennian, as well as upper Frasnian, reefal deposits are composed primarily of stromatoporoid and tabulate coral remains, calcareous blue-green, red, and spherical algae, and variable amounts of crinoid, foraminifera, and other skeletal organic material (Ovanesov and others, 1972). The reef rocks tend to be very pure carbonate (insolubles one percent or less) and are partly dolomitized in places.

Tournaisian (Kinderhook-Osage) (fig. 19)

The predominantly organic carbonate deposition characteristic of the Famennian continued into the Tournaisian with no evidence of disconformity. Biohermal and organic carbonate mound bodies continued to build up along the borders of the Kamsko-Kinel troughs and prograded further across the trough slopes. Carbonate buildups spread laterally across most of the eastern part of the platform and in places shifted toward the centers of the troughs as they filled. Tournaisian organic carbonate buildups are composed mainly of calcareous algae, foraminifera, Syringopora and other corals, crinoids, sponge remains, and other miscellaneous skeletal debris, which is only partly dolomitized. Maximum thickness reaches as much as 400 m (1,300 ft). Biohermal growth occurred along the length of the Kamsko-Kinel system on both sides of the troughs, with the most pronounced buildups on the Perm-Bashkir arch, Birsk saddle, and the west flank of the Al'met'yev high of the Tatar arch. The Domanik facies continued to be deposited in the Kamsko-Kinel trough system, which reached its narrowest dimension at this time. Thickness of the dark high-organic carbonate and shale beds of the Domanik facies is as much as 200 m (650 ft) in places.

Origin of the unique Kamsko-Kinel trough system has been a subject of some discussion by Soviet geologists. Uspenskaya and others (1972) suggested that the troughs formed between large paleo-arches (defined by Mirchink and others, 1965) and were associated with block tectonic movement of the basement. Active subsidence of the basement created narrow deeper water troughs where "noncompensated" sedimentation occurred, and reef belts formed along the uplifted blocks that flanked the troughs. Isolated reefs and atolls developed within the troughs at places where differentially aligned faults and the troughs intersect. Others believe that the system was primarily a result of sedimentary processes, initiated with building up of organic reefal or mound bodies on the major paleo-arches, followed by prograding of the carbonate buildup toward the noncompensated deeper water regional depressions where buildups did not occur (Ovanesov and others, 1972). The deeper water trough system narrowed as organic buildup encroached on the troughs, this process reaching culmination in Famennian-Tournaisian time when maximum transgression and optimum marine circulation conditions prevailed on the shelf, and organic growth was at a maximum. Stratigraphic and paleotectonic evidence suggests that both processes were probably important in producing the final result. The early phase of trough system development appears to be related to initial development of the Domanik facies within large previously subsiding areas that were probably related to older basement depressions, but as the carbonate organic deposits build-up on adjacent paleostructurlly high features, progradation of carbonate buildup toward the depressions produced the final expression of the narrowed Kamsko-Kinel trough system.

Second Paleozoic cycle (Visean, Namurian, and Bashkirian)

This cycle comprised a 50 m (160 ft) to about 800 m (2,600 ft) sequence of terrigenous clastic deposits of early and middle Visean age, followed by fossiliferous marine carbonates of late Visean, Namurian, and Bashkirian ages. The basal Visean beds are continental and nearshore marine sandstone and shale, which 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. Visean 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.

Visean (Meramec-early Chester) (fig. 20)

General emergence of the Russian platform occurred following deposition of the Tournaisian reefal and other carbonate facies. Weathering, leaching, and probably partial dolomitization of the underlying carbonates occurred. Solution karst features are reported in the upper Tournaisian section at places (Dakhnov and Galimov, 1960), and deep channeling of underlying beds by early Visean stream systems is reported in the Kamsko-Kinel troughs and adjacent highs (Nikulin and Sharonov, 1960). Deposition of the Visean clastic sediments essentially completed the filling of the Kamsko-Kinel troughs; these beds are 400 m (1,300 ft) or more thick in some of the troughs (fig. 20). After Visean time, no evidence of the Kamsko-Kinel trough system is found

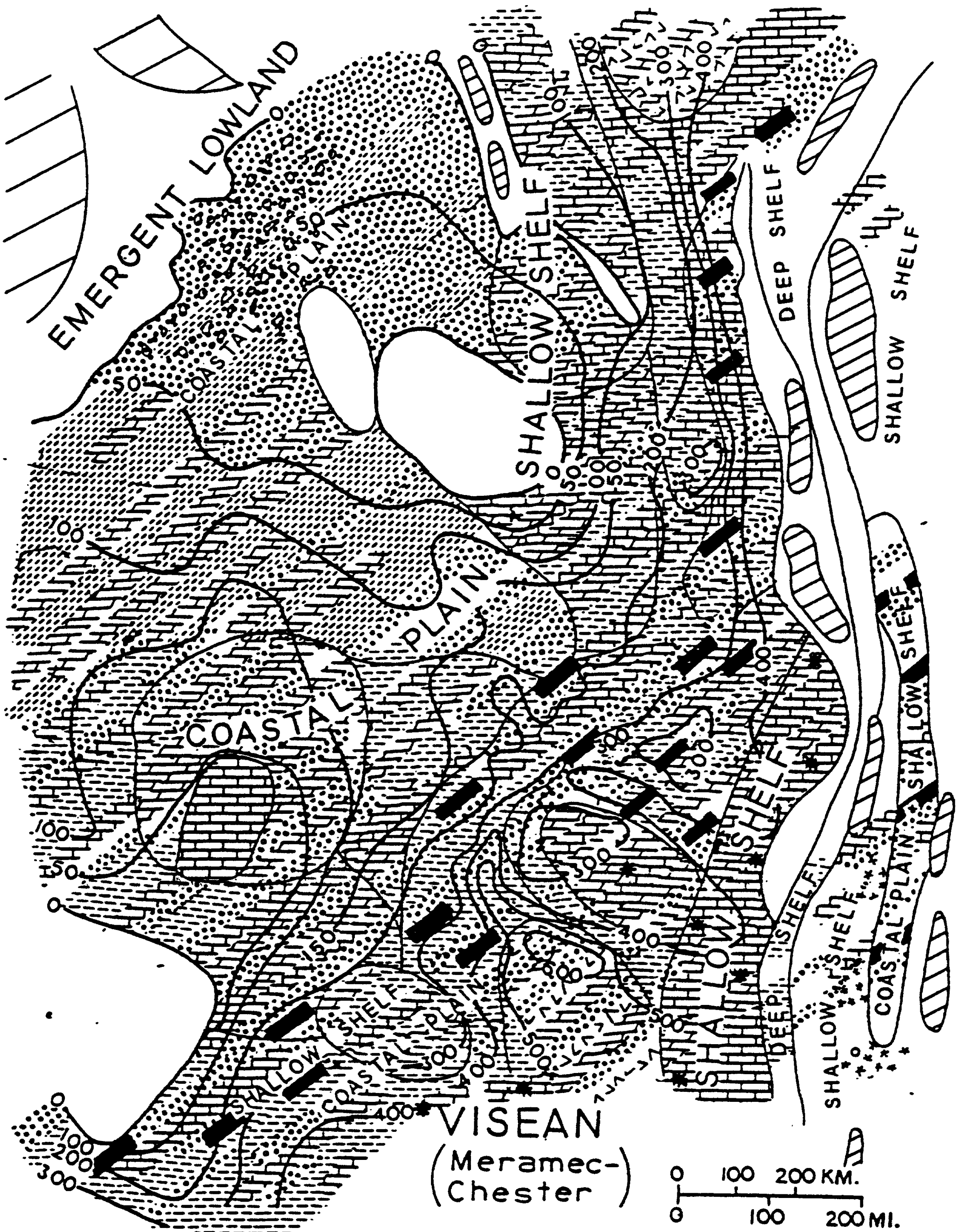


Fig. 20. Thickness in meters and facies map, Visean (Meramecian-Chesterian). See explanation on fig. 13.

(Maksimov and others, 1970). An intricate network of channel sandstones is reported on the west flank of the Bashkir arch where at least 25 sandstone belts are identified; they are 1/4 to 1-1/4 km wide and up to 80 km (50 mi) long (Tsotsur, 1974). Similar channel sandstones are reported also in many other parts of the platform (Voytovich and Shel'nova, 1977; Baymukhametov, 1976). The sandstone bodies are generally linear in a north-south direction, highly variable in thickness, and the thicker sands are more persistent and less lensing, except for the channel sandstones in the troughs, some of which cut deeply into the beds below in canyon-like depressions. Upward in the section, the stream channel sandstones change to nearshore marine and deltaic deposits and become interbedded with dark gray transgressive marine shale beds. The middle Visean section contains several marine sandstone intervals, indicative of minor cyclic shoreline fluctuations, but overall the Visean changes upward to mainly carbonate beds. The major source area for Visean clastics was the Baltic Shield to the northwest; a second less important source was in the vicinity of the Voronezh crystalline massif.

Some interbedded gypsiferous strata are present in the Buzuluk depression. Coal deposits are present in the coastal plain and shallow marine facies that filled the Kamsko-Kinel troughs and also along the north and east borders of the Voronezh high.

Namurian (late Chester) (fig. 21)

Rocks of Namurian (latest Early Carboniferous) age are marine limestone and dolomite; some interbedded thin gray shale beds are present north and west of the province. The Namurian beds form a blanket-like, relatively thin carbonate wedge across the province, ranging in thickness from about 20-40 m (65-130 ft) over the Tatar arch to about 80-100 m (260-325 ft) on the southeast flanks of the platform (fig. 21). Evidence of brief emergence and some erosion in parts of the province at the close of Namurian deposition is present on the northern and southern crests of the Tatar arch, and on the crests of the Zhigulevsko-Pugachev block and the Bashkir high (Maksimov and others, 1970).

Bashkirian (Morrowan-Atokan) (fig. 22)

Rocks of Bashkirian age are almost entirely fossiliferous dolomite and limestone beds on the Volga-Ural regional high. Some of these have good porosity. The carbonate section is interbedded with marine gray shale on the east and south flanks of the province, and red shale and siltstone are present to the west. Some marine sandstone and shale are present to the southwest in the Lower Volga depression. The Bashkirian carbonates are highly fossiliferous and contain oolitic limestone and dolomite beds with abundant shell debris, foraminifera and algae (Armishev and others, 1976; Kaleda and Kotel'nikova, 1974). Regional emergence of the platform occurred at the close of Bashkirian deposition, and in places, conglomerate beds with rounded carbonate fragments are present. Leaching and karstification of the

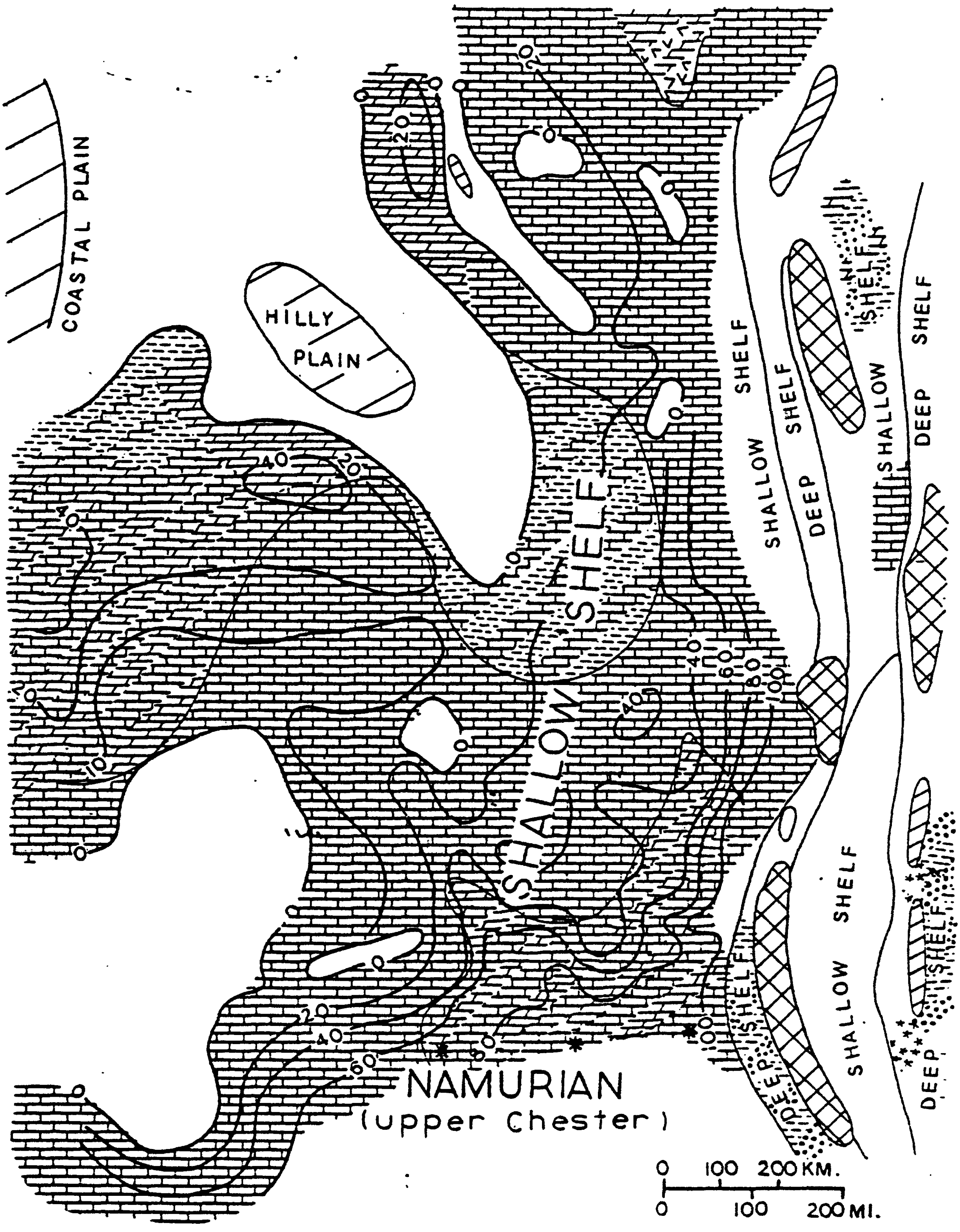


Fig. 21. Thickness in meters and facies map, Namurian (upper Chesterian). See explanation on fig. 13.

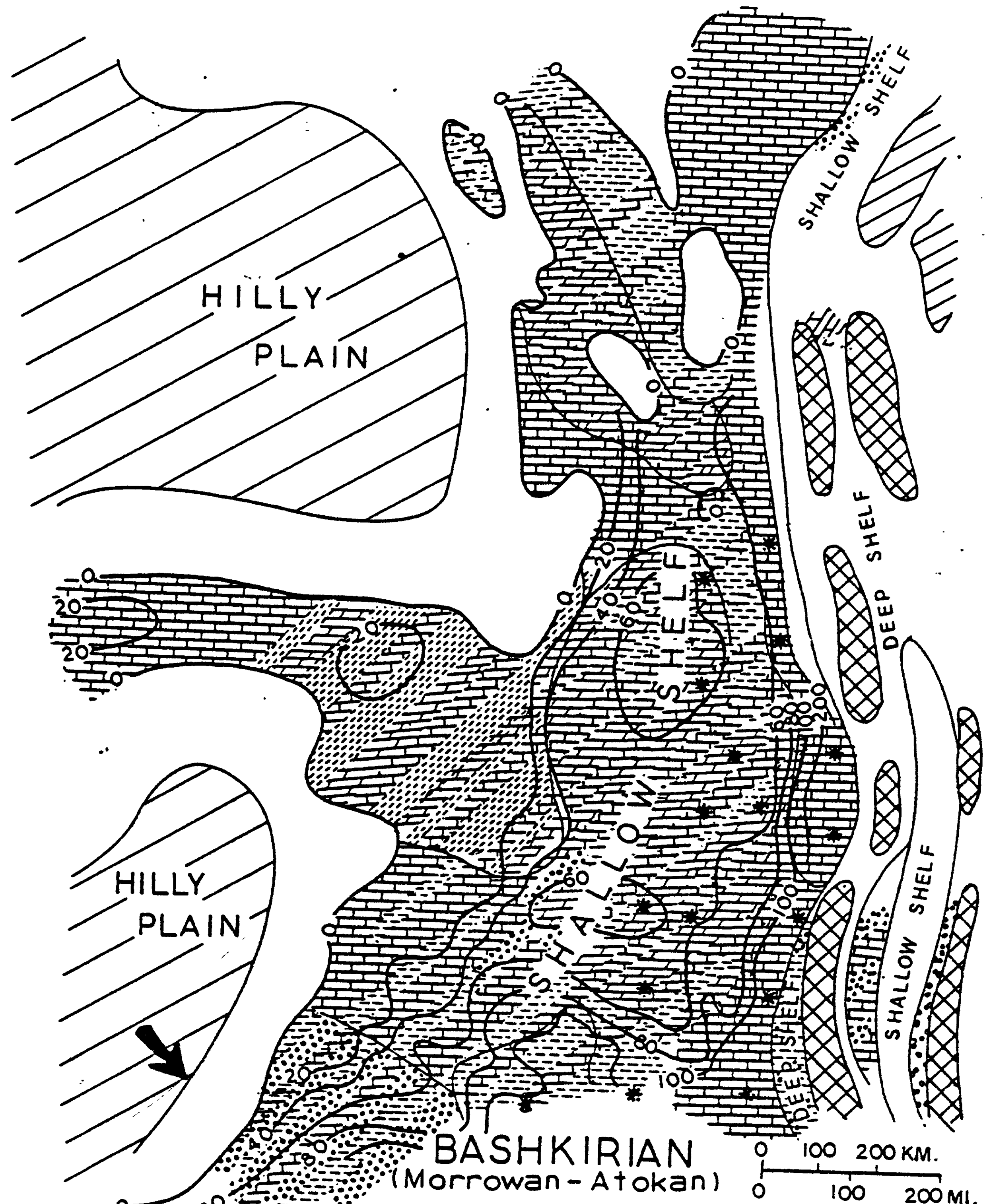


Fig. 22. Thickness in meters and facies map, Bashkirian (Morrowan-Atokan). See explanation on fig. 13.

Bashkirian carbonates occurred at this time; this process is considered to be important in reservoir development within these beds (Dakhnov and Galinov, 1960).

Third Paleozoic Cycle (Moscovian through Early Permian)

This cycle consists of terrigenous clastic deposits of early Moscovian age followed by fossiliferous marine carbonate beds of late Moscovian, Late Carboniferous, and Early Permian age. Total thickness of the sediments of this cycle is 1,000 m (3,250 ft) to more than 3,000 m (9,750 ft). The Carboniferous carbonate units contain organic mounds over much of the shelf area, and 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 deep-water Ural foredeep and the Peri-Caspian depression (fig. 25). 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 backreef carbonate, evaporite, and fine clastic beds.

Moscovian (Desmoinesian) (fig. 23)

Marine sandstone, siltstone, and gray shale are present in the basal units of the Moscovian section over all of the eastern part of the platform. These beds disconformably overlie the Bashkirian carbonate interval and represent the initial deposits of the third Paleozoic transgressive-regressive depositional cycle that spread westward and northward across the platform (fig. 23). To the west, continental redbed deposition persisted through much of this time, intertonguing with marine carbonate beds in the upper part of the section. Source areas for Moscovian clastics were essentially the same as for the Visean, but by this time many of the earlier source areas had become covered with carbonate and fine mud deposits, diminishing the supply of coarse clastic material. Moscovian sandstones are primarily of marine origin grading to a relatively narrow band of deltaic and inter-deltaic facies to the west and northwest of the Volga-Ural regional high. The sand bodies are generally of lensing nature and tend to be best developed on the crests of paleoarches, grading to silt and clay on the flanks (Ashirov and Kolesov, 1974). This geometric pattern is in contrast with the lower Visean sands which fill the Kamsko-Kinel troughs, and many of which are thick channel-like deposits filling erosion depressions in the underlying beds. The lower Moscovian sandstone and shale sequence (Verey beds) grades upward to marine limestone and dolomite beds that intertongue with marine gray shale and in places form organic mound buildups. The carbonate bodies are highly porous in places (as much as 20 percent or more) (Potapov and Abashev, 1974) and are best developed on the south crest of the Tatar arch, the Perm-Bashkir arch, the Birsk saddle area, and along the east flank of the platform. Seismic data suggest that Moscovian carbonate buildups may also be present along the north borders of the Peri-Caspian

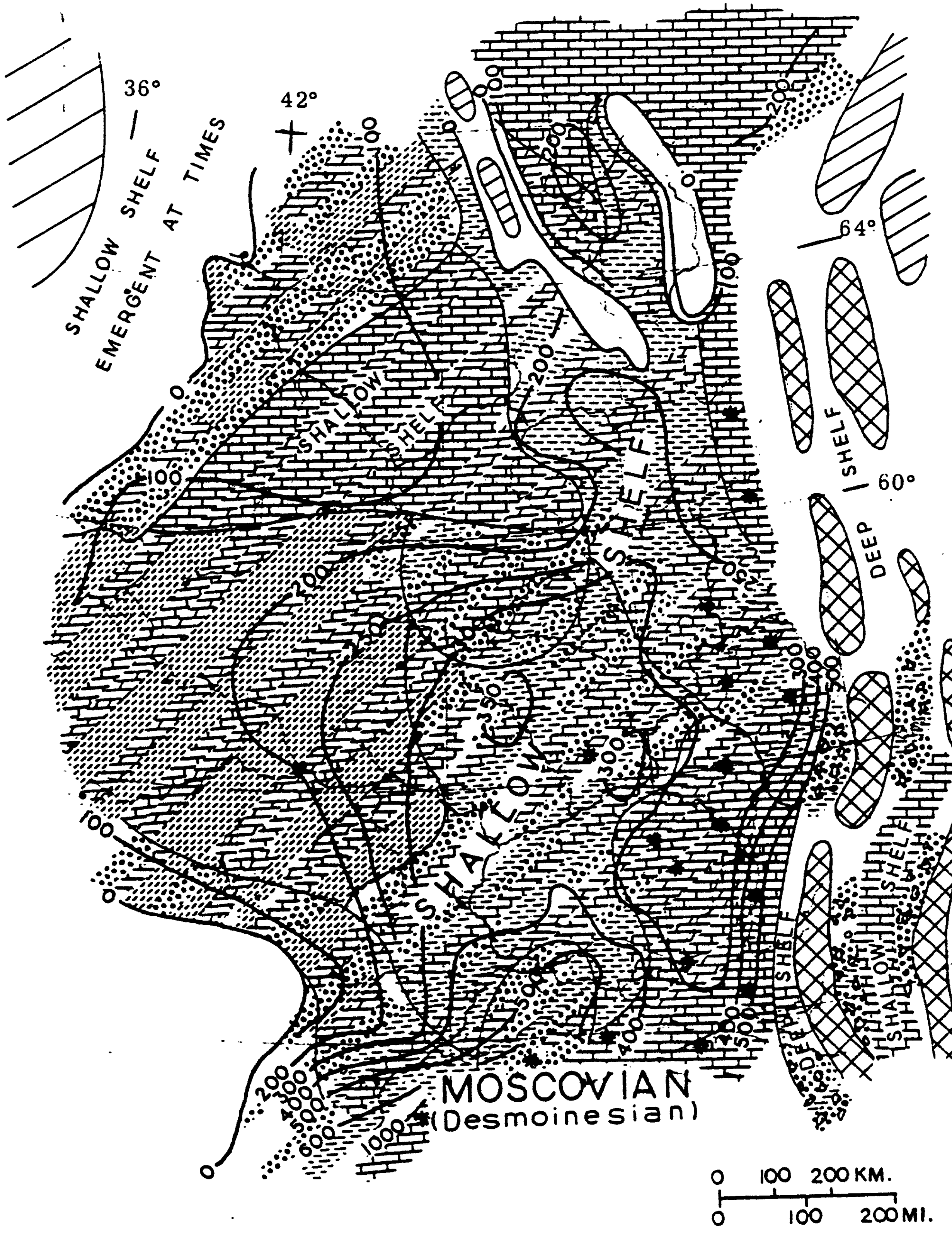


Fig. 23. Thickness in meters and facies map, Moscovian (Middle Carboniferous). See explanation on fig. 13.

depression (Borushko and Solov'yev, 1974). Moscovian carbonate beds contain a rich fauna of brachiopods, Chaetetes and other corals, small foraminifera, crinoids, echinoids, and calcareous algae (Strakhov, 1962). Rocks of Moscovian age are 250-300 m (810-975 ft) thick over most of the Volga-Ural regional high and thicken to more than 500 m (1,625 ft) on the east and south flanks.

Late Carboniferous (Missourian and Virgilian) (fig. 24)

Rocks of Late Carboniferous age are fossiliferous limestone and dolomite beds in most of the Russian platform area; some redbeds intertongue with marine carbonates in the western part. Gypsiferous deposits are present in the upper part of the section in the Timan depression to the north and also in the Buzuluk depression to the south. The Upper Carboniferous beds form a blanket-like carbonate deposit 150-200 m (490-650 ft) thick over most of the Volga-Ural regional high (fig. 24), marking the maximum transgressive stage of the third Paleozoic (third Hercynian) cycle of deposition. In stratigraphic and geographic position, they are much like the Namurian-Bashkirian carbonate beds that closed the second cycle.

Asselian-Sakmarian (Wolfcampian) (fig. 25)

Rocks of earliest Permian (Asselian) age are mainly shallow-water carbonates (dolomite with minor limestone), which conformably overlie the Upper Carboniferous carbonate beds almost everywhere in the eastern part of the platform. Subsidence was greatest east of the platform in the Ural foredeep, which was actively downwarping at this time (Maksimov and others, 1970) and accumulated a thick deposit of deep-water dark gray muds (800-1,000 m or 2,600-3,250 ft) (Kuznetsov and others, 1976) containing as much as three to four percent organic carbon. These beds grade eastward into shallow-water conglomerate, sandstone, and dark shale facies in the eastern part of the foredeep adjacent to the growing Ural Mountain chain, which had begun to rise in Late Carboniferous time. Early Permian reef growth was initiated in a narrow, relatively continuous north-south belt along the eastern margin of the platform adjacent to the deep-water Ural foredeep. Seismic and drilling data indicate that the belt of reefs continue westward along the extreme southern rim of the platform on the north margin of the Peri-Caspian depression, which also underwent increased subsidence in Early Permian time (Benderovich and others, 1976; Svetlakova and Kopytchenko, 1978).

General marine regression of the Permian seaway began in Sakmarian time, salinity on the platform increased, evaporites (mainly gypsum with some halite beds in the Soligliach depression) interbedded with finely crystralline dolomite, and some fine clastics were deposited over all of the platform area. Reef growth continued along the border of the subsiding Ural foredeep and the north fringe of the Peri-Caspian depression. The Asselian-Sakmarian section is about 150-300 m (485-975 ft) thick over most of the eastern platform, more

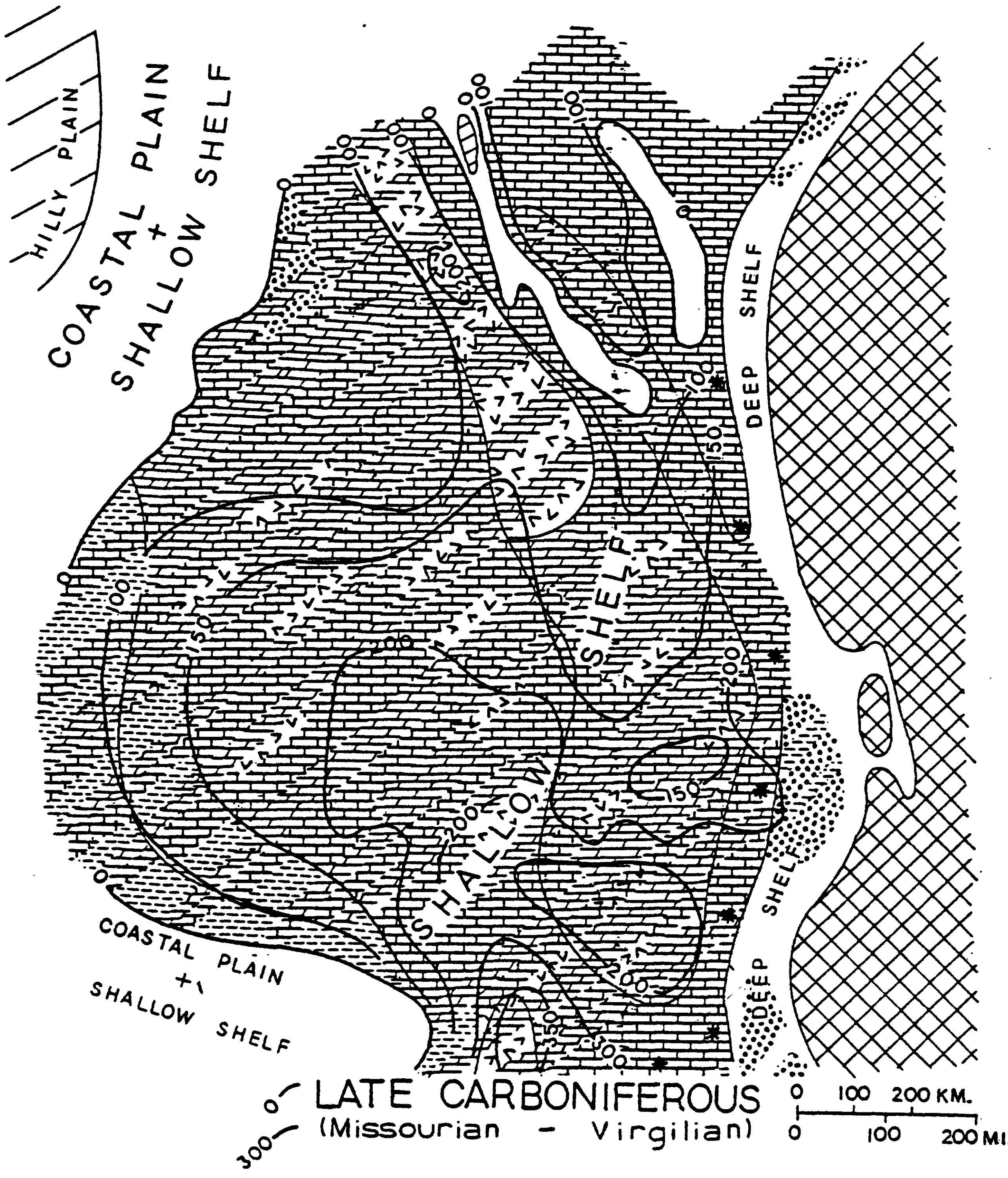


Fig. 24. Thickness in meters and facies map, Late Carboniferous (Missourian-Virgilian). See explanation on fig. 13.

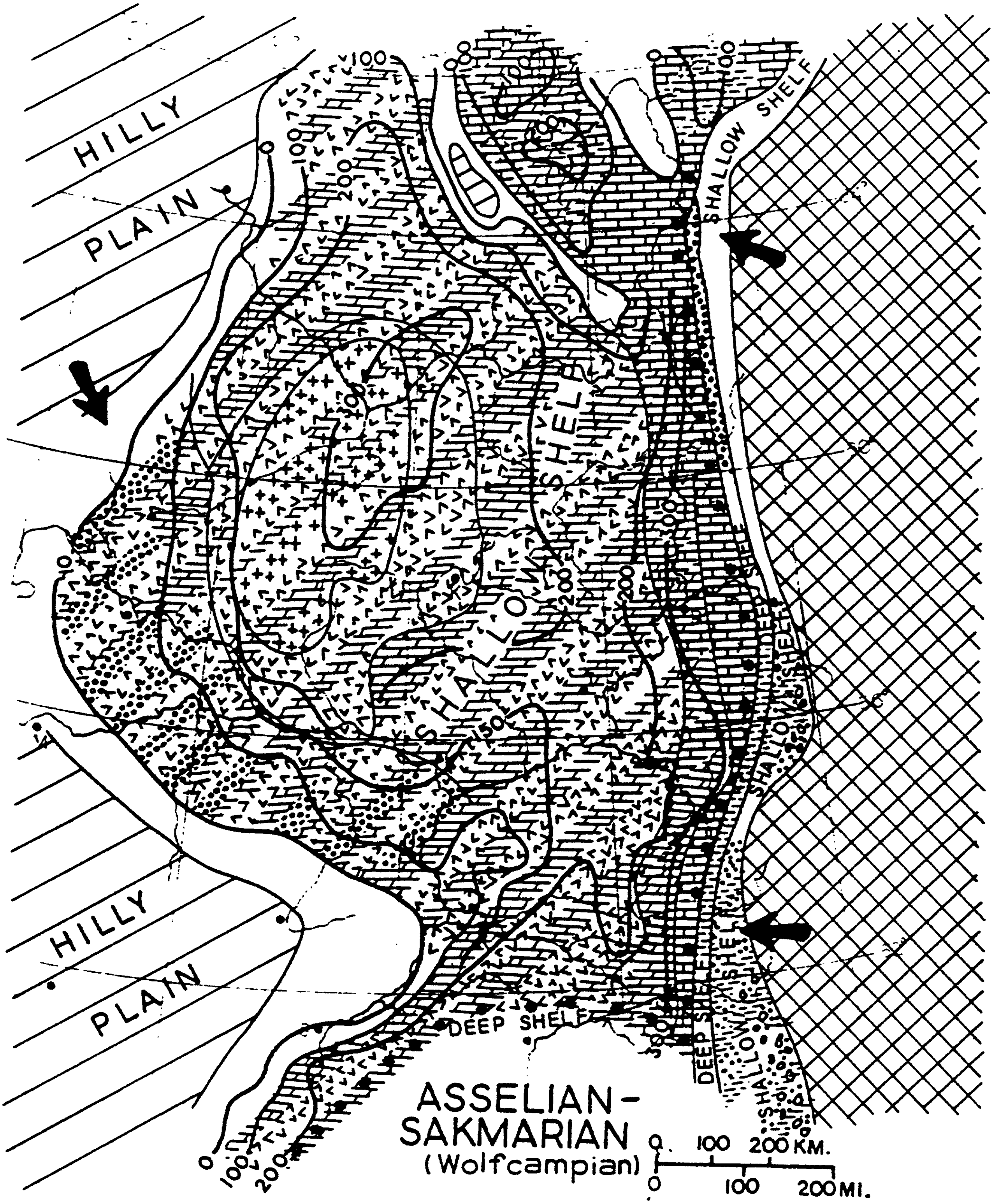


Fig. 25. Thickness in meters and facies map, Asselian-Sakmarian (Lower Permian). See explanation on fig. 13.

than 300 m (975 ft) in the reef belts, and is greater than 2,000 m (6,500 ft) thick in parts of the Ural foredeep. Reef bodies are primarily limestone that are in varying degree dolomitized. Some are long and narrow and interconnected; others are solitary and symmetrical. They range in thickness up to several hundred meters and have variable porosity (Kuznetsov and others, 1976). The reef bodies are composed of organo-clastic debris that consists of abundant crinoid, bryozoan, calcareous algae, hydrozoan, rarely coral, and other fossil material.

Artinskian-Kungurian (Leonardian) (fig. 26)

General subsidence of the eastern part of the platform increased, but the western area became emergent and underwent broad erosion in Artinskian-Kungurian time. Rocks of this age are more than 1,000 m (3,250 ft) thick in the southeastern part of the platform (fig. 26) and are more than 3,000 m (9,750 ft) thick in parts of the Ural foredeep and the Caspian depression. Rocks of Artinskian age make up the uppermost deposits of the third Paleozoic cycle of deposition and are similar to those of the Sakmarian, primarily gypsum and fine crystalline dolomite with reef growth along parts of the eastern platform border. Kungurian rocks are mainly evaporites, consisting of gypsum or anhydrite and some dolomite on the main platform, and thick deposits of halite, gypsum or anhydrite and some dolomite in the southeastern part of the platform and in the Peri-Caspian depression and southern Ural foredeep (figs. 9, 26). Thick beds of conglomerate, sandstone, and gray shale were deposited in the eastern part of the Ural foredeep trough, derived from the Ural Mountain chain which began to uplift vigorously near the close of Early Permian time (Maksimov and others, 1970). The upper Kungurian beds mark the beginning of the fourth and final Paleozoic cycle of deposition.

Fourth Paleozoic Cycle (latest Early Permian and Late Permian)

This cycle reflects the maximum growth of the Ural Mountains and associated Ural foredeep. At the close of the third Paleozoic cycle in latest Kungurian time, evaporites, 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, which intertongue eastward with clastic sediments from the Ural Mountains. During the remainder of the 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. 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 south part of the Ural foredeep and the Peri-Caspian depression.

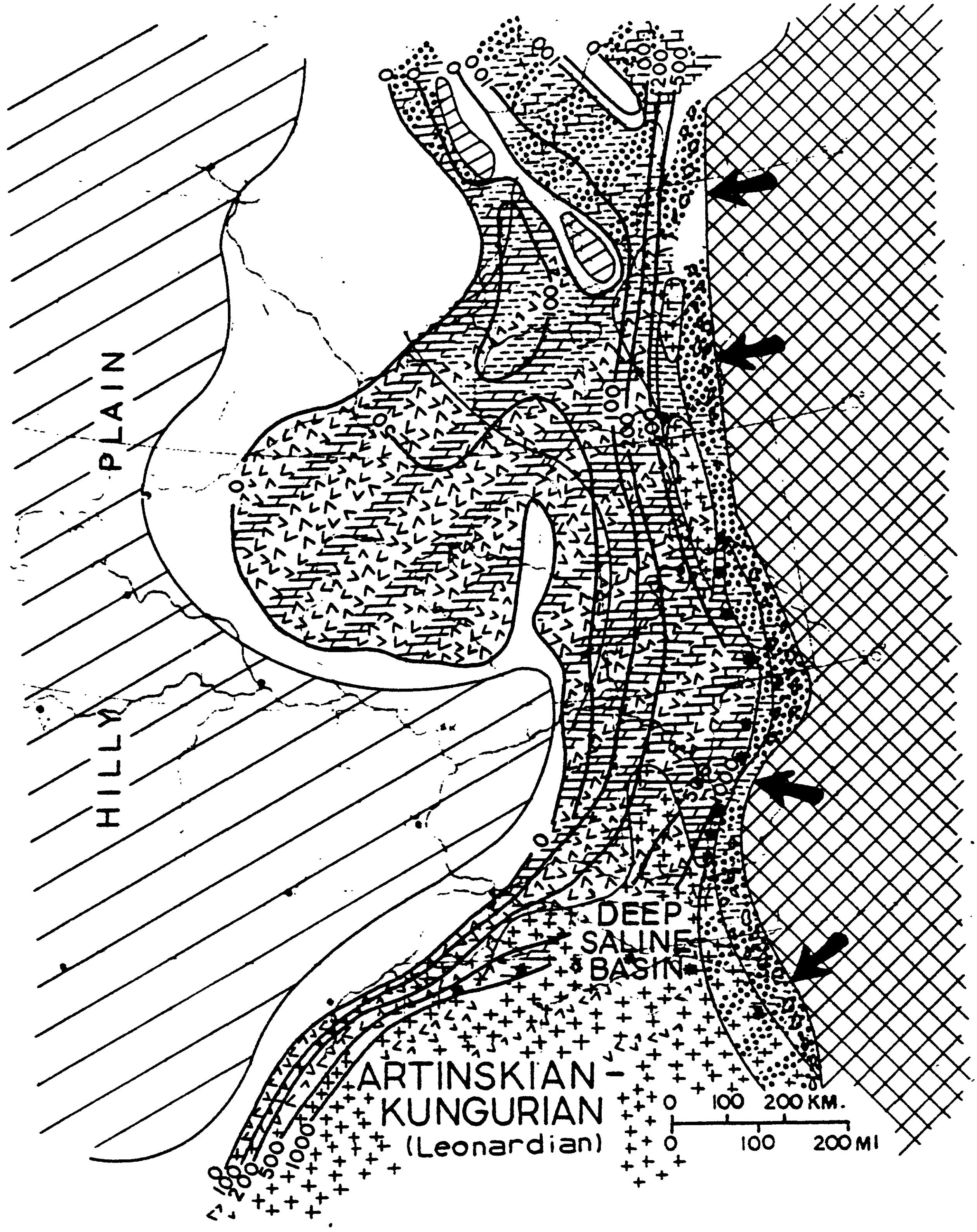


Fig. 26. Thickness in meters and facies map, Artinskian-Kungurian (Lower Permian). See explanation on fig. 13.

Ufimian-Kazanian (early Guadalupian) (fig. 27)

Rocks of Ufimian-Kazanian age are 100 m (325 ft) to 500 m (1,625 ft) thick where preserved on the platform. The Ufimian beds are slightly more widespread than those of the Artinskian-Kungurian, reflecting overlap and transgression onto the platform at this time. Rocks of this age are mainly limestone and dolomite interbedded with gypsum or anhydrite, intertonguing eastward with clastic sediments derived from the Ural Mountains uplift.

Kazanian rocks are a complex facies of marine, lagoonal, and fresh-water origin overlain by continental redbeds, sandstone, and conglomerate derived from the Ural Mountains uplift. By the end of Kazanian time, the Ural foredeep was largely filled with clastic deposits, and continental beds deposited by streams off the uplift were spreading westward across the platform, with marine conditions gradually receding southward toward the Peri-Caspian depression.

Tatarian (late Guadalupian-Ochoan) (fig. 28)

Continental conditions became prevalent throughout the platform area during latest Permian time. At the beginning of Tatarian time, mainly clastics derived from the Ural Mountains uplift and the western highlands and some carbonate and gypsum beds were deposited. These were succeeded by red sand, silt, and clay with some thick conglomerate beds deposited by streams flowing westward off the Ural Mountain uplift, which had probably achieved maximum elevation by this time. Some fresh-water ostracod and gastropod-bearing lacustrine limestones are present, and terrestrial vertebrate remains have been recovered from the continental beds.

At the end of Permian time, general emergence of the platform occurred, and an extensive period of erosion or nondeposition ensued. The amount of section removed by erosion during this time is not known, but according to several Soviet authors, only a small thickness was removed, mainly over the central part of the platform.

Mesozoic

Mesozoic sedimentary rocks are not present in most of the platform area and according to some Soviet authors may not have been deposited there. Continental redbeds and marine clastic rocks of Triassic age as much as 1,000 m (3,250 ft) or more thick are present in the Peri-Caspian depression. A Middle and Upper Jurassic marine sandstone and shale sequence as much as 1,000 m (3,250 ft) or more thick is also present there, as well as in the southwestern, western, and northern parts of the Russian Platform (figs. 7, 9, 11, 12). These rocks, however, are absent over the central and eastern parts of the platform in the Volga-Ural province. A relatively complete

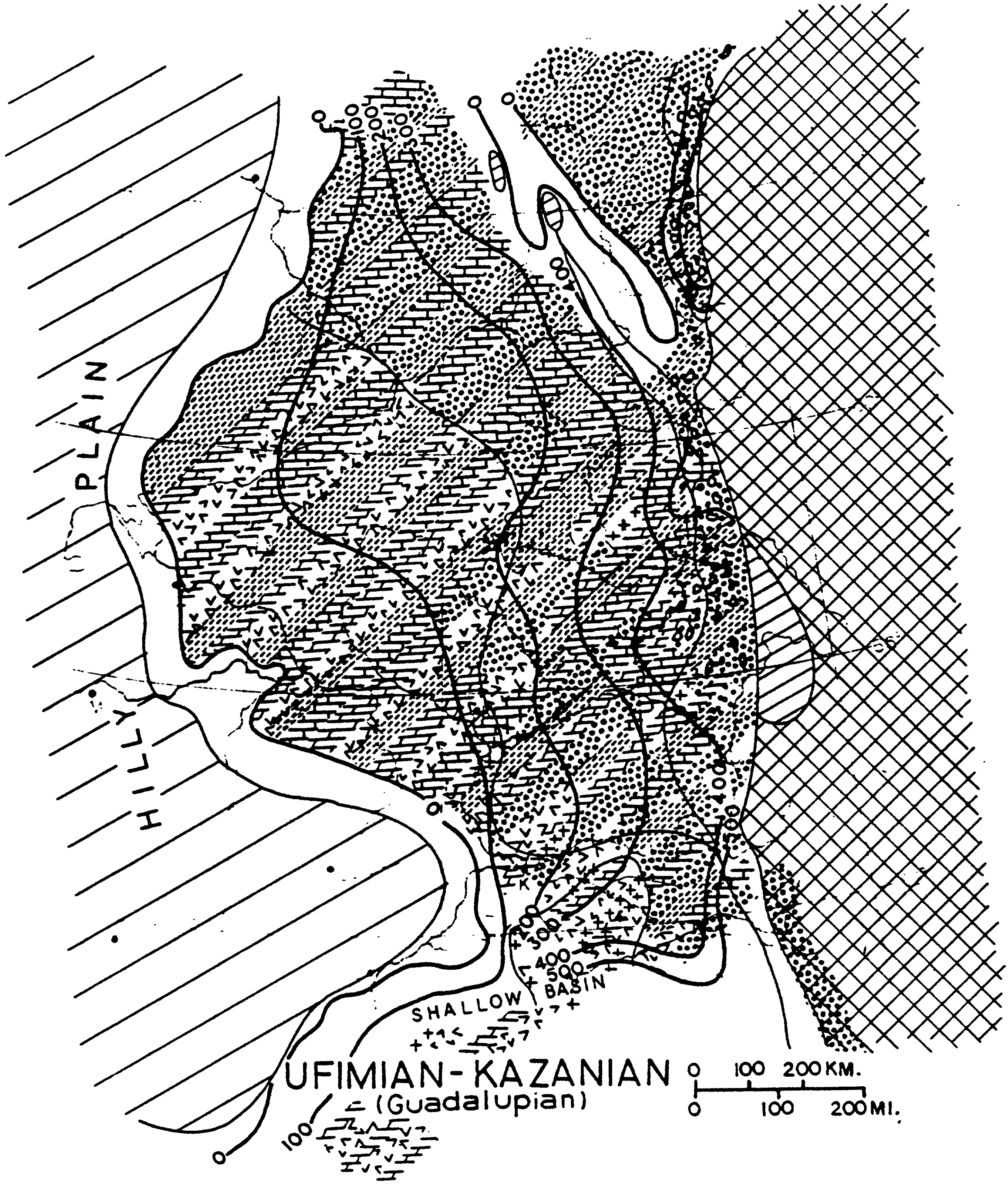


Fig. 27. Thickness in meters and facies map, Ufimian-Kazanian (Upper Permian). See explanation on fig. 13.

