UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Sedimentary basins of Northeastern USSR

by

James W. Clarke[1]

Open-File Report 88-264

This report is preliminary and has not been reviewed for conformity with U.S. Geological Survey editorial standards and stratigraphic nomenclature.

[1] Reston, Virginia

1988

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ABSTRACT

The main structural features of the Soviet Far Northeast are: massifs of Precambrian and Paleozoic age, the Verkhoyansk-Chukotsk Mesozoic folded region on the north and west, the Koryak-Kamchatka Cenozoic folded region on the southeast, and the Okhotsk-Chukotsk Late Cretaceous-Paleogene volcanic belt in between. The sedimentary basins described in this paper are superimposed on these large structural features.

The Il'pin and Olyutor basins are filled by clastic sediments several thousand meters thick. Eocene-Oligocene and Lower Miocene source beds are present in both basins. Reservoir rocks, seals, and traps are also present. These basins are gas-prone.

The Khatyrka basin is largely offshore. The fill consists of Cretaceous and Cenozoic marine clastic deposits up to 13-15 km thick. Some source beds have been found, and these are in the oil window. Eocene-Oligocene and Lower-Middle Miocene plays have potential here.

The Pustorets basin has a folded basement of Cretaceous rocks and a Cenozoic fill several thousand meters thick. Albian-Aptian sedimentary rocks of the basement are a possible oil-gas play. Paleocene-Eocene source rocks are within the oil window. Sufficient reservoir rocks, seals, and traps appear to be present. An area of 13,000 km^2 is assessed as favorable.

The Penzhin basin is filled by Aptian-Middle Albian argillites and siltstones 3-5 km thick, Upper Cretaceous sandstones and volcanic rocks several thousand meters thick, and Paleogene volcanic and coal-bearing clastic rocks a few hundred meters thick. No oil plays are recognized because of lack of source beds. Gas may be present in deep parts of the basin.

The Parapol basin is a half graben filled by Upper Cretaceous and Tertiary coarse-clastic near-shore marine and continental deposits.

The Anadyr basin is largely offshore. The main basin fill is upper Eocene-Oligocene and Neogene clastic and volcanic deposits, which are 3 and 3.5-5 km thick, respectively. Possible oil source beds are present in the Eocene and Oligocene series; also, they are in the oil window. The Neogene section is not mature enough for oil but may contain gas pools. Two gas pools and one oil field have been discovered in the basin.

The Indigirka-Zyryanka basin has an area of 70,000 km^2 and is filled almost entirely by Upper Jurassic and Cretaceous sediments. The Volgian Series consists of up to 8 km of sandstone, siltstone, and shale. The Lower Cretaceous is also several thousand meters thick and likewise is composed of clastic sediments. The Upper Cretaceous consists of a few hundred meters of clastic deposits. Possible source rocks are present in the folded Paleozoic sedimentary rocks of the basement of this basin. Devonian Domanik facies are found in some places here. The Upper Jurassic and Lower Cretaceous argillaceous rocks are source beds and have entered the oil window. The Lower Cretaceous will be more gas-prone because of the humic character of its

organic matter. Two plays are recognized; the Paleozoic play and a Lower Cretaceous play.

The Moma basin contains in general the same rock types as the Indigirka-Zyryanka except that the section is thinner. This basin is assessed as having no oil-gas potential because of low contents of organic matter and unsatisfactory reservoirs.

INTRODUCTION

The geologic history of the Soviet Far Northeast has been marked by great diversity, and much remains to be learned as to the nature of the tectonic collisions and volcanic activity that have been central in the accretion of this vast area. The present paper addresses the latest structural features of the region, the sedimentary basins, which are Late Mesozoic and Cenozoic in age. The descriptions are taken largely from Til'man and others (1969) and Ivanov (1985).

REGIONAL GEOLOGY

The structural divisions of the northeast part of the USSR are based on the age of folding of the terranes. This is the late geosynclinal or orogenic stage. The following structural features are recognized: massifs of Precambrian and Paleozoic age, Verkhoyansk-Chukotsk Mesozoic folded region, Koryak-Kamchatka Cenozoic folded region, and the Okhotsk-Chukotsk volcanic belt (fig. 1). The Precambrian and Paleozoic massifs are basement for the folded regions and volcanic belt.

Verkhoyansk-Chukotsk Mesozoic folded region

Extensive areas of mountains and lowlands of northeastern Asia are underlain by folded geosynclinal rocks of Mesozoic age. On the west between the Siberian craton and the Kolyma massif is the Yana-Kolyma belt, and on the east is the Chukotsk belt. Common to both these belts is that the principal orogenic pulse was in Late Jurassic-Early Cretaceous time. This coincides in time with the early pulses of the Laramide orogeny in western North America. The boundary between the Yana-Kolyma and Chukotsk belts is along the Kolyma suture (fig. 1).