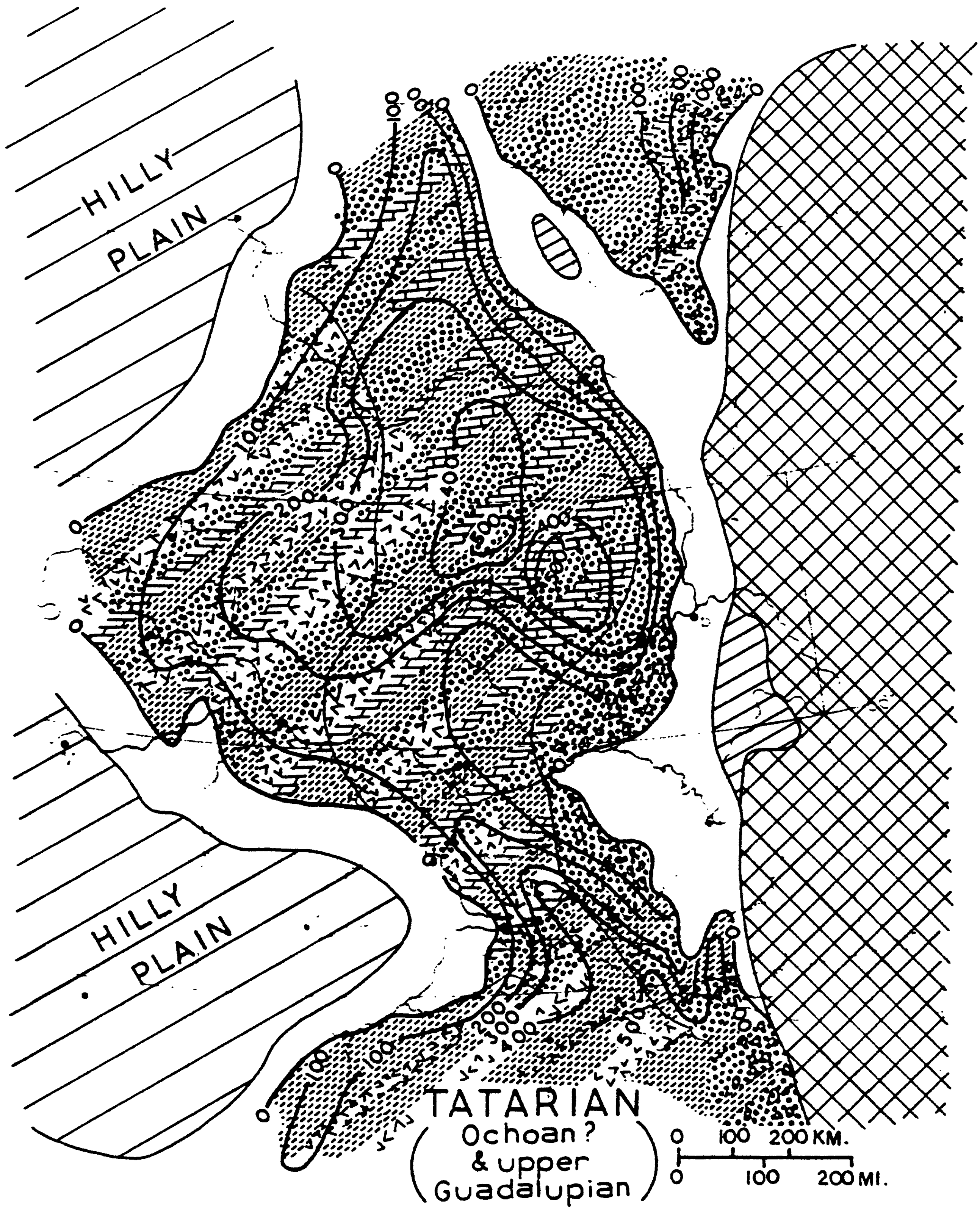


Fig. 28. Thickness in meters and facies map, Tatarian (Upper Permian). See explanation on fig. 13.

shallow-water marine Cretaceous sandstone, shale, and limestone section is also present in about the same area, slightly overlapping the Jurassic beds. These rocks are at least 600-800 m (1,950-2,600 ft) thick in the Peri-Caspian depression and 100 to 250 m (325-810 ft) thick in the western platform area, but are absent over the Volga-Ural regional high (figs. 9, 11, 12).

Cenozoic

Lower and middle Tertiary rocks are not reported in the province, and there is no evidence to show that they were ever deposited there. However, continental beds (conglomerate, sandstone, and shale) of Pliocene age 100 to 500 m (325-1,625 ft) thick are present in the middle and southern parts of the platform (figs. 11, 12).

HYDROGEOLOGY

The Volga-Ural petroleum province is a single artesian system that developed in a complex manner beginning in the Precambrian. The principal aquifers and impermeable seals are:

1. Lower - Upper Bavly (Proterozoic) aquifer
2. Upper Bavly impermeable seal
3. Middle Devonian aquifer
4. Middle Devonian impermeable seal
5. Middle - Upper Devonian aquifer
6. Upper Devonian impermeable seal
7. Upper Devonian - Lower Carboniferous aquifer
8. Lower - Middle Carboniferous impermeable seal
9. Lower - Middle Carboniferous aquifer
10. Middle Carboniferous impermeable seal
11. Middle - Upper Carboniferous - Lower Permian aquifer
12. Lower Permian impermeable seal
13. Upper Permian aquifer

The areas with greatest hydraulic head are in the eastern parts of the basin near places where the aquifers crop out on the western slopes of the Ural Mountains. Heads are also high in the northwestern and western areas on large structural highs such as the Komi-Perm arch, northern crest of the Tatar arch, Tokmovo arch, and Voronezh arch (fig. 2). The Peri-Caspian basin is the principal drainage area of the artesian system (Maksimov and others, 1970, p. 76-77).

The lithofacies of the aquifer system are not persistent, and there is some flow between aquifers. Faults also exert strong influence on pressure distributions within each aquifer. In fact, copious flows of water have been recovered from fracture zones deep within the Archean basement at Romashkino oil field (Zor'kin and others, 1979, p. 36-40).

The potentiometric surface for the Middle-Upper Devonian aquifer (fig. 29) shows a south-plunging nose that coincides with the Komi-Tatar ridge system of the regional structure (fig. 2). Potentiometric readings are also high in the eastern part of the basin near the Ural Mountains. From high values here of 150-200 m (485-650 ft), this surface slopes gently toward the Peri-Caspian depression to where values of 50 m (163 ft) are recorded. Anomalous highs and lows on this surface are associated with jointing and fracturing of the rocks.

Potentiometric surfaces of other aquifer systems as well as for the regional impermeable seals similarly show highs associated with structural highs and also slope toward the Peri-Caspian depression.

The rate of movement of subsurface waters in the Middle-Upper Devonian aquifer is approxmately 10 cm (4 in) per year (Kartsev, 1963, p. 220). The rate of water flow in the Lower Carboniferous aquifers reaches 20-50 cm (8-20 in) per year due to the Kamsko-Kinel system of troughs (Maksimov and others, 1970, p. 84).

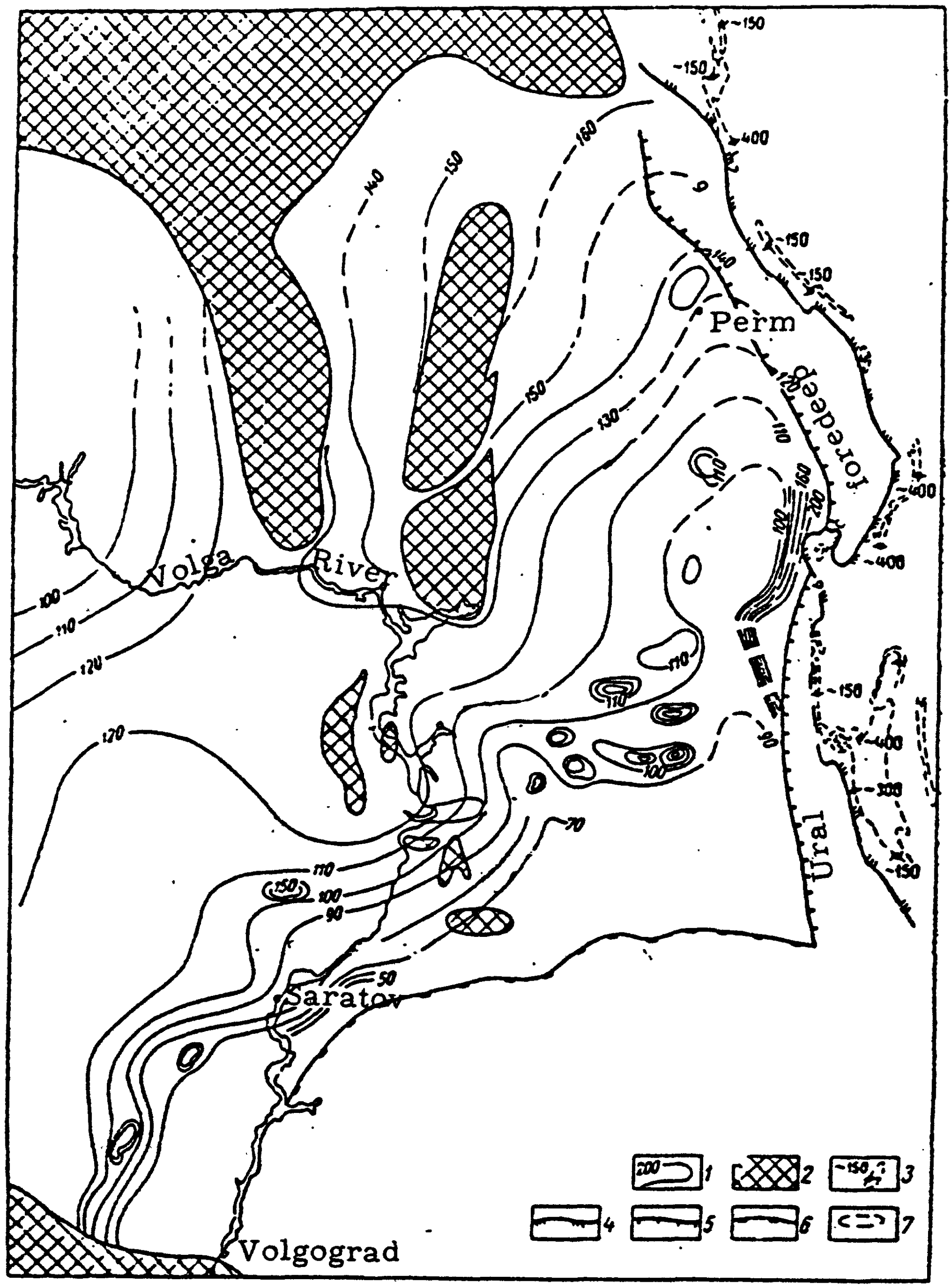


Fig. 29. Map of potentiometric surface of waters of Middle-Upper Devonian aquifer of the Volga-Ural oil-gas province (from Maksimov and others, 1970).
1 - Isopiestic lines; 2 - areas where sediments of the aquifer are absent; 3 - level of water in aquifer in regions of outcrop and along rivers; 4 - boundary of the folded Urals; 5 - west border of Ural foredeep; 6 - north border of Peri-Caspian depression; 7 - surface outcrops of sediments.

Throughout most of the basin, potentiometric values for the Lower Carboniferous sediments are higher than for the Devonian and pre-Devonian sediments. This suggests the possibility of extensive introduction of water from the Lower Carboniferous into the Devonian. This could also have a bearing on the presence of the large oil pools in the Devonian in reservoirs that are stratigraphically below the Domanik source beds.

The principal water-charging area for the aquifers of the Volga-Ural petroleum province extends northeastward from the Voronezh arch across the Ryazano-Saratov depression to the Tokmovo arch, hence across the Kazansko-Kirov aulacogen to the Kukmor and Nemsk highs of the Tatar arch (fig. 2). The Ural Mountains are not the principal charging area for this basin.

As waters moved from the areas of intake toward the Peri-Caspian depression, they dissolved components from the sediments and acquired the chemical characteristics that presently distinguish them. Two general types of water or hydrochemical stages are present; they are separated by the impermeable Lower Permian salt and carbonate sediments. The upper hydrochemical stage contains the Upper Permian aquifer, and the water is a fresh to slightly mineralized calcium bicarbonate and magnesium sulfate type. The waters of the lower hydrochemical stage are in the Devonian and Carboniferous aquifers. Calcium chloride type waters predominate here and mineralization is high. The degree of metamorphism of the waters of this lower hydrochemical stage almost totally repeats the potentiometric surface of a given aquifer system (Maksimov and others, 1970, p. 88).

Epeirogenic movements during the extended time of existence of the Volga-Ural artesian basin led to relatively frequent changes in hydrogeologic regimen. During downward movements connate water was expelled, and the basins were the sites from which centrifugal water moved outward toward structural highs. These were times of petrolum migration and accumulation. During times of tectonic uplift the aquifers were exposed at the surface on structural highs, and surface water infiltrated into the system. This centripetal water reversed the direction of flow in the aquifers and had a disruptive effect on the process of petroleum accumulation and on the pools that had already formed. There were several times during the Paleozoic when uplift led to an infiltration regime, and since the end of the Paleozoic, the region has been dominated by an infiltration regime.

The greatest water exchange and most intensive infiltration charging of the Volga-Ural artesian system have taken place and are taking place within the areas of the Voronezh, Tokmovo, and Komi-Perm arches and the north crest of the Tatar arch. Conditions here are unfavorable for the accumulation and preservation of oil pools, and in fact no significant deposits have been found here.

PETROLEUM GEOLOGY

Introduction

The Volga-Ural petroleum province (fig. 30) covers an area of about 190,000 square kilometers (49,500 mi^2). The petroleum-producing stratigraphic section (Middle Devonian through Upper Permian) ranges in thickness from a minimum of about 1,100 m (3,600 ft) on the north crest of the Tatar arch to more than 3,000 m (10,000 feet) on the eastern and southern borders of the province (fig. 31); average is about 2,000 m (6,500 ft), and a total volume of primarily marine sedimentary rock is about 1,400,000 cubic kilometers (340,000 cubic miles). Maksimov and others (1970) list 525 fields in the province (fig. 30), 480 oil or oil and gas, and 45 gas, with 1,450 recognized oil or gas pools, 425 of which are in Devonian rocks, 890 in Carboniferous, and 135 in Permian. Since publication of the Maksimov report, a large number of additional fields have been discovered, notably in the Ural foredeep and on the northern border of the Peri-Caspian depression. Bol'shakov (1975) reports 1,900 oil and gas pools in the province. Many of the fields are small; several are giants. Halbouty (1970) lists seven giant (more than 500 million bbls) oil fields totaling about 28 billion barrels of recoverable reserves, and two giant gas fields of which Orenburg (about 70 Tcf) is the largest. St. John (1980) lists nine giant oil fields and two giant gas fields. 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 versus purely structural 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 (Maksimov and others, 1970). The province is in a mature stage of exploration and production, and increasing emphasis is being placed on exploration for both clastic and carbonate stratigraphic trap prospects which were not emphasized during the structural stage of development (Aleksin and others, 1974; Zubov and Dement'yuva, 1975; Muslimov and others, 1976a, 1976b; Makarov and others, 1976; Provorov and others, 1976). These exploration efforts, aided by refined methods of seismic interpretation, have resulted in the discovery of many fields of both the stratigraphic and structural type in recent years (Medvedev and Burovoy, 1974; Kamaletdinov and Kazantsev, 1976; Shikhov and others, 1976; Sokolov and others, 1976; Varentsov and others, 1976; Yarullin and Yunusov, 1976, Konovalov, 1977; Kukharenko and others, 1977). A large percentage of the total reserves of the province are depleted, but Soviet geologists have identified a significant number of deeper and more complex prospects that promise to add continuing reserves for some time.

Maksimov and others (1970) divide the petroleum-bearing and prospective strata into nine main productive sequences (fig. 8), based on stratigraphic characteristics, nature of oil and gas occurrence, hydrologic conditions, and geochemical character of the oil and gas. These divisions are as follows:

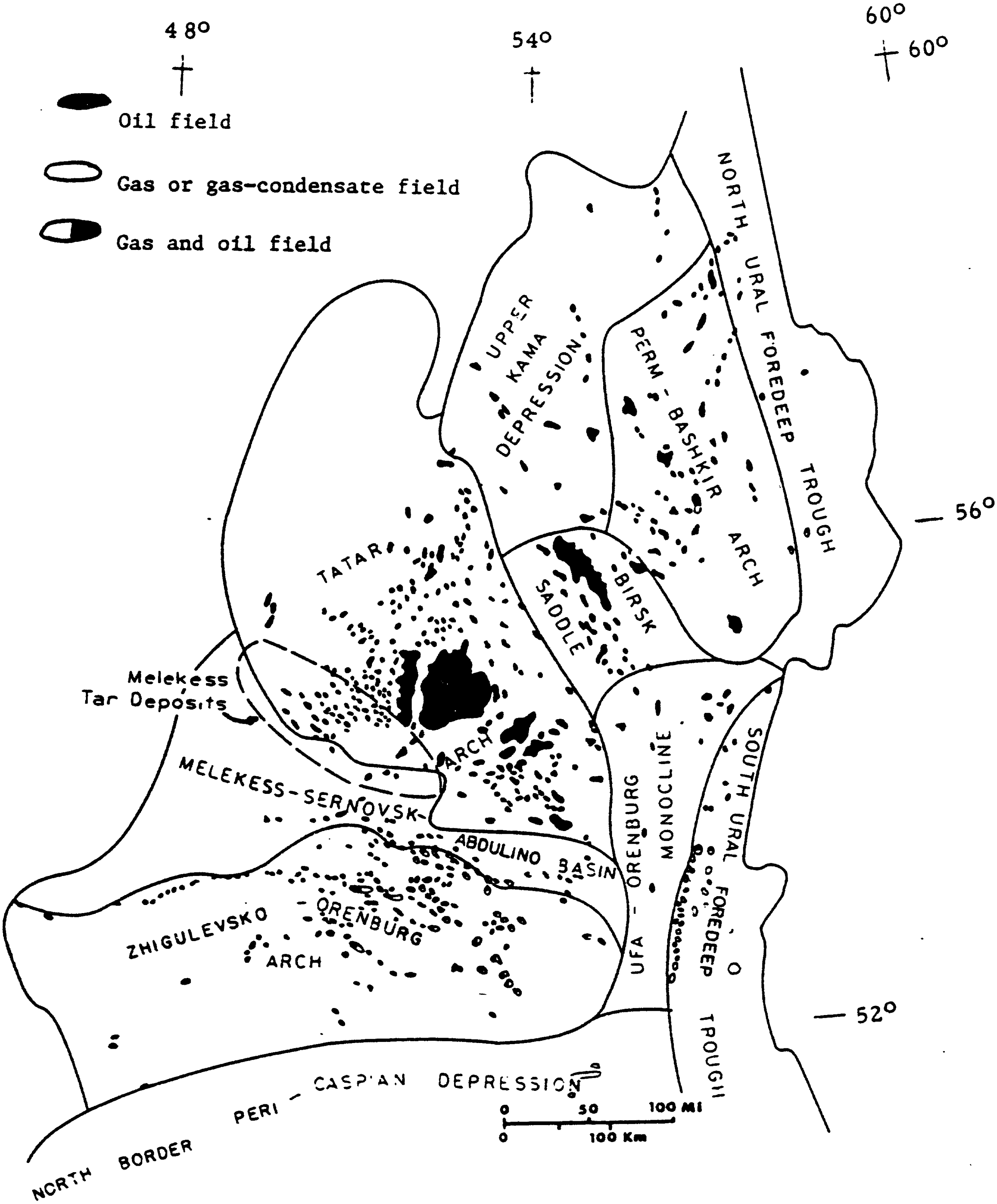


Fig. 30. Main productive areas and oil and gas fields, Volga-Ural province.

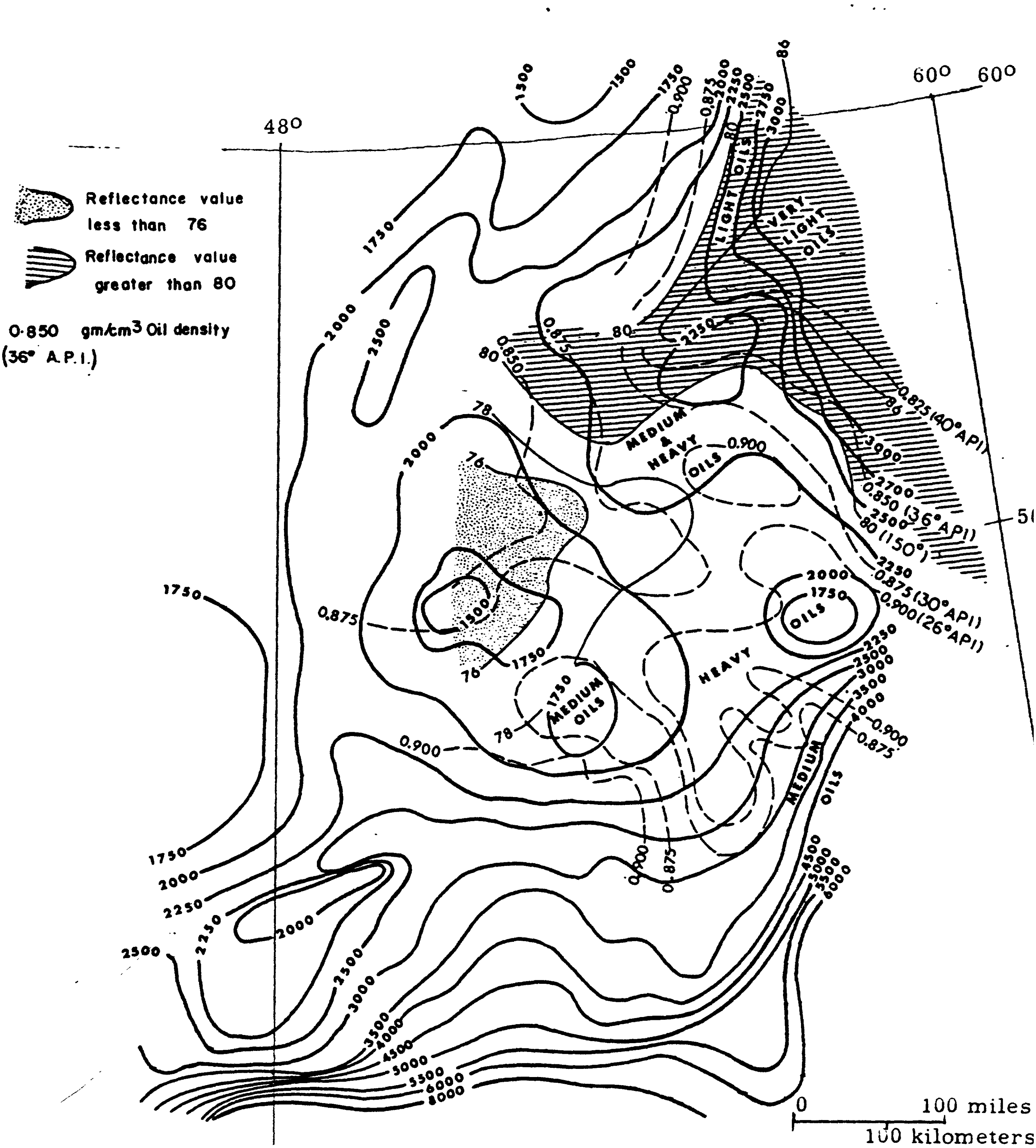


Fig. 31. Thickness in meters, post-Proterozoic sedimentary cover, showing distribution of oil types and reflectance values of Frasnian (Upper Devonian) dark shale source rocks.

1. Upper Proterozic (Bavly beds), considered to be promising but no commerical production yet.

2. Clastic Devonian (Middle and lower Upper Devonian), which contains the major share of the known oil reserves.

3. Carbonate Upper Devonian and lowermost Carboniferous (upper Frasnian through Tournaisian), one of the main reef-bearing intervals.

4. Visean clastics (Lower Carboniferous).

5. Carbonate Lower and Middle Carbonfierous (upper Visean through Bashkirian).

6. Clastic Moscovian - mainly lower Moscovian sandstone and siltstone beds.

7. Carbonate Middle and Upper Carboniferous (upper Moscovian and Upper Carboniferous).

8. Carbonate-evaporite Lower Permian, a major reefal and other carbonate interval that contains the major gas reserves and the lower part of the large Melekess tar deposits.

9. Clastic-carbonate Upper Permian, which contains the major part of the Melekess tar deposits.

Upper Proterozoic (Bavly beds)

Reservoir rocks

Soviet geologists report that the upper Riphean and Vendian part of the upper Proterozoic is not highly metamorphosed and contains a significant thickness of porous marine and continental sandstone beds that have good reservoir quality (Yarullin and Romanov, 1974; Suleymanov and Bazev, 1974). The Bavly beds are also extensively fractured and faulted in areas of the eastern part of the province and are therefore prospective for non-indigenous petroleum. Areas of interest are in the eastern border of the Ural foredeep and the western part of the folded and faulted Urals where a thick Proterozoic section with good reservoir rocks is reported, and the eastern part of the Tatar arch where reservoir quality is good and some oil shows have been reported (Stankevich and others, 1977).

Source rocks

Carbonaceous and bituminous rocks are reported in the upper Proterozoic sequence (Keller and others, 1968; Yarullin and Romanov, 1974), and this section also contains beds of stromatolitic and spore-bearing carbonates. Organic carbon content is moderate at best; however, the normal marine nature of much of the section along with indications of petroleum in several occurrences maintain interest in the section as a potential petroleum objective. Original depth of burial and thermal history will no doubt be important factors in evaluation of this sequence. The Vendian and the upper and lower Riphean beds are targets of current active drilling programs (Muslimov and others, 1976b).

Clastic Devonian (figs. 32, 33)

The clastic Devonian section of Middle and earliest Late Devonian age has been the main oil objective of the Volga-Ural province (fig. 8). These beds contain the major recoverable oil accumulations on the Tatar arch, which includes the Romashkino, Novoyelkhov-Aktash, Tuymazy, Shkapovo, Mukhanovo, and Yarino-Kamenyy oil fields, among the largest in the province. In addition to the Tatar arch, significant production from these beds, mainly oil, is also present in all other segments of the province (fig. 33). More than 200 oil fields produce from the clastic Devonian reservoirs (Zubov and Dement'yeva, 1975), and nine main productive sandstone or siltstone horizons are reported. The main pays occur in the uppermost Givetian and lower Frasnian sequence, and almost half of the Devonian pools of the Volga-Ural region are in the lower Frasnian clastic section (Aranova and others, 1967). The clastic Devonian sandstone, shale, and minor limestone interval occurs in a north-south belt extending across the central part of the Volga-Ural province. The greatest thickness is in the northern and southern parts of the region (fig. 32).

Reservoir rocks

The reservoirs are part of a littoral and shallow-water marine facies of beach, bar, and other shoreline sand bodies deposited by southward flowing longshore currents on the edge of the advancing Devonian seaway. Net sandstone content is highest to the north and northwest (174-300 m or 565-975 ft) in the direction of the main clastic source area. A partially isolated belt of sandstone facies also extends from north to south across the southeastern segment of the Tatar arch (fig. 32). Sandstone intervals pinch out to the west along the east flank of the north crest of the Tatar arch and the Komi-Perm arch, and also to the east along the border of the platform. Individual sandstone beds also tend to drop out toward the south and southwest in the downstream direction of longshore marine currents. Eifelian sandstone reservoirs tend to be relatively thin and are present only in the eastern part of the province (fig. 15). The Givetian reservoirs

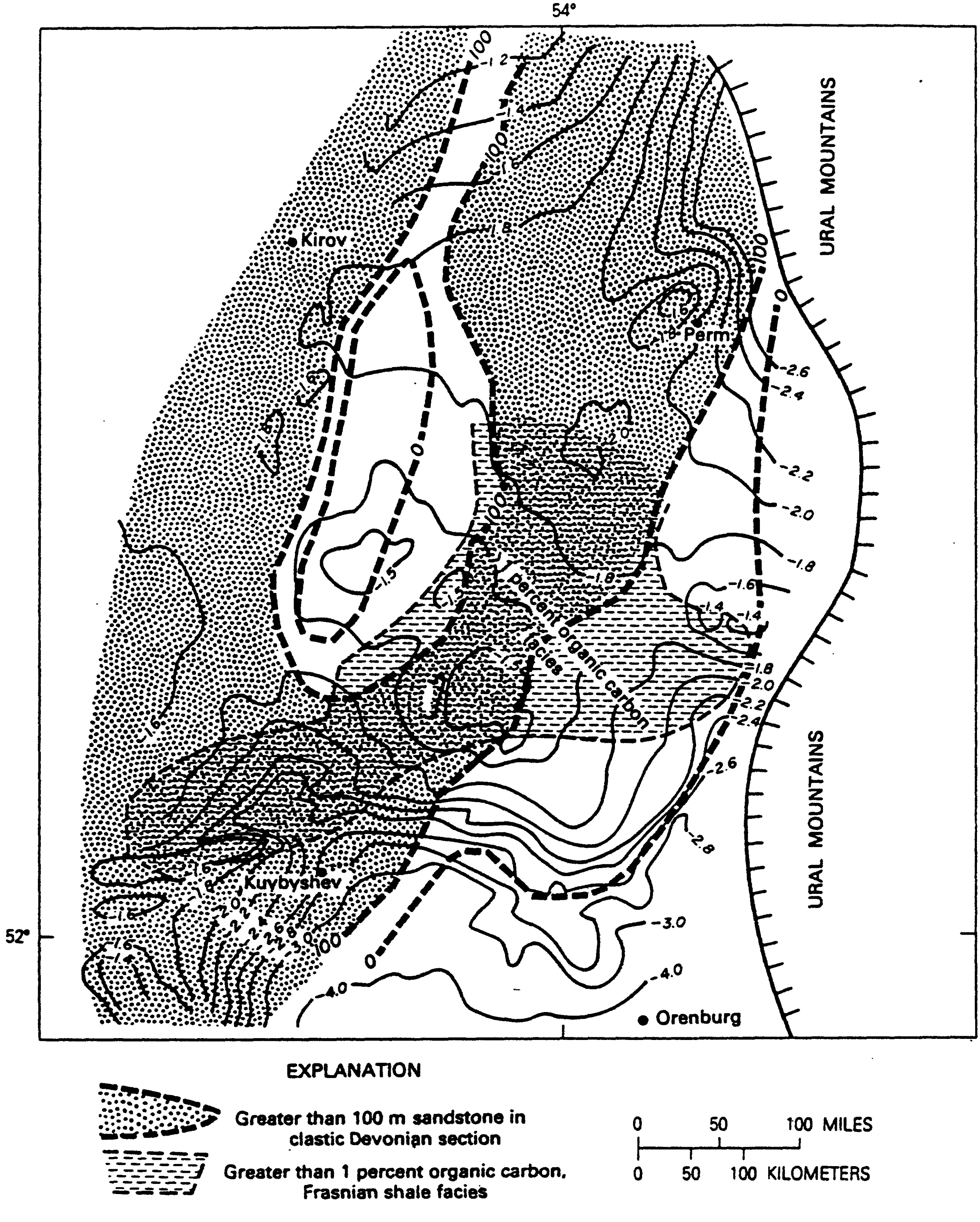


Fig. 32. Structure map in kilometers, lower Frasnian (Upper Devonian), showing net sandstone content of clastic Devonian and areas of Frasnian shale with greater than one percent organic carbon content.

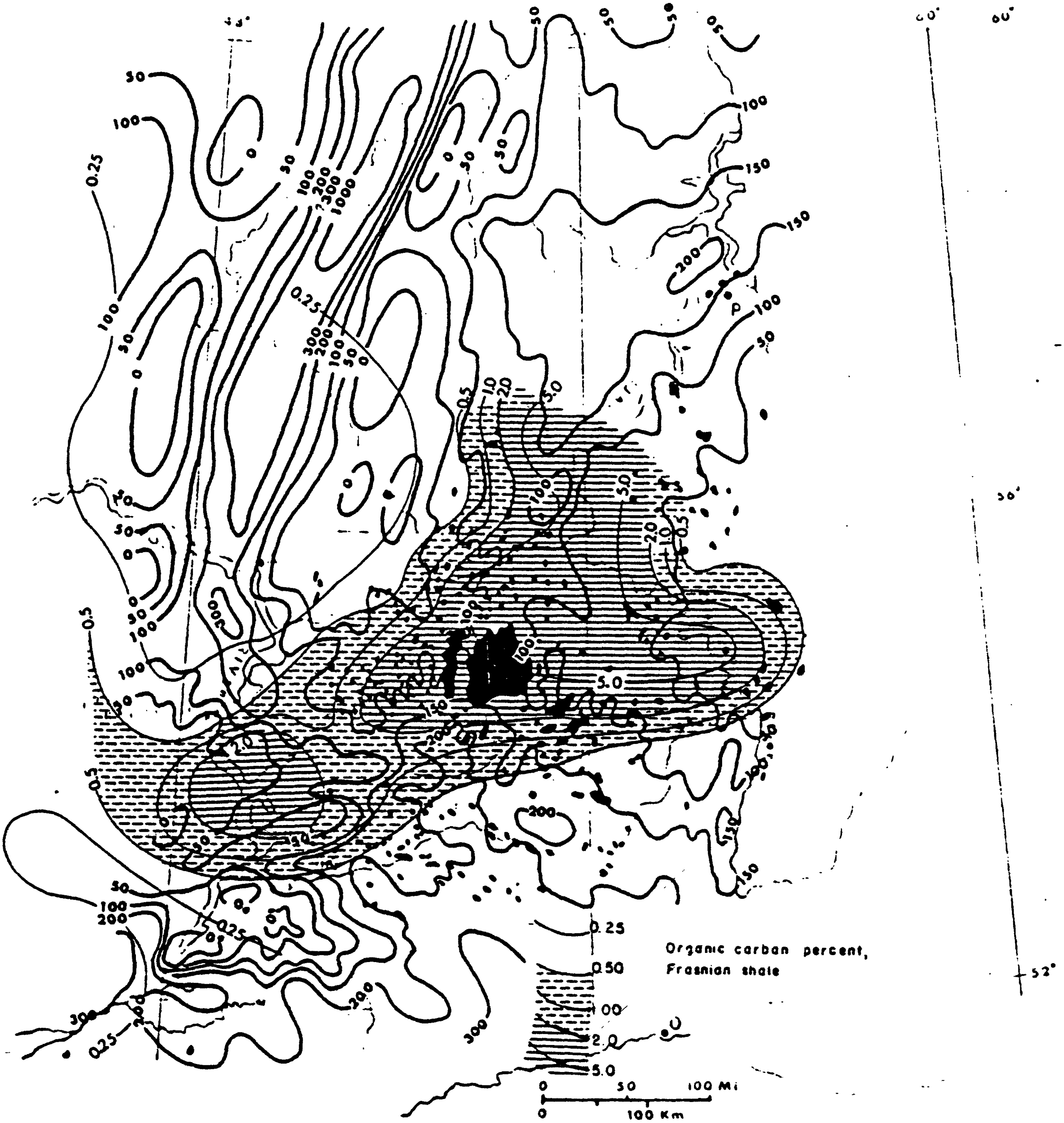


Fig. 33. Thickness in meters, clastic Devonian, showing oil fields producing from clastic Devonian reservoirs and percent of organic carbon in Frasnian shale source rock facies.

(fig. 16) are more widespread, pinching out along the western borders of the province. The individual reservoir bodies in the lowermost Frasnian (Pashiya beds) (fig. 17) are generally thicker and more widespread than those of the Givetian. The overlying Kynov sandstones are generally lensing and interbedded with dark shale. Porosity and permeability are highly variable in the clastic Devonian reservoir facies, ranging from very low in siltstone reservoirs to as much as 25-30 percent and 3-4 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.

Source rocks

The sandstone beds of the clastic Devonian are interbedded with dark nearshore marine and lagoonal dark shale beds, which have a variable content of organic carbon. 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 deposit in the more depressed areas of the platform. Intertonguing and interbedding of the dark organic shale beds with individual sandstone reservoir bodies, many of which are lensing in nature, has provided an efficient interrelationship for generation and preservation of petroleum accumulations. Depth of burial estimates for these beds range from about 2,700-3,000 m (9,000-10,000 ft) over the central part of the province to 4,500-6,000 m (15,000-20,000 ft) in the southeastern and southern borders. Soviet geologists indicate the source rock maturity as medium to high in all of the region.

Traps

Most of the important oil fields are located on structural closures, mainly anticlinal, but some are also at least partly fault controlled. Numerous "lithologic" (stratigraphic) accumulations have been found during field development drilling, mainly on the flanks of the larger structures. More than 300 pools of this type are reported (Zubov and Dement'yeva, 1975). 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 both stratigraphic and structural pools.

Analogs

Possible analogs to the Devonian clastic section of the Volga-Ural province include the productive Chester (Upper Mississippian) sandstone and shale sequence of the northern midwest United States (Illinois basin and adjacent area), the Upper Devonian clastic section of the northern

Appalachians (Bradford and other sands), and the Simpson Sandstone beds (Middle Ordovician) of the midcontinent region. Of these three, the Chester sequence is probably the best analog with respect to paleogeography, nature of sandstone facies and its source, and interrelation with indigenous source-rock facies. However, in the Volga-Ural province, the areal extent of the marine sandstone facies is much greater; organic content of source-rock facies is much higher (3 to 5 percent or more for the Volga-Urals versus 1 to 1.5 percent for the Chester sequence in the United States); size of many of the structures is very great; and the extent and antiquity of paleostructural growth and its influence on reservoir and source-rock facies are greater. The presence of very large structural-paleostructural arches of regional size (Tatar, Perm-Bashkir, Zhigulevsko-Orenburg, and others), located within the extensive belt of shelf margin marine nearshore sandstone and dark organic shale facies, provides conditions for optimum petroleum generation and accumulation in the Devonian clastic sequence. Ultimate recovery from Chester sandstone reservoirs of the Illinois basin and vicinity is estimated to be on the order of 3 billion barrels, of which, according to Bond and others (1971), about 60 percent is structural and 40 percent stratigraphic trapped. These trapping characteristics seem to conform reasonably well with those described by Soviet geologists for the Volga-Ural province, but ultimate recovery in the Volga-Ural province is much greater.

Carbonate Upper Devonian and lowermost Carboniferous (upper Frasnian, Famennian, and Tournaisian) (fig. 34)

This interval contains the most widespread and fully developed reef and organic carbonate facies of the Volga-Ural province, reaching more than 500 m (1,625 ft) in thickness in all of the paleostructurally high areas of the province (fig. 34). At least 150 fields are productive from these beds, although the total amount of oil discovered is considerably less than that found in the clastic Devonian.

Reservoir rocks

At least ten reservoir intervals are reported from the carbonate Upper Devonian-Tournaisian. In general, the carbonates are composed primarily of relatively pure limestone with discontinuous areas of generally low to moderate porosity. Most of the oil pools of this interval are in the Tournaisian reefal and organic mound carbonate section, especially in its upper part, which in most places is considerably thicker than the underlying Upper Devonian carbonate beds. Most pools found thus far are in structural traps in reservoirs with primary inter-crystalline and skeletal porosity, along with fracture and vuggy porosity. Porosity is generally not high, averaging about 8-10 percent. Karst with associated solution porosity and some dolomitization appears to be important in localizing reservoir intervals in the uppermost Tournaisian carbonate beds.

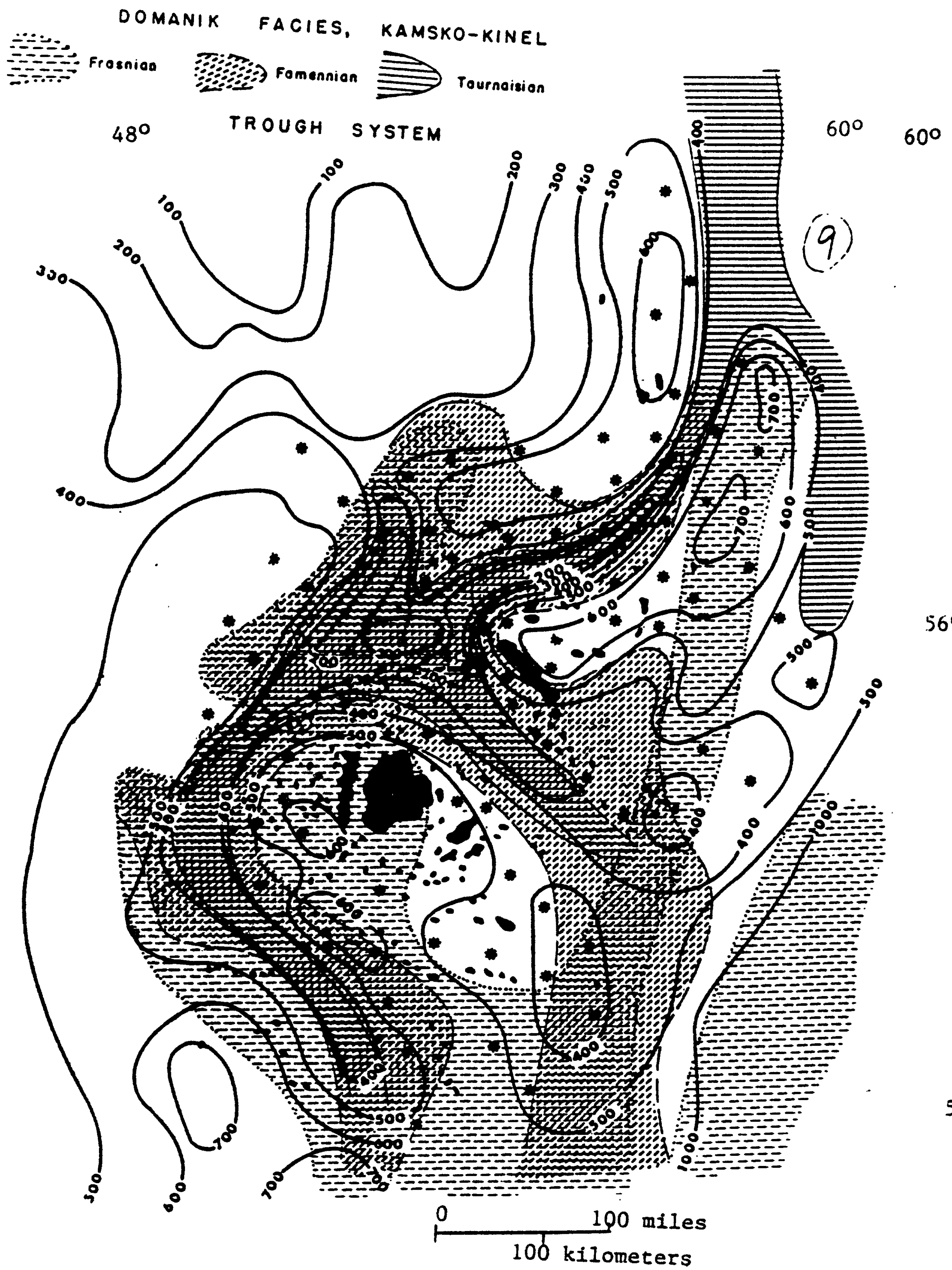


Fig. 34. Thickness in meters, Upper Devonian-Tournaisian carbonate sequence, showing oil fields producing from this interval and distribution of Frasnian, Famennian, and Tournaisian high-organic Domanik facies in Kamsko-Kinel trough system.