Yana-Kolyma belt. The basement for this belt consists largely of Riphean and Lower-Middle Paleozoic carbonate and clastic sedimentary rocks. Their thickness is as much as 16,000 m. These rocks appear to be platformal deposits that rest on Proterozoic and Archean metamorphic rocks, which are exposed in several places. They pass upward with no significant break into the Verkhoyansk complex, which is the main sedimentary fill of the geosyncline that was destined to become the Yana-Kolyma belt. Deposition of the Verkhoyansk complex began at about the time of the Hercynian orogenic closure of the Ural-Mongolian geosynclinal belt to the southwest and west. The subsidence may have been a sagging phenomenon on the trailing edge of the Asiatic plate.

The Verkhoyansk complex consists of sedimentary rocks from the Middle Carboniferous to the Callovian, inclusively (7 of fig. 2). At the crests of anticlinoria are Middle-Upper Carboniferous and Lower Permian units, and on the flanks are Upper Permian and Lower Triassic. The transition to synclinoria is smooth, rarely accompanied by faulting. The borders of the synclinoria are composed of Middle-Upper Triassic rocks, and Jurassic units are in the axial zones.

The folds of the Verkhoyansk complex are very large, extending several hundred kilometers in length and not less than 80 km wide. They are generally open to steep (fig. 3) but not overturned, except on the west where these rocks are overthrust onto the Cis-Verkhoyansk foredeep.

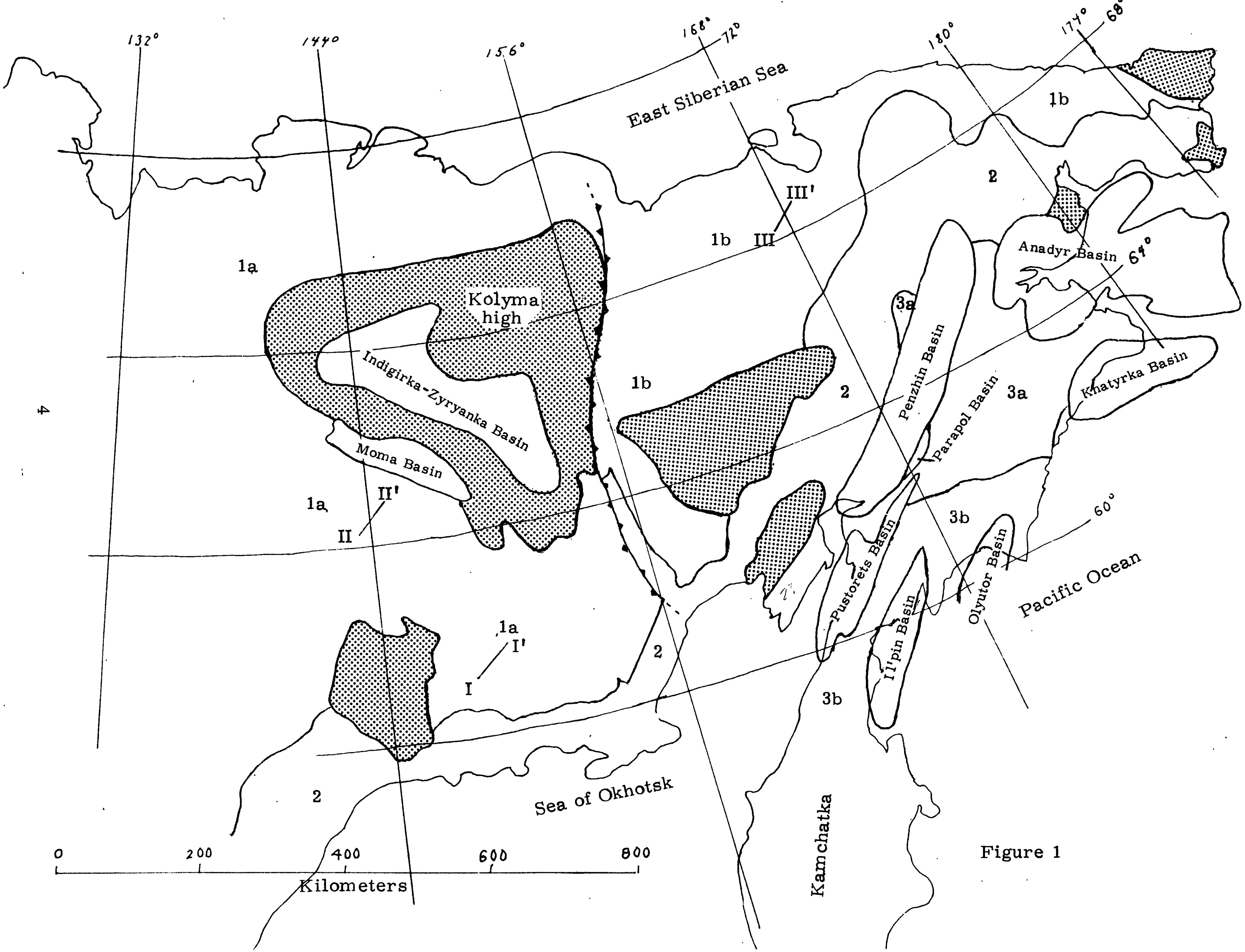
132°
144°
156°
168°
72°
180°
174°
68°
64°
60°
East Siberian Sea
1a
1b
2
3a
3b
III'
III
II'
II
I'
I
Kolyma high
Indigirka-Zyryanka Basin
Moma Basin
Anadyr Basin
Khatyrka Basin
Penzhin Basin
Parapol Basin
Pustorets Basin
Il'pin Basin
Olyutor Basin
Pacific Ocean
Sea of Okhotsk
Kamchatka
0
200
400
600
800
Kilometers

Figure 1

Figure 1. Tectonic map of Soviet Far Northeast, showing location of basins described in this report (compiled from numerous sources)

1 - Verkhoyansk-Chukotsk Mesozoic folded region
- 1a - Yana-Kolyma belt
- 1b - Chukotsk belt

2 - Okhotsk-Chukotsk volcanic belt

3 - Koryak-Kamchatka Cenozoic folded region
- 3a - Anadyr-Koryak belt
- 3b - Olyutor-Kamchatka belt

Precambrian and Paleozoic massifs

Kolyma suture

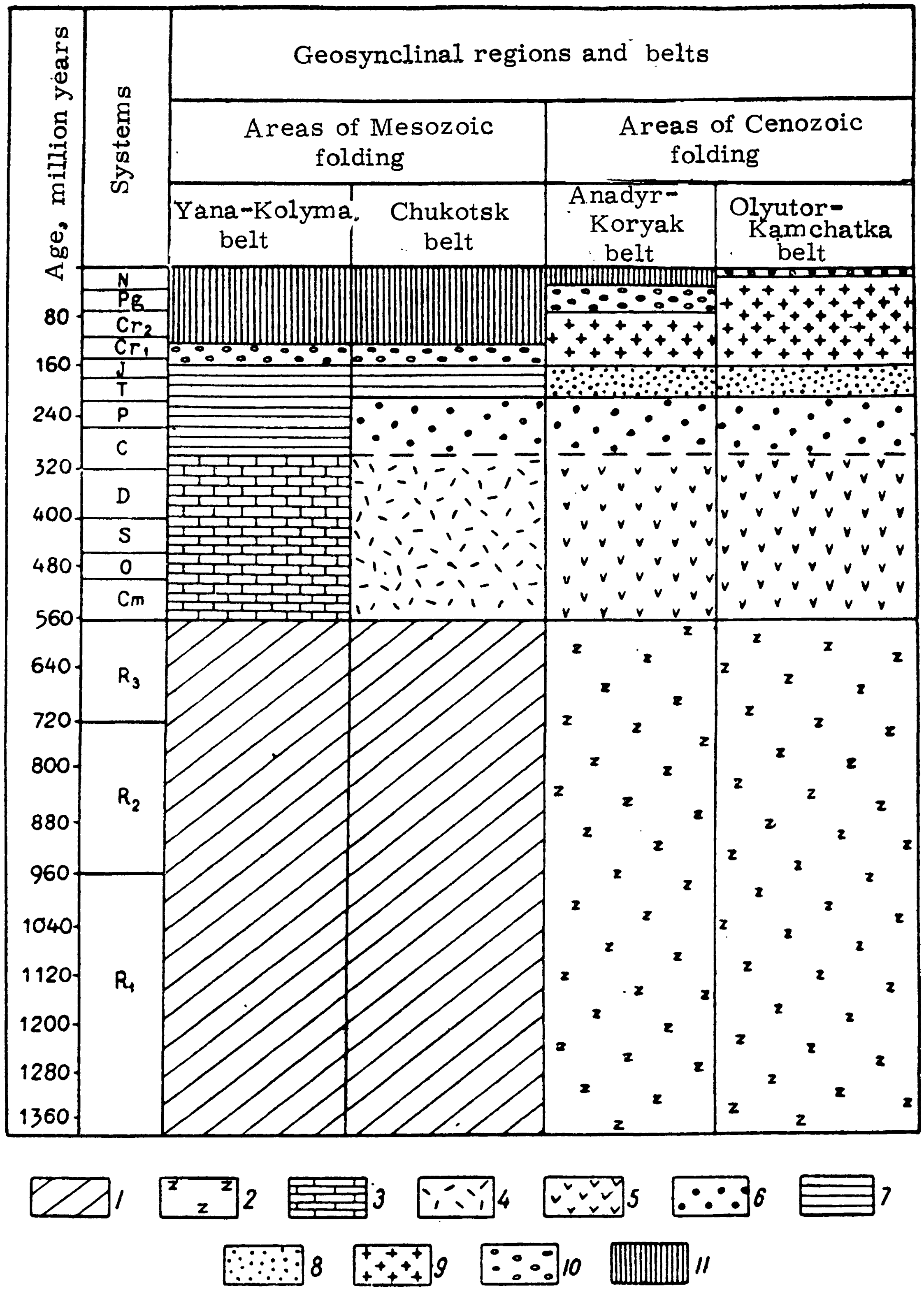
Age, million years
Systems
Geosynclinal regions and belts
Areas of Mesozoic folding
Areas of Cenozoic folding
Yana-Kolyma belt
Chukotsk belt
Anadyr-Koryak belt
Olyutor-Kamchatka belt
N
Pg
Cr2
Cr1
J
T
P
C
D
S
O
Cm
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Figure 2