Source rocks

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 (fig. 34). These beds are highly bituminous; organic carbon content is as much as five percent or more. The Domanik facies beds, however, generally do not intertongue widely with the carbonate buildup facies and thus may not be as highly effective as a source-rock facies for these carbonate reservoirs as they are for the underlying Frasnian and Givetian clastic reservoirs.

Traps

The Upper Devonian and Tournaisian carbonate sequence is overlain by the basal sandstone beds of the Visean clastic section with no regional impermeable cap-rock interval between. This relationship may have prevented widespread trapping of petroleum in the carbonate beds during upward or lateral migration from the Domanik source rock facies. The reef structures, however, serve a dual purpose: they are not only isolated carbonate traps but are also the cores for draping structures in the overlying Visean clastic section.

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

Analogs

The Upper Devonian reefal and organic carbonate facies of the Volga-Ural province appears to be similar in faunal content and continental shelf position to that present in western North America (northern United States and western Canada). Likewise, the Tournaisian carbonate section of the Russian platform is much like the approximate age-equivalent Kinderhook-Osage facies of the Cordilleran shelf in the western United States and Canada, particularly with respect to faunal content. However, the northern United States and much of the Canadian facies commonly is moderately to highly dolomitized, with good porosity development over much of the area of occurrence; whereas the Volga-Ural section apparently contains a larger percentage of limestone, often of very pure composition but low in porosity. The productive Upper Devonian reefs of Canada form thick, massive buildups, many of which are relatively isolated, are closely associated with adjacent source rock and overlying regional cap-rock facies, and contain large volumes of dolomite porosity. Likewise, Mississippian carbonate mound petroleum accumulations in the Williston basin of northern United States and Canada tend to be found in relatively isolated dolomite porosity facies in close association with source-rock facies and overlying evaporite or shale cap-rock beds. The Volga-Ural carbonate section, on the other hand, occurs in more widespread belts, contains less dolomite porosity, less effective cap-rock beds, and the bituminous Domanik source rock facies tends to be areally separated from the reefal facies with little interbedding between the two. The Domanik is in part the age equivalent of the highly bituminous Chattanooga Shale and equivalent facies, which are present in much of the central and western part of the North American continent.

Visean Clastics (Lower Carboniferous) (fig. 35)

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

Reservoir rocks

Visean clastic reservoirs in general are highly lensing, discontinuous elongate quartz sandstone bodies of highly variable thickness and extent. Many of them are sinuous channel sandstones, particularly well developed within the Kamsko-Kinel trough areas, which contain many of the oil fields producing from these beds (fig. 35). Many of the reservoirs are classed as "stray sands," and considerable well density is important for adequate exploration (Baymukhametov, 1976). The thicker sands tend to be more widespread, except for some of the basal channel sandstones, which occur in deep erosion cuts in the underlying Domanik facies beds and Tournaisian carbonates (Voytovich and Shel'nova, 1977). Porosity and permeability characteristics are highly variable, ranging from very low in siltstone reservoirs to as much as 35-40 percent and 4-5 darcies in coarser sandstones. Lower Visean sandstone reservoirs in the Kuybyshev region have average porosities of about 22 percent and average permeabilities of about 650 millidarcies (Aleksin and others, 1974).

Source rocks

Dark bituminous shales of good source-rock quality are present in the Visean clastic section; total thickness increases in general from west to

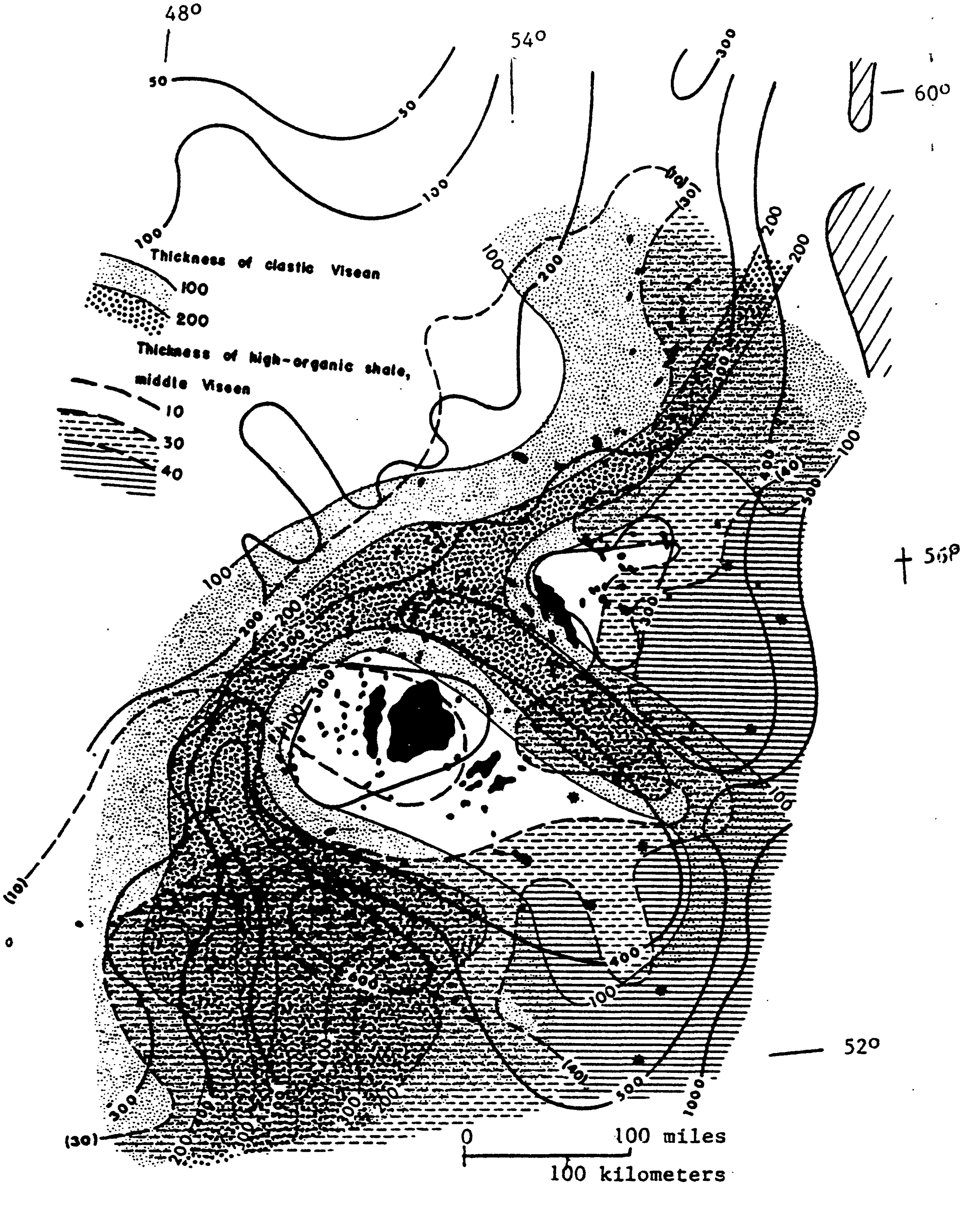


Fig. 35. Thickness in meters, Visean clastic-carbonate sequence (heavy lines), showing oil fields producing from this interval, and thickness of clastic Visean (light solid lines) and thickness of high-organic middle Visean shale source-rock facies (dashed lines).

east across the Volga-Ural province (fig. 35). 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, which includes the area of greatest concentration of Visean oil fields (fig. 35). The mid-Visean section (Yasnopolyana beds) contains the greatest thickness of medium to good quality source beds, which have been buried to depths of about 1,800-2,100 m (6,000-7,000 ft) in the central and northern part and over 3,000 m (10,000 ft) in the southern and eastern parts of the province. The underlying highly bituminous Tournaisian Domanik facies, which is cut deeply in many places by lower Visean sandstone beds, also provides a good associated source-rock interval, particularly for reservoirs in the lowermost Visean.

Traps

Many of the oil fields producing from the clastic Visean were discovered on structural closures, mostly anticlines or domes, mapped on Permian strata at the surface or in shallow seismic horizons. Traps formed by draping over Late Devonian-Tournaisian reefs are widespread. Arlan field, the second largest 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 of the sand bodies, many primarily stratigraphic trap fields have been found. Many of these are relatively small, but according to Soviet geologists, significant reserves are now being added by current emphasis on delineation of 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 clastic Visean section form a regional impermeable seal that extends across all of the province.

Analogs

The clastic Visean section is comparable with the productive Chester sandstone section of north-central United States, which contains numerous petroleum accumulations in deltaic and nearshore marine lensing and sinuate sandstone bodies that are interbedded with dark marine shale facies. Source areas for the clastic Visean and the Chester quartz sandstones are comparable; in both cases, reworking and redeposition of previously deposited sands by streams flowing off the margins of a cratonic continental mass into an advancing marine seaway are involved. The concentration of clastic Visean sandstone bodies within the Kamsko-Kinel trough system is unique to the Volga-Ural region, although basal Chester sandstones in the Illinois basin often channel deeply into the underlying beds also. However, total petroleum accumulation in the Chester sandstone reservoirs is considerably less than that of the Volga-Ural Visean section, partly because of smaller areal size of the north-central United States productive area. The association of the Devonian-Lower Carboniferous Domanik bituminous facies, truncated and channeled by overlying basal Visean sandstones, plus the interbedding of Visean sandstone bodies with age-equivalent, high-organic dark shale facies, are also important factors in improving the petroleum yield quality of these beds in the Volga-Ural province.

A second analogous stratigraphic association similar to the Visean of the Volga-Ural province is that of the Lower to Middle Pennsylvanian clastic sequence of the midcontinent and the upper Midwest United States. Discontinuous sandstone bodies of this sequence channel into the underlying Late Mississippian organic shale beds and, particularly in the midcontinent, are also interbedded with age-equivalent dark marine shale beds of source-rock quality. Pennsylvanian rocks, mainly sandstone reservoirs similar to those of the Volga-Ural Visean section, have produced more than seven billion barrels of oil in the midcontinent region, a major part of which occurs in stratigraphic traps (Adler, 1971).

Carbonate Lower and Middle Carboniferous (upper Visean, Namurian, and Bashkirian) (fig. 36)

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 (fig. 36). Large areas of good porosity are present within this carbonate wedge, occurring primarily in the Bashkirian beds of the upper part of the section. This sequence, however, thus far has been of secondary importance in number of oil fields (about 100) and volume of oil reserves found.

Reservoir rocks

The upper Visean and Namurian carbonate beds are mainly limestone with generally low porosity; few significant productive horizons have been delineated. The Bashkirian carbonates, however, are more porous and are characterized by a much more variable facies of organic carbonate buildups and dolomitized sectors. Kaleda and Kotel'nikova (1974) list six main petrographic types of reservoirs in the Bashkirian section: 1) biomorphic limestones, mainly with primary porosity values greater than 25 percent; 2) organo-clastic limestones with secondary leaching porosity and some primary porosity; 3) organo-detrital limestones largely of fine shell fragments, having secondary leaching porosity; 4) oolitic limestones with both primary and secondary porosity; 5) fine- and medium-grained crystalline limestones with secondary porosity (epigenetic); and 6) inequigranular dolomites with a large range of porosity values. Karst is present at the top of the Bashkirian section, and leaching porosity, probably related in part to karst development, is an important component of the more porous reservoirs. Low porosity reservoirs commonly show secondary cementation by calcite or calcium sulphate. Fracturing is also an important aspect of good reservoir characteristics.

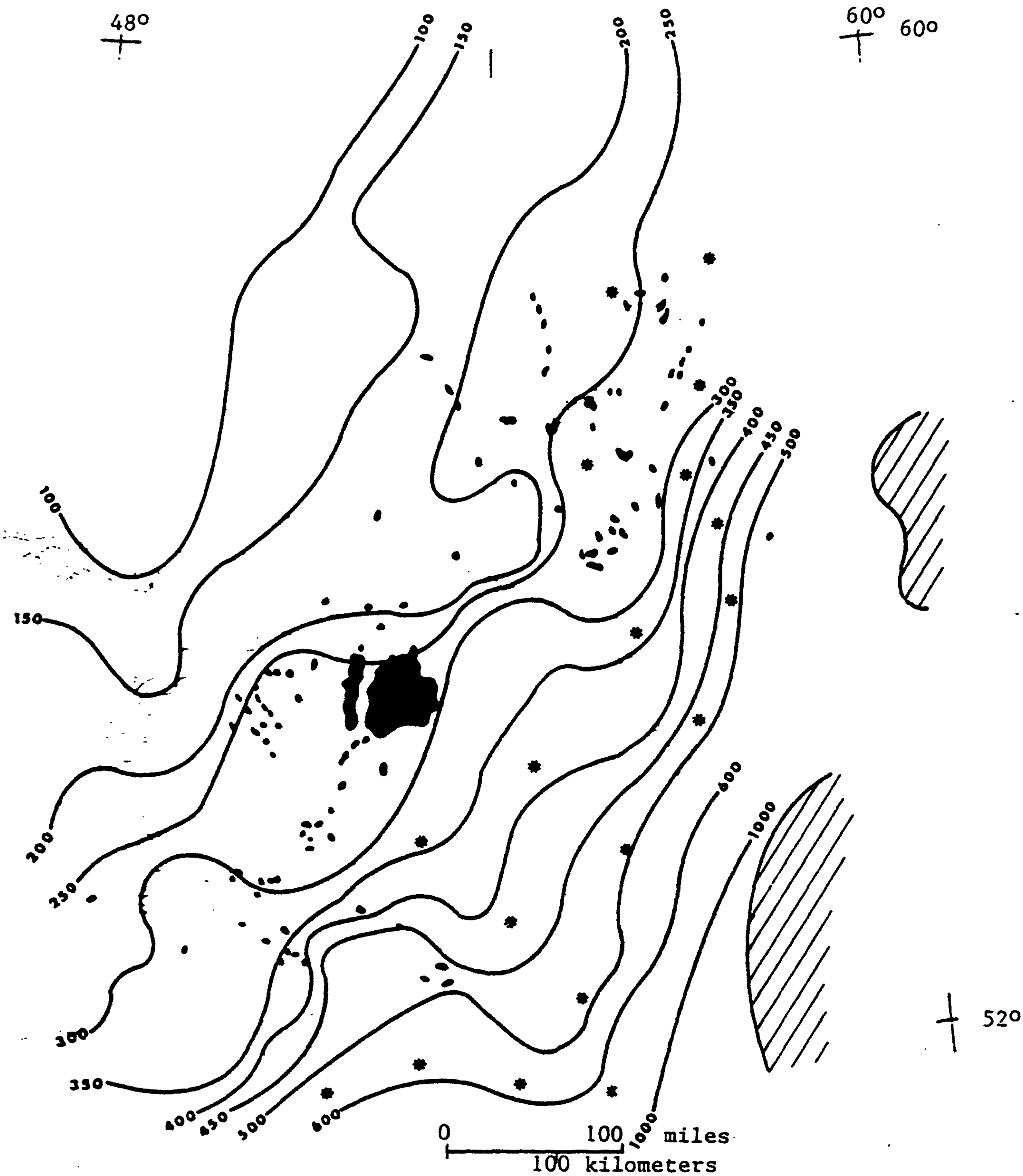


Fig. 36. Thickness in meters, carbonate upper Visean-Namurian-Bashkirian sequence, showing oil and gas fields producing from this interval.

Source rocks

High organic source-rock shale or carbonate beds are not reported in this section, and it seems likely that petroleum in these reservoirs originated from underlying dark shale beds of the upper part of the clastic Visean section, or the overlying lower Moscovian clastic beds.

Traps

Most of the accumulations in these reservoirs are on seismic or surface-mapped structures, although stratigraphic porosity traps are also commonly reported. The lower Moscovian shale and sandstone section forms a regional cap-rock interval overlying the carbonate Lower and Middle Carboniferous section.

Analogs

A somewhat similar analog to this carbonate section may be the widespread carbonate beds of Late Pennsylvanian and Early Permian age in the Kansas and Nebraska part of the midcontinent area, United States. In this area, the reservoirs for oil and gas accumulations in structural and and stratigraphic traps owe their capacity to porosity variations in organic carbonate beds.

Clastic Moscovian (Middle Carboniferous) (fig. 37)

The clastic Moscovian 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 (163 ft) along the eastern border of the province where the section grades into a dark marine shale facies. About 100 oil with minor gas-oil fields produce from these sandstone and siltstone reservoirs 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 clastic Moscovian is of secondary importance as an exploratory objective.

Reservoir rocks

Clastic Moscovian reservoirs are mainly discontinuous marine quartz sandstone or siltstone bodies that occur sporadically within the predominantly

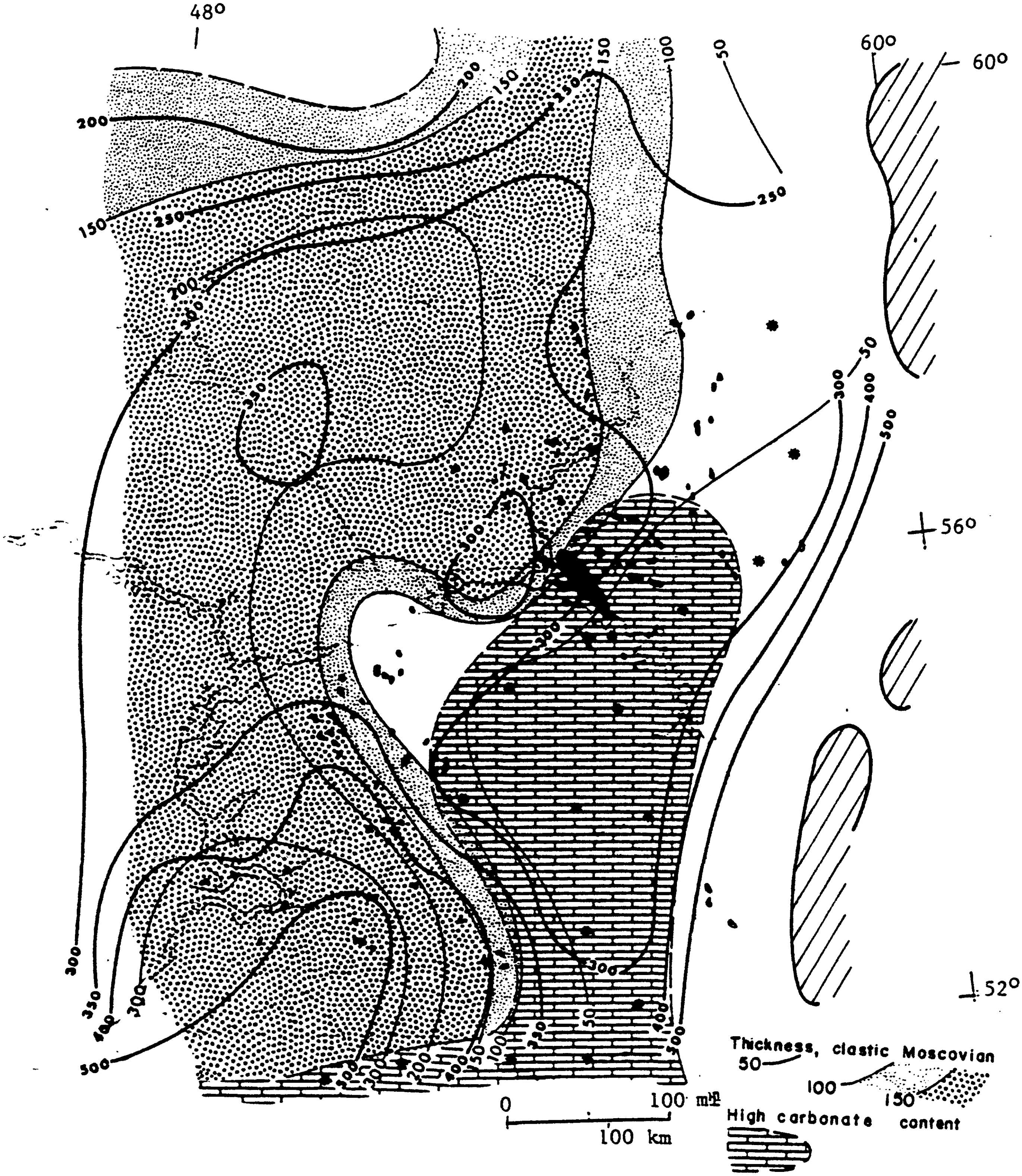


Fig. 37. Thickness in meters, Moscovian clastic-carbonate sequence (heavy lines), showing thickness of clastic Moscovian, oil and gas fields producing from this interval, and main clastic and carbonate facies.

gray shale and argillaceous carbonate beds that dominate the section. Porosity is generally low, the better reservoirs tending to occur on or near the crests of paleo-arches (Ashinov and Kolesov, 1974).

Source rocks

The dark gray marine shale beds that enclose the Moscovian quartz sandstone reservoirs are the most likely petroleum source beds for this section where it has been buried deeply enough, although source-rock data are lacking.

Traps

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

Analogs

The Moscovian clastic section is more or less a repeat of the Visean clastic sequence with the important exception that Moscovian sandstone beds and associated dark shale facies are of lesser reservoir and source rock quality. Analogs applicable to the Visean clastic sequence apply also to the Moscovian but with lesser productive potential. An additional analog, perhaps more closely paralleling Moscovian reservoir and source rock conditions, is that of the Tyler sandstone-dark shale sequence of the Williston basin.

Carbonate Middle and Upper Carboniferous (fig. 38)

Only a scattered few fields produce from these beds. Upper Moscovian reservoirs are porous, in places cavernous, fossiliferous limestones, with some dolomite intervals. Except for the underlying marine gray 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 maturation of organic matter. 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.

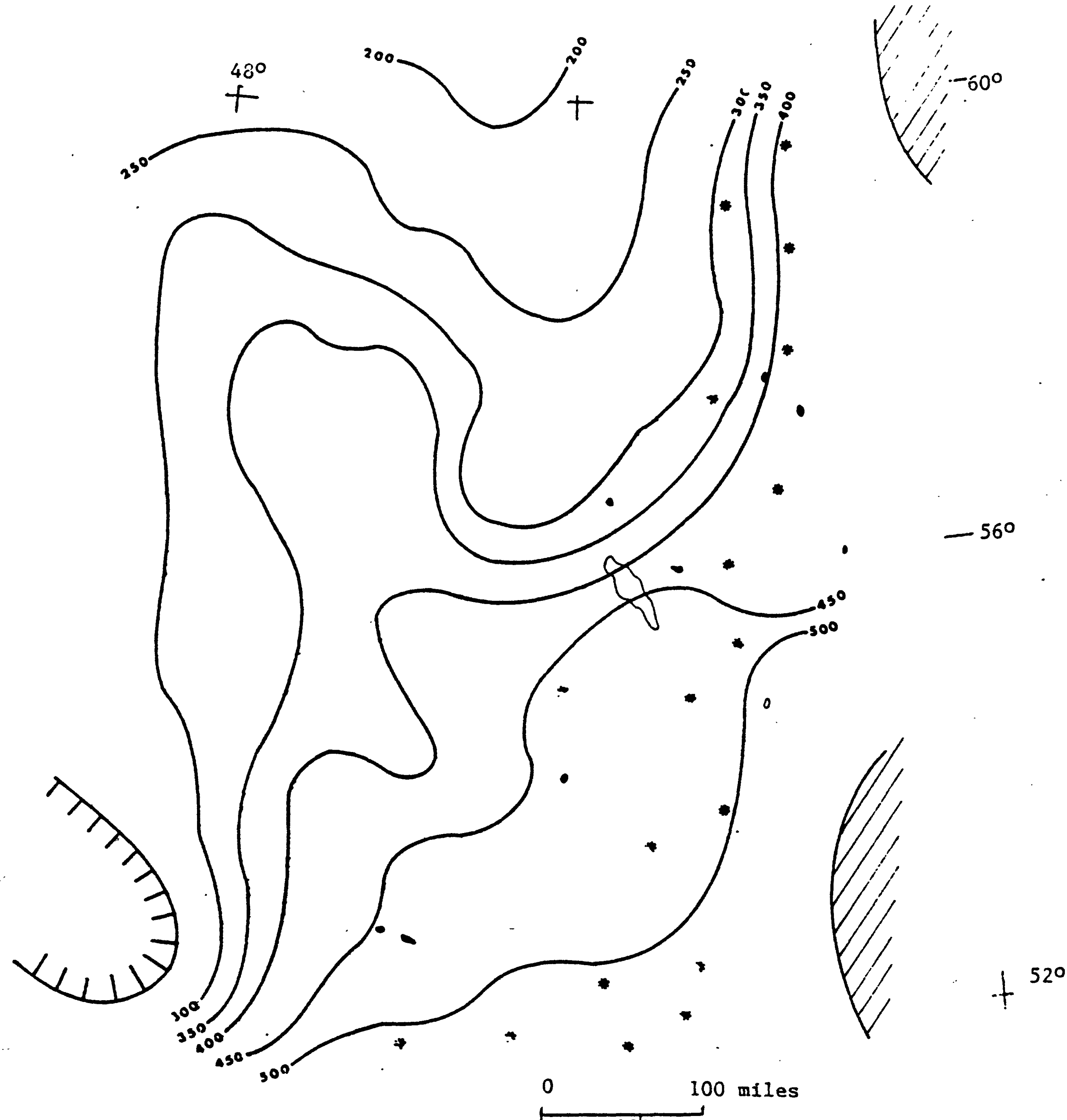


Fig. 38. Thickness in meters, carbonate upper Moscovian-Upper Carboniferous sequence, showing oil and gas fields producing from this interval.

Analogs

This carbonate sequence is similar in general character and distribution to that of the upper Visean-Namurian-Bashkirian interval, but the isolation of carbonate porosity variations from associated source-rock facies diminishes the quality of this section as a petroleum objective.

Carbonate-evaporite Lower Permian
(Asselian, Sakmarian, Artinskian and Kungurian) (fig. 39)

Oil and gas production from this 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 gas or gas-condensate fields and a few oil fields have been discovered, mainly in reefs along the eastern edge of the platform and in dolomite reservoirs of the Zhigulevsko-Orenburg arch.

Reservoir rocks

Lower Permian carbonate reservoirs are highly variable in porosity and permeability, ranging from very low to as much as 30-35 percent and 1 to 2 darcies, respectively. Some of the reef reservoirs along the platform edge are dolomite beds with very low porosity and permeablility, but the net productive section is often high (as much as 600 m or 2,000 feet), and fracture permeability is very important. Reservoirs in the Zhigulevsko-Orenburg arch area are mainly fine- to medium-grained crystalline dolomites with variable porosity and permeability. 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 (fig. 25).

Source rocks

Permian carbonate reservoirs on the Volga-Ural regional high are interbedded with anhydrite or gypsum, with minor fine-grained marine clastic beds and some redbeds. 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. 39). 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.

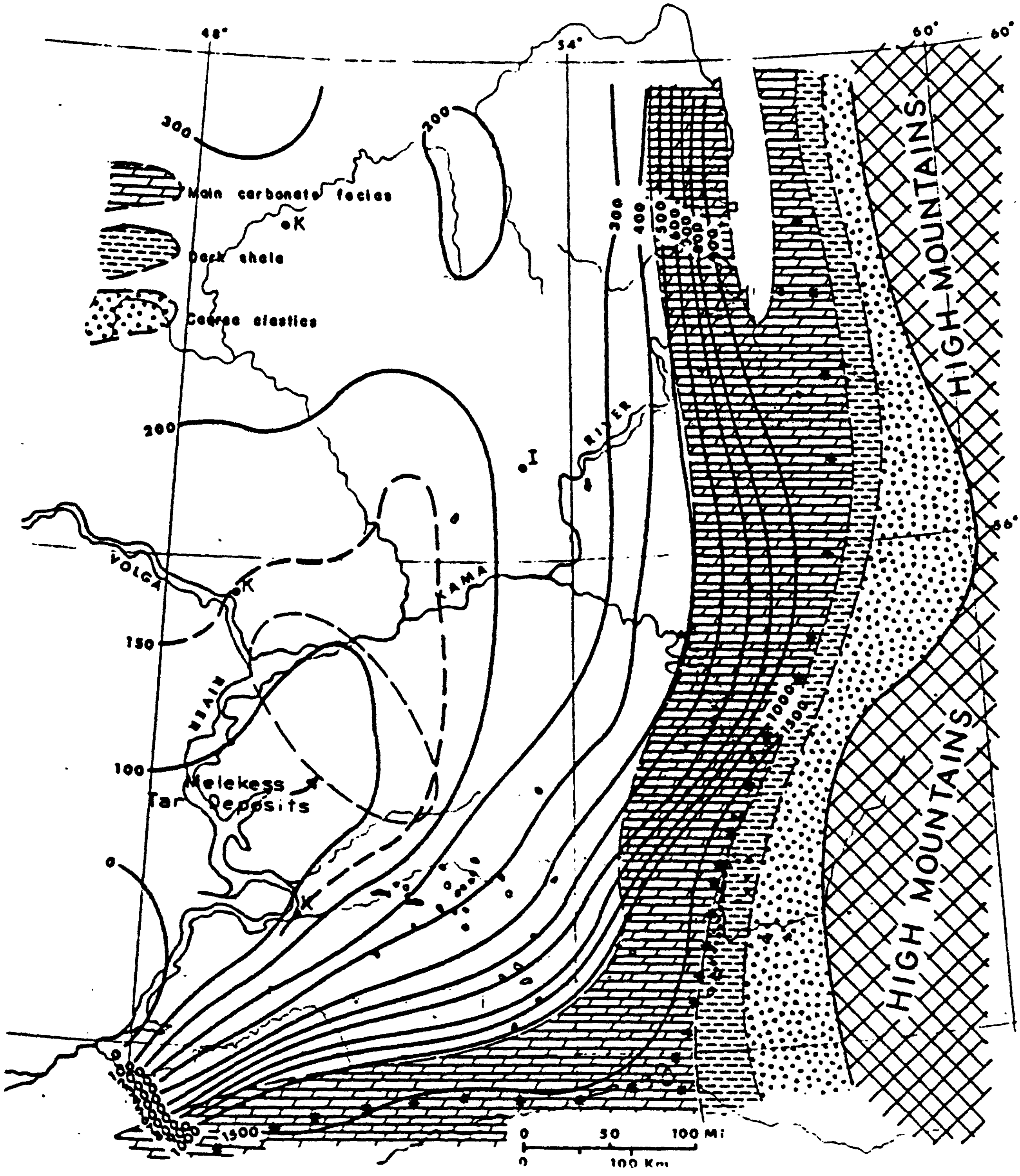


Fig. 39. Thickness in meters, Lower Permian, showing oil and gas fields producing from this interval, main carbonate facies, and reef trends.

Traps

Most of the oil and gas fields on the Zhigulevsko-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 are thrust faulted. The Orenburg gas field, largest in the province (70 Tcf), is located on a large faulted anticlinal fold. The Kungurian halite and gypsum-anhydrite facies overlies the productive carbonate and carbonate-reef section, forming a regional impermeable cap-rock facies over most of the province.

Analogs

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 Permian basin reefs are closely associated with a marine source rock facies, probably of much higher organic carbon content than that of the Volga-Ural province. Probably for this reason, and because in much of the southeastern and southern parts of the Volga-Ural province the Lower Permian beds have been buried to greater depths, mainly gas and gas-condensate accumulations occur there versus major oil accumulations in the Permian basin.

Clastic-carbonate Upper Permian (Ufimian, Kazanian, and Tatarian) (fig. 40)

Production (mainly gas with minor oil or condensate) from this interval is confined to the southern part of the province, mainly the Zhigulevsko-Orenburg arch and the Sernovodsko-Abdulino aulacogen.

Reservoir rocks

According to Maksimov and others (1970), three productive intervals are present in the Upper Permian section, the lower two containing sandstone and siltstone, with minor dolomite, reservoirs of Ufimian age and an upper more widespread interval with 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. These accumulations, which make up the greater part of the Melekess deposits, appear to be related to updip pinchout of porous sandstone, siltstone, and some dolomite beds along the southwest flank of the Tatar arch, on the margin of a major Upper Permian deltaic complex (figs. 9, 11, 12, 27, 40). Comments on the origin of these deposits are found in Demaison (1977).

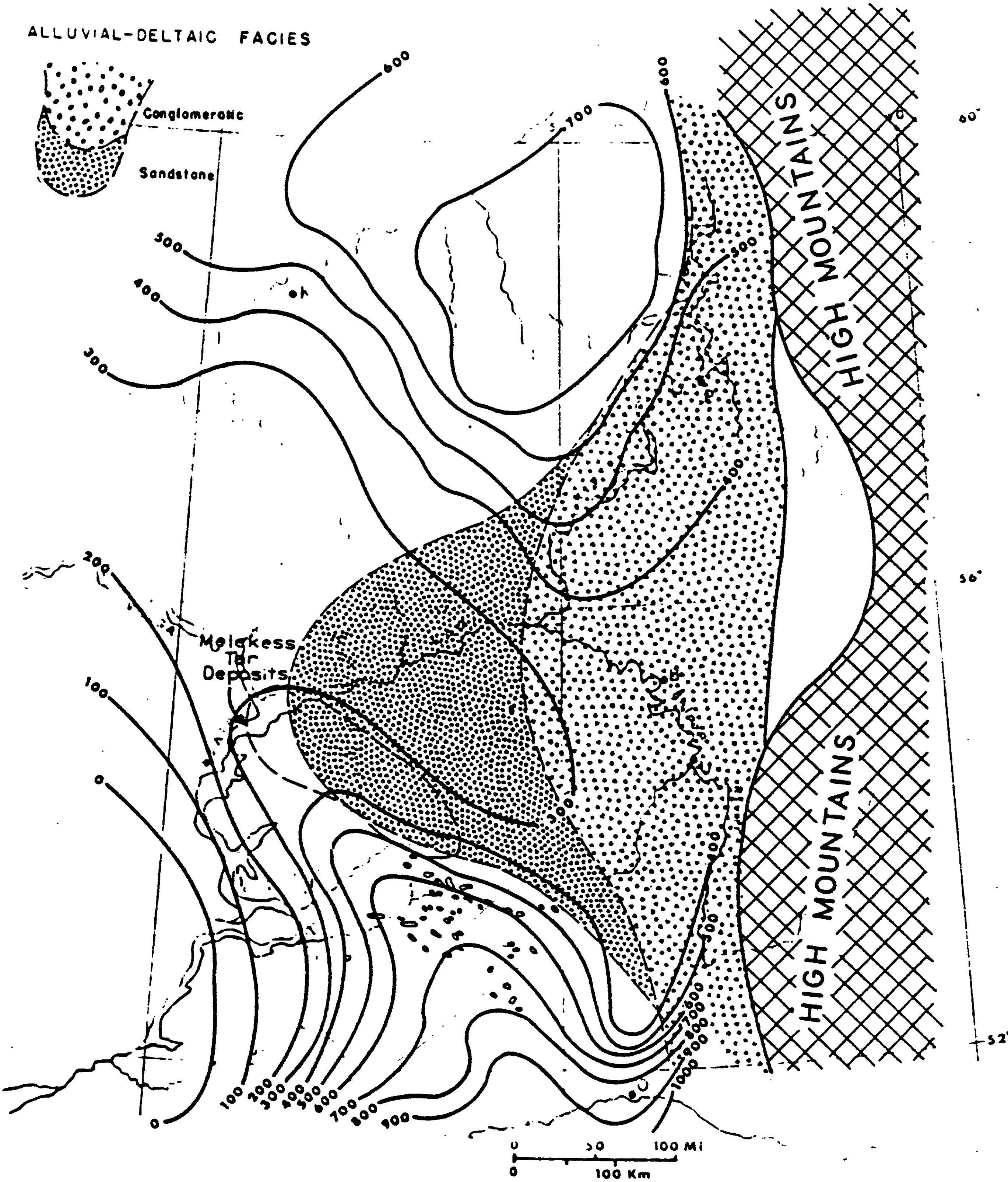


Fig. 40. Thickness in meters, Upper Permian, showing oil and gas fields producing from this interval and main facies patterns.

Source rocks

Evidence for the presence of petroleum source rocks is lacking in this interval, which is dominated by evaporites and redbed clastics. Some marine shales of possible source-rock quality may be present in the Peri-Caspian depression or the south 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).

Traps

Fields producing from this interval occur mainly on local anticlinal or domal structures, some of which are faulted. Anhydrite, gypsum, and halite beds are widespread in the upper Kazanian sequence, forming a regional impermeable cap rock facies.

SUMMARY OF PETROLEUM OCCURRENCE AND RESOURCE DATA

Introduction

All of the geological factors necessary for efficient generation and accumulation of large petroleum deposits (reservoirs, source rocks, traps, migration, and preservation conditions) are exceptionally well exemplified in the Volga-Ural province.

Reservoirs

Excellent sandstone reservoirs and fair to good fine-grained sandstone or siltstone reservoirs are present in the clastic Devonian, clastic Visean, clastic part of the Permian, and are less widespread in part of the clastic Moscovian. Good quality carbonate reservoirs occur in the Bashkirian and Upper Devonian-Tournaisian section in parts of the province, and are more locally present in the upper Moscovian and Permian. Moderate to low quality, but thick, carbonate reservoirs characterize the Lower Permian reef belt on the east and south borders of the province. Moderate to low quality siltstone or carbonate reservoirs are present in all parts of the stratigraphic section throughout the province. Widespread blanket reservoirs are not present in any part of the section, and some degree of discontinuity is characteristic of all porous bodies, ranging from lensing and channel sandstones or isolated reef or carbonate mound bodies to sandstone sheets over paleostructural highs or locally extensive dolomite facies within regional carbonate sequences.

Source rocks

Exceptionally rich high-organic marine shale or shaly carbonate beds are present in the Domanik facies of Upper Devonian and Tournaisian age, and good to excellent widespread source rocks occur in the Visean clastic section. Moderate to good source rocks are also present in the Moscovian clastic section and probably in the Lower Permian dark shale beds of the Ural foredeep and the Peri-Caspian depression. In all cases, the potential source rock facies interbeds with or intertongues with clastic and in places carbonate reservoir bodies. In some parts of the region, particularly on regional arches, the Visean and younger potential source beds probably have not been buried deeply enough to become mature source rocks. However, in almost all places, the Domanik beds, and in most cases the Visean beds, are mature source rocks. In the Ural foredeep and the Peri-Caspian depression, all of the Lower Permian and older section has been deeply buried, and much of the potential source-rock section has reached the post-mature stage. Consequently, these areas are mainly gas or gas-condensate prone regions.

Traps

An unusual combination of structural and stratigraphic trapping conditions is present throughout the Volga-Ural province. A great number of anticlinal structures have been mapped by surface and geophysical methods in the shallower (mainly Permian) beds, and most of the exploratory drilling apparently has been based on this work. In a significant number of cases, however, these are rootless structures related to draping over Devonian or Lower Carboniferous reefal buildups, a notable example being the giant Arlan oil field. Many of the folds are broad and gentle, and most of the larger ones have a long history of growth; many were initiated in Precambrian or possibly early Paleozoic times. The common presence of discontinuous sandstone and siltstone reservoir bodies and carbonate organic buildups or other discontinuous porous carbonate facies, results in numerous updip stratigraphic traps on the flanks of major paleostructures. At least half of the oil and gas pools occur under combination structure and stratigraphic trapping conditions.

Migration

The Soviet literature indicates differences of opinion regarding long distance versus local migration of hydrocarbons. The Ural foredeep and the Peri-Caspian depression probably contain a significant thickness of Devonian and Carboniferous potential source rock facies, and these beds were buried deeply enough for petroleum generation quite early in geologic history, probably by Late Carboniferous or Early Permian time. For this reason, long distance migration possibilities are an attractive hypothesis. However, the commonly discontinuous nature of both clastic and carbonate reservoir bodies and the close intertonguing of clastic reservoirs and high organic shale facies argue against long distance migration but favor the presence of an efficient mechanism for short distance migration from source beds to closely associated reservoir bodies. Evidence shows that the highest quality source rock facies occurs on the platform in close association with the better reservoir facies, rather than in the deeper water facies bordering the platform. Short distance migration into closely adjacent and interbedded reservoir bodies is also suggested by the common grouping of oil pools on paleostructural elements within areas of good source rock facies and their general absence in areas of poor source rock facies.

Preservation conditions

The Volga-Ural province is a preserved Paleozoic shelf or cratonic margin that has been subjected to only mild tectonism since marine deposition ended in Permian time. Most of the prominent structural elements date back to early Paleozoic or late Precambrian time. Continuous paleostructural growth of these features during deposition was a very important factor in determining the distribution of sandstone and carbonate reservoir facies and the closely interrelated high organic source rock facies and in the development of an early trapping and migration system. Post-accumulation structural movements have only mildly affected early formed traps, and very little of the original petroleum deposits has been removed by subsequent erosion.

Production Areas

Maksimov and others (1970) divide the Volga-Ural province into several productive regions based on differences in structural and paleostructural factors, distribution of reservoir and source rock facies, and the general composition of the petroleum accumulations. This system is followed closely here, with the exception that the north border of the Peri-Caspian depression is considered as a distinct and separate region (fig. 30). General information on each of these subdivisions follows, and more detailed information on several parameters related to petroleum occurrence is listed in figure 41.

Tatar arch (110,000 square km; 43,000 square miles)

This large structural feature, about 600 km (370 mi) long and 300 km (185 mi) wide, dominates the central part of the Volga-Ural province (fig. 2). It is the most important productive area, containing 46 percent of the oil reserves of the Volga-Ural province and 18 percent of the oil fields (about 250). No gas fields are present. The clastic Devonian sequence is by far the most important productive interval, but significant reserves have also been discovered in the clastic Visean section, the Upper Devonian-Tournaisian carbonate beds, and the clastic Moscovian section. Most of the production occurs on the structurally lower south crest of the arch; only minor production comes from the structurally higher north crest. Possible reasons for this are the fact that the clastic Devonian beds are absent over much of the north crest, depth of burial may not have been sufficient to generate significant petroleum from Devonian and younger source rock facies, and the reservoirs are flushed by subsurface waters. The south crest, on the other hand, contains a thick section of clastic Devonian reservoir and source-rock facies, which has been deeply buried, and numerous good reservoir intervals also occur in the Upper Devonian-Tournaisian carbonate section, the Visean clastics, the Lower and Middle Carboniferous carbonates, and the Moscovian clastics. Optimum development of the Domanik and lower Visean source-rock quality also occurs on the south crest of the arch.

The majority of the oils on the Tatar arch are of low density (less than 0.83 g/cm^3, or 30° API or more) and sour (S = 0.51 - 2 percent).

Figure 41.--Tabulated summary of reported petroleum geology and production parameters for main productive and prospective areas of Volga-Ural province.

AREA	SIZE (mi^2)	SED. ROCK THICKNESS (feet)	VOL. OF SED. ROCK (mi^3)	NO. OF FIELDS	NO. OF POOLS	NO. OF PAYS	RESER-VOIRS	RESER-VOIR TYPE	NET PAY (feet) Range	NET PAY (feet) Av.
TATAR ARCH	43,000	3,650 - 7,550 (av. = 5,400)	44,000	250 (oil)	400 (oil)		Dc	Ss, St	3-140	35
							Vc	Ss, St	3-80	30
							Du-T	Ls, Dol	3-60	25
							VNB	Ls, Dol	7-100	35
							Mc	St, Ss	5-83	?
							MuCu	Ls, Dol	?	?
BIRSK SADDLE	7,000	5,900 - 6,900 (av. = 6,250)	8,200	25-30 (oil)	75 (oil)		Vc	Ss, St	6-115	55
							Dc	St, Ss	4-50	?
							Du-T	Ls, Dol	15-60	?
							Mc	St, Ss	?	?
							MuCu	Ls, Dol	13-30	?
UPPER KAMA DEPRESSION	17,000	6,500-10,000 (av. = 7,200)	23,000	20-25 (oil)	65-75 (oil)		Vc	Ss, St	5-115	40
							VNB	Ls, Dol	13-100	30
							Mc	St, Ss	?	?
							Du-T	Ls, Dol	50-60	?
							MuCu	Ls, Dol	4-85	25
							Dc	St?	?	?
PERM-BASHKIR ARCH	20,000	5,400 - 9,500 (av. = 7,200)	27,000	45-50 (oil) 15-20 (O&G) 2-3 (gas)	275 (oil) 15 (O,G) 10) (gas)		VNB	Ls, Dol	6-110	55
							Mc	St, Ss	?	?
							Vc	Ss, St	10-170	65
							Du-T	Ls, Dol	23-51	?
							Dc	Ss, St	3-147	45
							MuCu	Ls, Dol	6-85	30
UFA-ORENBURG MONOCLINE	10,000	6,500-15,000 (av. = 8,000)	15,000	15-20 (oil)	30-35 (oil)		Dc	Ss, St	10-35	17
							Du-T	Ls, Dol	15-60	?
							Vc	St, Ss	?	?
							MuCu	Ls, Dol	?	?
MELEKESS-SERNOVSKO-ABDULINO BASIN	18,000	6,200 - 9,500 (av. = 7,200)	25,000	15 (oil) 15 (O&G)	100 (oil) 10 (O&G) 15 (gas)		Vc	Ss, St,	6-500	80
							Dc	Ss, St	13-95	45
							Mc	St. Ss	10-100	50
							Du-T	Ls, Dol	10-20	?
							VNB	Ls, Dol	?	?
							Pl	Dol.	25-40	?
							Pu	Ss	?	?

Figure 41 (continued)

AREA	SIZE (mi^2)	SED. ROCK THICKNESS (feet)	VOL. OF SED. ROCK (mi^3)	NO. OF FIELDS	NO. OF POOLS	NO. OF PAYS	RESERVOIRS	RESERVOIR TYPE	NET PAY (feet) Range	NET PAY (feet) Av.
ZHIGULEVSKO-ORENBURG ARCH	20,000	4,900-15,000 (av. = 8,200)	45,000	65-75 (oil) 40-50 (O&G) 15-25 (gas)	335 (oil) 30 (O&G) 60 (gas)		Vc	Ss, St	6-200	80
							Dc	Ss, St	6-170	65
							Mc	Ss, St	15-300	70
							Du-T	Ls, Dol	25-200	65
							VNB	Ls, Dol	25-140	80
							Pl	Dol, Ss	15-160	75
							MuCu	Ls, Dol	?	?
							Pu	Ss	6-100	45
URAL FOREDEEP	25,000	10,000-30,000 (av. = 18,000)	80,000	50-150 (oil, O&G, & g-cond)	50-200?		Pl	Dol, Ls	30-600	300
							Dc	Ss, St	?	?
							Vc	Ss, St	6-20	?
							VNB	Ls, Dol	3-40	?
							Mc	St, Ss	?	?
							MuCu	Ls, Dol	65-650	?
							Du-T	Ls, Dol	?	?
NORTH BORDER CASPIAN DEPRESSION	20,000	10,000-30,000 (av. = 18,000)	75,000	8-10?	?		Pl	Dol, Ls	650 (Orenburg)	
TOTALS	189,000	(Av.= 9,500)	342,000	5-600 (oil, O& G, gas)	1,400-1,800					

Figure 41 (continued)

AREA	POROSITY (percent) Range	POROSITY (percent) Av.	PERMEABILITY (millidarcies) Range	PERMEABILITY (millidarcies) Av.	SEAL	PROBABLE SOURCE ROCKS	PRODUCTION Oil	PRODUCTION Gas	PRODUCTION O&G	PRODUCTION Cond	API GRAVITY Range	API GRAVITY Av.	SULFUR (per-cent)	OIL TYPE	GAS TYPE
TATAR ARCH	15-27	20	40-2,000	300	Dev, sh	Domanik	x				22-40	35	2		
	4-28	17	10-3,700	400	Vc, sh	Dom & Vc	x				18-36	28	3		
	3-27	15	5-960	200	Vc, sh	Domanik	x				27-32	30	3-4		
	3-30	18	10-2,500	400	Vc, Mc	Vc & Mc?	x				18-31	24	?		
	1-31	16	1-2,050	?	Mc, sh	Mc	x				25-34	?	?		
	8-20	15	40-1,200	?	P sh-evap	Mc	x				?	?			
BIRSK SADDLE	10-26	18	10-1,200	250	Vc, sh	Dom & Vc	x				18-28	25	3-3.5		
	17-22	18	45-240	?	Dev, sh	Domanik	x				25-30	28	2-3		
	12-18	15	?	?	Vc, sh	Domanik	x				?	25	3-4		
	13-30	15	750-800	?	Mc, sh	Mc sh	x				?	?	?		
	?	12	?	?	P sh	Mc	x				29-32	?	?		
UPPER KAMA DEPRESSION	10-25	17	50-2,750	250	Vc, sh	Vc	x				20-32	25	1.6		
	8-25	15	50-130	80	Mc Sh	Vc & Mc?	x				27-34	30	1.6		
	?	15	?	?	Mc	Mc	x				?	?	?		
	?	15	3-775	?	Vc, sh	Domanik	x				23-27	25	3.5		
	5-18	12	45-1,100	75	P sh-evap	Mc	x				25-32	28	1.6		
	?	?	?	?	Dev, sh	Domanik	x				?	?	?		
PERM-BASHKIR ARCH	3-28	14	10-530	100	Mc, sh	Vc & Mc	x	x	x		28-38	33	2-3		
	?	10	?	?	Mc, sh	Mc	x	x	x		?	?	?		
	5-28	16	5-2,000	400	Vc, sh	Dom & Vc	x	x			24-43	35	2-3		
	?	12	70-155	?	Vc, sh	Domanik	x				17-40	?	3-5		
	4-23	16	35-970	325	Dev, sh	Domanik	x				26-38	30	2-3		
	9-26	12	18-140	60	P sh-evap	Mc?	x	x	x		23-37	30	2.5		
UFA-ORENBURG MONOCLINE	12-23	17	10-4,400	?	Dev, sh	Domanik	x				29-33	31	2		
	?	10	?	?	Vc, sh	Domanik	x				28-32	30	2.5		
	?	15	?	?	Vc, sh	Dom & Vc	x				?	?	?		
	?	15	?	?	P sh-evap	Mc?	x				24-27	?	2.5		
MELEKESS-SERNOVSKO-ABDULINO BASIN	3-30	17	10-3,700	400	Vc, sh	Dom & Vc	x				25-34	30	3		
	8-22	17	45-1,350	400	Dev, sh	Domanik	x				21-35	30	1.5		
	1-32	17	1,2,000	250	Mc, sh	Mc?	x				28-33	31	2.2		
	?	12	?	?	Vc, sh	Domanik	x				?	32	2		
	?	17	?	?	Mc	Vc & Mc	x				?	32	2		
	6-37	9	5-250	?	P sh-evap	Pl sh, Dom		x			?	?	3		
	?	17	?	?	P sh-evap	Pl sh, Dom		x			?	?	3		

Figure 41. (continued)

AREA	POROSITY (percent)		PERMEABILITY (millidarcies)		SEAL	PROBABLE SOURCE ROCKS	PRODUCTION				API GRAVITY		SULFUR (percent)	OIL TYPE	GAS TYPE
	Range	Av.	Range	Av.			Oil	Gas	O&G	Cond	Range	Av.			
ZHIGULEVSKO ORENBURG ARCH	8-40	19	3-4,500	600	Vc sh	Dom & Vc	x				31-43	35	1.8		
	5-30	16	15-1,500	250	Dev, sh	Domanik	x				32-46	38	1.0		
	6-35	18	60-1,700	200	Mc sh	Mc?	x	x	x		31-43	35	2		
	8-20	14	6-340	80	Vc sh	Domanik	x				27-37	33	1.3		
	4-35	17	1-3,500	250	Mc sh	Vc & Mc?	x				30-37	34	1.3		
	4-32	13	1-300	65	P sh-evap	Pl sh? Dom	x	x	x		27-57	40	1.2		
	8-25	15	?	?	P sh-evap	Mc?, Dom?	x	x	x		?	34	2.3		
	1-38	15	1-520	100	P sh-evap	Pl sh? Dom		x	x		?	?	?		
URAL FOREDEEP	2-13	9	?	?	P sh-evap	Pl sh	x	x	x	x	21-57	?	4		
	?	10	?	?	Dev, sh	Dev, sh	x				?	?	?		
	8-16	12	?	?	Vc sh	Vc sh	x				?	40	0.5		
	?	8	?	?	Mc sh?	Mc, VNB sh	x				?	41	0.8		
	6-14	10	70-2,000	?	Mc sh?	Mc	x	x	x	x	?	28	4		
	?	10	?	?	Mc Pl	Mc or Pl	x	x		x	?	53	2.5		
	?	11	?	?	Vc sh	Dev,-T sh	x				?	?	?		
NORTH BORDER CASPIAN DEPRESSION	10 Orenburg		1-1,800	?	Pu evap & sh	Pl sh		x		x	?	?	?		
TOTALS															

Figure 41. (concluded)

AREA	GOR Range	DRIVE	TEMP GRADIENT	SIP
TATAR ARCH	115-700	W	N-N1	N
	20-225	W	N-N1	N
	40-170	W	N-N1	N
	60-100	?	N-N1	N
	80-120	W	N-N1	N
	?	?	?	N
BIRSK SADDLE	60-110	?	N	Nh
	90-165	?	N	Nh
	71-85	?	N	Nh
	?	?	N	Nh
	?	?	N	Nh
UPPER KAMA DEPRESSION	50-120	W?	N1	N-Nh
	?	W	N1	N-Nh
	?	?	N1	N-Nh
	?	?	N1	N-Nh
	?	W?	N1	N-Nh
	?	?	N1	N-Nh
PERM-BASHKIR ARCH	?	W&G	L	Na-N1
	?	?	L	Na-N1
	90-825	W	L	Na-N1
	80-750	W, G	L	Na-N1
	200-225	W	L	Na-N1
	?	?	L	Na-N1
UFA-ORENBURG MONOCLINE	190-315	G	N1	Na
	220-300	G	N1	Na
	?	?	N1	Na
	?	?	N1	Na
MELEKESS-SERNOVSKO-ABDULINO BASIN	30-225	W?	N	Na
	65-900	W?	N	Na
	80-320	W?	N	Na
	?	W?	N	Na
	60-100	W?	N	Na
	?	G	N?	Na?
	?	G	?	?
ZHIGULEVSKO ORENBURG ARCH	30-740	W	H	H
	65-2,110	W	H	N1
	60-800	W, G	H	H
	185-380	W	H	N1
	50-675	W, G	H	N1
	35-250	W?, G	H	H
	?	?	?	?
	?	W?, G	?	?
URAL FOREDEEP	55-500	?	Vrbl.	Vrbl.
	?	?	?	?
	?	?	Vrbl.	Vrbl.
	?	?	Vrbl.	Vrbl.
	?	?	Vrbl.	Vrbl.
	?	?	Vrbl.	Vrbl.
	?	?	?	?
NORTH BORDER CASPIAN DEPRESSION	?	G	Na?	Na?
TOTALS				

ABBREVIATIONS

Temp. gradient and SIP (shut in pressure)

N = normal
N1 = lower than normal
Nh = higher than normal
Na = above normal
L = low
H = high

Reservoirs

Pu = Upper Permian clastics
Pl = Lower Permian carbonates-clastics
Cu = Upper Carboniferous carbonates
Mu = Upper Moscovian carbonates
Mc = clastic Moscovian
VNB = carbonate Upper Visean, Namurian, and Bashkirian
Vc = clastic Visean
T = Tournaisian carbonates
Du = Upper Devonian carbonates
Dc = clastic Devonian

In addition to the important Devonian, Carboniferous, and other oil accumulations, the large Melekess tar deposits (1.25 billion barrels in place, according to Demaison, 1977) occur in Permian clastic and carbonate reservoirs in the shallow subsurface along the middle Volga River and its tributaries. These deposits occur on the seaward fringe of a major deltaic complex that projects southwesterly from the Ural Mountains uplift across the Tatar arch (fig. 40).

Birsk saddle (18,000 square km; 7,000 square miles)

The Birsk saddle forms a broad gentle structural sag between the Tatar and Perm-Bashkir arches. The area, which lies within the belt of high organic-carbon shale and carbonate facies of the Domanik and Visean, contains a thick section of Visean clastic reservoirs, and the east half contains a thick belt of Upper Devonian-Tournaisian carbonate reef buildup. Good porosity also occurs in the upper Moscovian carbonate section. About 25-30 oil fields are present in the Birsk saddle; these account for 14 percent of the oil reserves of the Volga-Ural province. The main oil reserves occur in clastic Visean sandstone and siltstone reservoirs. Important reserves also occur in the clastic Devonian, Upper Devonian-Tournaisian carbonate beds, and the clastic Moscovian. Less important accumulations are present in the carbonate upper Moscovian-Upper Carboniferous. It contains about 14 percent of the reserves of the Volga-Ural province. The majority of the oils are of high density (greater than 0.91 gm/cm^3, or less than 24° API) and high sulphur (greater than 2 percent). No gas fields are present.

Upper Kama depression (45,000 square km; 17,000 square miles)

The upper Kama depression makes up the northern part of the Volga-Ural province and forms the depressed area north of the Birsk saddle and the Perm-Bashkir arch, separating the latter feature from the north extension of the Tatar arch. The depression is within the area of maximum thickness of Devonian sandstone facies; the Domanik facies is generally thick; and the Visean contains relatively thick sandstone beds and good source rock facies. Despite these conditions, only a relatively small number of fields have been discovered. It contains less than 2 percent of the oil reserves of the Volga-Ural province. Possible reasons for this are that the area is a regional depression dating back to early Paleozoic or Precambrian time and few local accumulations are present; most of the generated hydrocarbons probably have migrated out of the basin area into structural and stratigraphic traps localized on adjacent regional uplifts (the Perm-Baskhir arch, Birsk saddle, and Tatar arch).

Perm-Bashkir arch (50,000 square km; 20,000 square miles)

This large structural feature, which forms the eastern margin of the Russian platform, has existed as a major paleostructural arch since early Paleozoic or Precambrian time. The northern and southern parts of the regional structure are occupied by the Perm high and the Bashkir high, respectively. The high organic Domanik facies bounds this uplift on the west and cuts across its center in a segment of the Kamsko-Kinel trough system. Good source rocks are also present in the Visean clastic beds. The area is one of generally high carbonate content with thick reef or carbonate mound development in the Upper Devonian-Tournaisian and the Middle Carboniferous. The area is primarily an oil producing region, and clastic Moscovian and carbonate Bashkirian reservoirs contain the greatest number of oil pools and the greatest reserves (Maksimov and others, 1970). Several oil pools are also present in the clastic Devonian and the carbonate Upper Devonian-Tournaisian, and minor production is found in the upper Moscovian-Upper Carboniferous carbonate beds. About 40-50 oil fields, 15-20 oil and gas fields, and 2-3 gas fields have been found containing about 300 oil and gas pools. It contains about 13 percent of the oil reserves and 16 percent of the oil fields of the Volga-Ural province.

Ufa-Orenburg monocline (26,000 square km; 10,000 square miles)

This area forms the eastern slope of the Russian platform south of the Perm-Bashkir arch and is adjacent to the southern Ural foredeep. The area lies on the eastern borders of the main clastic Devonian, clastic Visean, and clastic Moscovian sandstone-siltstone reservoir facies. High carbonate content occurs in the uppermost Devonian and parts of the Carboniferous, but generally these carbonate beds tend to be argillaceous to shaly, and reservoir quality is poor to moderate. The sparsity of good local structures and inadequate reservoir facies probably explains the small number of fields, plus the probability that the area has long been a monoclinal slope into the Ural foreland trough, with little development of local structures. It contains 1.5 percent of the oil reserves of the Volga-Ural province. About 15 oil fields have been discovered, productive mainly from clastic Devonian reservoirs. Several smaller oil pools are also present in carbonate Upper Devonian-Tournaisian and clastic Visean beds. All of these are in the northern part of the area. The oils are of low gravity and medium- to high-sulphur content. No gas fields are present.

Melekess-Sernovodsko-Abdulino basin (45,000 square km; 18,000 square miles)

This depression separates the Tatar and Zhigulevsko-Orenburg arches. The area contains thick sandstone facies in the clastic Devonian, Visean, and Moscovian, particularly in its western part, and a thick section of Domanik and Visean potential source-rock beds. However, because the area has been a major paleostructural downwarp since Late Proterozoic time and local structural closures are rare, petroleum generated in the trough has probably migrated into the adjacent northern margin of the Zhigulevsko-Orenburg arch and the southern part of the Tatar arch. Reserves of this depression account for only 4 percent of the total for the Volga-Ural province. The known fields occur where local structures are present in the approximate center of the depression. A large number of oil pools and reserves occur in the middle part of the clastic Visean beds (Bobrikov horizon). An equally large number of pools have been found in the Moscovian beds, but reserves are much less. Several oil pools also occur in the clastic Devonian with total reserves greater than that of the Moscovian. Additional oil pools have been found in the carbonate Upper Devonian-Tournaisian and a few in the carbonate Bashkirian. In the eastern part of the area, gas and gas-condensate pools occur in the carbonate and clastic Permian reservoirs. Carboniferous reservoirs produce generally low-gravity and high-sulfur oils, and the Devonian clastic reservoirs contain higher gravity, sour oils. About 15 oil and 15 combination oil and gas fields have been found containing about 125 pools.

Zhigulevsko-Orenburg arch (75,000 square km; 29,000 square miles)

The largest number of oil pools and reserves occurs in the clastic Visean section, mainly in sandstone reservoirs of the lower part (Malinovka beds). Numerous oil pools are also present in the clastic Devonian, carbonate Upper Devonian-Tournaisian, Bashkirian, and clastic Moscovian beds. Several fields produce gas and combination oil and gas from Lower and Upper Permian carbonate and clastic reservoirs. Most of the oils are high gravity and have very low sulphur content. The main part of the clastic Devonian sandstone belt passes across the western part of this region, but few pools have been found in these beds there. Most clastic Devonian accumulations (about 75 known oil pools) occur in the north central part where Domanik shale facies is well developed, many local structures are present, and the clastic Devonian reservoirs are moderately to well developed. Many oil pools are also present in the Upper Devonian-Tournaisian reef and organic carbonate buildup facies bordering the Kamsko-Kinel trough that crosses the central part of the area. Clastic Visean sandstone reservoirs and associated source-rock facies reach maximum development across the western part of this area, where at least 75 oil pools are present in these beds. A broad belt of carbonate porosity is also present in the Bashkirian carbonate beds, which contain at least 25 oil pools. Several oil pools are also present in the Moscovian clastic section, and at least 125 oil and gas pools have been found in Lower and Upper Permian carbonate and clastic reservoirs. Almost all of the gas production of the area is from Permian carbonate and clastic reservoirs. It contains about 13 percent of the oil reserves of the Volga-Ural province and 23 percent of the fields.

Ural foredeep (65,000 square km; 25,000 square miles)

This productive region occupies the area between the Ural Mountains and the Russian platform and makes up the eastern border of the Volga-Ural petroleum province. It contains 2 percent of the oil reserves and 2.5 percent of the fields of the province. The largest number of fields and reserves thus far are in the southern part of the foredeep, where the main production is gas and gas-condensate from Lower Permian reef facies. Some Moscovian and clastic Devonian oil pools also occur here. A few fields have been found in the northern part of the province, producing gas-condensate and some oil from Lower Permian reefs and Moscovian beds and oil from middle Visean clastics. Many new fields have been discovered in clastic Devonian and Permian sandstone and carbonate reservoirs in the southern Ural foredeep in recent years, some in faulted anticline or fault traps. Much of the Devonian and Carboniferous section is shale or argillaceous carbonate in the Ural foredeep, and apparently the reservoir quality is generally poor. However, the Lower Permian reef facies is highly developed, and the Upper Permian clastic section contains a significant thickness of porous sandstone beds, particularly in the southern part. Judging from recent Soviet reports, the area is estimated to contain a total of 50-150 oil, oil and gas, and gascondensate fields, and is continuing to be heavily explored as deeper drilling progresses.

North border of Peri-Caspian depression (50,000 square km; 20,000 square miles)

The north border of the Peri-Caspian depression is a relatively unexplored area with several unique geological characteristics. For this reason it is separated from the Zhigulevsko-Orenburg arch region as a distinct petroleum province. Main exploration targets in this area are the Lower Permian reef belt, production at the supergiant Orenburg gas field (70 TCF), and potential carbonate buildups in the Middle and Upper Carboniferous. Soviet geological and geophysical studies indicate that the Permian reef belt extends westward along the northern border of the Peri-Caspian depression and continues southward along the western border of the depression. Seismic studies also indicate the possible presence of carbonate buildup belts in the Carboniferous. Reservoir beds are at depths of 3,000-9,000 m (10,000-30,000 ft) or more; the region is primarily prospective for gas or gas-condensate and may contain very large reserves.

Present Exploration and Future Prospects

Exploration activity in the Volga-Ural province has declined significantly in recent years, partly because of the greatly increased emphasis on the West Siberian basin, which has utilized a major share of available drilling equipment. However, judging from reports in Soviet geological journals and other publications, exploration interest remains high in several parts of the province, particularly the Ural foredeep, Perm-Bashkir arch, Upper Kama depression and the north border of the Peri-Caspian depression. At least 125 discoveries have been made in these areas in the past ten 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 Visean discontinuous sandstone reservoirs in the areas of the main oil fields.

The thrust belt which makes up the west flank of the Ural Mountains is of major interest, as are the graben and other fault structures in the Ural foredeep. Most of these are gas or gas-condensate prospects. 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 along the western border of the Ural foredeep and the north border of the Peri-Caspian depression. These are also primarily of gas and gas-condensate potential, but the reserves may be great. The pre-Devonian Bavly beds are of interest, primarily because of their good reservoir quality and thickness. These reservoirs appear to be especially promising for oil in faulted areas of major uplifts, particularly the Perm-Bashkir arch, and for gas in the western Urals thrust belt.

ROMASHKINO OIL FIELD

Introduction

Romashkino is a super-giant oil field almost in the middle of the oily belt that extends along the eastern part of the Russian platform (figs. 2 and 30). The domal structure was first detected by geological surveys in 1934 and the discovery was in 1948. For twenty years between the middle fifties and the middle seventies this was the largest producer in the U.S.S.R. providing a significant portion of their total production.

The field covers an area of 3,600 sq. km., and more than 10,000 wells have been drilled. Cumulative production as of January 1, 1981, was 12 billion barrels. Although the field is now in decline, production during 1981 was still 400 million barrels (International Petroleum Encyclopedia, 1982, p. 353).

Stratigraphy

The Paleozoic section at Romashkino oil field is about 2,000 m thick and rests directly on gneisses and migmatites of the Precambrian crystalline basement. No Riphean or Vendian sediments are present here (Mal'tsev, 1957, p. 50). The section of a stratigraphic well within the field is illustrated in figure 42. Note that depth is given on this log and not sea-level position as is used on all other illustrations in this report.

At the base of the Paleozoic section are sediments of the Middle Devonian Givetian Stage, which consist of alternating quartz sandstones and shales as well as a marker called the "middle limestone." Pay zones D_{IV}, D_{III}, and D_{II} (ascending order) are present in this stage. Total thickness of the Givetian at Romashkino is 55-125 m (figs. 42 and 8).

Overlying the Givetian Stage is the Frasnian Stage, which is subdivided into three substages: lower, middle, and upper. The lower substage consists of three formations: Pashiy, Kynov, and Sargayevo (in ascending order).

The Pashiy sediments are an extremely complex succession of beds and lenses of sandstone, siltstone, and shale. This formation is pay zone D-I, which has produced more than 90 percent of the oil at Romashkino. Thickness of the Pashiy rocks is 20-50 m.

The Kynov Formation consists largely of shales and siltstones with subordinate limestones and dolomites. At the base of the formation is a persistent stratum known as the "upper limestone." In the middle of the Kynov Formation is a sandy silty stratum called the Mikhaylov horizon, which is 3-7 m thick. At Romashkino it is present only in the northwest part of the field where it is the D-0 pay zone. Total thickness of the Kynov Formation at Romashkino is 20-40 m.

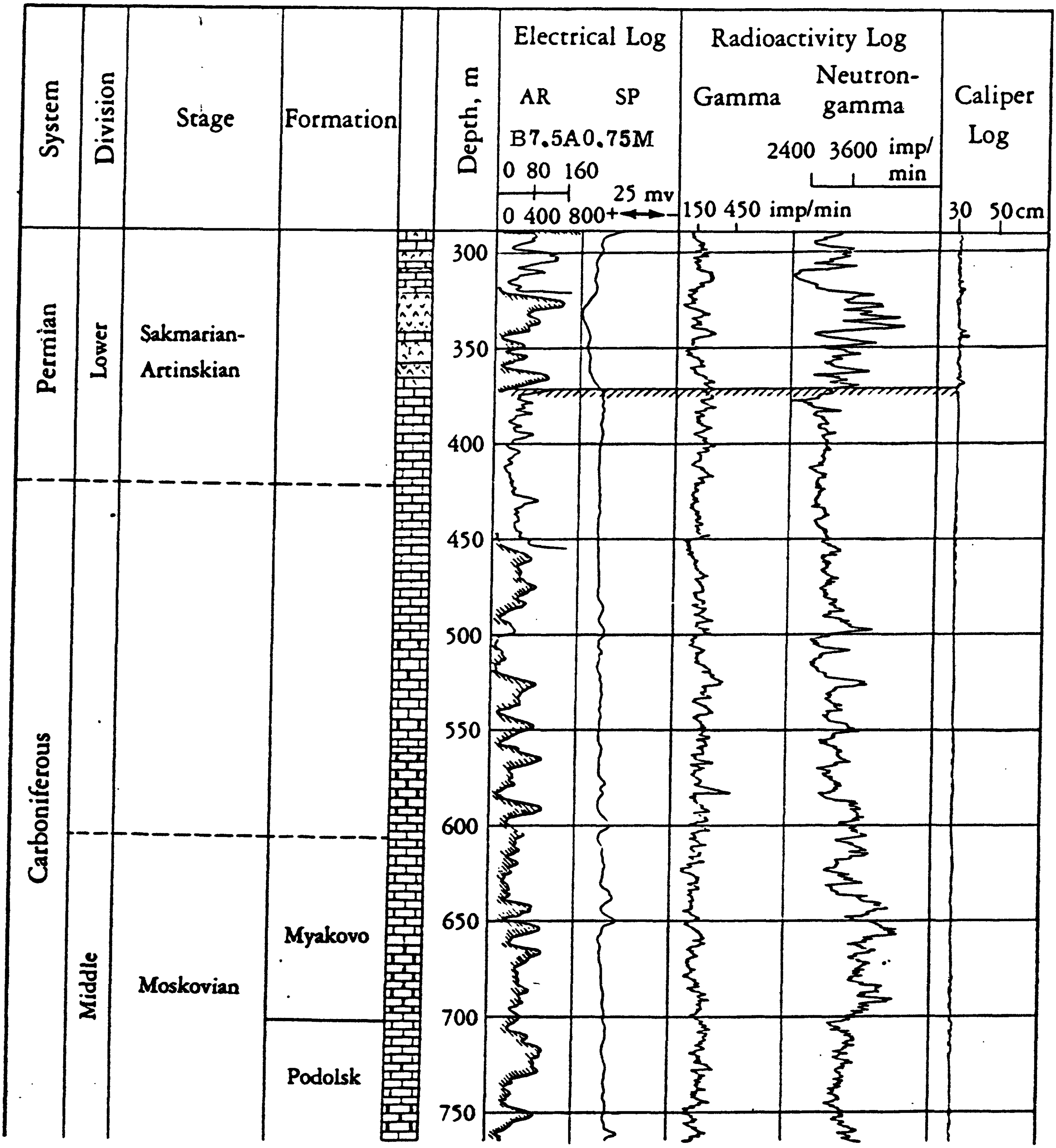


Fig. 42. Typical well log of section of Permian, Carboniferous, and Devonian sediments of Romashkino field (from Per'kov, 1961). This figure is continued on the next three pages, and the explanation is on the last page.

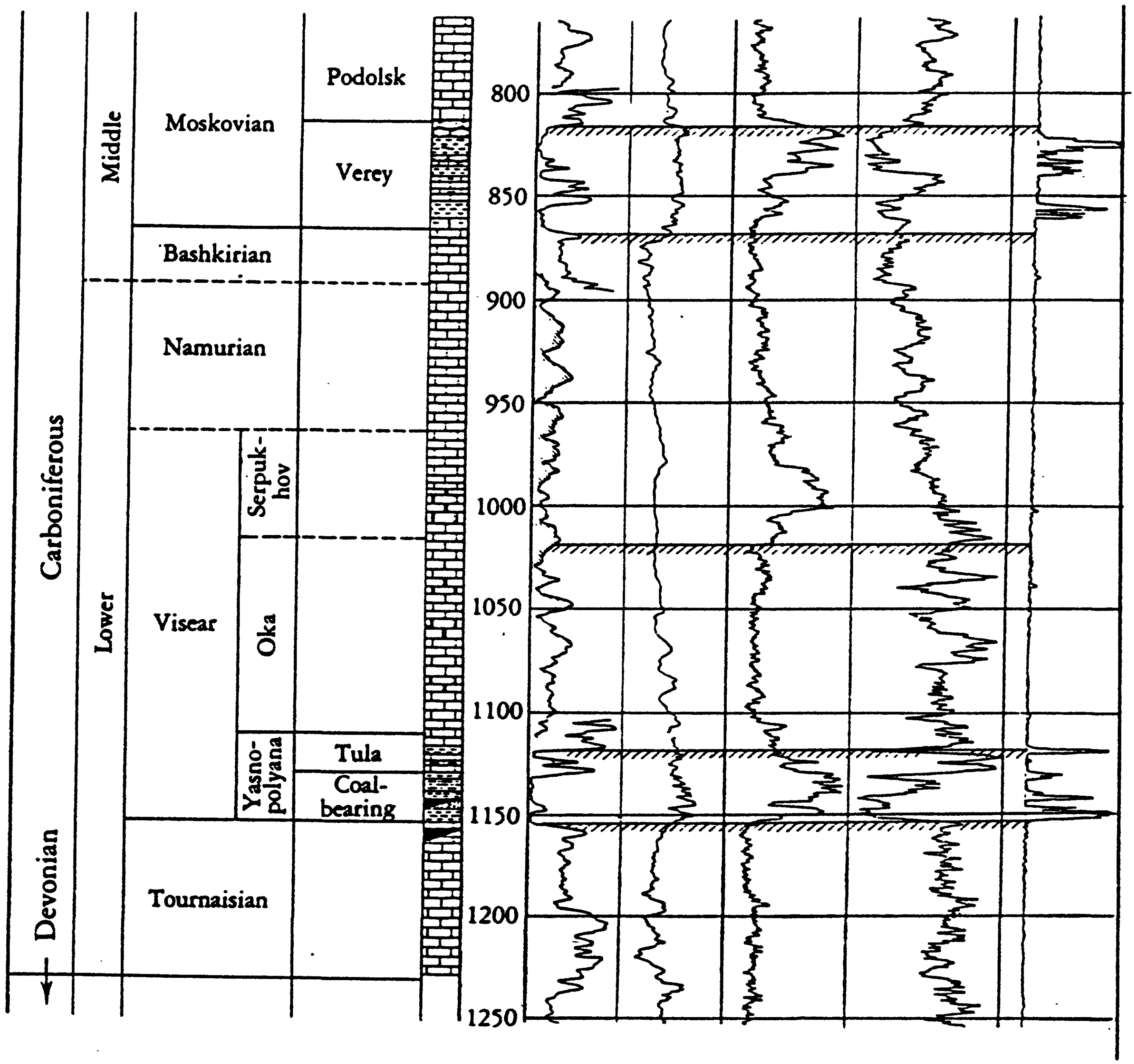


Fig. 42 (continued).

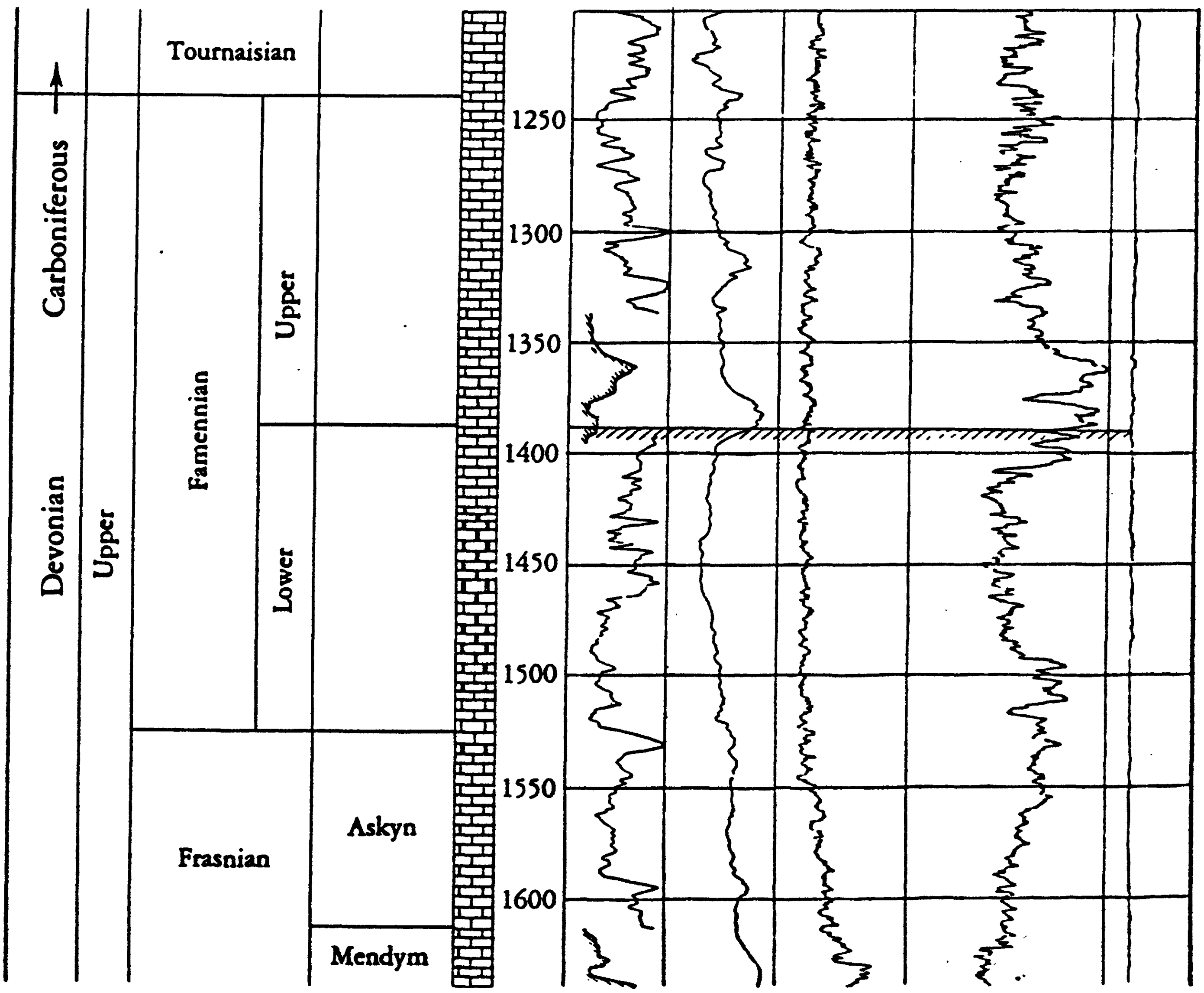


Fig. 42 (continued).

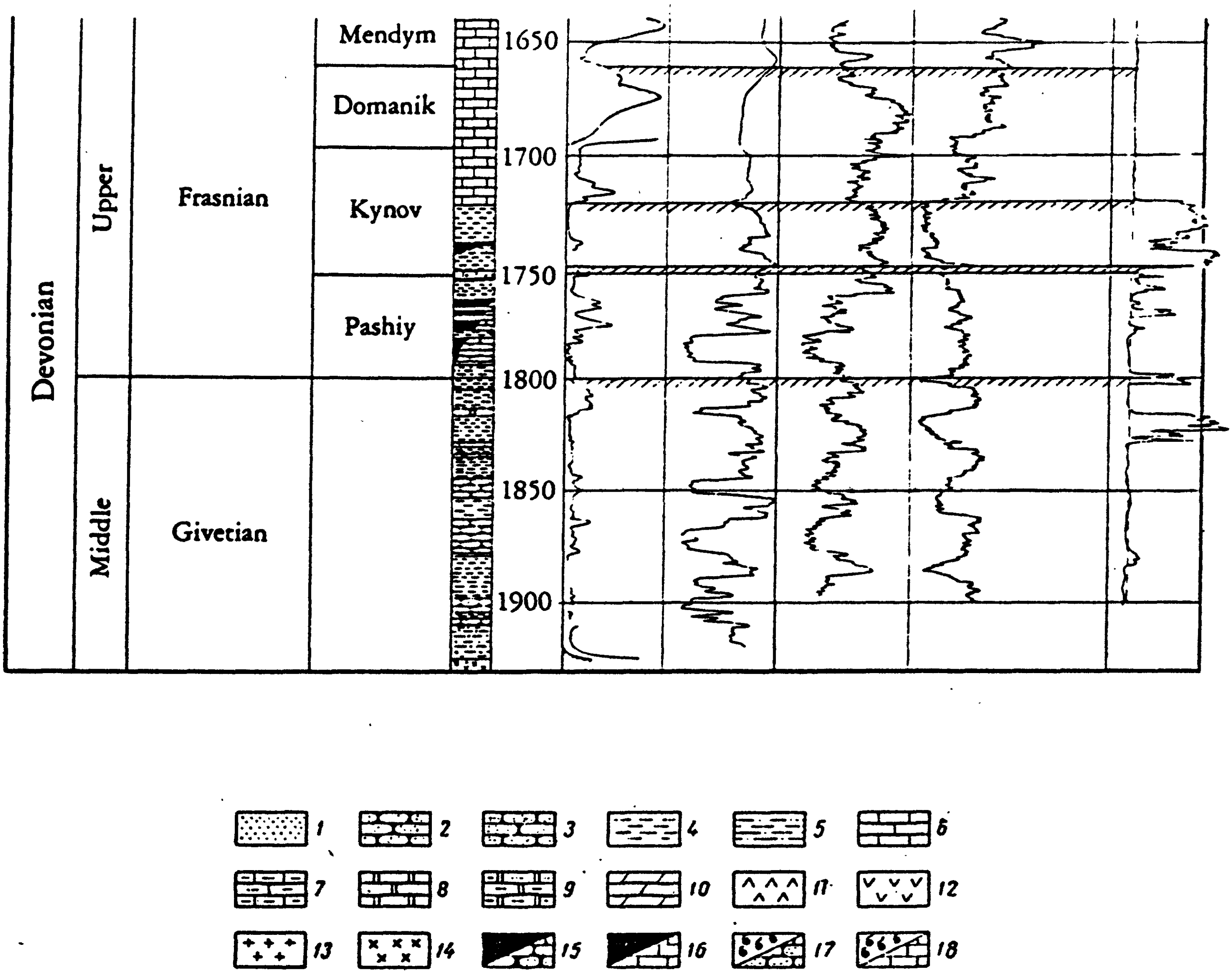


Fig. 42 (continued). Explanation: 1 - sand, 2 - sandstone, 3 - clayey sandstone, 4 - argillite, 5 - siltstone, 6 - limestone, 7 - clayey limestone, 8 - dolomite, 9 - clayey dolomite, 10 - marl, 11 - anhydrite, 12 - gypsum, 13 - salt, 14 - crystalline basement, 15 - oil-bearing sandstone, 16 - oil-bearing limestone, 17 - gas-bearing sandstone, 18 - gas-bearing limestone.

The Devonian section up through the Kynov Formation is known informally in the Soviet literature as the "clastic Devonian."

The Sargayevo sediments are dark gray shales, marls, and limestones, and are commonly bituminous. Their thickness ranges from 6 to 45 m.

The middle Frasnian substage consists of the Domanik and Mendym Formations. The Domanik sediments are dark gray to black bituminous limestones, marls, and shales and their thickness is 25-45 m. The Mendym deposits are dark gray to gray brecciated limestone and marl 30 to 70 m thick.

The upper Frasnian at Romashkino consists of the Askyn beds, which are gray to dark gray limestones 75 to 140 m thick.

Next above the Frasnian is the Famennian stage, which is divided into lower and upper divisions. The lower Famennian sediments are light gray dolomites, and the upper Famennian are gray limestones with beds of light gray dolomite and dark gray shale. Total thickness of the Famennian here is 240-285 m. This unit is the topmost of the Devonian.

The Lower Carboniferous at Romashkino includes the Tournaisian, Visean, and Namurian Stages.

The Tournaisian consists of limestones and thin beds of dolomite and clay. There are traces of erosion at the top. Thickness is 60-75 m here.

In the lower part of the Visean are clays, siltstones, sandstones, and shales of the Coal-bearing and Tula Formations. The sandstones of the Coal-bearing (Bobrikov) Formation, which is at the base of the Visean, are poorly sorted and unevenly oil-bearing; they shale out abruptly. In the northeast part of Romashkino oil field are coal deposits of economic significance in this unit. Thickness of the Coal-bearing Formation is 10-35 m here. Higher in the Visean section are limestones and dolomites. Total thickness of the Visean at Romashkino is 175-240 m.

The Namurian is composed of dolomites and dolomitized limestones 80-100 m thick.

The Middle and Upper Carboniferous rocks are largely dolomites and limestones; these are locally gypsiferous. Their total thickness at Romashkino is 350-560 m.

The Lower Permian Sakmarian-Artinskian sediments are dolomites, gypsum, anhydrite, and some limestone. Thickness is 90-120 m. To the east of the field are Kungurian gypsum, anhydrite, and dolomites. The Kungurian is absent at Romashkino, and redbeds of the Ufa Formation rest directly on the Artinsk. The Ufa deposits are 40-90 m thick.

At the top of the section at Romashkino are sandstones, clays, marls, and limestones of the Kazanian and Tatarian stages more than 170 m thick.

Structure

The crystalline basement in the area of Romashkino oil field is a broad hummocky structural plateau 80-90 km in diameter outlined by the -1,640 m structure contour on the basement surface. The highest points on this surface are at -1,540 to -1,530 m, and the lowest are at -1,650 m. Closure does not exceed 110 m. The Al'met'yev basement high (fig. 43) on this structural plateau is the core of the Romashkino structure (Mal'tsev, 1957, p. 52).

The structure map for the top of the Pashiy Formation, 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 of this broad high is differentiated into several smaller highs and intervening lows. These smaller scale highs (Minnibayevo, Abdrakhmanov, Pavlov, etc.) were used as a basis for dividing the field into producing sectors. See section on Production History. The smaller highs have a general radial pattern off the high in the Abdrakhmanov sector, except for the Aznakeyev sector which is separated from the rest of the field by a deeper downwarp (fig. 44).

Closure on the Paskiy sediments is about 60 m, and angles of dip generally do not exceed 30'. Maximum depth relative to sea level of the top of the Pashiy is -1,435 m in the Minnibayevo and Abdrakhmanov sectors, -1,450 m in Pavlov, and -1,462 m in Aznakayev. The downwarps between the smaller highs are at -1,455 to -1,480 m.

Although the structure on the top of the Pashiy corresponds with that of the top of the crystalline basement in form and dimensions (Mal'tsev, 1957, p. 52), the smaller structures on these surfaces seem not to correspond. Most of the basement closures in figure 43 are only structural noses in figure 44. Also, the basement highs on the cross section (fig. 45) are not directly beneath the highs on the top of Pashiy horizon (fig. 44). The cross section shows thicker net pays beneath highs on the top of the Pashiy. This suggests greater thickness of sandstones at these sites. Consequently, the Pashiy highs may be due in part to differential compaction, with the areas of greater sandstone thickness compacting less and thereby contributing to the development of the highs. This seems to be the only mechanism available because neither faults nor reef buildups have produced structure within the field.

On the base of the Coal-bearing (Bobrikov) Formation, the Romashkino structure is a broad gentle high complicated by warps with dimensions of 1-15 km on their long axes. The trends of these small structures are diverse; however, southeast-northwest trends are predominant. The structures within the Coal-bearing Formation here are due largely to deposition on an erosional surface on the underlying upper Tournaisian sediments.

Romashkino oil field is bounded on the west by the long narrow Altunino-Shunak downwarp, which separates it from the Aktashsko-Novo-Yelkhov high (fig. 44). Maximum amplitude of this downwarp is more than 100 m on the basement surface. It is less well expressed on the Carboniferous and shows up hardly at all on the Permian sediments (Mel'nikov and Voytovich, 1960, p. 257).

Fig. 43. Structure map of the Al'met'yev high on the surface of the crystalline basement (after Mal'tsev, 1957, p. 52). Contour interval is 5 m. The Soviets seldom place a scale or coordinates on their maps; further, the maps may not be oriented with north exactly toward the top of the page. Although the orientation of this map is uncertain, it is presented in order to convey the general hummocky configuration of the basement surface. The area of this map coincides in general with the large solid black area on fig. 2.