Figure 2. Stages in the development of the geosynclinal-folded regions and systems of Northeastern USSR (after Til'man and others, 1969)

1--Riphean substrat, miogeosynclinal complex; 2--same, probably eugeosynclinal complex; 3--Lower and Middle Paleozoic substrat, miogeosynclinal (carbonate) complex; 4--same, miogeosynclinal and eugeosynclinal complexes changing from one to the other with time and laterally; 5--same, essentially eugeosynclinal; 6--late geosynclinal (molasse) complex of Paleozoic folded substrate; 7--Mesozoic (Verkhoyansk) geosynclinal complex; 8--Early Mesozoic (quasi-platformal) substrat of Cenozoic fold belts; 9--geosynclinal complex of Cenozoic fold belts; 10--orogenic (late geosynclinal) complex; 11--post-geosynclinal deposits.

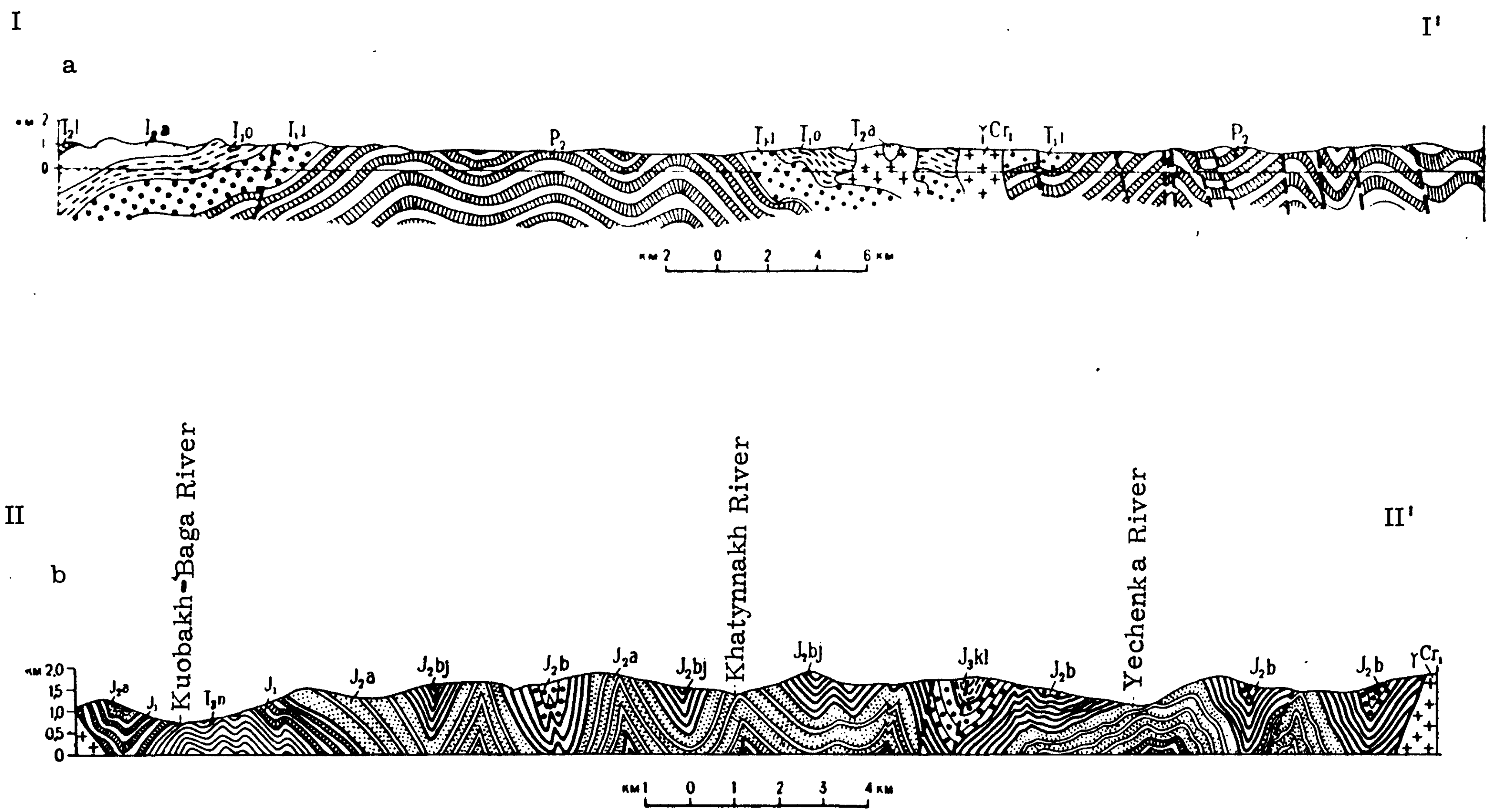

Figure 3. Cross sections of the Verkhoyansk complex of the Yana-Kolyma system: a- I-I' - section through the Ayan-Uryakh anticlinorium; b- II-II' - section through central part of In'yali-Debin synclinorium (after Til'man and others, 1969). See figure 1 for location of these cross sections. This cross section is presented to show the structure. The original Russian paper does not have an explanation of the symbols.

The Verkhoyansk complex consists almost entirely of clastic rocks. These were deposited in four stages.

The first stage was Middle Carboniferous-Early Permian in age. It was the time of maximum downwarping, and thick sandstones and shales were deposited and locally some carbonates.

The second stage was Late Permian-Early Triassic, and here the area of downwarping was reduced. Some large uplifts formed at this time within the geosynclinal basin. Coarse variegated sediments were deposited in places.

The third stage includes the Middle and Late Triassic. Almost the entire area was covered by a transgressive sea.

The fourth stage was the Early, Middle, and early Late Jurassic; here deposition was in narrow, deep basins.