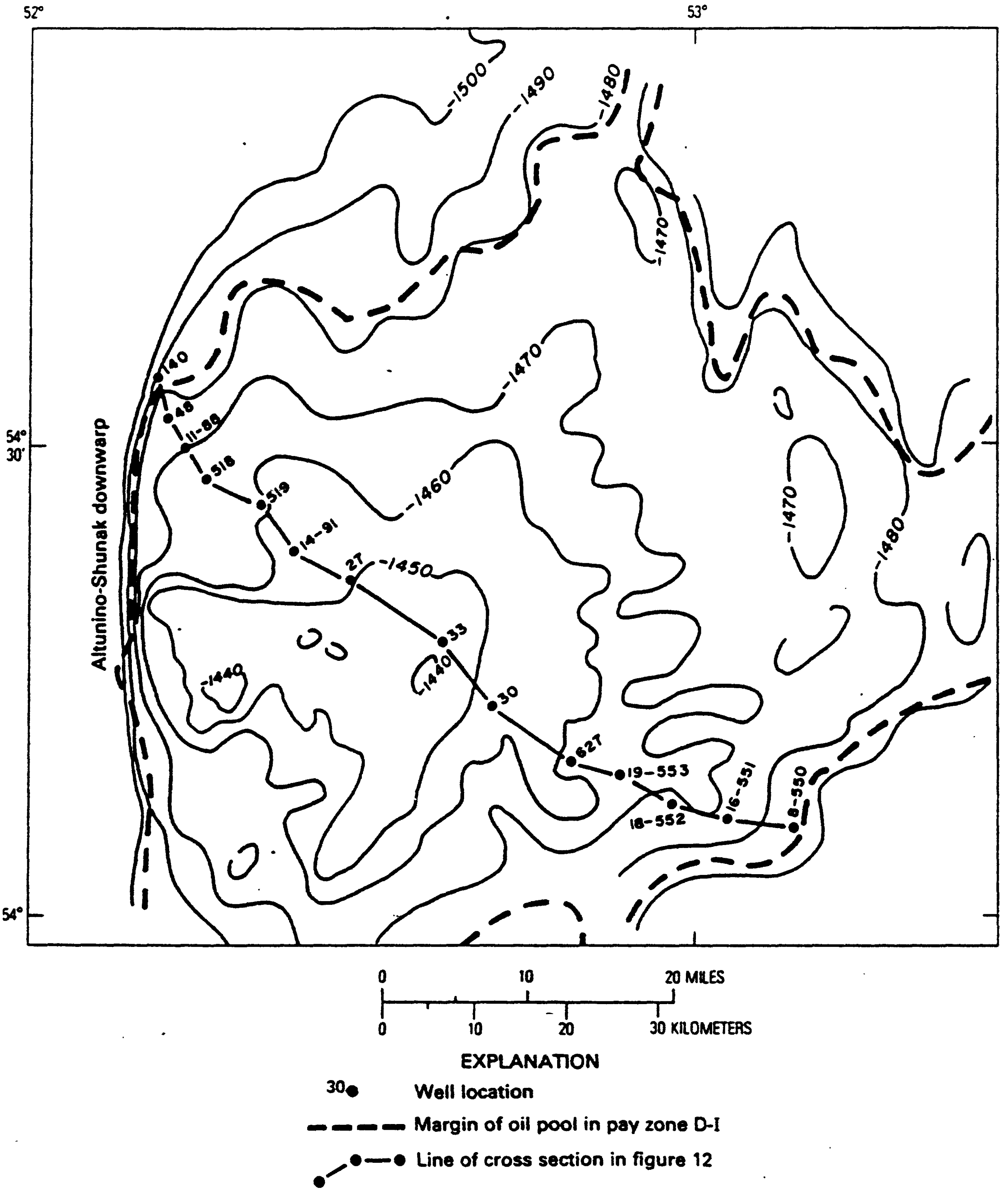


Fig. 44. Structure map of top of Pashiy horizon in Romashkino oil field (after Maksimov and others, 1970, p. 122).

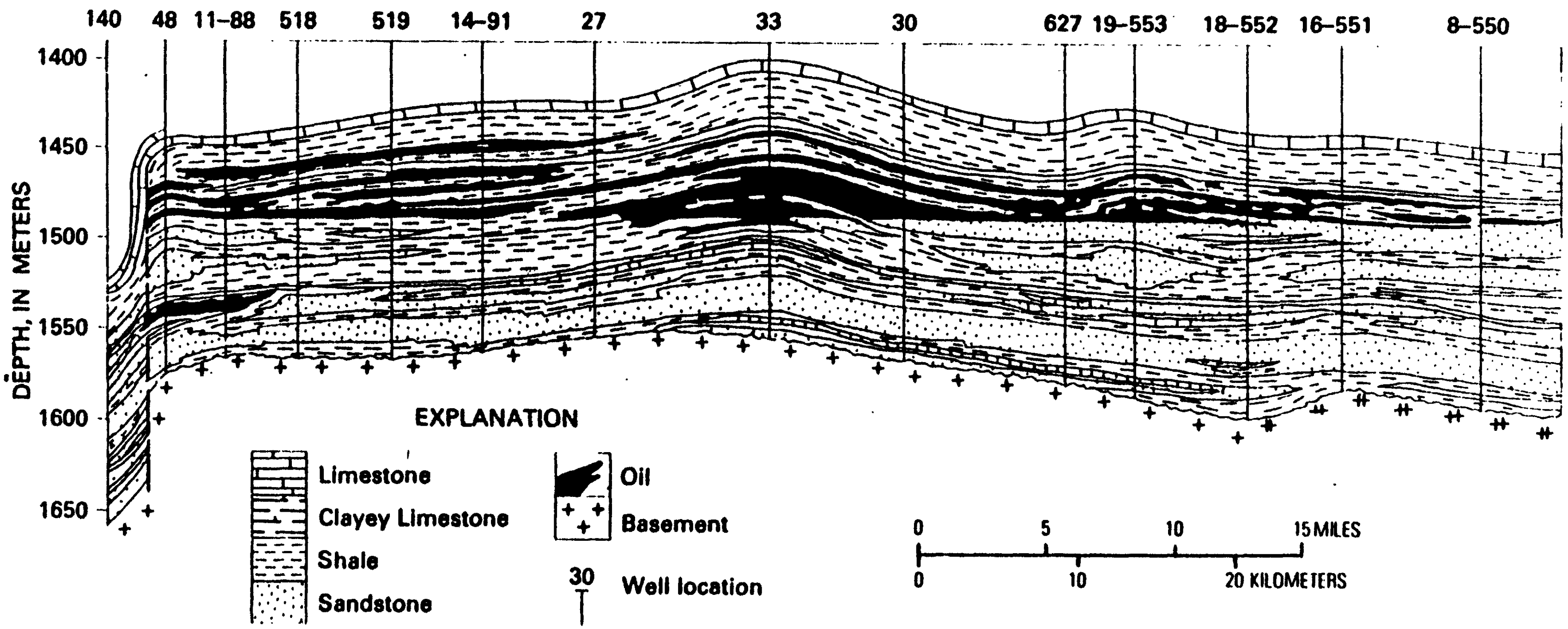


Fig. 45. Profile of clastic Devonian of Romashkino oil field (after Maksimov and others, 1970, p. 122).

Pay Zones

In the clastic Devonian section at Romashkino are five pay zones: D-IV, D-III, and D-II in the Givetian Stage, D-I in the Pashiy horizon, and D-0 in the Kynov horizon, the last two units being in the Frasnian Stage (figs. 42 and 46). These are the principal pays. In addition, flows of oil have been recovered from limestones of the Domanik Formation, carbonates of the upper Famennian, carbonates of the Tournaisian Stage of the Lower Carboniferous, clastics of the Tula and Bobrikov Formations of the Lower Carboniferous, and carbonates at the base of the Middle Carboniferous.

D-IV pay zone

The oldest oil-bearing rocks at Romashkino are basal sandstones and siltstones of the Vorob'yevka Formation (D-IV) of the lower Givetian Stage. Three pools have been found here in the Pavlov and Yuzhno-Romashkino sectors. (See fig. 56 for location of sectors.) The water-oil contact is at -1,537 to -1,550 m. Open porosity is an average of 21 percent. The pools are in structures associated with small basement highs (Trebin and others, 1974, p. 90; Maksimov and others, 1970, p. 120). Maksimov, and others (1970, p. 121) show D-IV as including both the Vorob'yevka Formation and part of the overlying Starooskol, and the D-IV pool is placed in the Starooskol (fig. 46).

D-III pay zone

Overlying the Vorob'yevka Formation are the Ardatov beds (horizon D-III) of the Starooskol Formation of the middle Givetian. This pay is composed of sandy-silty rocks, which commonly shale out. Seven pools are known here in the Severo-Al'met'yev, Abdrakhmanov, Yuzhno-Romashkino, Pavlov, and Leninogor sectors. These pools are in both structural and stratigraphic traps. The water-oil contact is at -1,524 to -1,554 m.

Thickness of D-III ranges from zero to 20 m. Effective porosity is 10-24 percent, and permeability ranges from 10 to 400 md. Geophysical logging indicates some 40 small areas where oil pools may possibly be present (Trebin, and others, 1974, p. 90; Maksimov, and others, 1970, p. 120-121).

D-II pay zone

At the top of the Givetian Stage is the Mullino Formation (D-II), which consists of sandy-silty rocks that commonly shale out. Eight small oil pools have been found in this pay zone in the Al'met'yev, Minnibayevo, Abdrakhmanov, and Yuzhno-Romashkino sectors.

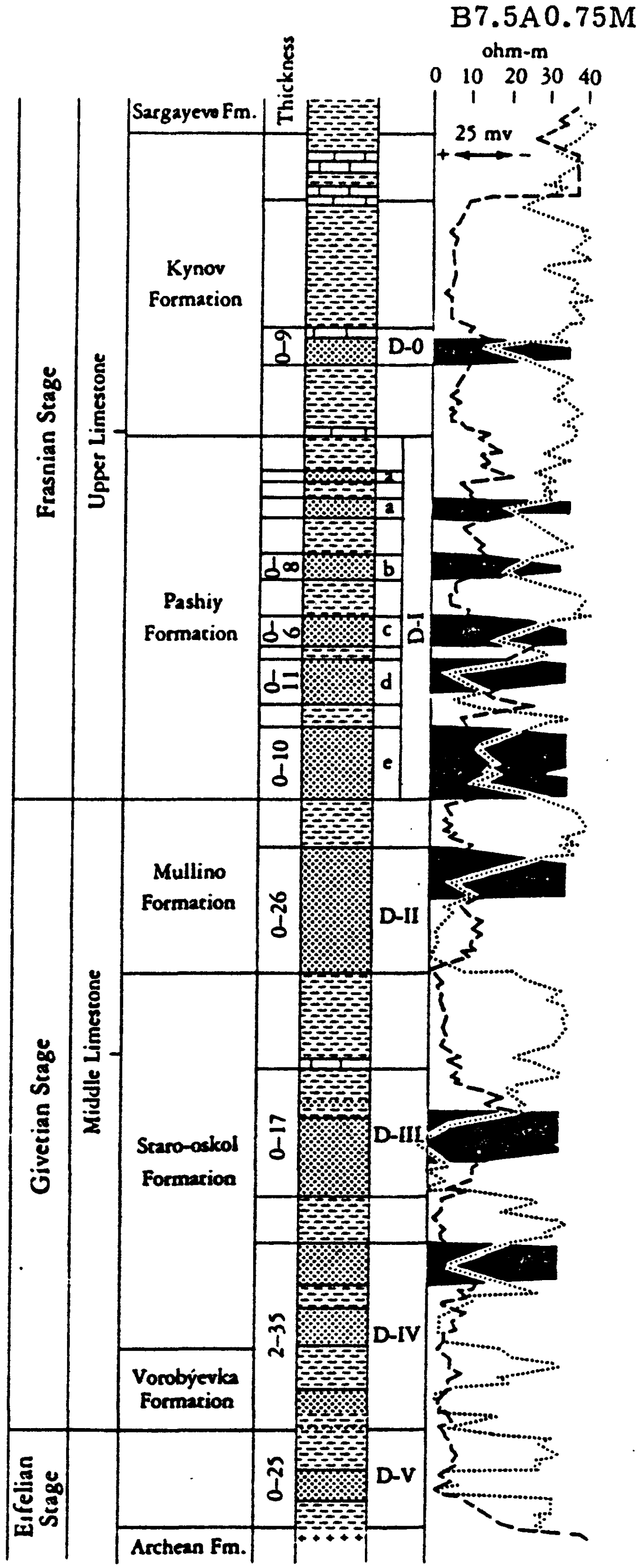


Fig. 46. Pay zones of Romashkino field (from Maksimov and others, 1970). See fig. 45 for explanation.

Open porosity of the reservoirs of D-II is an average of 20 percent. The water-oil contact is at -1,485 to -1,490 m except where D-II merges with D-I, and here it is at -1,503 to -1,505 (Trebin, and others, 1974, p. 90; Maksimov, and others, 1970, p. 123-124).

D-I pay zone

At the base of the Frasnian Stage is the Pashiy Formation (D-I), which contains the main pool at Romashkino. About 90 percent of the reserves of the field are in this pay (Mirchink, 1964, p. 309). Total thickness of D-I is 30-50 m, and net pay is 10-15 m (Maksimov, and others, 1970, p. 124).

The permeable beds of D-I occur generally as lenses of irregular size and 1 m or less in thickness. Thick beds commonly shale out in a distance of 500 m or less (Svishchev and Militko, 1958, p. 571; Gattemberger and Khalimov, 1958, p. 719-721; Begishev and others, 1963, p. 556-557). Consequently, there is a myriad of isolated reservoirs, making correlation difficult and requiring extensive infill drilling.

Fourteen permeable beds are recognized in D-I in the Abdrakhmanov sector, which is in the central part of the field. See figure 56 for location of sectors. It is characteristic that not in a single well are all fourteen of these pays found; they shale out or merge with a bed above or below into a single stratum. At Romashkino, 100 md is taken as the transition value between low and medium permeability reservoirs. Figure 47 shows the distribution of areas in the Abdrakhmanov sector with permeability greater than 100 md for one of these 14 beds of D-I. Average thickness of the uppermost of the 14 beds is 1.2 m and that of the lowermost is 3.4 m. These are also the extreme values, all other average thicknesses ranging from 2.1 to 3.0 m. The permeable zones of each of the 14 beds are present over varying amounts of the total Abdrakhmanov area ranging from 16 to 71 percent.

In the rest of the field a smaller number of beds are recognized in D-I. In the Zay-Karatay sector, for example, six permeable beds are distinguished. One-third of all wells in this sector penetrate a section that consists only of siltstones. About half of the oil in place in this sector occurs in siltstone, and the areal and vertical distribution of siltstone here is said to be typical for the entire Romashkino field (Maksimov and Rybitskaya, 1976, p. 245-258). Figures 48 or 49 show reservoir distribution of two beds of D-I in several sectors of the central part of Romashkino field.

Pay zones D-I and D-II merge at several places in Romashkino field; the clay divider thins or is absent all together at these places. The two producing horizons are connected hydrodynamically through these "windows." Water has flowed from D-II into D-I, and oil and water from D-I into D-II, depending on pressure differentials between the two pay zones (Litvinov, 1960, p. 230-235; Mirchink, 1964, p. 315).

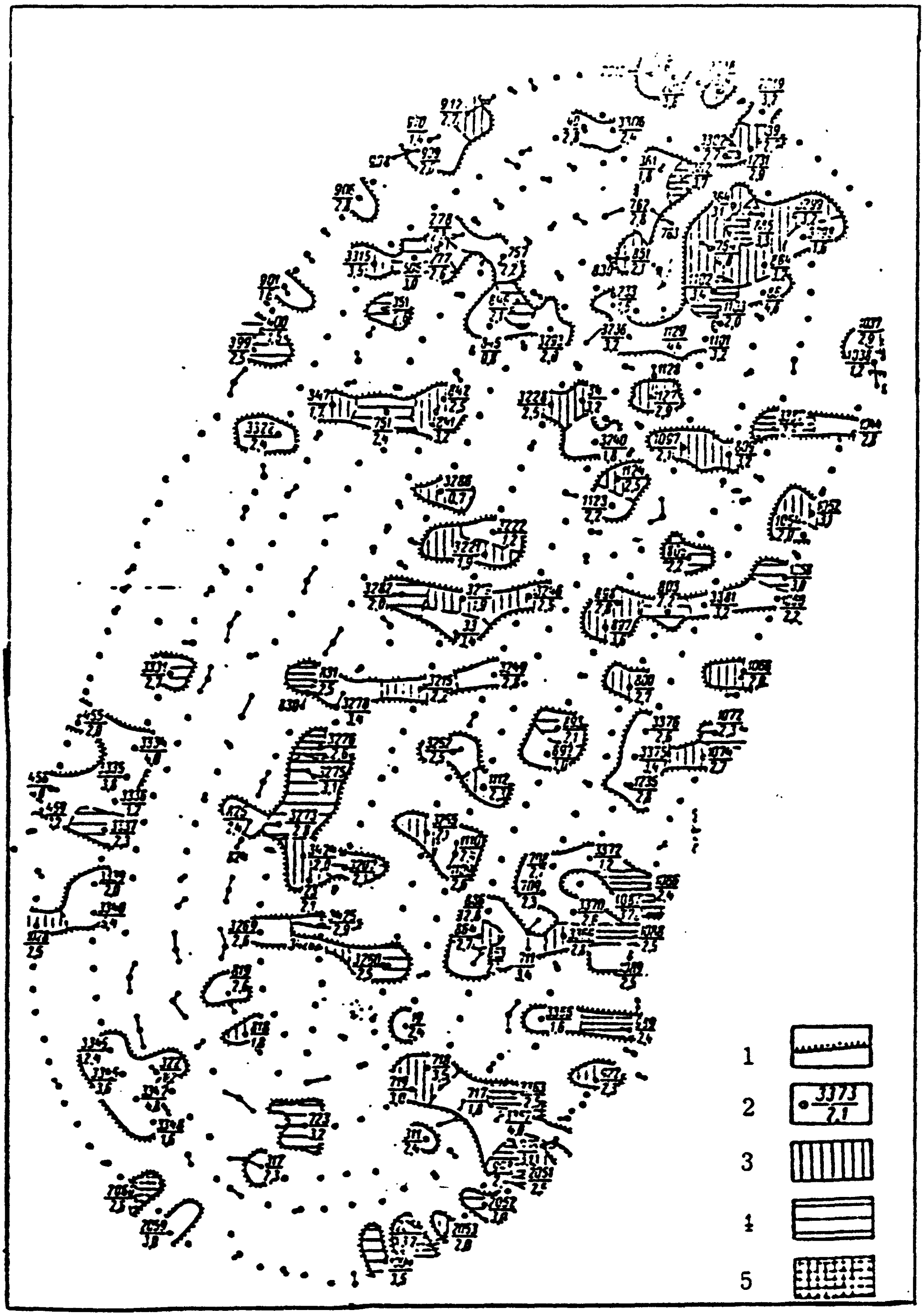


Fig. 47. Permeability map of Abdrakhmanov area, bed b_2^3 (permeability greater than 100 md). From Voinov, 1966.

1-Limits of occurrence of beds; 2- $\frac{\text{well number}}{\text{thickness, perm 100 md}}$; 3-zone of merging with lower bed; 4-zone of merging with upper bed; 5-zone of merging with lower and upper beds.

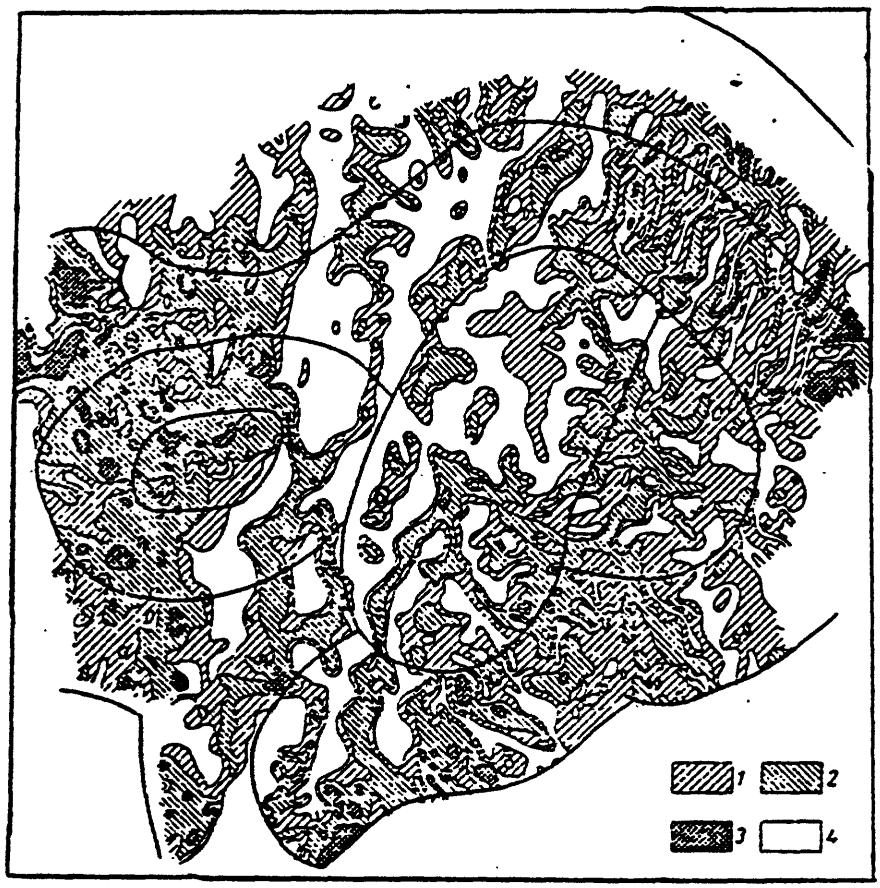


Figure 48.--Litholgic map of stratum D-Ib_{1+2} of central part of Romashkino field (from Mukharskiy and Lysenko, 1972, p. 213).

1 - Siltstone transmissivity less than 25); 2 - sandstone transmissivity more than 25); 3 - zones of merging with overlying bed; 4 - non-reservoirs.

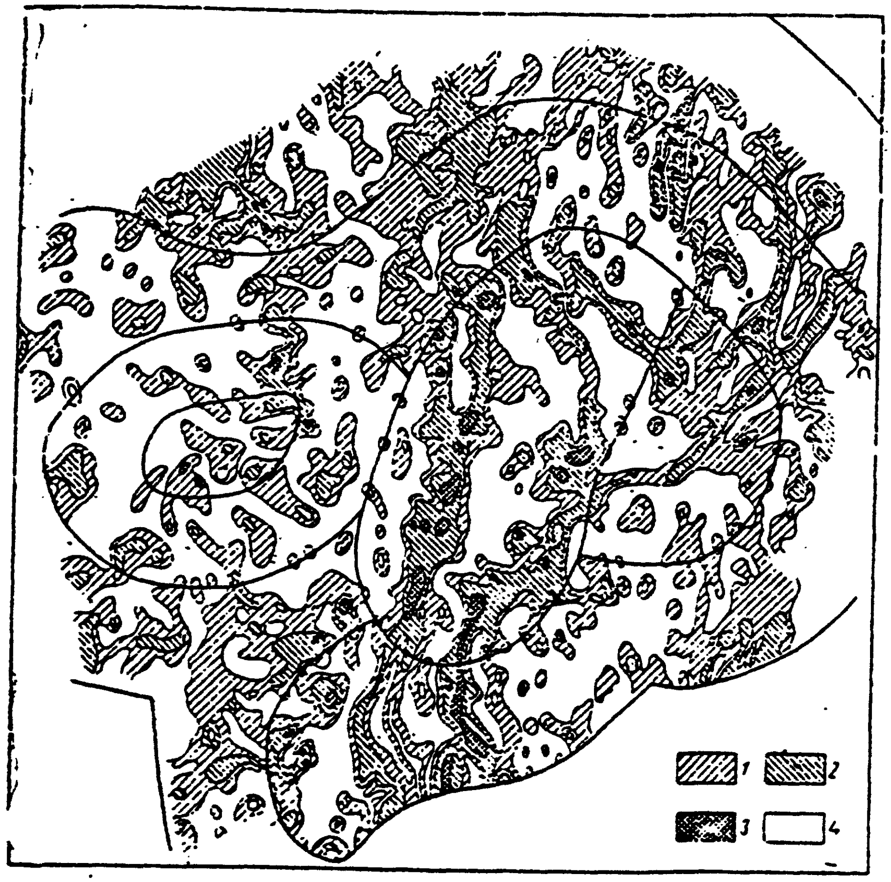


Fig. 49. Lithologic map of bed D_Ic of central part of Romashkino field. 1-Sandstone (transmissivity less than 25); 2-sandstone (transmissivity more than 25); 3-zones of merging with overlying beds; 4-non-reservoirs. From Mukharskiy and Lysenko, 1972, p. 214.

Porosity and permeability of D-I have a great range. The dispersion of values on the graph (fig. 50) indicates a very general direct relationship between these two parameters. Most values of porosity are in the 18-24 percent range, and the average is 21 percent. Permeability ranges from 40 to 2,000 md, and the average is 500-600 md (Semin, 1960, p. 20; Mirchink, 1964, p. 309). Cores of sandstone with a permeability of more than 100 md are almost completely flushed by drilling fluid. This characteristic is used to predict final recovery factor (Yudintsev, 1979, p. 65).

The sandstones and siltstones of D-I as well as of the other Devonian pays consist of 85-99 percent quartz grains. Clays have little effect on reservoir properties because they constitute no more than 2-7 percent of the reservoir rocks. Silicification does cause worsening of reservoir properties, however. This silicification is the result not of new authigenic quartz grains but rather of redistribution of the silica composing the quartz grains. Grain contacts are lengthened, and the grains grow together (Smirnova, 1961, p. 376-381).

D-O pay zone

At the top of the lower Frasnian stage is the Kynov Formation in which the D-O pay zone is present over a large area in the northwest part of Romashkino oil field, including the Minnibayevo, Al'met'yev, Severo-Al'met'yev, Berezov, and part of the Chishmin sectors. This pool is bounded on the west by the deep, narrow Altunino-Shunak downwarp, on the south and east by pinchout, and on the north by the flank of the Romashkino high.

The pool is in sandy-silty rocks in the middle of the Kynov Formation. In the northwest part of the pool, D-O merges in places with D-I creating a single hydrodynamic system. Both pay zones here have a common water-oil contact at -1,489 m to -1,490 m.

Thickness of D-O ranges from zero to 9 m, thinning to the south and east as it pinches out. In the north part of the pool where the sandstones are thickest, porosity is 10-22 percent and permeability is 100-800 md. The oil column is an average of 3.2 m high (Maksimov, and others, 1970, p. 125).

Domanik pay zone

The clastic Devonian passes upward into carbonates. Near the base of the carbonate section is the Domanik Formation, a bituminous shale in the middle Frasnian, which contains some carbonate. These carbonates are oil-bearing in the Minnibayevo and Aznakayev sectors (Maksimov and others, 1970, p. 125) and are probably oil-bearing in many other areas. See figure 42 for stratigraphic position of this and the following pay zones.

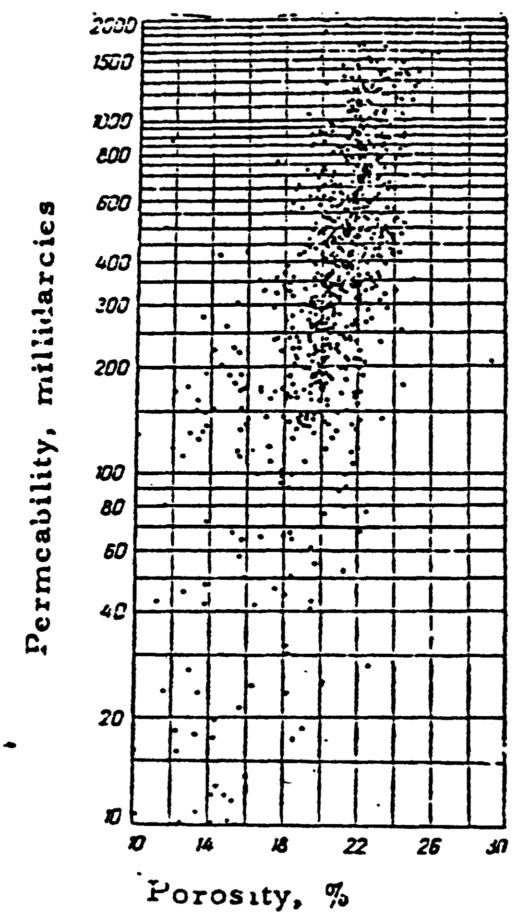


Figure 50.--Relationship between porosity and permeability for reservoirs of pay zone D-I of Romashkino field.

Upper Famennian pay zones

Shows of oil have been recorded in upper Famennian carbonates in many wells of Romashkino field. Oil-saturated cores have been recovered in the Zay-Karatay, Al'keyev, and Minnibayevo sectors (Maksimov, and others, 1970, p. 125).

Tournaisian pay zones

Commercial flows of oil have been recovered from the Lower Carboniferous Tournaisian carbonates. Two small pools have been found in the Zavolga Formation: one in the Minnibayevo sector with a water-oil contact at -953 m, and another in the Severo-Al'met'yev sector with a water-oil contact at -953 m. About 70 small pools have been found in the upper Tournaisian carbonates. The position of the water-oil contact ranges from -830 m on the west to -925 m on the east (Trebin, and others, 1974, p. 91).

Lower Carboniferous clastic pay zones

The middle Visean (Yasnopolyan "super-stage") clastic sediments are oil-bearing in Romashkino oil field, and about 70 pools have been found in these rocks within the field. The pools are in sandy-silty deposits of stratum B-1 of the Tula Formation and stratum B-2 of the Bobrikov (Coal-bearing) Formation. Stratum B-1 is very widespread; however, it passes abruptly into impermeable rocks. Thickness ranges from 0 to 10 meters. Stratum B-2 is from 0 to 8 m thick, is widely distributed, and is separated from B-1 by 1.5-2 m of shale. The two pays merge where this shale is absent (Maksimov, and others, 1970, p. 126).

Middle Carboniferous carbonate pay zone

A comparatively large oil pool is present in the Bashkirian-Namurian limestones in the Kuak-Bash sector in the southwest corner of Romashkino field. It occurs on a clearly expressed structural high that has a closure of 40-45 m. The water-oil contact is at -548 m (Maksimov, and others, 1970, p. 128).

Parameters of the Oils

The principal oil pool (D-I) at Romashkino is so large that many of the parameters of the oils vary with position on the structure. Initial formation pressure was 175 atm in this pool. Saturation pressure, however, increases from southeast to northwest across the pool from about 81 to 95 atm. There is an abrupt increase in this parameter in the Vostochno-Leninogor sector (fig. 51). Viscosity decreases in this same direction from values of 4.5 to 2.6 centipoises, again with an abrupt change in the Vostochno-Leninogor sector (fig. 52). The oil is thus greatly undersaturated by gas (Mukharskiy and Lysenko, 1972, p. 49-50). The oils in the western part of the field have a lower asphalt content due possibly to adsorption by clay particles. Clays are indeed more abundant in D-I in this part of the field. This adsorption of tars may contribute to the lower viscosity of the oil on the west (Botneva, 1958, p. 487). Gas-oil ratios are highest in the central part of the pool in the Abdrakhmanov, Pavlov, and Zelenogor sectors. Values here are 53-54 m^3/m^3, whereas values of 41-48 m^3/m^3 are characteristic of the sectors on the north, east, and south. Average values on the western margin of the pool are 48-52 m^3/m^3 (Trebin, and others, 1974, p. 92).

The density of the formation oil of pay zone D-I is about 0.805 g/cm^3 in most parts of Romashkino, although values range from 0.796 to 0.820 g/cm^3. Under surface conditions the density is 0.853-0.869 g/cm^3. Sulfur content is 1.5-2.1 percent, paraffin is 2.6-5.4 percent, and tar content is 30-48 percent. The casing-head gas contains 34-44 percent CH_4, 17-22 percent C_2H_6, 17-22 percent C_3H_8, 7-10 percent C_4H_{10}, 4-6 percent higher hydrocabons, 0.4-1.7 percent CO_2, and 6-11 percent nitrogen and rare gases (Trebin, and others, 1974, p. 92-93).

The oils of the Tournaisian carbonates differ from those of the Pashiy Formation (D-I) by being considerably heavier (0.870 g/cm^3 under formation conditions and 0.908 g/cm^3 for the de-gassed). They contain less dissolved gas (gas-oil ratio of 15.7-16.8) and are very viscous (20.7 cp). Formation temperature is 20-25°C, and saturation pressure is 52-55 atm (Trebin, and others, 1974, p. 92-93).

The oils of the middle Visean (Yasnopolyan "super-stage") clastics at Romashkino are similar to those in the Tournaisian limestones. Density under formation conditions is 0.876 g/cm^3 and that of the degassed oil is 0.892-0.895 g/cm^3. The gas-oil ratio is 11.0-19.3; viscosity is 18.5-28.4 cp; formation temperature is 20°C; and saturation pressure is 49-61 atm (Trebin, and others, 1974, p. 93).

The oils of the Middle Carboniferous carbonate pay zone have a density of 0.902 g/cm^3. They contain 2.11 percent sulfur and 60 percent tar.

Trebin and others (1972, p. 92) give the formation temperature of the main pool (D-I) as about 48°C. A map of isotherms on the top of pay zone D-I (fig. 53) shows a thermal high enclosed by the 38°C geoisotherm at the highest part of the structure on the top of the D-I pay zone. Geothermal maps constructed for the 1,500 m, 1,000 m, and other depth surfaces show an anomalous high above Romashkino field (D'yakonov, and others, 1973, p. 54-56). Sinyaskiy, and others (1973, p. 100) attribute this anomaly to differences in geothermal gradient.

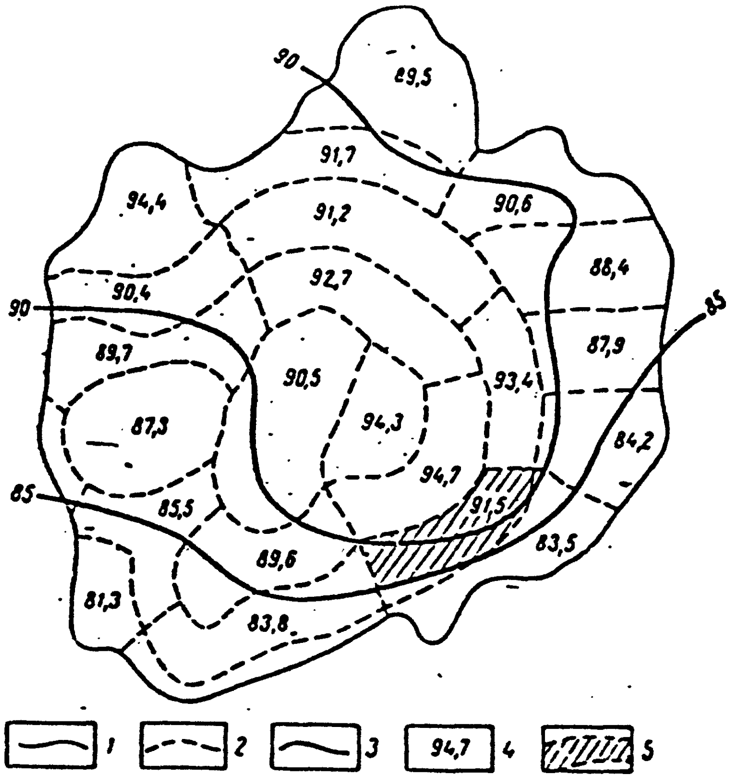


Figure 51.--Map of values of saturation pressure at Romashkino field (from Mukharskiy and Lysenko, 1972).

1 - margin of field; 2 - sector boundaries; 3 - contours of saturation pressure, atm; 4 - average value of saturation pressure for each area; 5 - Vostochno-Leninogor sector.

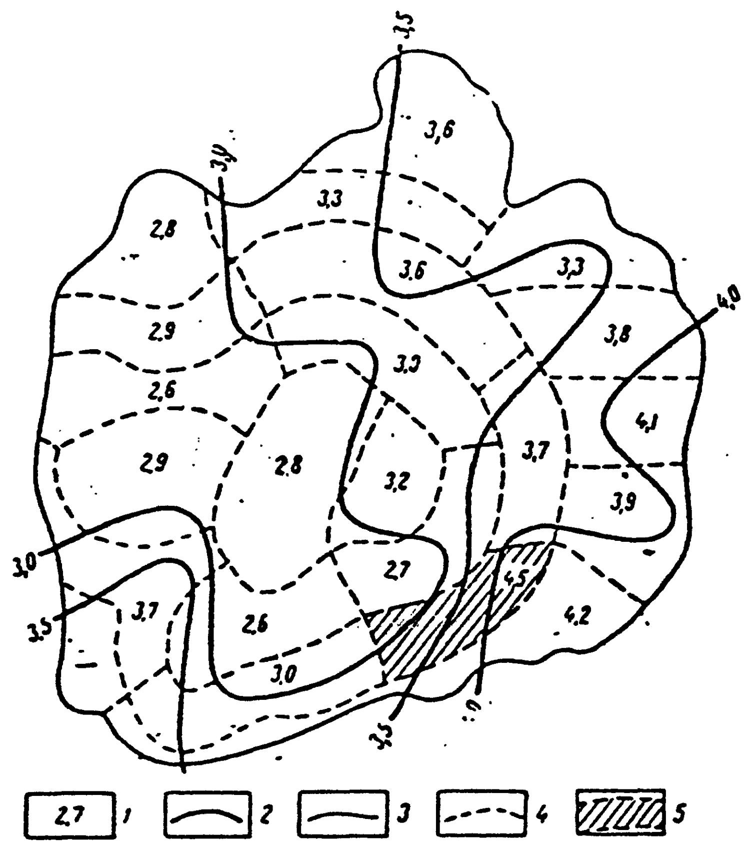


Figure 52.--Map of values of viscosity of formation oil at Romashkino field (from Mukharskiy and Lysenko, 1972).

1 - viscosity, centipoise; 2 - contours showing equal viscosity; 3 - margin of pool; 4 - sector boundaries; 5 - Vostochno-Leninogor sector.

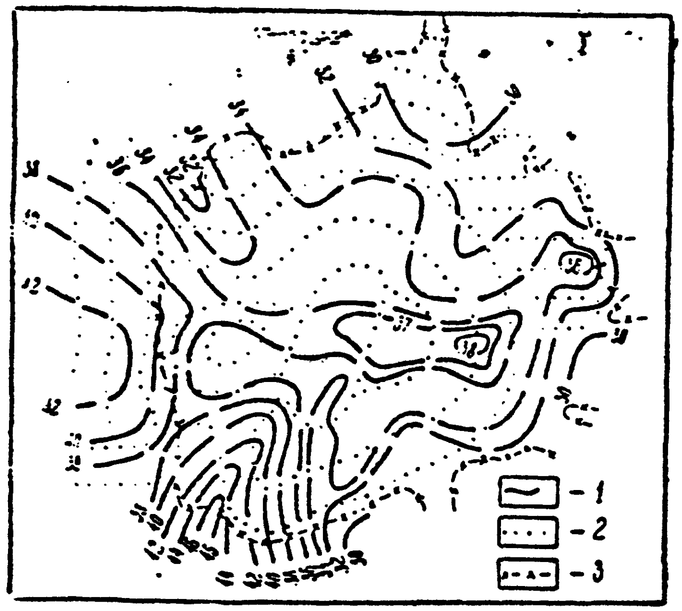


Figure 53.--Schematic map of initial isotherms of the top of pay zone D-I of Romashkino and Novo-Yelkov fields (from Sinyavskiy and Neprimerov, 1971, p. 4).

1 - Isotherms, °C; 2 - sectioning rows; 3 - outer margin of pool.

Water-oil contact

The water-oil contact of the oil pool in horizon D-I at Romashkino is inclined from -1,480 to -1,482 m on the north to -1,489 to -1,490 m on the south (figs. 54 and 55). This inclination has been attributed generally to hydrodynamic pressure of southward moving formation water. Further indication of this process is the form of the surface of the water-oil contact in the area between the zones where no water-oil contact is present. Contours on the water-oil contact are closer spaces in the Pavlov and Zelenogor areas in the "narrows" between the two zones of no water-oil contact (fig. 54 and 55). This "narrows" appears to channel the southward flow of water, thereby producing a steeper gradient (Likhodedov, and others, 1970, p. 49-54). The two areas of absence of a water-oil contact are structurally high, bringing underlying impermeable beds above the horizontal projection of the contact.

Pressure differentials indicate that the inclination should actually be more than is observed. Denisty of the oil appears to be the modifying factor here. The density of the oil in the north of the pool is higher than in the south. The inclination of the water-oil contact is interpreted as being governed by the combined effect of movement of the formation water, and this difference is density of the oil (Gattenberger, 1972, p. 14).

In the Romashkino oil field there is no abrupt separation of oil and water in the oil-bearing beds in the majority of the wells. The transition along a well section is generally a zone in which the resistivity gradually decreases until the appearance of formation water. Specific resistivity ranges from 10 to 1 ohm-m, and the thickness of the transition zone is 0.5 to 6 m. (Zabirov, 1958, p. 943). The transition zone is probably caused by rapid alternation of sandy-silty and clayey beds (Melik-Pashayev, 1960 p. 4). According to Azamatov and others (1968, p. 30), the transition zone may be caused by penetration of water from the drilling mud into the pay zone at the water-oil contact. Such water has a specific gravity intermediate between that of oil and formation water. This zone has been produced successfully over a long period (Mamleyev and Timonin, 1960, p. 229).

The water-oil contact is placed at the base of the transition zone by Mamleyev and Timonin (1960, p. 229) and at the top of this zone by Zabirov (1958, p. 943). Shapiro (1962, p. 565-566) points out that if the water-oil contact is taken as the top of the transition zone, then no consistent surface is defined. This is attributed to great variability in thickness of the transition zone due to lithologic variations. If the base of the transition zone is taken as the water-oil contact, a surface is defined that maintains consistency.

The water-oil contact may be locally 3-5 m lower than the average position in a given sector due to tectonic movements subsequent to formation of the pool (Shapiro, 1962, p. 566). Where stratum D-I and D-II merge, the water-oil contact is commonly down in D-II (Rybin, 1960, p. 86-95).

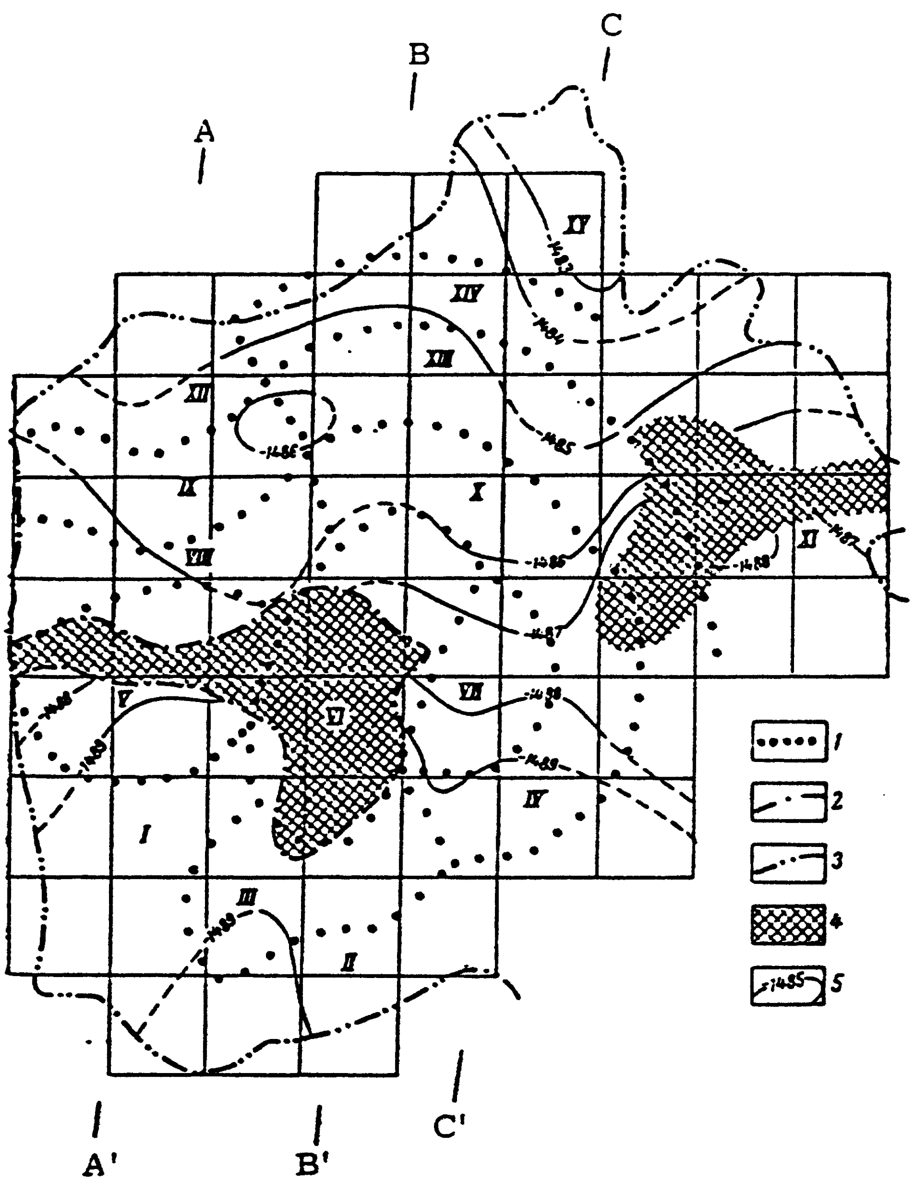


Figure 54.--Surface of water-oil contact of oil pool of pay zone D-I of Romashkino field (from Likhodedov and others, 1970,p. 50).

1 - sector boundaries; 2 - inner boundary of pool; 3 - outer boundary of pool; 4 - zone with no water beneath the oil; 5 - contours on the water-oil contact.

Areas: I - Zay-Karatau, II - Leninogor, III - Yuzhno-Romashkino, IV - Zelenogor, V - Minnebayevo, VI - Abdrakhmanov, VII - Pavlov, VIII - Al'met'yev, IX - Severo Al'met'yev, X - Vostochno-Suleyev, XI - Asmakayev, XII - Berezov, XIII - Alkeyev, XIV - Chishmin, XV - Tashliyar

Production History

Partitioning of the field

The vast size of the Romashkino oil field (3,600 sq. km.) presented a problem as to how to produce it. Buchin (1960, p. 20) reported that if water flooding were applied just along the margins, a hundred years would have been required to recover the oil, and that the rate of production would not have exceeded 7 million tons per year.

The decision was made to divide the field into 23 sectors (fig. 56) separated by rows of injection wells and to produce each sector as an independent unit (Vakhitov and Sultanov, 1961, p. 236). Where possible the rows of injection wells were placed along structural lows between domal highs within the field. Pay zone D-I, which consists of up to 14 separate reservoir sandstones, is worked as a single completion in both the production and injection wells. Each sector is produced according to a strategy formulated specifically for it.

The Minnibayevo and Abdrakhmanov sectors were developed first; production began here in 1950 (Kulchitskaya and others, 1958, p. 743). The well spacing in general was 600 m on the production rows, and the distance between rows was 1,000 m. This was the first attempt at producing a field with a thin well net in the U.S.S.R. (Maksimov, 1962, p. 443). The density of such a net is 150 acres per well.

Minnibayevo and Abdrakhmanov sectors were described in detail in the Soviet geological literature during the Sixties. There is, however, a paucity of information available on the other sectors. The Minnibayevo and Abdrakhmanov sectors are described here because of this availability of information. Production was begun in these two sectors probably because they are structurally the highest, and greatest oil recovery could be expected.

Minnibayevo sector

Injection was begun here along the outer row of wells in 1954 and then along a central circular row in 1959 (fig. 57). Variants were proposed by Smirnova (1963, p. 77) for producing Minnibayevo in which the sector was divided into 18 parts for purposes of the calculations (fig. 57). These production models showed depletion of the sector by 1974. Areal distribution of three beds of pay zone D-I is illustrated in figure 58.

During 1967-1968, production was intensified at Minnibayevo by dropping pressure in the production wells, bringing new wells into production, and increasing pressure in the injection wells. These increases were put into effect at 3-month intervals. The succession of transfer to the new production levels is shown in figure 59.

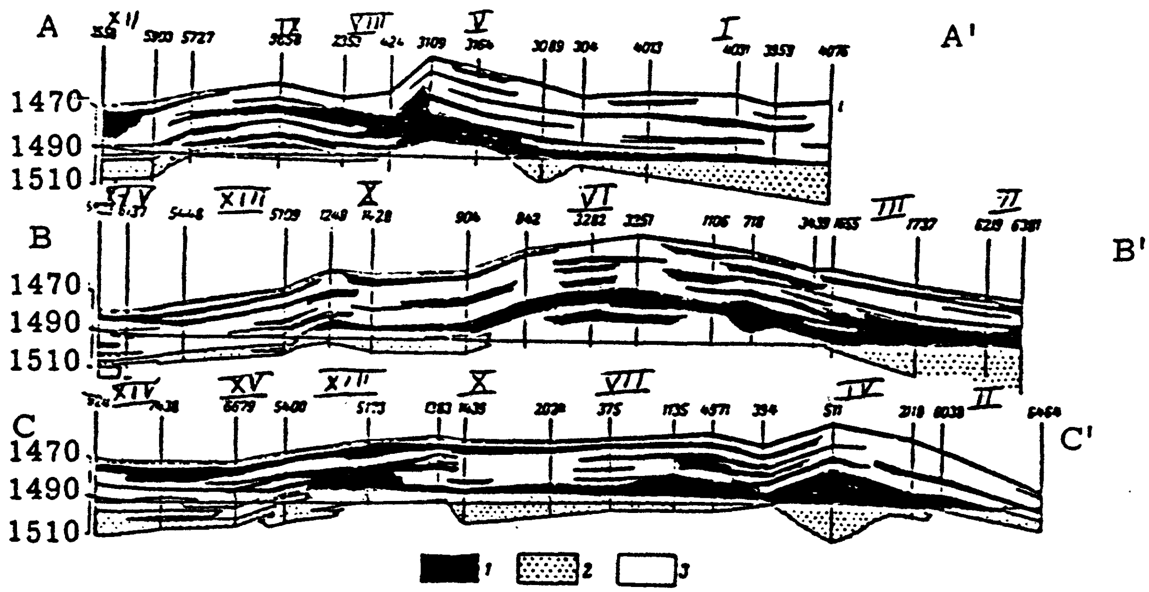


Figure 55.--Effect of water-free zone on the water-oil contact.
(See figure 54 for position of lines of cross sections.)

1 - oil-bearing sandstones; 2 - water-bearing sandstones;
3 - non-reservoir rocks.

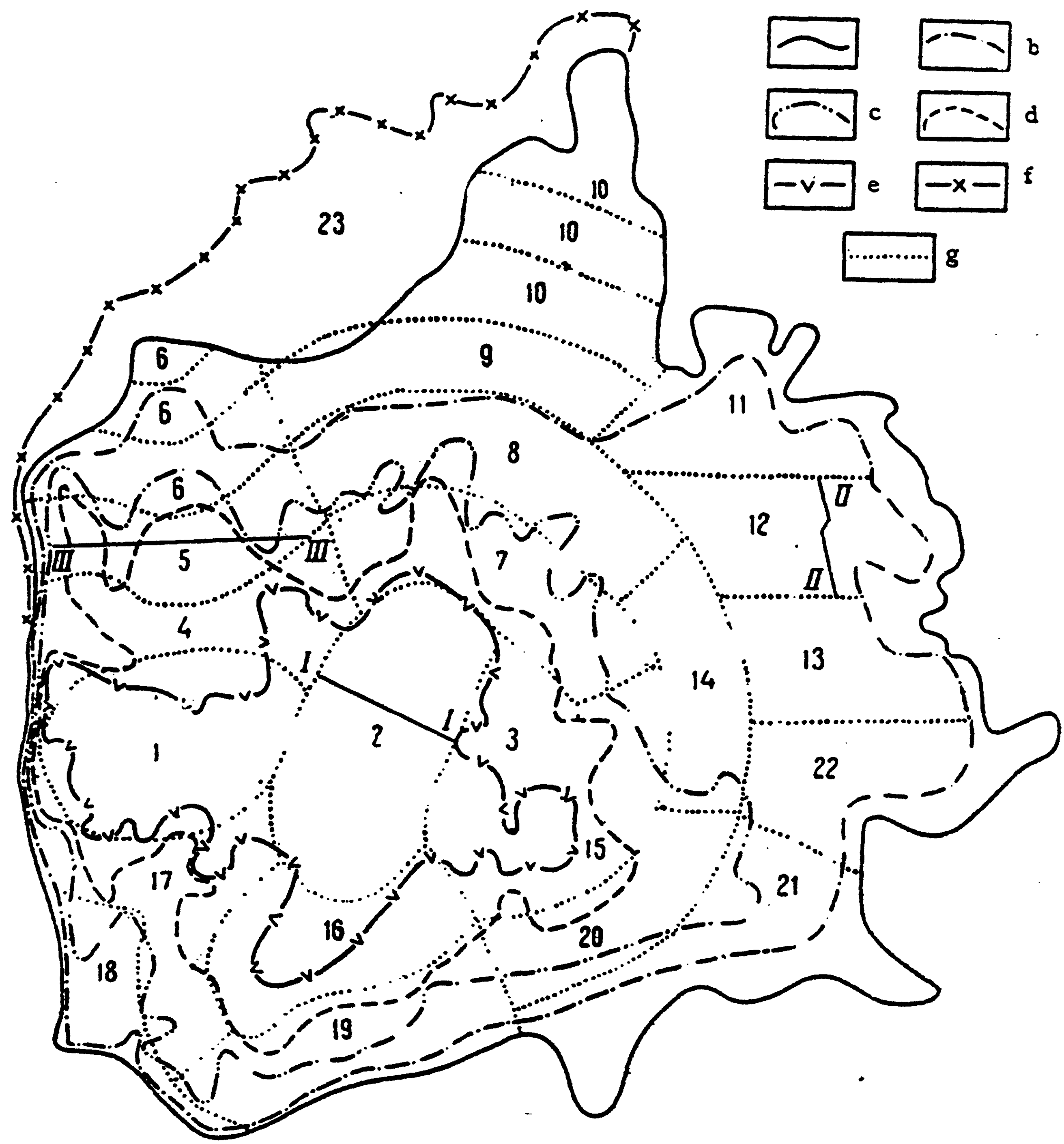


Fig. 56. Map of outer margins of oil pools of pay zones D-I and D-0 of Romashkino field.
Outer margin for beds: a-D-Ia; b-D-Ib; c-D-Ic; d-D-Id; e-D-Ie; f-D-0; g-boundaries of sectors.
Sectors: 1-Minnibayevo, 2-Abdrakhmanov, 3-Pavlov, 4-Al'met'yev, 5-Severo-Al'met'yev, 6-Berezov, 7-Vostochno-Suleyev, 8-Alkeyev, 9-Chishmin, 10-Tashliyar, 11-Severo-Aznakayev, 12-Tsentral'no-Aznakayev, 13-Yuzhno-Aznakayev, 14-Kholmov, 15-Zelonogora, 16-Yuzhno-Romashkino, 17-Zay-Karatayev, 18-Kuak Bash, 19-Zapadno-Leningora, 20-Vostochno-Leningora, 21-Yuzhnaya, 22-Karmalin, 23-Sarmanov.

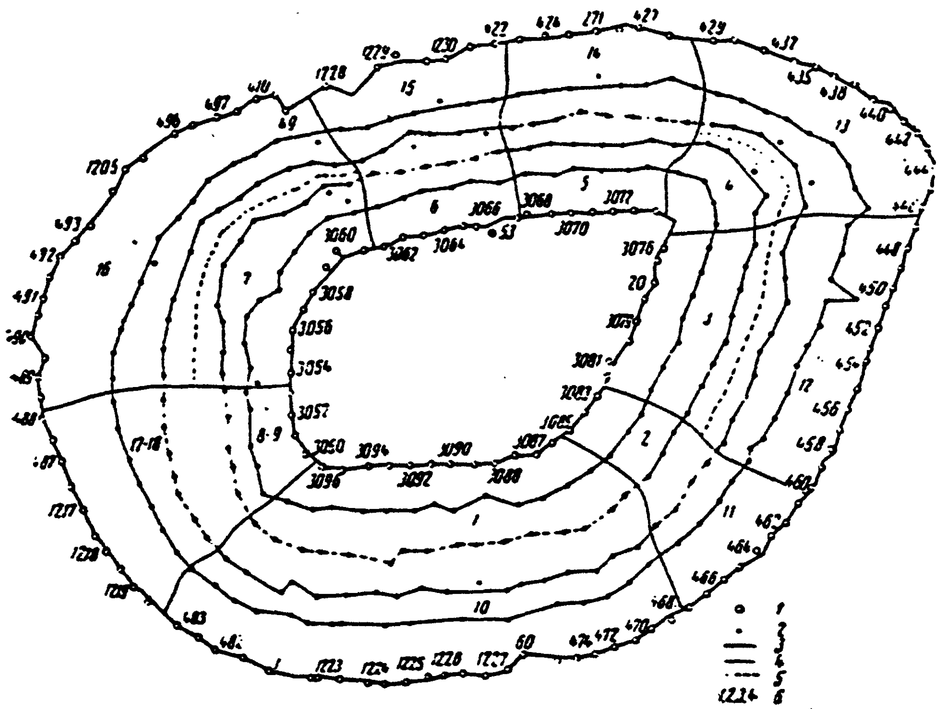
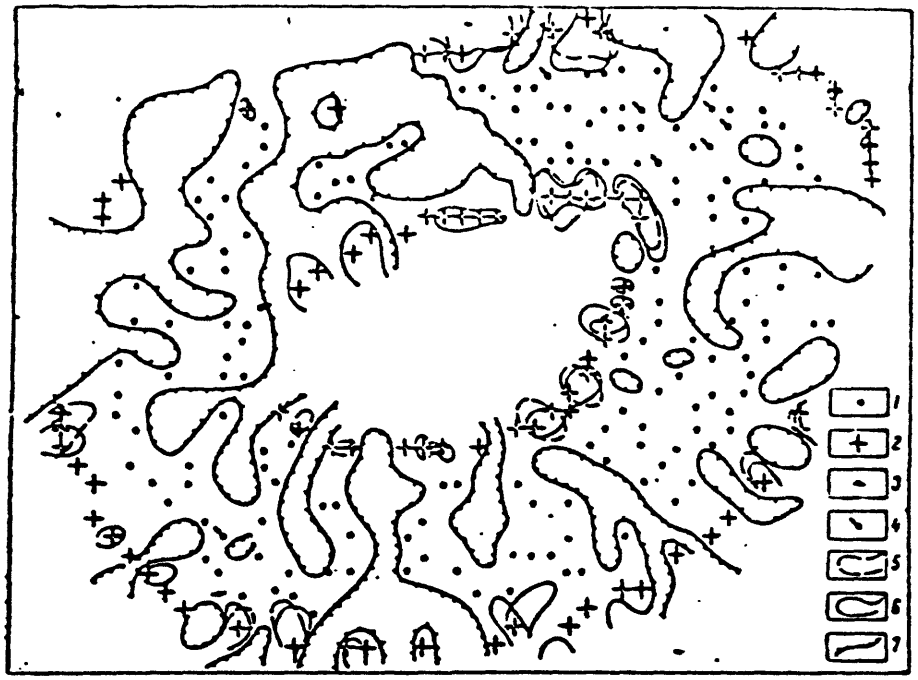
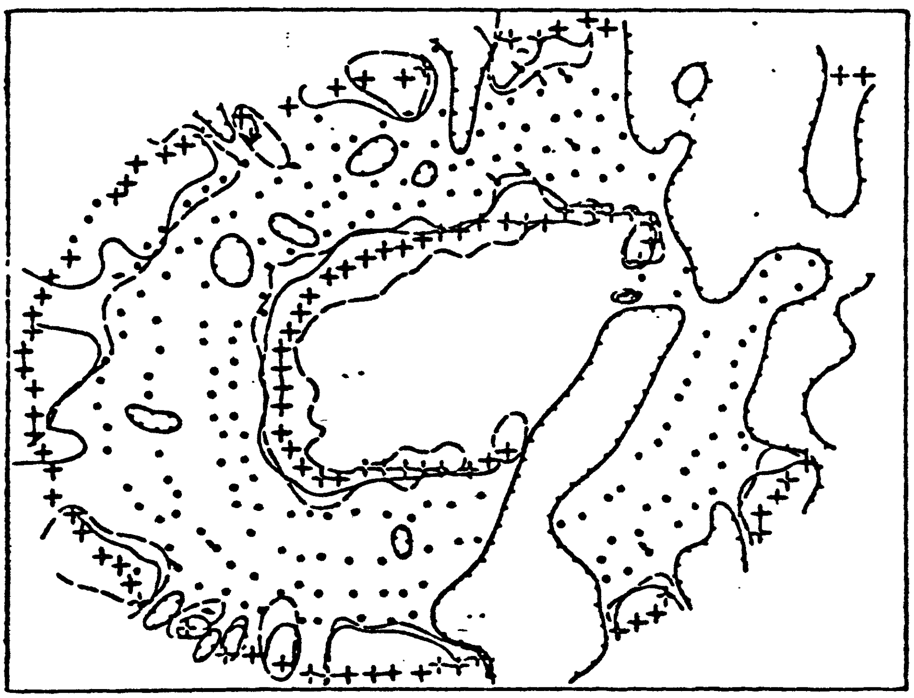


Fig. 57. Distribution of wells in Minnebayevo sector of Romashkino field. 1-Injection wells; 2-production wells; 3-boundaries of parts; 4-rows of production wells; 5-calculated line of constriction of water-oil interface; 6-numbers designation parts. From Smirnova, 1963, p. 77.



a



b

Figure 58.--Comparison of margins of oil pool in Minnebayevo sector as of January 1, 1963.

a - for bed b_1; b - for bed b_2; c - for bed c.

Wells: 1 - production, 2 - injection, 3 - control, 4 - observation. Margin of injected water: 5 - based on production data, 6 - based on computer modelling, 7 - zone of replacement of reservoirs by shale.

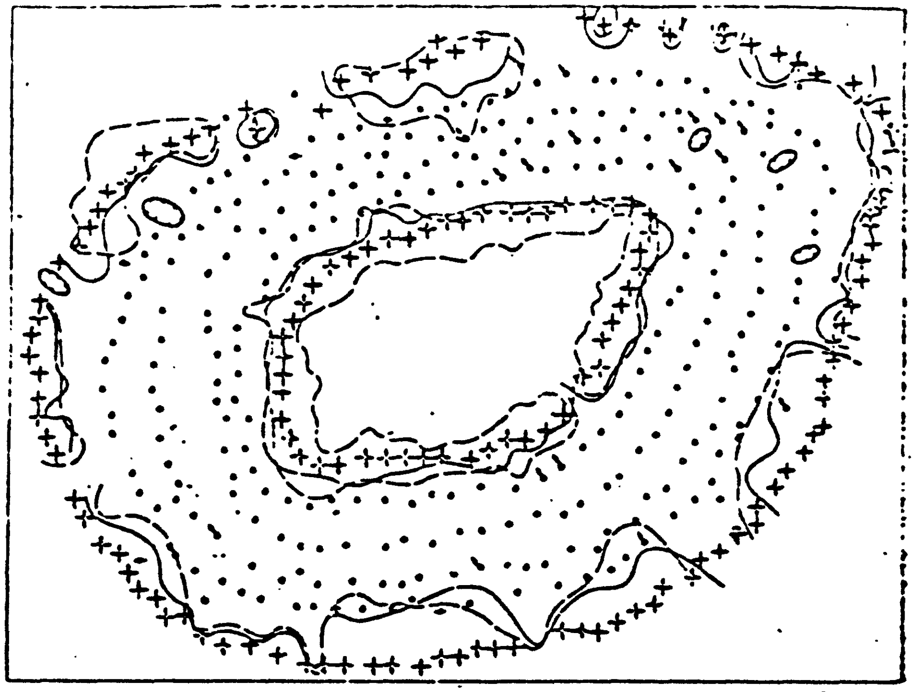


Fig. 58 c.

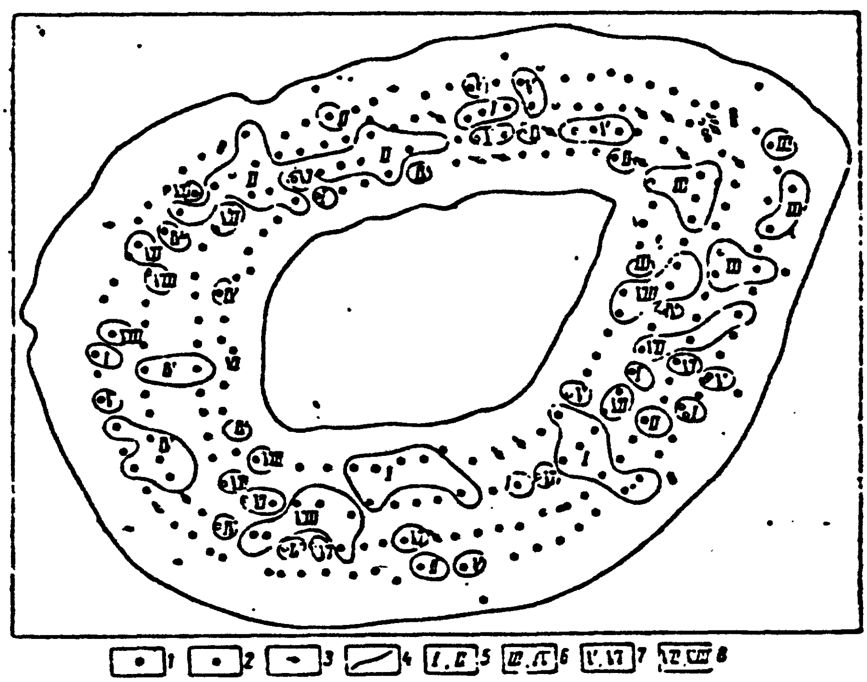


Figure 59.--Map of succession of transfer of production well to intensive recovery in Minnebayevo sector.

Wells: 1 - production, 2 - control, 3 - observations, 4 - position of rows of injection wells. Times of transfer: 5-I and II quarters of 1967; 6-III and IV quarters of 1967; 7-I and II quarters of 1968; 8-III and IV quarters of 1968.

Maximum productivity of wells with a 127-mm casing was 200 m^3/day, and with a 168-mm casing it was 350 m^3/day. These figures are probably true only for 1976. (Maksimov and Rybitskaya, 1976, p. 227-237.)

Abdrakhmanov sector

By 1957 the Abdrakhmanov area had been drilled by a single outer ring of injection wells and three interior rings of production wells. The distance between the injection row and the first row of production wells was 2,000 m, and the distance between production rows was 1,000 m. The injection wells were spaced at 500 m and the production wells at 600 m along the rows. The central part of the area was not drilled. All oil-bearing beds of pay zone D-I were perforated in all production and injection wells. All the injection wells were produced by the flowing method before they were completed as injection wells.

The status of the water injection in the Abdrakhmanov area as of the end of 1957 is shown in figure 60. Diagonal ruling indicates areas where wells reacted to injection by increases in formation pressures. In the horizontally ruled areas no change in pressure was observed. In the central, unruled areas, pressures dropped significantly; wells here were either shut in or worked by pumps.

In March of 1957, the decision was made to drill a central row of injection wells and two additional rings of production wells, one between the outer injection row and the outer production row at a distance of 700 m from the latter, and the second in the central part of the area at a distance of 700 m from the innermost production row. The status as of July 1, 1958, is shown in figure 61.

Water flooding

Although facies changes result in abrupt termination of permeable beds throughout the Romashkino field, there is a remarkable hydrodynamic interconnection within individual strata over great distances. Gerasimov (1964, p. 396) reports variations in water level of hydrogeologic observation wells in response to water injection at Romashkino at distances of as much as 60 km from this super-giant field. Other observation wells only 10 km from the field, however, show no responses to the production activity. Within the field some wells at a distance of only 500 m from one another show no hydrodynamic interconnection.

Water flooding at Romashkino has been very uneven. The more permeable beds have been flushed, whereas less permeable beds have remained virtually undisturbed. Recognition of oil-saturated beds in cased wells became a problem. In 1962, impulse neutron-neutron logging was used experimentally to detect such oil saturation in the Aznakayev, Pavlov, and Zelenogorsk

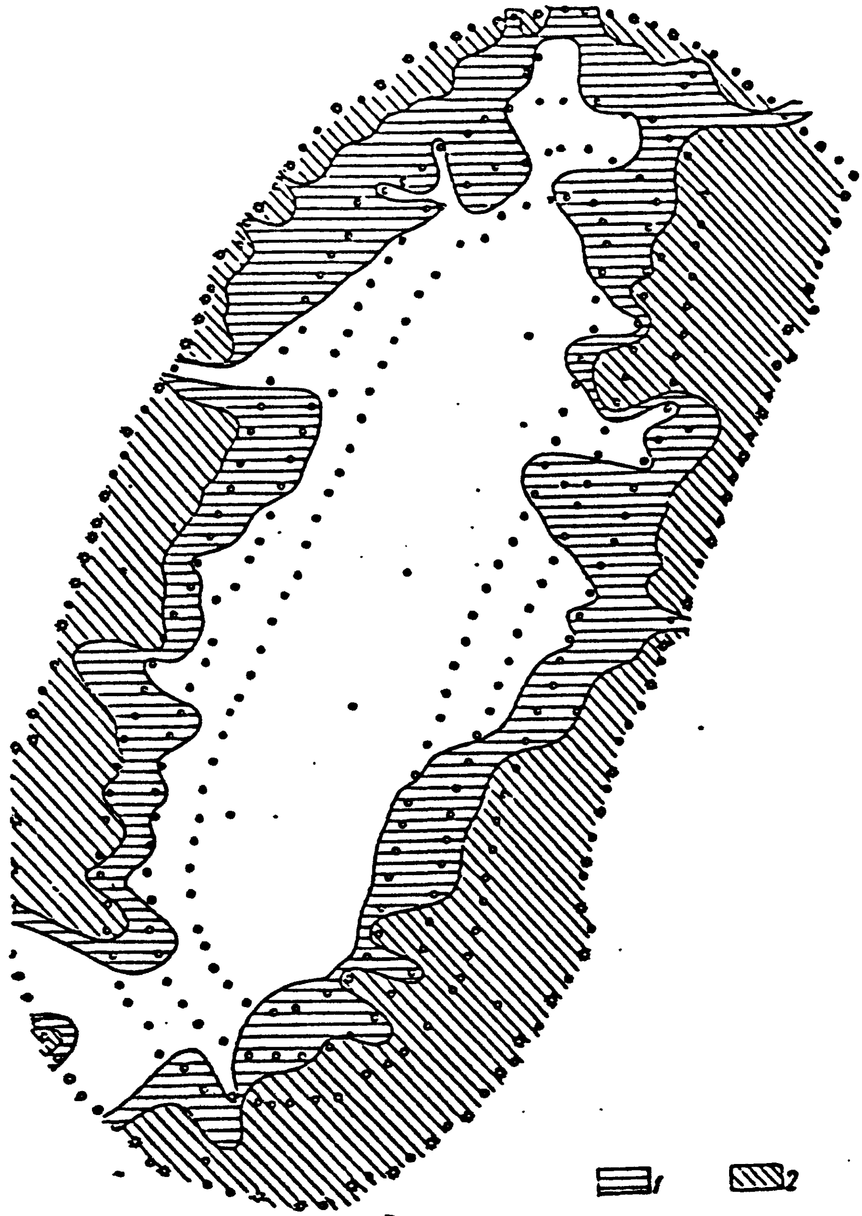


Figure 60.--Map of effect of water injection on pay zone D-I of the Abdrakhmanov sector.

1 - areas of little effect of injection; 2 - areas of active effect of injection, The outer row of wells is for injection, and those with radiating tick marks have already been changed from an initial production status to their intended injection function.

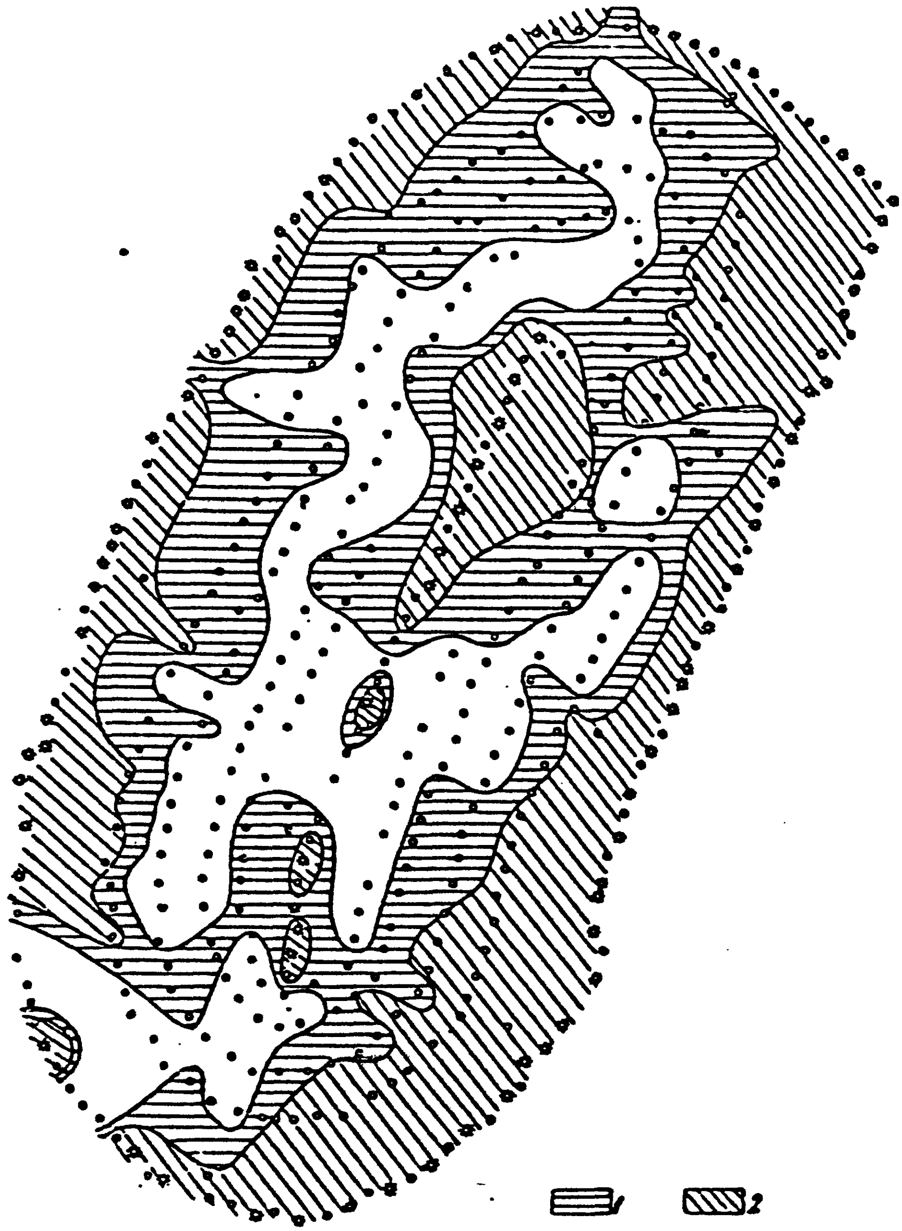


Figure 61.--Map of effect of injection on pay zone D-I of the Abdrakhmanov area as of July 1, 1958.

Symbols same as in Figure 60.

areas (Kildayeva, 1964, p. 123). The wells were overhauled and reperforated at intervals above the water-oil contact as indicated by the impulse neutron-neutron log. Satisfactory production was gained from these newly perforated intervals.

Where water is injected into a completely oil-saturated stratum, the water-oil contact is close to the vertical. This is very apparent in the south part of the Pavlov-Abdrakhmanov dividing row, the Abdrakhmanov-Yuzhno-Romashkino and Abdrakhmanov-Minnibayevo rows, and the central Minnibayevo and Abdrakhmanov rows. The production wells opposite these dividing rows yielded pure oil for a long time and then were flooded on the arrival of the front of injected water. There is almost a piston-like displacement of the oil by the injected water (Cholovskiy and Kinzikeyeva, 1962, p. 453-454).

Stimulation measures

The rate at which oil is recovered from the various sandstone beds of pay zone D-I varies greatly. Yearly yields of initial extractable reserves range from more than 5 percent to less than 1 percent (Begishev and others, 1963, p. 558). Where pay zones D-I and D-II are hydrodynamically connected, pressure differentials created by production caused fluids to flow from one zone to the other: oil into D-II and water into D-I (Rybin, 1960, p. 86-95). Water-bearing intervals are closed off by shutting down the wells and overhauling them (Poddubnyy, 1977, p. 8-10).

The interval in which flow is obtained in production wells and reception in injection wells at Romashkino is as a rule less than the perforated interval. The non-flowing intervals may be clogged with drilling mud or simply be zones of low permeability. These intervals are stimulated by increasing formation pressure and the pressure differential. These measures clean out the non-flowing intervals (Danilova and Diyashev, 1979, p. 23-27). In order to secure flow from low permeable intervals in general, high pressures are maintained on the injection wells: 180-374 atm in the Pavlov sector, up to 466 atm in Yuzhno-Romashkino, 300-400 atm in Zay-Karaloy, and up to more than 500 atm in Al'met'yev (Begishev and others, 1963, p. 559).

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 new parts of the field with high-flowing wells on stream (Mirchink, 1964, p. 308-309).

Origin of field

Several suggestions have been made by Soviet geologists as to the factors that led to localization of the huge accumulation of oil at Romashkino.

According to Rostovtsev (1964, p. 363), there is a regional water-oil contact in Tataria and Bashkiria, and pay zone D-I is oil-bearing where it lies above this surface and water-bearing where it is below. This phenomenon, to the extent that it is real, would appear to be a reflection of coincidence of hypsometric position of reservoirs and seals rather than being caused by some regional hydrodynamic equilibrium, as is implied.

The regional distribution of productive and nonproductive areas has a bearing on explaining the origin of Romashkino oil field. The region of the Tatar arch can be divided into an eastern, productive area and a western, nonproductive area. The eastern area includes the south crest of the Tatar arch and the eastern flank of the north crest. The non-productive area includes the north crest and western flank of the arch and extends southward into the Melekess depression and westward into the Kazan-Kirov aulocogen and Tokmovo arch. Mel'nikov and Shpil'man (1958, p. 859) attribute this distribution of oil to a more rapid subsidence of the western area during the Late Devonian (Shugurovo time), causing migration of hydrocarbons toward the east. Also, the Pashiy and Givetian sediments, in which pay zones D-IV-D-I occcur, are absent in a large part of the western area. The absence of the pay zones on the west may certainly be one of the factors in the nonproductivity there. Migration of hydrocarbons to the east during the Late Devonian could hardly have been a reality, however, because burial was not yet deep enough for maturation of kerogen to yield oil. Further, the closure of the structures at the end of the Devonian was only 25-40 percent of the present closure (Ashirov, 1960, p. 337).

Eremenko and Maksimov (1960, p. 328) cite the Ural-Volga basin as a typical example of oil-gas occurrence on a platform adjacent to a foreland downwarp and geosyncline. However, abrupt lithofacies changes in the transition from the geosyncline limestones to the platform clastics make it unlikely that hydrocarbons migrated from the geosyncline onto the platform.

Romashkino oil field is certainly associated with a definite hinge line. The gradient of increase in total thickness of the Devonian and Carboniferous sediments changes abruptly beyond the 1,500 m isopach (Fig. 62). The boundary between the areas of gentle and steep gradients is to the west of the belt of fields that contains Romashkino (Borisov, 1961, p. 353-354).

The association of the Volga-Ural fields with a hinge line (fig. 62) may not be a genetic relationship per se, but rather an indirect effect of the distribution of paleo-temperatures. The temperature of the oil at Romashkino is 40°C at the present time; however, paleo-temperatures were adequate for maturation of organic matter in source rocks within the present oil-rich region. Vitrine reflectance is 76-78 percent in lower Frasnian clastics in the Romashkino area. This corresponds with a temperature of 125-135°C. In the Ural-Volga region nearly all of the oil pools (80 percent of reserves) occur in the area where vitrine reflectance is 72-80 percent (75-175°C). No commercial pools are present to the east where reflectance is higher, and very few are present to the west where it is lower (Rovenskaya and Kalmykov, 1978, p. 13).

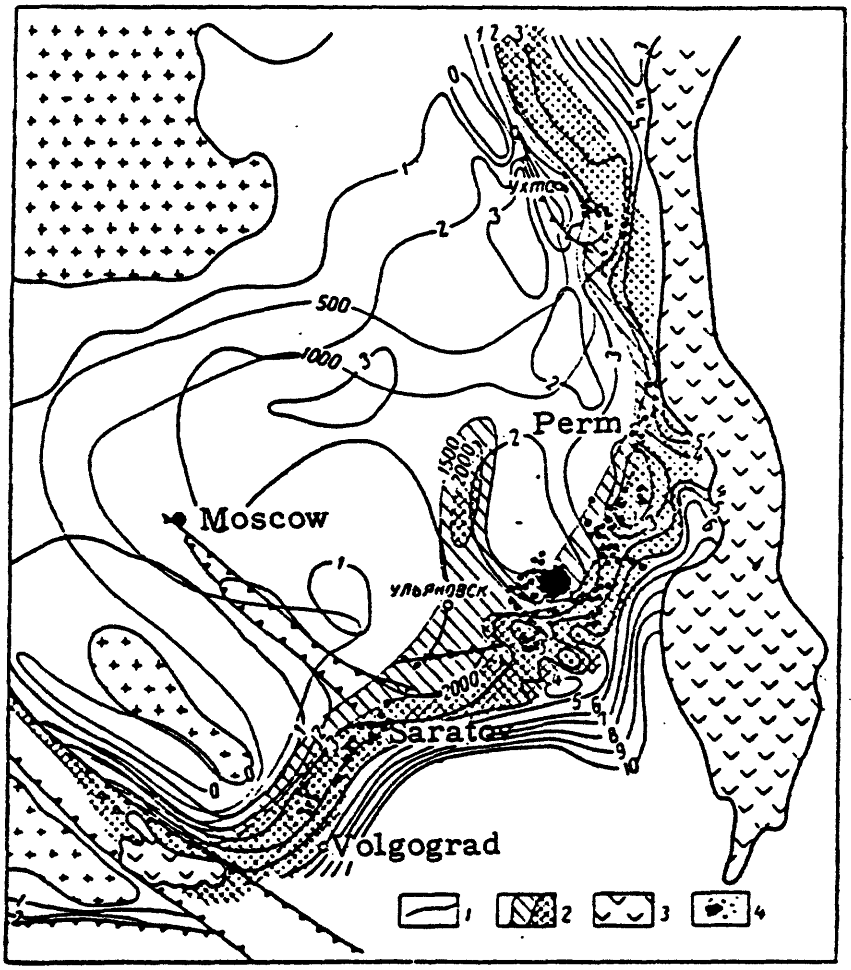


Figure 62.--Schematic map of the relief of the Precambrian, and the total thickness and oil-gas productivity of the Devonian and Carboniferous in the Volga-Ural petroleum province (after Borisov, 1961, p. 352).

1 - Structural contours on the surface of the Precambrian; 2 - total thickness of the Devonian and Carboniferous (a - <1500 m; b - from 1500 to 2000 m; and c - >2000 m); 3 - Paleozoic folded structures at the surface; 4 - oil and gas pools in the Devonian and Carboniferous.

The coincidence of Romashkino and its associated fields with a belt of favorable vitrine reflectance suggests that the source beds were within the same belt; there was no extensive lateral migration. However, accumulation of the oil at Romashkino had to be by lateral migration into the field itself because: 1) the oils show no vertical zonation within the Devonian pay zones as they probably would if migration had been vertically into the pool (Botneva, 1958, p. 487), and 2) the Domanik source rocks are stratigraphically above pay zone D-I and are consequently above the pays at the site of the field.

The oil of Romashkino oil field must have migrated largely from the south and southwest. Such a direction of migration is suggested by the increase in density of oil in the field from 0.86 in the south and west to 0.88 in the northeast (Uspenskaya and Khachatryan, 1977, p. 107). The inclination of the water-oil contact may indeed be the result of filling the field from the south. The huge size of the field (3,600 sq. km) could be cause enough for there to be an extended lag in establishing hydrodynamic equilibrium on the water-oil interface, particularly if oil is still being fed into the field by disruption of smaller pools by recent tectonic movements. Such recent movements are very apparent from geomorphology, which reflects the Paleozoic structure.

The source beds for the Romashkino oil appear to be the Domanik carbonaceous shales, which are stratigraphically higher. Off the Romashkino high, however, these shales are lower in elevation (Rodionova, 1964, p. 675). Faulting and fracturing are sufficiently extensive to provide the necessary channelways.

The overall similar composition of the oils of all the pools in the Devonian clastics (D-0 through D-IV) at Romashkino suggests a single history of their formation and a simultaneous introduction of oil into all the pay zones due to lateral migration from immediately adjacent structural lows (Botneva, 1958, p. 487). The main concentrations of hydrocarbons in the Romashkino oil field formed due to continuous-discontinuous introduction of hydrocarbons with gradual "creep" of the water-oil contact during filling of the main D-I pay. During periods of slack introduction of hydrocarbons, there are indications of stabilization of the water-oil contact accompanied by more intensive sulfate-reducing processes with oxidation of the hydrocarbons and intensive pyritization of the rocks. There are cases, however, of relatively rapid filling of the reservoirs or parts of them where no clearly expressed zones of pyritization are present.

The oil entered the trap at Romashkino largely during the Mesozoic and Cenozoic when the present structure had finally developed (Ashirov, 1960, p. 337; Uspenskaya and Khachatryan, 1977, p. 107).

Future of Romashkino

The logs of wells that were completed in Devonian clastics are now being analyzed for favorable targets in the stratigraphically higher carbonates of the Devonian and Carboniferous (Muslimov, 1978, p. 192). No references to positive results from these measures have been found; however, to the south on the Serafimovka-Ballayevo arch, re-entry on Famennian and Tournaisian carbonates in an otherwise unsuccessful well has been very successful (Lisovskiy and others, 1978, p. 29). Carbon dioxide flood has been started, and fire flood seems to be a possibility at some future time (Melik-Pashayev and others, 1978, p. 59-60).

Infill drilling at Romashkino is in its third round in some sectors and fourth in others. Yet, the drilling rate seems to be on the increase. Total wells in the field have increased from about 8,000 in 1978 to more than 10,000 in 1980; this includes 20 to 25 percent injection wells. With a total area of about 900,000 acres in the field, this is about 90 acres per well, including the injection wells. Although no new extensions of the field can be expected, there seems to be enough oil left in small lenses and in by-passed zones to support a rate of production that will decline slowly rather than drop precipitously.

ARLAN OIL FIELD

Introduction

Arlan is a giant field, the second largest producer in the Volga-Ural oil-gas province and the third largest in the U.S.S.R. in cumulative production. Geological surveys were made in this region in 1946-51, and wildcat drilling began in 1951. The first discovery was in 1955. Subsequent discoveries in 1956-58 disclosed the great size of the field.

The field is about 90 km long and 15-20 km wide (Maksimov and others, 1970, p. 314; Kulikov, 1959, p. 84). Production during 1981 was 62 million barrels, and cumulative production as of January 1, 1981, was 2.12 billion barrels (International Petroleum Encyclopedia, 1982, p. 353).

Regional setting

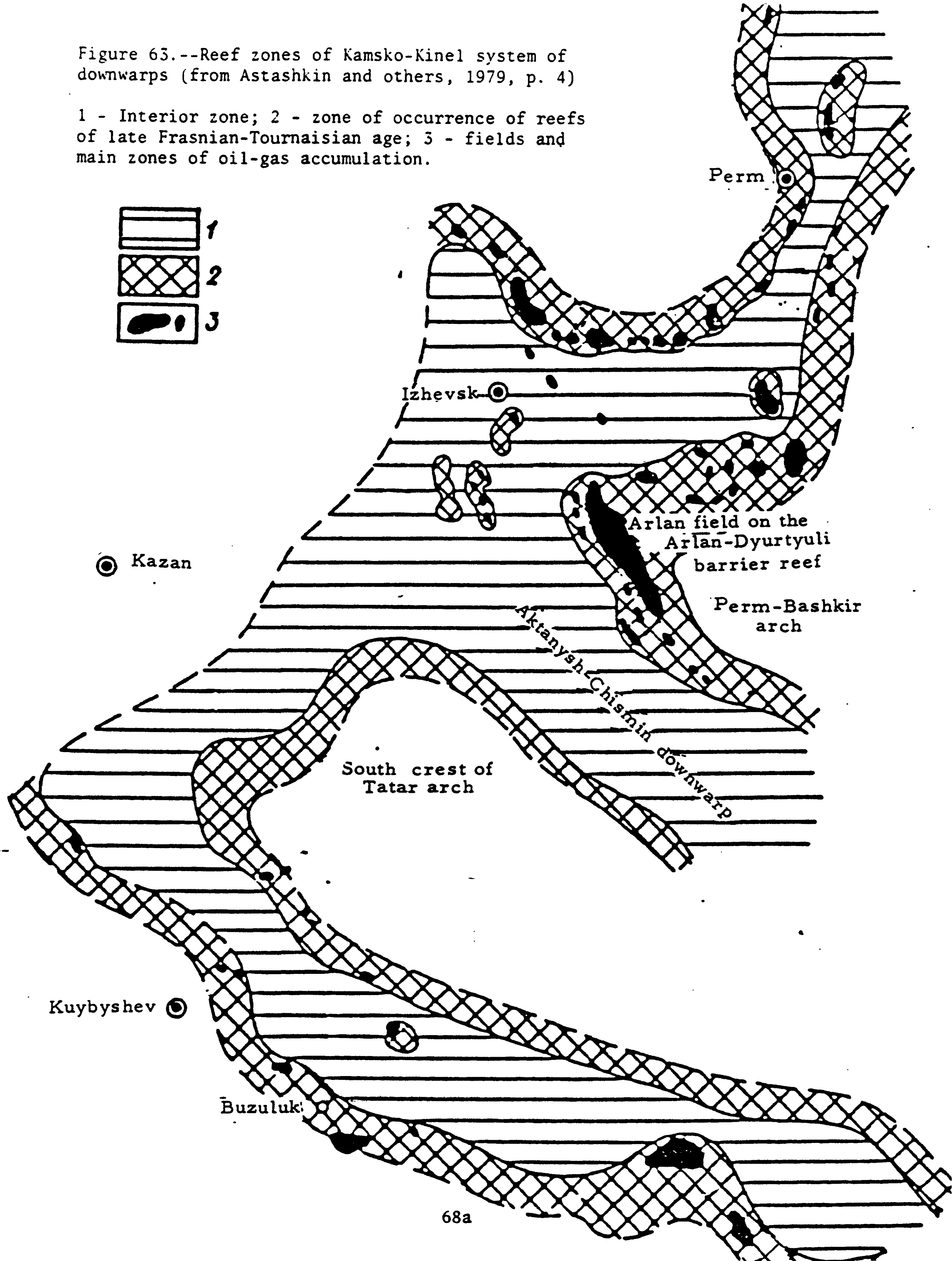
During the Middle Devonian Epoch an epicontinental sea spread northwestward onto the Russian platform from the Ural geosyncline. By middle Frasnian time (late in the Devonian), deposition had smoothed out most of the original irregularities of the basin bottom, and the Domanik (Chattanooga-like) carbonaceous shales were deposited as a relatively even blanket over the region.

Following deposition of the Domanik, the Kamsko-Kinel system of uncompensated troughs developed across the area in response to renewed movements on zones of weakness within the crystalline basement. The troughs of this system have no direct reflection in the underlying clastic Devonian, in the older Precambrian sediments, or on the surface of the crystalline basement (Mirchink and others, 1970, p. 4). Extensive reefs formed along the margins and within the troughs of the Kamsko-Kinel system during the Frasnian and Famennian. The Arlan-Dyurtyuli barrier reef was deposited along the northeast margin of the Aktanysch-Chishmin downwarp at its junction with the Perm-Bashkir arch to the northeast (fig. 63).

The Arlan-Dyurtyuli barrier reef is the core of the Arlan-Dyurtyuli anticlinal zone on which Arlan oil field occurs. This anticlinal zone is located within the Birsk saddle (fig. 2), which is a structural low between the Tatar arch on the southwest and the Perm-Bashkir arch on the northeast.

Figure 63.--Reef zones of Kamsko-Kinel system of downwarps (from Astashkin and others, 1979, p. 4)

1 - Interior zone; 2 - zone of occurrence of reefs of late Frasnian-Tournaisian age; 3 - fields and main zones of oil-gas accumulation.



Stratigraphy

Beneath the Paleozoic sedimentary section in Arlan well no. 7000 are more than 3,000 m of Late Precambrian Riphean-Vendian aulocogen sediments. These rest on Archean crystalline basement (Muslimov and others, 1979, p. 65).

Unconformably above the Vendian deposits are about 1,800 m of platform sediments, which range in age from Middle Devonian to Late Permian.

The Devonian at Arlan is 500-600 m thick and consists of two lithologies. The lower 50 m of the section is composed of clastics of Eifelian-early Frasnian age, and the upper 450-550 m consists of carbonates of late Frasnian-Famennian age (Kulikov, 1959, p. 90). The Devonian here has received little attention because it contains no commercial oil or gas; only shows have been observed. The upper Frasnian-Famennian carbonates, however, are a reef buildup over which the overlying Lower Carboniferous pay zones are draped, thereby forming the traps for this enormous field. The variation in thickness of the reef accounts for the range in thickness from 450 to 550 m.

The Lower Carboniferous at Arlan is composed of Tournaisian carbonates and Visean clastics (fig. 64). The Tournaisian carbonates are about 100 m thick and drape over the Devonian reefs (Chernousov, 1963, p. 43). Post-Tournaisian erosion cut canyon-like valleys into the Tournaisian carbonates and underlying Famennian at sites of structural lows created by the Famennian reefs (Kulikov and Ovanesov, 1958, p. 697).

Visean clastics contain the main pay zones and rest on the post-Tournaisian erosion surface (fig. 65). Their thickness ranges from 36 m where the Tournaisian was not eroded, or only slightly so, to 112 m in the deep erosional cuts. Where the clastics are 50 m or more thick, lenses of sandstone and coal are present below the lower oil-bearing sandstones; these pinch out against the canyon-like channels (Kulikov, 1959, p. 86).

The Visean at Arlan is represented by the Yelkhov, Radayev, Bobrikov, Tula, and Aleksin Formations.

At the base of the Visean is the Yelkhov Formation. It is up to 17 m thick and is present only in the erosional cuts into the Tournaisian and Famennian rocks. Two sandy zones are recognized in this unit, C-IX and C-VIII. These sandy zones are water-bearing and nowhere contain commercial oil (Musin, and others, 1963, p. 38-41).

Overlying the Yelkhov is the Radayev Formation, which also is present only in the erosional lows. It is up to 34 m thick and contains one sandy zone, C-VII. This zone is also water-bearing; it carries no commercial oil.

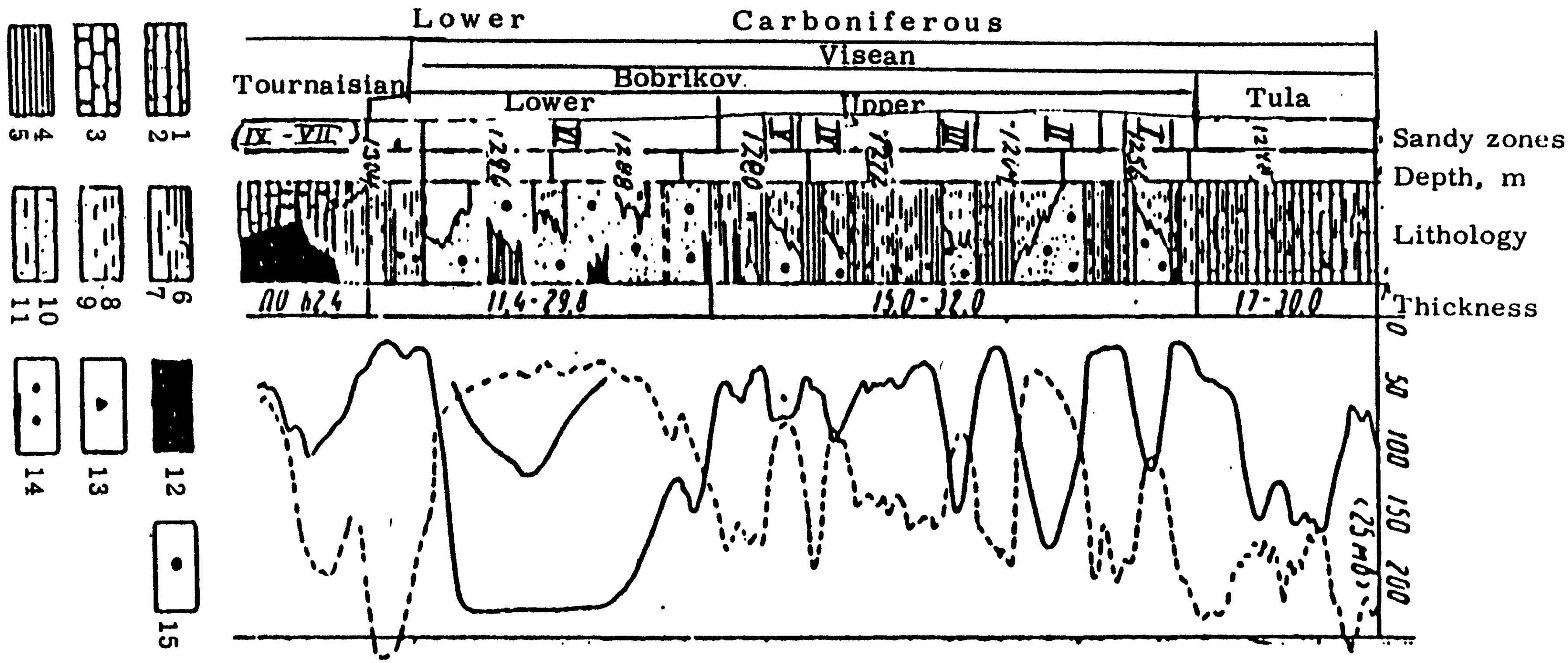


Figure 64.--Composite geological-geophysical section of the coal-bearing unit of the Arlan oil field.

1 - Limestone; 2 - argillaceous limestone; 3 - dolomite; 4 - shale; 5 - clay; 6 - pyritic shale; 7 - calcareous shale; 8 - siltstone; 9 - sandy siltstone; 10 - sandstone; 11 - clayey sandstone; 12 - carbonaceous rocks; 13 - (not designated); 14 - commercial oil; 15 - oil show (from Ovanesov and others, 1963, p. 540).

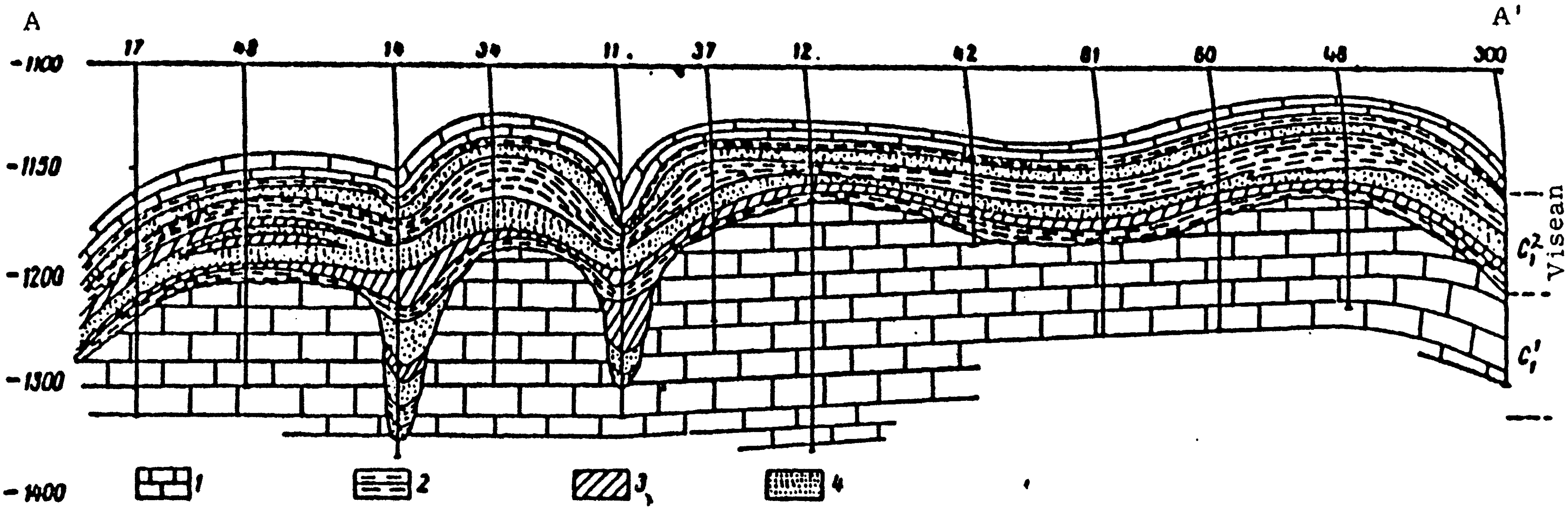


Figure 65.--Geologic section along the crest of the Arlan structure.

1 - limestones; 2 - argillites and siltstones; 3 - coals and shales; 4 - sandstones (from Kulikov, 1959, p. 87).

The Bobrikov Formation is 10-56 m thick and rests on an erosional surface that extends across rocks of the Radayev, Yelkhov, and older formations. Sandy pay zone C-VI is present here as well as some coal beds. The Bobrikov is also known as the Coal-bearing Formation and as the Stalinogorsk Formation (Vissarionova, 1959, p. 358-359).

The Bobrikov is overlain by the Tula Formation, which is up to 25 m thick at Arlan. This unit contains five sandy pay zones: C-V through C-I.

Overlying the Tula Formation is the Aleksin Formation, which is a carbonate unit that contains numerous anastomosing channel sands (Tsotur, 1975, p. 489).

Overlying the Visean clastics at Arlan are about 800 m of carbonates of the Middle Carboniferous Bashkirian and Moskovian stages. The Kashira and Podolsk Formations of the Moskovian are oil-bearing.

At the top of the section are 300-400 m of Permian carbonates and anhydrite (fig. 66).

Structure

Arlan oil field has a northwest trend in a region where structural trends are in general to the northeast. The northeast regional trend is a reflection of the southeast flank of the Russian platform. The transverse position of the structure at Arlan had its beginning in an aulocogen that developed in this region during the Proterozoic (Navlivkin, and others, 1964, p. 143). A broad graben-like feature, the Kaltasy aulocogen, formed in the general area of the Birsk saddle between the ancestral Tatar and Perm-Bashkir arches. The faulted northeast boundary of this aulocogen passed through the present area of Arlan field. This northwest-trending zone of weakness appears to have persisted on into the Paleozoic.

The Devonian clastics at Arlan dip monoclinally away from a high that is situated to the south (Kulikov, 1959, p. 89; 1961, p. 484). The structure in these clastics is in no way reflected in the stratigraphically higher units. This can be seen by examining figure 66 at a low grazing angle from the right or left.

Development of the oil-trapping structure at Arlan began with formation of the Kamsko-Kinel system of troughs. The Arlan-Dyurtyuli reef produced a rootless structural relief at the top of the Devonian carbonates. Tournaisian carbonates then draped over these reefs, and the relief on the post-Tournaisian surface was further enhanced by erosion and karstification that cut into both the Tournaisian and underlying Devonian. The Visean clastics were then draped over the topographic highs on the post-Tournaisian erosion surface (Mkrtchyan, and others, 1965, p. 116-117; Yurullin and Yunusov, 1976, p. 30). This draping accounts for the closure at Arlan (figs. 68 and 69).

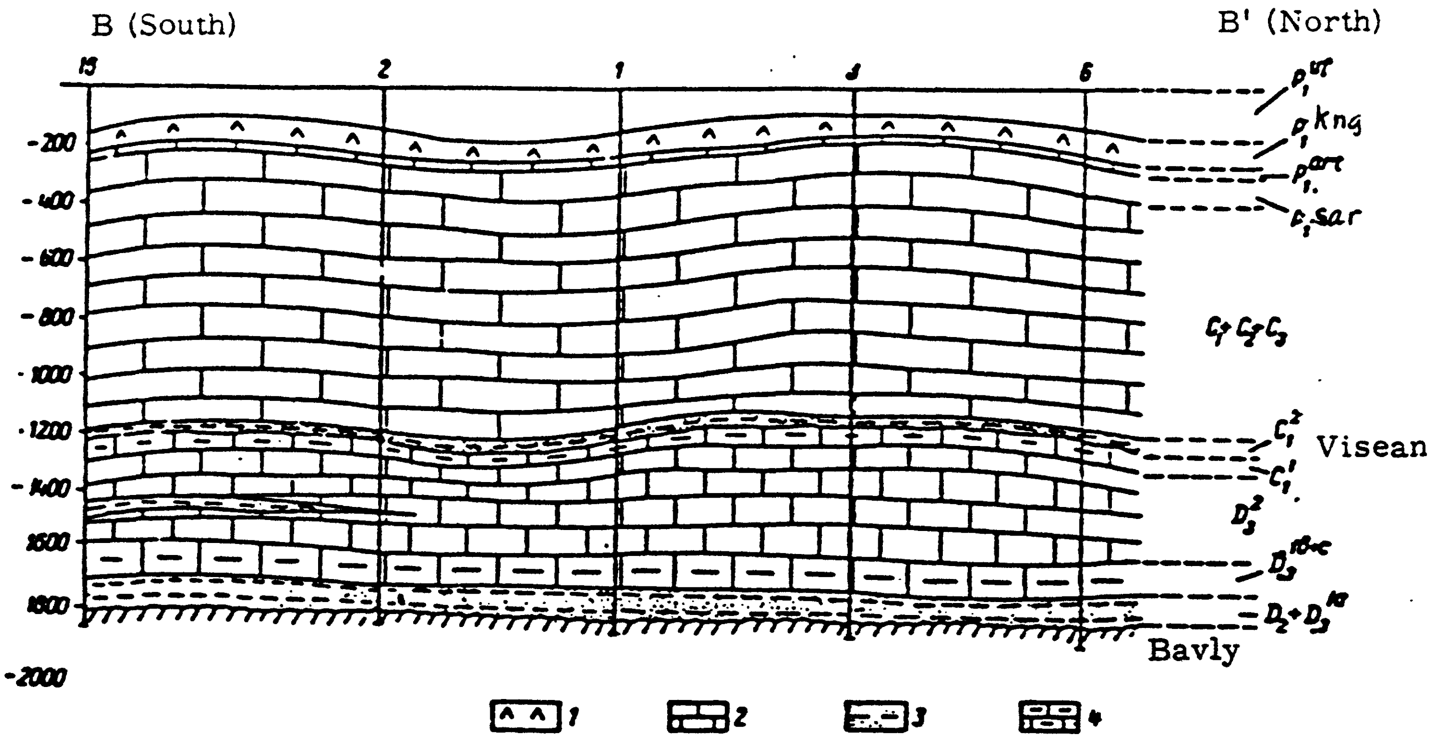


Figure 66.--Transverse geologic section of the Arlan structure.

1 - Anhydrites; 2 - limestones; 3 - sandstones with interbedded clays; 4 - limestones with interbedded shales (from Kulikov, 1959, p. 90).

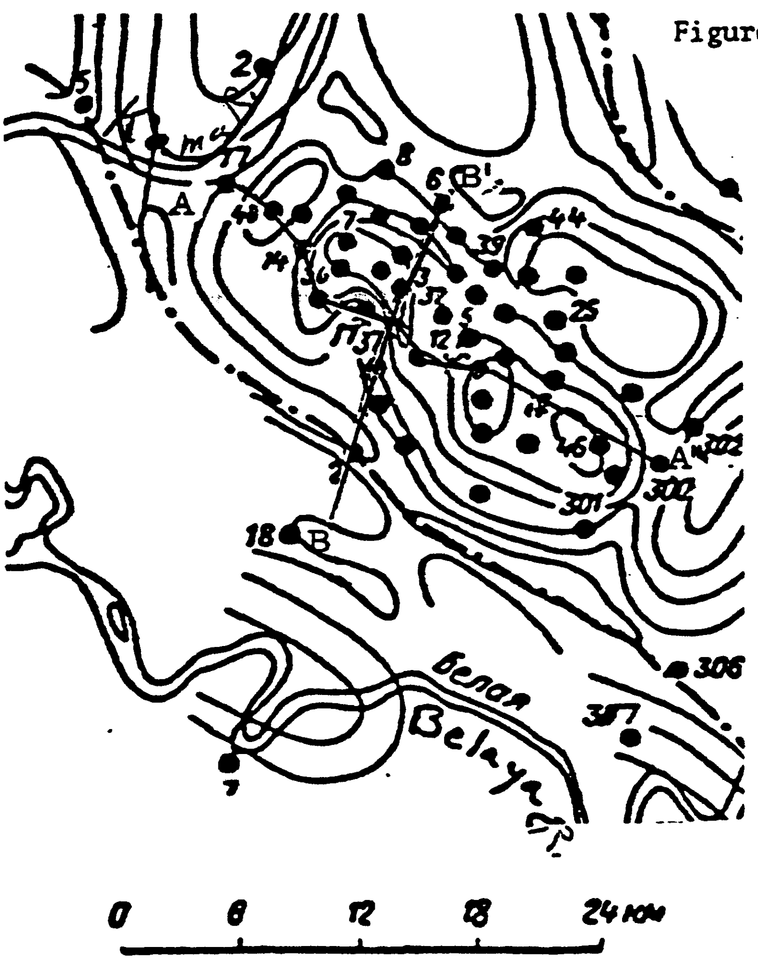


Figure 67.--Location of cross sections of figs. 65 and 66 on the Arlan high proper (from Kulikov, 1959, p. 85).

Structure contours are on the top of the Visean stage. See fig. 70 for location of Arlan structure.

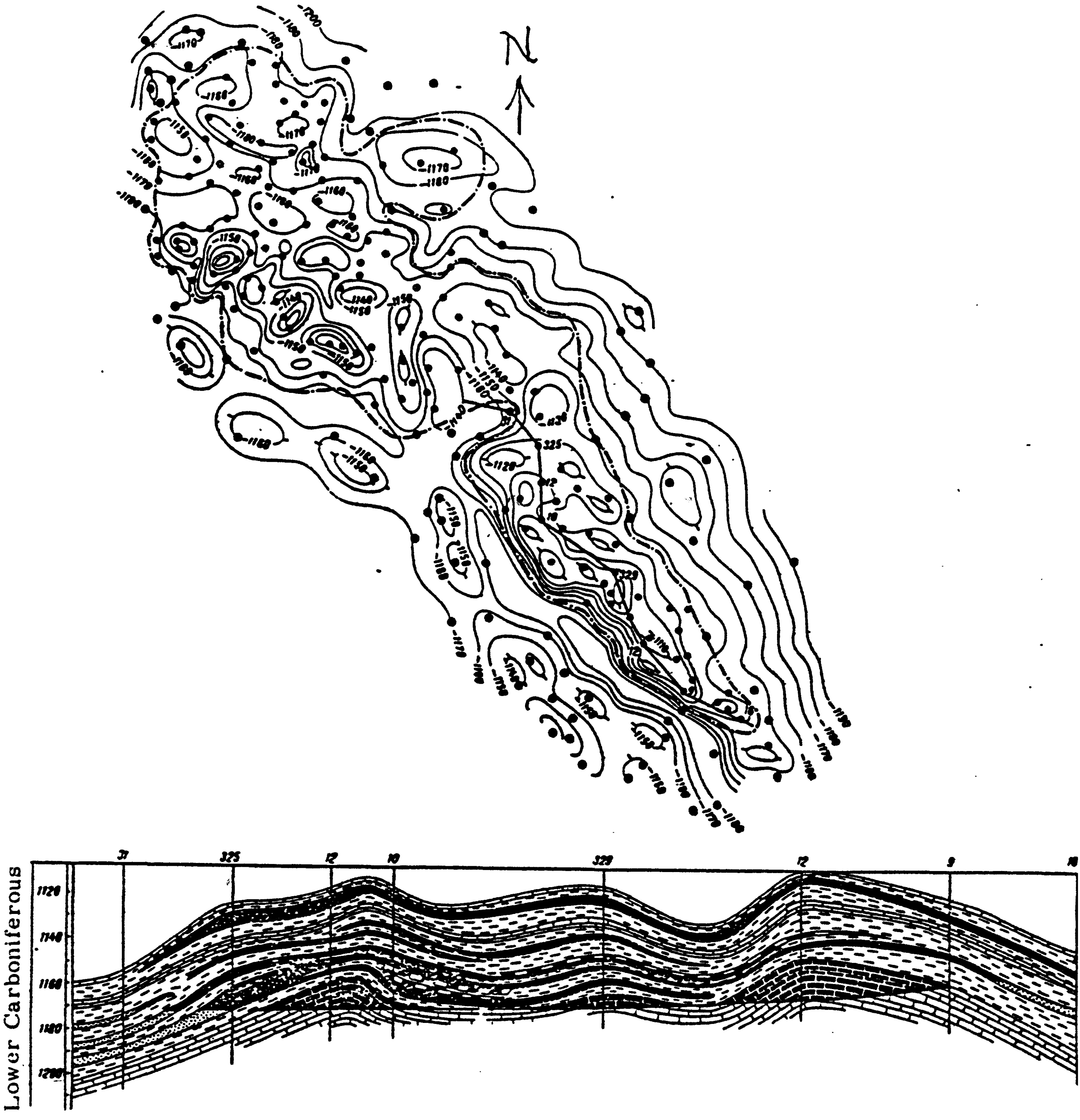


Figure 68.--Structure map and cross section of Arlan oil field (from Klubova and others, 1968).

a - Structure map on top of Yasnopolyan super-horizon (Bobrikov and Tula horizons); b - Geologic profile of Yasnopolyan (strata I-VI) and Tournaisian pools.

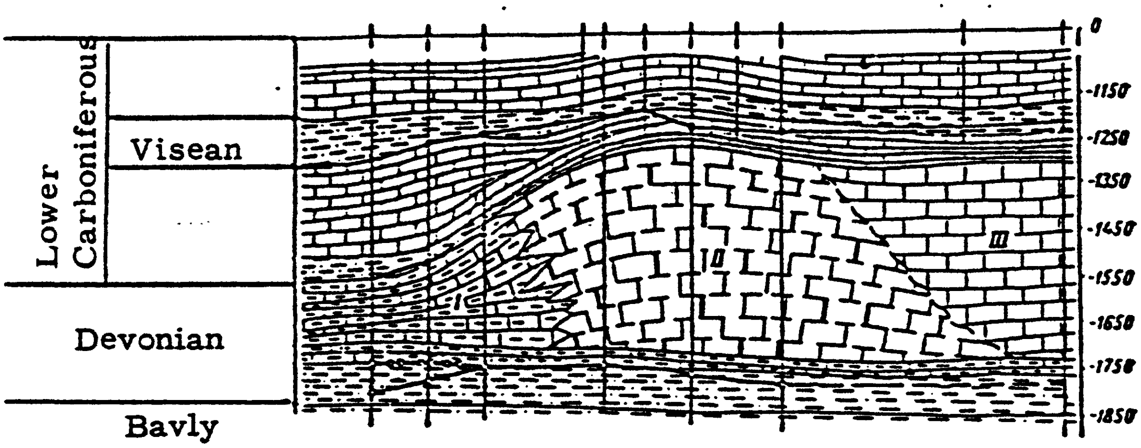


Figure 69.--Section through the Arlan field showing draping over a reef buildup (from Mkrtchyan and others, 1965, p. 50).

Carbonate rocks
Clastic rocks
Facies: I-depression, II-reef, III-back reef.

Four separate highs are present in the Arlan-Dyurtyuli anticlinal zone: Arlan, Urtaul, Vyat, and Yusupovo-Novo-Kazin (fig. 70). On each of these highs are smaller highs.

The Arlan-Dyurtyuli anticlinal structure closes on the -1,170 m structure contour on the top of the Tula Formation. The highest point on this horizon is -1,080 m at Yusupovo (fig. 70). Closure is 90 m (Klyucharev and Fattakhutdinov, 1967, p. 26-29).

The section from the base of the Visean through the Permian at the top of the section is conformable (Kulikov, 1961, p. 484). Angles of dip, however, decrease upward along the section: 5° 30' on the top of the Tula Formation, 2° 50'-0° 20' on the top of the Verey, and 1° 10'-0° 15' on the top of the Artenskian (figs. 71 and 72, Klyucharev and Fattakhutdinov, 1967, p. 26-29).

Pay Zones

Tournaisian stage

Oil pools are present in Tournaisian carbonates on structural highs where the anticlinal crests on these rocks extend above the water-oil contact of the field (fig. 68). Reservoirs are the pore and cavity types in organoclastic and foraminiferal varieties. Porosity ranges from 1 to 17 percent, and permeability is in the tens of millidarcies to 140 millidarcies. The most porous varieties are at the crests of structures where conditions were more favorable for leaching (Yurchak, V.P., 1965, p. 268). The oil column is up to 17 m high.

Visean stage

Six pay zones are present in the Bobrikov and Tula Formations of the Visean stage. These pays are not persistent, and in some places the section contains no reservoirs (Chernousov, 1965, p. 226-228). The sandstones and siltstones are composed largely of quartz. The grains are angular to semirounded.

Pay zone C-VI is the lowest in the section and is in the Bobrikov Formation. It is present throughout the field but is oil-bearing only on the highs; in the intervening downwarps it is water-bearing (Sayfullin and Pavlov, 1964, p. 570). In the Novo-Khazin area, pay zone VI is subdivided into four beds separated by seals. In the Urtaul and other areas, however, C-VI is a single stratum (Chunosov, 1965, p. 213). Total thickness of C-VI ranges from 3 to 30.6 m. Porosity ranges from 10 to 30 percent, and permeability from 10 to 8,750 millidarcies (Nadezhkin, and others, 1963, p. 67).

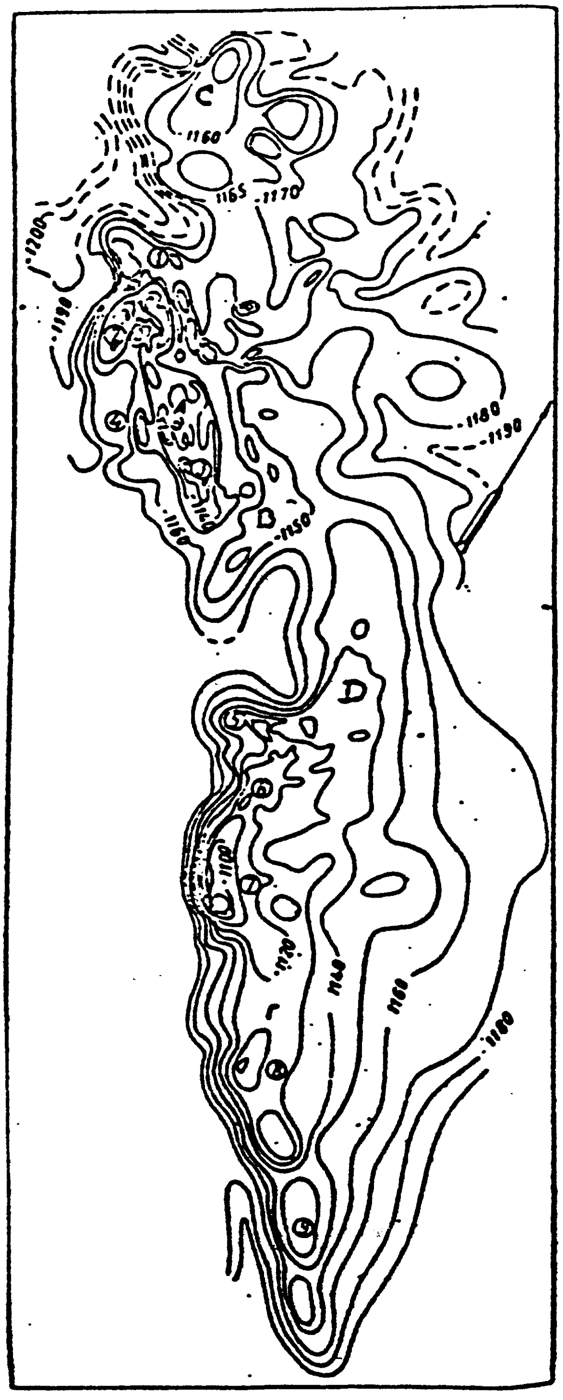


Figure 70.--Structure map of Arlan-Dyurtyuli zone on top of Tula horizon.

Main highs: A - Arlan, B - Urtaul, C - Vyat, D - Yusopovo-Novo-Khazin.

Smaller highs: 1 - Saklov, 2 - Ashit, 3 - Nagayevo-Aktanyshbash, 4 - Shishmin, 5 - Novo-Khazin north, 6 - Novo-Khazin south, 7 - Yusupovo, 8 - Ivanayev, 9 - Sultanbekov.

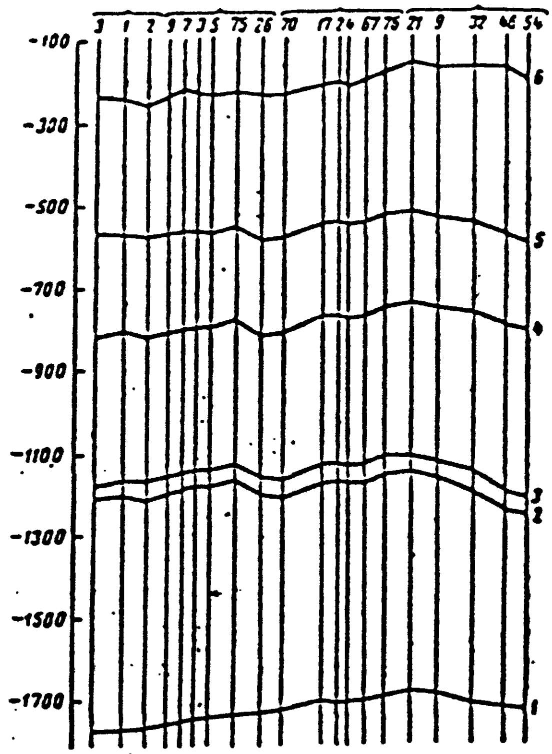


Figure 72.--Geologic profile along axis of Arlan-Dyurtyuli anticlinal zone.

Tops of: 1. - Kynoy horizon, 2 - Tournaisian stage, 3 - Tula horizon, 4 - Verey horizon, 5 - Middle Carboniferous, 6 - Artinsk stage.

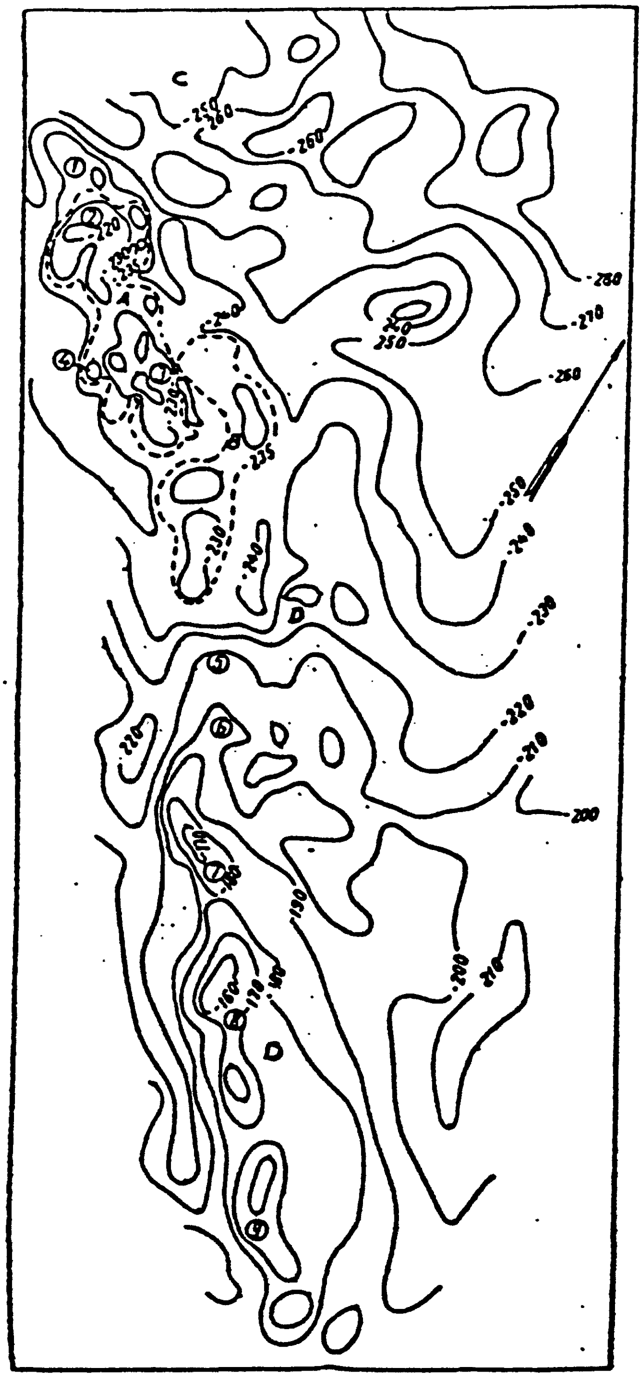


Figure 71.--Structure map on top of Artinsk stage of Arlan structure.

Symbols same as in fig. 70.

Five pay zones are present in the Tula Formation. Pay zone C-V occurs generally as lenses 2-3 m thick that shale out. It is not extensive in its occurrence. Pay zone C-IV is more widespread than C-V but also occurs as lenses; these are 1.5-2 m thick. Pay zone C-III occurs as north-trending channel deposits. These belts are up to 6 km wide (Tsotsur, 1974, p. 36). Pay zone C-II is the main producer at Arlan (Klubova, and others, 1968, p. 228). Oil-saturated sandstones within it are as much as 10.8 m thick. Elsewhere in the field, however, this pay is absent over large areas. Pay zone C-I occurs as channel deposits up to 2 km wide and 30 km long.

Porosity of the pay zones of the Tula horizon ranges from 16 to 22 percent. Average permeability is 632 millidarcies; however, values are as high as 5 darcies.

An oil pool is present in a channel sand of the Aleksin Formation on the northeast flank of the Arlan high. This pool is 4.5 km long, 0.3-1 km wide, and the oil column is up to 12.2 m high.

The seal for the pool is a unit of dense limestones of the Oka Formation. The height of the oil column is 30-35 m (Klubova, and others, 1968, p. 228-229).

Middle Carboniferous

The pay zones in the Kashira and Podolsk Formations are porous and cavernous dolomitized limestones and dolomites. Ten separate pay zones with a total thickness of 30-35 m are present (Klubova, and others, 1968, p. 229). Porosity is 7-30 percent, and permeabiltiy reaches 320 millidarcies. The reservoirs are lenses and beds 0.2-9 m thick. Total thickness of the reservoirs is up to 30 m (Vissarionova and Tyurikhin, 1963, p. 44-45). Nadeshkin (1962, p. 90-95) gives the height of the oil column here as 18.8 m.

Formation Conditions and Parameters of the Oil

Initial formation pressure in the Visean pools at Arlan is given as 142 atm by Maksimov and others (1970, p. 318). Trebin and others (1974, p. 138) list formation pressure at 99 atm. Saturation pressure is given as 81 atm and 75-79 atm by these same two sources. Formation temperature is 23-24° C. Gas-oil ratio is 16-21 m^3 per ton.

The oil is very viscous. Values range from 15 to 20 cps, whereas 2.0-1.5 is common for the Devonian oils of the region. Density is 0.874-0.881. Both density and viscosity increase downward along the section. Before deposition of the Visean horizon, there was a long break in deposition that lasted several million years. Oxidized rocks associated with this break are suggested as the causal factor in the oils in the lower part of the section having higher density and greater viscosity (Khalimov, and others 1978, p. 50-51). The asphalt (6-8 percent) and tar (20 percent) contents of the

Arlan oils are among the highest of all the fields of the Soviet Union (Berezin and Alekseyeva, 1963, p. 172). Sulfur content is 2.8-3.4 percent.

The oils of the Visean and Tournaisian stages are almost identical (Yegorova, 1963, p. 58). The pools are continous from the sediments of one stage to the other.

The oils of the pools in the Middle Carboniferous Kashira and Podolsk Formations differ from those of the Visean. Density is 0.866-0.868; sulfur content is 2.2-2.7 percent; asphalt content is 4 percent; and tar content is 12 percent. Carbon-sulfur isotopic ratios suggest that the oils of the Lower (Visean) and Middle (Kashira and Podolsk) Carboniferous formed independently of one another.

Development of the Field

In the Arlan region, structure is conformable from the Permian Artinsk down through the Lower Carboniferous pay zones. Exploration drilling was targeted on the top of the Artinsk; this surface was mapped by drilling shallow holes. Deep holes then explored the highs found on the top of the Artinsk (Ovanesov, 1960, p. 69). Seismic surveys were also made. The discovery well turned out to be on the crest of the structure on the Bobrikov Formation but on the northwest flank of the seismic structure (Ivanov, 1959, p. 556-557).

The six pay zones of Arlan field were grouped into two independent production zones, and each zone was drilled by an independent net of wells. According to Ovanesov and others (1963, p. 540), the upper production zone combines zones I-V and the lower is zone VI. Well density was 48 hectares per well, and 560 production wells were planned. Musin and others (1978, p. 1-7) state that there are 8 pay zones: I, II, III, IV°, IV, V, VI°, and VI. Zones I-III are grouped in the upper production zone, and IV°-VI in the lower. The original plan is said here to have called for 4,796 wells, 2,704 of which were production wells. As of January 1, 1975, a total of 4,690 wells had been drilled, and density was 1 well per 26 hectares. The International Petroleum Encyclopedia (1982, p. 353) places the number of wells at Arlan as 3,000. This last number may be the total production wells for the field.

Of the first 175 step-out wells only 12 failed to be commercial (Kulikov, 1961, p.484). The lensing nature of the reservoirs, however, requires infill drilling to pick up small isolated pools. Also, small structures with closure of 10-12 m are found to be present between wells drilled on a 800 by 600 m net. With an average thickness of sandstone of 2 m, 20 percent of the reserves will be missed using a 200 by 200 m well net, and 80 percent would be lost using an 800 by 800 m net. Where thickness is greater than 6 m, the density of the well net is not so important (Baymukhametov, 1976, p. 242-244).

Formation pressure has been maintained by injection. For the lower zone, the injection wells were beyond the margin of the field, and for the upper zone they were placed both beyond the margins and within the field. The pressure differential between lines of injection and producing wells was to be 70 atm for the lower zone and 90 atm for the upper (Ovanesov and others, 1963, p. 541).

Ovanesov and others (1963, p. 541) estimate a final recovery factor of 55 percent for Arlan. Kuzilov (1967, p. 252-253) gives an expected recovery of 42 percent for a well spacing of 24 hectares per well. Karimov and others (1978, p. 5-9) show recovery factors ranging from 27 to 38 percent for pay zones C_{II} and C_{VI} in the Novokhazin area of Arlan field. Musin and others (1978, p. 17) state that final recovery at Arlan should be 36.6 percent.

REFERENCES

Adler, F. J., 1971, Future petroleum provinces of the Mid-Continent, in Future Petroleum Provinces of the United States - their Geology and Potential: American Association Petroleum Geologists, Memoir 15, p. 985-1042.

Afanas'yev, T. P., 1975, Geothermal conditions of oil-gas regions: International Geological Review, v. 17, no. 2, p. 164-166.

Akishev, I. M., Muslimov, R. K., Lebedev, N. P., and Troyepol'skiy, 1974, Bitumen deposits of the Permian sediments of Tataria and prospects for their exploration: Geologiya Nefti i Gaza, no. 3, p. 23-28 (English translation in Petroleum Geology, v. 12, no. 3, p. 122-123).

Aleksin, A. G., Alekseyev, G. I., Mityakhina, L. I., and Khanin, I. L., 1974, Exploration for oil and gas pools of the non-dome type: Geologiya Nefti i Gaza, no. 10, p. 22-27 (English translation in Petroleum Geology, v. 12, no. 10, p. 487-488).

Aranova, S. M., Gassanova, I. G., Krems, A. Y., Lotsman, O. A., Liashenko, A. I., Maximov, S. P., Nechitailo, S. K., Pistrak, R. M., Radionova, K. P., and Sokolova, L. I., 1967, Devonian of the Russian Platform, in International Symposium on the Devonian System: Alberta Society Petroleum Geologists, Calgary, p. 379-396.

Armishev, A. M., and others, 1976, Geologic conditions for working the gas-oil pool in the Bashkir sediments of the Chutyrsko-Kiyengop field: Neftegazovaya Geologiya i Geofizika, no. 11, p. 13-16 (English translation in Petroleum Geology, v. 14, no. 6, p. 241-242).

Ashirov, K. B., 1960, Problem of the time for formation of the oil and gas pools of the Middle Volga area: Petroleum Geology, v. 4, no. 6-A, p. 336-339.

Ashirov, K. B., and Kolesov, V. S., 1974, Relationship of oil-gas productivity of the Verey horizon to lithology of sediments in the territory of the Kuybyshev-Orenburg region: Neftegazovaya Geologiya i Geofizika, no. 11, p. 18-20 (English translation in Petroleum Geology, v. 12, no. 5, p. 241-242).

Ashirov, K. B., Yefrenov, P. Y., and Trofimova, A. N., 1975, Characteristics of the salt-bearing unit of the Lower Permian on the Orenburg swell: Neftegazovaya Geologiya i Geofizika, no. 6, p. 20-23 (English translation in Petroleum Geology, v. 12, no. 11, p. 527-529).

Azamatov, V. I., Likhodedov, V. P., and Svikhnushin, N. M., 1968, O prirode zony perekhodnykh soprotivleniy v neftevodonosnykh plastakh gorizonta D_I Romashkinskogo mestorozhdeniya [Nature of the zone of transtional resistivities in water-bearing strata of horizon D_I of Romashkino field]: Geologiya Nefti i Gaza, no. 8, p. 26-30.

Baymukhametov, K. S., 1976, Systematic variations in the geology of clastic reservoirs of the Devonian and Lower Carboniferous and procedure for selection of production objectives in multi-strata pools in the early stages of planning (in the example of the Ural-Volga fields): Neftegazovaya Geologiya i Geofizika, no. 6, p. 17-21 (English translation in Petroleum Geology, v. 14, no. 1, p. 10-12).

Baymukhametov, K. S., 1976, Geologic features of the clastic unit of the Lower Carboniferous in the north part of Bashkiria and their effect on working the oil pools: Petroleum Geology, v. 14, no. 6, p. 242-244.

Begishev, F. A., Vakhitov, G. G., Sultanov, S. A., and Cholovskiy, L. P., 1963, Regulation of processes of working horizon D_I of Romashkino field: Petroleum Geology, v. 7, no. 10, p. 556-561.

Benderovich, L. Y., and others, 1977, Lower Permian reefs of the west border zone of the peri-Caspian depression: Petroleum Geology, v. 14, no. 7, p. 291-292.

Bol'shakov, Y. Y., 1975, Some aspects of the formation of the oil pools in the Ural-Volga region: Geologiya Nefti i Gaza, no. 8, p. 30-35 (English translation in Petroleum Geology, v. 13, no. 8, p. 351-352).

Bol'shakov, Y. Y., 1976, Features of the formation and distribution of oil and gas pools in the Lower Permian sub-salt sediments of the Ural-Volga area: Geologiya Nefti i Gaza, no. 5, p. 23-29 (English translation in Petroleum Geology, v. 14, no. 5, p. 209-212).

Bol'shakov, Y. Y., 1976, Oil-gas productivity of the depressions of the cis-Ural downwarp and some causes of its differences: Neftegazovaya Geologiya i Geofizika, no. 6, p. 21-24 (English translation in Petroleum Geology, v. 14, no. 1, p. 13-15).

Bond, D. C., Atherton, E., Bristol, H. M., Buschbach, T. C., Stevenson, D. L., Becker, L. E., Dawson, T. A., Fernalld, E. C., Schwalb, H., Wilson, E. N., Statler, A. T., Stearns, R. G., and Buehner, J. H., 1971, Possible future petroleum potential of Region 9 - Illinois basin, Cincinnati arch, and northern Mississippi embayment, in Future Petroleum Provinces of the United States: American Association Petroleum Geologists, Memoir 15, p. 1165-1218.

Borisov, A. A., 1961, Spatial regularities in the distribution of oil and gas pools: Petroleum Geology, v. 5, no. 7, p. 351-355.

Borisov, A. V., Leshchenko, V. Y., and Nosovskiy, V. I., 1976, New direction for oil and gas exploration in the Verkhne-Pechora depression of the cis-Ural downwarp: Geologiya Nefti i Gaza, no. 8, p. 1-6 (English translation in Petroleum Geology, v. 14, no. 8, p. 343-345).

Borushko, T. S., and Solov'yev, B. A., 1974, Structure of the sub-salt supra-Verey carbonate unit of the north border zone of the Caspian depression: Geologiya Nefti i Gaza, no. 12, p. 31-36 (English translation in Petroleum Geology, v. 12, no. 12, p. 596-598).

Botneva, T. A., 1958, Change of composition of oils in the fields of south-eastern Tatary: Petroleum Geology, v. 2, no. 5-B, p. 481-490.

Buchin, A. N., 1960, Ekonomicheskiye voprosy proyektirovaniya razrabotki Romashkinskogo neftyanogo mestorozhdeniya [Economic questions of planned working of Romashkino oil field]: Trudy VNII, no. 26, p. 19-39.

Bukharov, A. V., Gorshkov, V. I., Dal'yan, I. B., and Mil'nichuk, V. S., 1977, Geochemical characteristics of the Lower Permian sediments in the Aktyubinst near-Ural region: Neftigazovaya Geologiya i Geofizika, no. 6, p. 24-25 (English translation in Petroleum Geology, v. 14, no. 12, p. 528-529).

Bush, E. A., and Offman, P. Y., 1975, Oil-gas productivity of the south Urals in the light of new data: Geologiya Nefti i Gaza, no. 4, p. 20-24 (English translation in Petroleum Geology, v. 13, no. 4, p. 179-180).

Chakabayev, S. Y., Zhivoderov, A. B., Kiryukhin, L. G., Sinitsin, F. Y., and Dzhumagaliyev, T. N., 1976, Results of geological exploration for oil and gas in the ninth five-year plan in the Kazakh SSR and goals of the tenth five-year plan: Geologiya Nefti i Gaza, no. 11, p. 5-11 (English translation in Petroleum Geology, v. 14, no. 11, p 482-483).

Chakhmakhchev, V. A., Glezer, V. G., and Punanova, S. A., 1976, Geochemical regularities in the formation of oil pools in the Perm Kama region: Neftigazovaya Geologiya i Geofizika, no. 7, p. 22-26 (English translation in Petroleum Geology, v. 14, no. 2, p. 58-59).

Chernousov, V. D., 1963, K voprosu o formirovanii struktury Arlanskogo neftyanogo mestorozhdeniya [Question of formation of structure of Arlan oil field]: Geologiya Nefti i Gaza, no. 8, p. 42-45.

Chernousov, V. D., 1965, Method of constructing maps of effective thickness in calculating oil and gas reserves in the Arlan field: Petroleum Geology, v. 9, no. 4, p. 226-229.

Chizh, Y. I., 1977, Proterozoic-Paleozoic formations of the Volyno-Podol area that are favorable for oil and gas: Petroleum Geology, v. 14, no. 10, p. 460-461.

Cholovskiy, I. P., and Kinzikeyeva, N. P., 1962, Characteristics of the movement of the margins of oil pools and the front of injected water along strata of horizon D_I of the Romashkino field: Petroleum Geology, v. 6, no. 8, p. 450-457.

Chunosov, P. I., 1965, Effect of density of well net on the loss of oil in the Novo-Khazin area of the Arlan field: Petroleum Geology, v. 9, no. 4, p. 213-215.

Dakhnov, V. N., and Galimov, E. M., 1960, Karst type of porosity of productive carbonate sediments: Petroleum Geology, v. 4, no. 2-B, p. 95-99.

Danilova, T. Ye., and Diyashev, R. N., 1980, Comparison of lithologic composition of oil-saturated strata with flow profiles: Petroleum Geology, v. 16, no. 7, p. 294-296.

Demaison, G. J., 1977, Tar sands and supergiant oil fields: American Association Petroleum Geologists Bulletin, v. 61, no. 11, p. 1959-1961.

D'yakonov, D. I., Yakovlev, B. A., Tuzhilin, G. A., and Parfenenko, N. V., 1973, Osnovnyye osobennosti geotermicheskoy kharakteristiki Volgo-Ural'skoy neftegazonosnoy provintsii i Romashkinskogo neftyanogo mestorozhdeniya [Main features of the geothermal environment of the Volga-Ural oil-gas province and of Romashkino oil field]: Geologiya Nefti i Gaza, no. 7, p. 52-58.

Eisenstadt, G. E. A., and others, 1964, Geological structure and oil and gas content of Caspian depression: 22nd International Geological Congress, Proceedings, Part I, p. 159-176.

Eremenko, N. A., and Maksimov, S. P., 1960, Features of the distribution of oil and gas accumulations in the fore-mountain downwarps and adjacent parts of platforms: Petroleum Geology, v. 4, no. 6-A, p. 326-331.

Eynor, G. L., Bel'govskiy, G. L., and Smirnov, G. A., 1970, Carboniferous geology and paleogeography of the USSR: International Geological Review, v. 12, no. 2, p. 105-113.

Garetsky, R. G., Golov, A. A., Shuravlev, V. S., Nevolin, N. V., Samodurov, V. I., Fomenko, K. E., Eentov, Y. S., and Yanshin, A. L., 1972, The Caspian depression - the deepest depression of old platforms: 24th International Geological Congress, Section 3, Tectonics, p. 348-354.

Gattenberger, Yu. P., 1972, Vliyaniye izmeneniy plotnosti nefti na polozheniye vodo-neftyanogo kontakta i smeshcheniye zalezhey [Effect of changes of density of oil on position of water-oil contact and displacement of fields]: Geologiya Nefti i Gaza, no. 8, p. 12-17.

Gattenberger, Yu. P., and Khalimov, E. M., 1958, Lithologic oil deposits in Devonian sediments of the Ural-Volga area: Petroleum Geology, v. 2, no. 8-A, p. 718-725.

Gerasimov, V. G., 1964, Some practical conclusions in connection with investigations of hydrogeological observation wells in Tatar USSR: Petroleum Geology, v. 8, no. 7, p. 395-400.

Gorshkov, V. I., 1975, Catagenesis and paleotherms of the rocks of the southern part of the Bashkirian near-Ural area in connection with their oil-gas prospects: Petroleum Geology, v. 13, no. 2, p. 102-103.

Gromeka, V. I., and Svishchev, V. M., 1976, Main features of the geology and oil-gas productivity of the middle part of the cis-Ural foreland downwarp: Geologiya i Neftegazonosnost Priural'ya i Zapadnogo Sklona Urala: Moscow, "Nedra," p. 31-35 (English translation in Petroleum Geology, v. 14, no. 11, p. 506-507).

Halbouty, Michel, 1970, Geology of giant petroleum fields: Tulsa American Association of Petroleum Geologists, 575 p.

Hamilton, W., 1970, The Uralides and the motion of the Russian and Siberian platforms: Geological Society America Bulletin, v. 81, p. 2553-2576.

International Petroleum Enclopedia, 1981, Tulsa, Penn Well Publishing Co., 452 p.

Ivanov, L. I., 1959, Use of seismic surveying for study of gentle platform structures of Bashkiria: Petroleum Geology, v. 13, no. 9-B, p. 552-559.

Kaleda, G. A., and Kotel'nikova, E. D., 1974, Regularities in the distribution of carbonate reservoirs of the Bashkir stage on the tectonic structures of the Ural-Volga region: Geologiya Nefti i Gaza, no. 9, p. 66-72 (English translation in Petroleum Geology, v. 12, no. 9, p. 446-448).

Kamaletdinov, M. A., and Kazantsev, Y. V., 1976, Structure of the Yuryuznao-Sylven depression and prospects for finding structural traps for oil and gas: Geologiya Nefti i Gaza, no. 8, p. 16-21 (English translation in Petroleum Geology, v. 14, no. 8, p. 382-383).

Karimov, M. Sh., Tokarev, M. A., and Shcherbinin, V. G., 1979, Estimation of the conformance of strata by water flood based on geologic and well-logging data: Petroleum Geology, v. 16, no. 2, p. 61-63.

Karstev, A. A., 1963, Gidrogeologiya neftyanykh i gazovykh mestorozhdeniy [Hydrogeology of oil and gas fields]: Moscow, Gostoptekhizdat, 353 p.

Keller, B. M., Korolev, V. G., Semikhatov, M. A., and Chumakov, N. M., 1968, The main features of the Late Proterozoic paleogeography of the USSR: 23rd International Geological Congress, v. 4, p. 189-202.

Khachatryan, R. O., 1977, Role of the Volga-Ural province in preparing a sound base for the oil-producing industry of the USSR: Neftegazovaya Geologiya i Geofizika, no. 10, p. 11-14 (English translation in Petroleum Geology, v. 15, no. 4, p. 162-163).

Khalimov, E. M., Ulbarisov, E. M., and Karimov, M. Sh., 1978, Conditions determining the physical-chemical properties of oils of northwestern Bashkiria: Petroleum Geology, v. 15, no. 2, p. 50-51.

Khomentovskaya, O. A., Fomina, G. V., Dentskevich, I. A., Girskaya, V. I., Aleksandrova, G. A., and Chirkina, L. N., 1977, Geologic features of the Orenburg sector of the border zone of the peri-Caspian synclize: Neftegazovaya Geologiya i Geofizika, no. 4, p. 5-9. (English translation in Petroleum Geology, v. 14, no. 11, p. 471-473).

Kildayeva, F. F., 1964, Application of the impulse neutron-neutron method in the oil industry of Tatoria: Petroleum Geology, v. 8, no. 3, p. 158-162.

Klubova, V. A., Nechitaylo, S. K., and Petropavlovskiy, eds., 1968, Geologicheskiye zakonomernosti razneshcheniya neftyanykh i gazovykh mestorozhdeniy Volgo-Ural'skoy oblasti [Geologic regularities in the distribution of oil and gas fields of the Volgo-Ural region]: Trudy VNIGNI, no. 67, 271 p.

Klyucharev, V. S., and Fattakhutdinov, G. A., 1967, Novyye dannyye po tektonike Arlano-Dyurtyulinskoy zony [New data on the tectonics of the Arlano-Dyurtyuli zone]: Geologiya Nefti i Gaza, no. 3, p. 26-29.

Klyuchnikov, N. I., and Kazantsev, Y. V., 1974, Oil-gas prospects of the cis-Ural downwarp: Geologiya Nefti i Gaza, no. 12, p. 12-14 (English translation in Petroleum Geology, v. 12, no. 12, p. 589-590).

Kondaurova, N. V., 1975, Main features of the geology of the clastic Devonian of Udmurtia: Neftegazovaya Geologiya i Geofizika, no. 9, p. 6-9 (English translation in Petroleum Geology, v. 13, no. 4, p. 155-157).

Kondiain, A. G., and others, 1967, Devonian of the western slope of the Urals, in International Symposium on the Devonian System: Alberta Society Petroleum Geology, Calgary, p. 413-420.

Konokov, V. F., Volgina, A. I., and Kozak, O. K., 1975, Results of use of high-accuracy gravity surveying for exploration for reefs in the Volgograd region: Neftegazovaya Geologiya i Geofizika, no. 5, p. 37-42 (English translation in Petroleum Geology, v. 12, no. 10, p. 481-483).

Konovalov, V. V., 1977, New data on the geology of the southwestern part of the Orenburg area: Neftegazovaya Geologiya i Geofizika, no. 3, p. 6-7 (English translation in Petroleum Geology, v. 14, no. 10, p. 450-451).

Krebs, W., 1974, Devonian carbonate complexes of central Europe, in Reefs in Time and Space: Society Economic Paleontologists and Mineralogists, Spec. Publ. 18, p. 155-208.

Krebs, W., Germany, F. R., and Mountjoy, E. W., 1972, Comparison of central European and western Canadian Devonian reef complexes: 24th International Geologic Congress, Sec. 6, p. 294-309.

Kukharenko, Y. N., Khat'yanov, F. I., and Yunusov, N. K., 1977, Main geological results using common-depth-point seismic surveying in Bashkiria and prospects for exploration for new oil and gas fields: Neftegazovaya Geologiya i Geofizika, no. 2, p. 29-38 (English translation in Petroleum Geology, v. 14, no. 9, p. 388-391).

Kulchitskaya, Yu. K., Gorbunov, A. T., and Korol, M. I., 1958, Analysis of the development of productive horizon D_I in the Minnibaev and Abdrakhmanov areas: Petroleum Geology, v. 2, no. 8-B, p. 743-746.

Kulikov, F. S., 1959, Arlano-Dyurtyulin oil-bearing zone: Petroleum Geology, v. 3, no. 2-A, p. 84-91.

Kulikov, F. S., 1961, Methods of exploration for oil fields in Bashkiria: Petroleum Geology, v. 5, no. 9, p. 481-486.

Kulikov, F. S. and Ovanesov, G. P., 1958, The geology of the northern part of the Bashkir ASSR: Petroleum Geology, v. 2, no. 8-A, p. 689-698.

Kuzilov, I. A., 1967, Opredeleniye konechnoy nefteotdachi Arlanskoy ploshchadi s uchetom vliyaniya plotnosti razmeshcheniya skvazhin [Determination of final recovery factor of the Arlan area taking into account the effect of density of distribution of wells]: Trudy UFNII, no. 17, p. 246-253.

Kuznetsov, V. G., and Proshlyakov, V.K., 1977, Paleozoic carbonate formations of the southeast part of the Russian Platform and their oil-gas productivity: Petroleum Geology, v. 14, no. 11, p. 490-491.

Levet, M. N., 1950, Summary of Russian papers on upper Paleozoic reefs: Journal of Geology, v. 58, p. 426-429.

Likhodedov, V. P., Orlinskiy, B. M., and Gil'manshin, A. F., 1970, Vliyaniye osobennostey Zalezhey nefti na formu poverkhnosti VHK i moshchnost' perekhodnoy zony [Effect of oil-pool characteristics on the form of the surface of the water-oil contact and thickness of the transition zone]: Geologiya Nefti i Gaza, no. 5, p. 49-54.

Lisovskiy, N. N., Afanas'yev, V. S., Khlebnikov, V. D., and Nadezhkin, A. D., New commercial oil-bearing horizon on the southeast flank of the Russian Platform: Geologiya Nefti i Gaza, no. 3, p. 33-37 (English translation in Petroleum Geology, v. 14, no. 3, p. 124-126).

Lisovskiy, N. N., Khlebnikov, V. D., Kukharenko, Y. N., and Khat'yanov, F. I., 1974, New oil-bearing zone controlled by graben-like downwarps in Bashkiria: Geologiya Nefti i Gaza, no. 11, p. 22-29 (English translation in Petroleum Geology, v. 12, no. 11, p. 543-546).

Lisovskiy, N. N., Afanas'yev, V. S., and Nadezhkin, A. D., 1978, Oil prospects of the Serafimovsko-Baltayevo swell: Petroleum Geology, v. 15, no. 9, p. 27-30.

Litvinov, A. A., 1960, Interaction of horizons D_I and D_{II} in the central areas of the Romashkino field: Petroleum Geology, v. 4, no. 4-B, p. 230-235.

Lyndolph, Paul E., 1964, Geography of the U.S.S.R., New York: John Wiley and Sons, 683 p.

Makarov, G. V., Makarova, S. P., and Tagangayev, F. M., 1976, Oil prospects of the pre-Devonian and Devonian sediments of the southeast regions of the Orenburg region: Geologiya Nefti i Gaza, no. 5, p. 20-23 (English translation in Petroleum Geology, v. 14, no. 5, p. 207-208).

Maksimov, M. I., 1962, Spacing of production wells - an important economic measure: Petroleum Geology, v. 6, no. 8, p. 443-450.

Maksimov, M. M., and Rybitskaya, L. P., 1976, Matematicheskoye modelirovaniye processov razrabothi neftyanykh mestorozhdeniy [Mathematical modelling of processes of working oil field]: Moscow, "Nedra," 262 p.

Maksimov, S. P., and others, 1970, Geologiya Neftyanykh i Gazovykh Mestorozhdeniy Volgo-Ural'skoy Neftegazonosnoy Provintsii: Izd-vo Nedra, 808 p.

Maksimov, S. P., and Safonova, G. I., 1973, Genetic characteristics of petroleum in Devonian deposits: International Geological Review, v. 15, no. 5, p. 497-507.

Maksimov, S. P., Dmitriyeva, B. I., and Larskaya, Y. S., 1974, Conditions of primary migration of hydrocarbons in the Paleozoic sediments of the Buzuluk depression and its frame: Geologiya Nefti i Gaza, no. 1, p. 31-38 (English translation in Petroleum Geology, v. 12, no. 1, p. 33-36).

Maksimov, S. P., and Lavrushko, I. P., 1975, Distribution of commercial reserves of oil and gas by structural element and stratigraphic section in the USSR: Geologiya Nefti i Gaza, no. 6, p. 34-36 (English translation in Petroleum Geology, v. 13, no. 6, p. 249-250).

Maksimov, S. P., and others, 1975, Conditions of primary migration of hydrocarbons in the Paleozoic sediments of the Buzuluk depression and its frame: Petroleum Geology, v. 12, no. 1, p. 33-36.

Maksimov, S. P., Larskaya, Y. S., and Khakhanova, I. N., 1976, Formation of the Orenburg gas-condensate field: Geologiya Nefti i Gaza, no. 11, p. 11-22 (English translation in Petroleum Geology, v. 14, no. 11, p. 584-587).

Mal'tsev, M. V., 1957, Geologicheskoye stroyeniye Romashkinskogo neftyanogo mestorozhdeniya [Geology of the Romashkino oil field]: Geologiya Nefti, no. 11, p. 50-56.

Mamleyev, R. Sh., and Timonin, V. I., 1960, Results of testing the "transition zone" in the Pavlov and Zelenogorsk areas: Petroleum Geology, v. 4, no. 4-B, p. 226-230.

Medvedev, N. F., and Burovoy, A. M., 1974, Oil exploration in the Devonian clastics of the southeast flank of the Russian Platform: Geologiya Nefti i Gaza, no. 1, p. 25-28 (English translation in Petroleum Geology, v. 12, no. 1, p. 29-30).

Melamud, E. L., 1976, Tectonic features and oil-gas prospects of the Orenburg-Aktyubinsk part of the zone of foreland folds: Geologiya i Neftigazonosnost Priural'ya i Zapadnogo Sklona Urala: Moscow, "Nedra," p. 36-45 (English translation in Petroleum Geology, v. 14, no. 11, p. 508-509).

Melik-Pashayev, V. S. 1960, Vliyaniye geologicheskikh usloviy na polozheniye vodoneftyanogo kontakta i chetkost'yego otbivki [Effect of geologic conditions on position of water-oil interface and clarity of its recording]: Trudy, VNII, no. 30, p. 3-17.

Melik-Pashayev, V. S., Seregina, V. N., and Vlasenko, V. V., 1976, Variations in saturation pressure in oil pools of the Ural-Volga area and west Turkmenia: Neftegazovaya Geologiya i Geofizika, no. 5, p. 3-5 (English translation in Petroleum Geology, v. 13, no. 11, p. 506-507).

Melik-Pashayev, V. S., Vlasenko, V. V., Seregina, V. N., and Klimushin, I. M., 1979, Geological criteria determining the selection of pools for intraformational combustion: Petroleum Geology, v. 16, no. 2, p. 59-60.

Mel'nikov, A. M., and Shpil'man, Ye. A., 1958, Current problems of deep exploratory drilling in Tatary: Petroleum Geology, v. 2, no. 10-A, p. 589-866.

Mel'nikov, A. M., and Voytovich, E. D., 1960, Problem of exploration of buried Devonian structures in the east border of the Melekess depression: Petroleum Geology, v. 4, no. 5-A, p. 255-259.

Mirchink, M. F., 1964, Status of theory and practice of working oil fields: Petroleum Geology, v. 8, no. 6, p. 307-316.

Mirchink, M. F., and others, 1959, Special features of the geological structure of platform regions in the Soviet Union in relation to their oil and gas saturation, in World Petroleum Congress, Proceedings, Sec. 1, p. 525-538.

Mirchink, M. F., and others, 1965, Oil prospects and direction of geological exploration in the Kamsko-Kinel system of depressions: Geologiya Nefti i Gaza, v. 9, no. 9 (English translation in Petroleum Geology, Jan. 1972, p. 491-495).

Mirchink, M. F., Abrekosov, I. Kh., Kozhevnikov. I. I., Aksenov, A. A., Vayner, K. M., Varushchenko, A. I., Vinnikovskiy, S. A. Vissarionova, A. Ya., Gromeka, V. I., Khachatryan, R. O., and Ezdrin, M. B., 1970, Osnovnyye napravleniya regional' nykh geologo-geofizicheskikh rabot v Volgo-Ural'skoy neftegazonosnoy provintsii na 1971-1975 gg [Main directions of geological-geophysical work in the Volga-Ural oil-gas province in 1971-75: Geologiya Nefti i Gaza, no. 5, p. 1-9].

Mkrtchyan, O. M., 1965, Relationship of local structures of Devonian and Carboniferous horizons in downwarps of the Kamsko-Kinel system: Petroleum Geology, v. 9, no. 9, p. 513-518.

Mkrtchyan, O. M., Khat'yanov, F. I., and Shalaginova, F. P., 1965, Use of seismic surveying in exploration for oil-bearing structures related to Upper Devonian reefs: Petroleum Geology, v. 9, no. 2, p. 116-121.

Mukharskiy, E. D., and Lysenko, V. D., 1972, Proyektirovaniye razrabotki neftyanykh mestorozhdeniy platformennogo tipa [Projection of working of oil fields of the platform type]: Moscow, "Nedra," 239 p.

Murchison, R., Verneuil, E., and Keyserling, A., 1845, The geology of Russia in Europe and Ural Mountains, v. 1, London, J. Murray, 700 p.

Musin, M. Kh., Chernomorskiy, V. N., and Chunosov, P. I., 1963, Sopostavleniye i stroyeniye peschanykh plastov terrigennoy tolshchi nizhnego karbona severo-zapadnoy Bashkirii [Correlation and structure of sandy beds of the clastic unit of the Lower Carboniferous and northwestern Bashkiria]: Geologiya Nefti i Gaza, no. 6, p. 38-41.

Musin, M. Kh., Vasil'yev, I. P., and Khalimov, E. M., 1978, Effective method of slowing rates of drop in oil production in the late stage of production: Petroleum Geology, v. 16, no. 1, p. 16-17.

Muslimov, R. K., 1975, Status and ways of increasing effectiveness of geological exploration in the Tatar ASSR: Geologiya Nefti i Gaza, no. 12, p. 6-12 (English translation in Petroleum Geology, v. 12, no. 12, p. 584-585.

Muslimov, R. Kh., 1978, Results of geological exploration for oil and goals of the Tenth Five Year Plan for the Tatar ASSR: Petroleum Geology, v. 15, no. 5, p. 192-195.

Muslimov, R. Kh., Abdullin, N. G., Kirshfel'dt, Y. E., and Suyetenkov, V. S., 1976a, Final exploration of carbonate sediments of the Devonian and Carboniferous of the Romashkino and Novo-Yelkhov fields of the Tatar ASSR: Neftegazovaya Geologiya i Geofizika, no. 5, p. 5-8 (English translation in Petroleum Geology, v. 13, no. 11, p. 507-508).

Muslimov, R. Kh., Suleymanov, E. I., and Mochalov, Y. Y., 1976b, Method of final outlining of small fields in Tataria: Neftegazovaya Geologiya i Geofizika, no. 10, p. 17-21 (English translation in Petroleum Geology, v. 14, no. 5, p. 192-193).

Muslimov, R. Kh., Kaveyev, I. Kh., and Baranov, V. V., 1979, Geologic factors in oil exploration in Riphean-Wendian sediments of East Tataria: Petroleum Geology, v. 16, no. 2, p. 65-67.

Nadezhkin, A. D., 1962, Characteristics of the oil productivity of the Carboniferous sediments of Bashkiria: Petroleum Geology, v. 6, no. 2, p. 90-95.

Nadezhkin, A. D., Seyfullin, M. S., and Chernomorskiy, V. N., 1963, Korrelyatsiya razrezov neftenosnykk gorizontov nizhnego karbona osnovnykh neftyanykh mestorozhdeniy Bashkirii [Correlation of sections of oil-bearing horizons of the Lower Carboniferous of the main oil fields of Bashkiria]: Trudy, UFNII, no. 9-10, p. 60-70.

Nalivkin, V. D., Kulikov, F. S., Morozov, S. G., and Slepov, Yu. N., 1964, New large autocogen in the east of the Ural-Volga area: Petroleum Geology, v. 8, no. 3., p. 143-147.

Nalivkin, D. V., 1967, Devonian reefs in the Urals, in International Symposium on the Devonian System: Alberta Society Petroleum Geology, v. 2, p. 331-332.

Nalivkin, V. D., 1976, Dynamics of the development of the Russian Platform structures, in Tectonophysics: Elsevier Publishing Co., p. 247-262.

Nikulin, A. V., and Sharonov, L. V., 1960, Structure and oil productivity of the upper Tournaisian and lower Visean sediments of southeast Tataria: Petroleum Geology, v. 4, no. 7-A, p. 386-389.

Ovanesov, G. P., 1960, Method of exploration and prospecting of large oil fields of Bashkiria: Petroleum Geology, v. 4, no. 2-A, p. 69-73.

Ovenesov, G. P., Abrikosov, I. K., and Khachatryan, R. O., 1972, Reefs of the Kamsk-Kinelsk system of troughs and their role in the process of oil accumulation: 24th International Geological Congress, Sec. 5, p. 99-103.

Ovanesov, G. P., Khalimov, E. M., and Sayfullin, M. S., 1963, Status and ways of improving the working of the Arlan oil field: Petroleum Geology, v. 7, no. 10, p. 539-545.

Per'kov, N. A., ed., 1961, Al'bom tipovykh geologo-geofizicheskikh pazrezov skvazhin neftyanykh rayonov Volgo-Ural'skoy provintsii [Album of typical geological-geophysical sections of wells of oil regions of the Volga-Ural province]: Moscow, Gostoptekhizdak, p. 59-62.

Petroconsultants S.A., Geneva 11, Switzerland.

Poddubnyy, Yu. A., 1977, Opredeleniye effektivnosti rabot po ogranicheniyu pritokov vody v neftyanyye skvazhiny [Determination of effectiveness of work on limiting flows of water in oil wells]: Neftyanoye Khozyaystvo, no. 8, p. 8-10.

Potapov, V. P., and Abashev, S. V., 1974, Estimation of reservoir properties and oil-gas saturation of Paleozoic sediments of the cis-Ural downwarp: Geologiya Nefti i Gaza, no. 3, p. 28-33 (English translation in Petroleum Geology, v. 12, no. 3, p. 124-125).

Provorov, V. M., Konev, P. N., Kuznetsov, Y. I., Chalov, B. Y., and Shvarev, V. N., 1976, Structure of the north border of the Sarapul depression of the Kamsko-Kinel system and further direction for oil exploration: Geologiya Nefti i Gaza, no. 8, p. 43-46 (English translation in Petroleum Geology, v. 14, no. 8, p. 357-358).

Robertson Research International Limited, 1976, The petroleum industry in the U.S.S.R., Petroleum geology of the sedimentary basins, v. 2: Rueil-Malmaison.

Rodionova, K. F., 1964, Estimation of potential oil reserves by the volume genetic method: Petroleum Geology, v. 8, no. 12, p. 671-678.

Ronov, A. B., 1958, Organic carbon in sedimentary rocks (in relation to the presence of petroleum): Geochemistry, v. 5, p. 510-536.

Rostovtsev, N. N., 1964, Methods for determining productivity of structures in oil and gas regions: Petroleum Geology, v. 8, no. 7, p. 361-367.

Rovenskaya, A. S., and Kalmykov, G. S., 1978, Zonality in the distribution of oils and catagenesis of Devonian and Lower Carboniferous units of the Ural-Volga region: Geologiya Nefti i Gaza, no. 6, p. 8-13.

Ryabukhin, G. Y., and Bykov, V. F., 1974, Prospects for discovery of oil and gas fields in reef masses and reef facies of the USSR: Geologiya Nefti i Gaza, no. 7, p. 27-33 (English translation in Petroleum Geology, v. 12, no. 7, p. 330-331).

Rybin, F. S., 1960, O gidrodinamicheskoy svazi gorizontov D_I and D_{II} tsentral'nykh ploshchadey Romashkinskogo mestorozhdeniya nefti [Hydrodynamc connection of horizons D_I and D_{II} of the central areas of Romashkino field]: Trudy VNII, no. 30, p. 86-95.

Rzhonsnitskaya, M. A., 1967, Devonian of the USSR, in International Symposium on the Devonian System: Alberta Society Petroleum Geology, Calgary, p. 331-348.

Sadreyev, A. M., and Sayfullin, Z. G., 1976, Features of the structure and formation of bitumen accumulations in lensoid strata of the Sheshmin sandstones on the west flank of the south cupola of the Tatar dome: Neftegazovaya Geologiya i Geofizika, no. 1, p. 23-27 (English translation in Petroleum Geology, v. 13, no. 6, p. 269-271).

Sayfullin, M. S., and Pavlov, V. P., 1964, Estimation of the current recovery factor for the flooded part of stratum VI of the Ashit sector of the Arlan oil field: Petroleum Geology, v. 8, no. 10, p. 570-575.

Semin, Ye. I., 1960, Izucheniye svyazi mezhadu poristost'yu i pronitsayemost'yu porod gorizonta D_I Romashkinskogo i Tuymazinskogo neftyanykh mestorozhdeniy [Study of the relationship between porosity and permeability of rocks of horizon D_I of Romashkino and Tyymazy fields]: Trudy, VNII, no. 30, p. 18-35.

Shadrina, N. N., 1975, Oil productivity of the Middle Carboniferous sediments in the Tavtimanov area of the Ufa region of Bashkiria: Neftegazovaya Geologiya i Geofizika, no. 12, p. 17-19 (English translation in Petroleum Geology, v. 13, no. 5, p. 234-235).

Shadrina, N. N., 1977, Exploration for Devonian oil pools associated with graben-like downwarps of the southeast flank of the Russian Platform: Neftegazovaya Geologiya i Geofizika, no. 6, p. 11-17 (English translation in Petroleum Geology, v. 14, no. 12, p. 522-525).

Shapiro, D. A., 1962, Determination of the initial water-oil contact in the clastic reservoirs of the Devonian of Tataria: Petroleum Geology, v. 6, no. 9, p. 563-568.

Shaykhutdinov, R. S., 1975, Prospects and exploration methods for structural-lithologic oil pools of the Tatar dome: Neftegazovaya Geologiya i Geofizika, no. 12, p. 13-16 (English translation in Petroleum Geology, v. 13, no. 5, p. 232-233).

Shikhov, S. A., Kuznetsov, Y. I., Provorov, V. M., Vetchinkin, V. E., and Sosland, S. A., 1976, Systematic variations in the distribution of Upper Devonian-Lower Carboniferous reefs in the north part of the Ural-Volga area and geophysical methods for distinguishing them: Geologiya Nefti i Gaza, no. 1, p. 55-60 (English translation in Petroleum Geology, v. 14, no. 1, p. 38-40).

Shishenina, Y. P., Kulibakina, I. B., Kazakova, K. I., Popova, N. V., Bavrina, A. F., and Yevdokimova, D. D., 1976, Composition of the organic matter and of hydrocarbon fluids in individual marginal depressions of the cis-Ural downwarp: Neftegazovaya Geologiya i Geofizika, no. 10, p. 22-26 (English translation in Petroleum Geology, v. 14, no. 5, p. 196-198).

Shvemberger, Y. N., 1979, Predicting the dimensions of oil and gas fields: International Geological Review, v. 21, no. 9, p. 1015-1017.

Sinyavskiy, Ye. I., Neprimerov, N. N., Nizamov, R. Kh., Nikolayev, S. A., and Khodyreva, E. Ya., 1973, Geotermicheskiye usloviya Romashkinskogo i Novo-Yelkhov neftyanykh mestorozhdeniy [Geothermal conditions at Romashkino and Novo-Yelkhov oil fields], in Voprosy eksperimental'noy geotermologii: Kazan, Izdatel'stvo Kazanskogo Universiteta, p. 97-101.

Smirnov, L. P., 1958, Oil-bearing basins on the eastern edge of the Russian Platform, in Habitat of Oil: American Association Petroleum Geologists Bulletin, p. 1168-1181.

Smirnova, A. A., 1963, Prognoz obvodnennosti otbirayemoy zhidkosti v usloviyakh intensifikatsii razrabotki kol'tsevoy chasti Minnibayevskoy ploshchadi Romashkinskogo mestorozhdeniya [Prediction of water content by withdrawn liquid under conditions of intensification of working the ring portion of the Minnibayevo area of Romashkino field]: VNII, Nauchno-tekhnicheskii sbornik po dobyche nefti, no. 19, p. 77-84.

Smirnova, N. V., 1961, Effect of silicification on the reservoir properties of the Devonian sandstones of the Volga-Ural area: Petroleum Geology, v. 5, no. 7, p. 376-381.

Sokolov, V. L., Garkusha, M. P., and Golubeva, Z. V., 1976, Elements of tectonic and oil-gas-geologic regionalization of the west flank of the south Urals, in Geologiya i Neftegazonosnost Priural'ya i Zapadnogo Sklon Urala: Moscow, "Nedra," p. 56-68 (English translation in Petroleum Geology, v. 14, no. 11, p. 514-517).

Stankevich, Y. F., and Zabirov, A. G., 1960, Static level of subsurface waters in the lower Kama and central Volga areas: Petroleum Geology, v. 4, no. 10-B, p. 581-583.

Stankevich, Y. F., and others, 1977, Hydrogeological bases of oil exploration in the Riphean-Wendian sediments of east Tataria: Petroleum Geology, v. 14, no. 12, p. 526-529.

Strakhov, N. M., 1962, Principles of historical geology: Washington, Office of Technical Service, 432 p.

Suleymanov, R. G., and Bazev, N. S., 1974, Petroleum potential of the Bavly (pre-Devonian) sediments of southwest Bashkiria: Geologiya Nefti i Gaza, no. 1, p. 28-31 (English translation in Petroleum Geology, v. 12, no. 1, p. 31-32).

Suleymanov, E. I., and Abdullin, N. G., 1975, Geological-production characteristics of the pay zones of the Middle Carboniferous in the small fields of the west flank of the south cupola of the Tatar dome in connection with placing them in production: Neftegazovaya Geologiya i Geofizika, no. 4, p. 11-15 (English translation in Petroleum Geology, v. 12, no. 9, p. 419-421).

Svetlakova, E. A., and Kopytchenko, V. N., 1978, Formation and distribution of gas-oil accumulations in the Paleozoic subsalt deposits of the northern marginal zone of the Caspian depression: International Geological Review, v. 20, no. 11, p. 1330-1338.

Svishchev, B. S., and Militko, I. F., 1958, Separation and classification of oil-bearing strata in the Minnibaev area: Petroleum Geology, v. 2, no. 6-B, p. 571-573.

Tikhy, N. Y., 1967, Main features of the Devonian history of the USSR, in International Symposium on the Devonian System: Alberta Society Petroleum Geology, Calgary, p. 349-358.

Trebin, G. F., Charygin, N. V., and Obukhova, T. M., 1980, Nefti mestorozhdeniy Sovetskogo Soyuza Moscow "Nedra", 582 p.

Tsotur, V. S., 1974, Channel oil pools in clastic sediments of the Lower Carboniferous of Western Bashkiria: Geologiya Nefti i Gaza, no. 10, p. 33-39, (English translation in Petroleum Geology, v. 12, no. 10, p. 489-491).

Uspenskaya, N. Y., and Bykov, V. F., 1972, Some regularities in the distribution of the reef-type oil and gas fields: 24th International Geological Congress, Sec. 5, Proceedings, Mineral Fuels Sec., p. 114-120.

Uspenskaya, N. Yu., and Khachatryan, R. O., 1977, Effect of hinge-movements on the formation of oil fields of the South Tatar arch: Doklady Earth Science Sections, v. 223, nos. 1-6, p. 105-107.

Vakhitov, G. G., and Sultanov, S. A., 1961, Experience in the development of the Romashkino oil field: Petroleum Geology, v. 5, no. 5, p. 236-241.

Valeyev, R. N., Klubov, V. A., and Ostrovskiy, M. I., 1969, A comparative analysis of the conditions of formation and spatial distribution of the aulacogens on the Russian Platform: International Geologic Review, v. 12, no. 4, p. 439-446.

Valilyev, V. G., Maksimov, S. P., and Trofimuk, A. A., 1964, Oil and gas-bearing basins of the USSR: 22nd International Geological Congress, Proceedings, Part I, Geology of Petroleum, p. 144-158.

Valitov, N. B., 1972, Regional variations in properties of oils of Tataria: International Geologic Review, v. 14, no. 1, p. 54-64.

Varentsov, M. I., Doroshko, S. M., Korolyuk, I. K., Tumanov, P. A., Bluket, A., Bogatskaya, G. I., Melamud, Y. L., Sidorov, A. D., Kirillova, I. A., and Chichmarev, V. G., 1976, Comparative characteristics of the geology and prospects for oil and gas of the northern and southern depressions of the cis-Ural foreland downwarp, in Geologiya i Neftegazonosnost Priural'ya i Zapadnogo sklona Urala: Moscow, "Nauka," p. 5-30, 1976 (English translation in Petroleum Geology, v. 14, no. 11, p. 502-505).

Vasil'yev, V. G., and others, 1963, Main results of oil and gas exploration in the USSR during 1962: Geologiya Nefti i Gaza, v. 7, no. 3 (English translation in Petroleum Geology, 1967, p. 115-122).

Vaynbaum, S. Y., and Chiruk, G. N., 1974, Structural noses and terraces in the upper horizons of the Paleozoic as exploration criteria for buried oil-gas structures: Geologiya Nefti i Gaza, no. 4, p. 33 (English translation in Petroleum Geology, v. 12, no. 4, p. 188-190).

Vinnikovskiy, S. A., Krasil'nikov, B. V., Kuznetsov, Y. I., Nikulin, A. V., and Rybakov, V. N., 1975, Distribution of Kamsko-Kinel system of downwarps in the northwest part of the Permian region: Geologiya Nefti i Gaza, no. 9, p. 20-23 (English translation in Petroleum Geology, v. 13, no. 9, p. 402-403).

Vinnikovskiy, S. A., Koblova, A. Z., and Belokon, T. V., 1976, New data on the content of vanadium and nickel complexes of porphyrins in oils and bitumens of rocks of the northeast of the Russian Platform and cis-Ural downwarp: Geologiya Nefti i Gaza, no. 9, p. 54-59 (English translation in Petroleum Geology, v. 14, no. 9, p. 402-404).

Vissarionova, A. Ya., 1959, Characteristics of the Lower Carboniferous terrigenous section of northwestern Bashkiria: Petroleum Geology, v. 3, no. 6-B, p. 357-361.

Voinov, V. V., 1966, Opyt izucheniya preryvistosti plasta po geologicheskim dannym [Experience in study of discontinuity of a stratum from geological data]: Trudy, VNII, no. 44, p. 31-40.

Voronov, A. V., 1975, Some systematic variations in the composition of natural gases in the north of the Volga-Ural area: Neftegazovaya Geologiya i Geofizika, no. 4, p. 15-18 (English translation in Petroleum Geology, v. 12, no. 9, p. 422-423).

Voytovich, Y. D., and Kenzin, F. A., 1974, Systematic distribution of oil in lower horizons of the carbonate Devonian of Tataria and methods of exploring them: Geologiya Nefti i Gaza, no. 3, p. 6-10 (English translation in Petroleum Geology, v. 12, no. 3, p. 120-121).

Voytovich, Y. D., and Shel'nova, A. K., 1977, Effect of pre-Vizean erosional incisement on the distribution of oil in Lower Carboniferous sediments of Tataria: Geologiya Nefti i Gaza, no. 3, p. 17-22 (English translation in Petroleum Geology, v. 14, no. 3, p. 122-124).

Yarullin, K. S., and Romanov, V. A., 1974, Exploration for oil and gas pools in the pre-Paleozoic sediments of the southern cis-Urals: Geologiya Nefti i Gaza, no. 12, p. 15-20 (English translation in Petroleum Geology, v. 12, no. 12, p. 591-593).

Yarullin, K. S., and Yanusov, 1976, Exploration for oil-bearing reefs in the platform part of Bashkiria: Geologiya Nefti i Gaza, no. 1, p. 39-44 (English translation in Petroleum Geology, v. 14, no. 1, p. 30-32).

Yarullin, K. S., and Yanusov, N. K., 1976, Exploration for oil-bearing reefs in the platform part of Bashkiria: Petroleum Geology, v. 14, no. 1, p. 30.

Yegorov, I. S., 1963, O dez'yunktivnom kharaktere ryada tektonicheskikh dislokatsiy Nizhnego Prikam'ya [Disjunctive character of several tectonic dislocations of the Lower Kama region]: Geologiya Nefti i Gaza, no. 8, p. 45-50.

Yudintsev, Ye. A., 1979, Water-drive factor in horizon D_I of fields of Tataria: Petroleum Geology, v. 16, no. 2, p. 64-65.

Yurchak, V. P., 1965, Litologicheskaya kharakteristica i kollektorskiye svoystva karbonatnykh porod Turneyskogo yarusa Arlanskogo mestorozhdeniya [Lithologic characteristics and reservoir properties of carbonate rocks of the Tournaisian stage of the Arlan field]: Trudy, VNII, no. 43, p. 260-269.

Zabirov, A. G., 1958, Some features of the water-oil contact of oil pools of the Devonian of the Romashkino oil field: Petroleum Geology, v. 2, no. 11-A, p. 943-945.

Zorkin, L.M., et al., Petroleum Geology, v. 11, no. 8, p. 348. Good regional study of subsurface water dynamics showing favorable and unfavorable areas.

Zubov, I. P., and Dement'yeva, G. V., 1975, Exploration for nonstructural oil pools in the clastic Devonian of the Volga-Ural oil-gas province: Neftegazovaya Geologiya i Geofizika, no. 12, p. 8-12 (English translation in Petroleum Geology, v. 13, no. 5, p. 230-232).