The Verkhoyansk complex is not everywhere folded. Dips are gentle above several large basement blocks within the fold system. These blocks may have been microplates from an earlier time.

Late Mesozoic granitic intrusive rocks are widely distributed in the Yana-Kolyma system. They were emplaced late in the Jurassic and early in the Cretaceous contemporaneously with deposition of molasse sediments, indicating that this was the time of orogenic climax.

<u>Chukotsk system.</u> This system consists of several zones separated from one another by basins (2b of fig. 1). The metamorphic basement consists of Archean and Proterozoic rocks, which are exposed in the cores of highs. These metamorphic cores are surrounded by geosynclinal deposits of Paleozoic and Mesozoic age. The Paleozoic part of the section consists of a lower portion Cambrian through Early Carboniferous in age, which consists of both miogeosynclinal and eugeosynclinal deposits (fig. 2). Following Hercynian orogenic activity of the Middle Carboniferous, molasse was deposited on through Permian and into Early Triassic time. Then followed deposition of the Mesozoic geosynclinal complex.

Deposition of the Mesozoic geosynclinal complex of the Chukotsk system began in Early Triassic time and continued into Middle Jurassic when folding took place. Molasse then began to be deposited and continued into the Early Cretaceous.

Folding in the Chukotsk system was more intense than in the Yana-Kolyma system. The folds are tight and in places overturned and thrust-faulted (fig. 4).

Granitic intrusions were emplaced in a variety of tectonic conditions: on highs, in downwarps, and on the flanks of the post-orogenic depressions.

Koryak-Kamchatka Cenozoic folded region

The Koryak-Kamchatka region of the Cenozoic folding extends over an enormous mountainous area from the Sea of Okhotsk to the Bering Sea (3 of fig. 1). It is separated from the Verkhoyansk-Chukotsk Mesozoic folded region

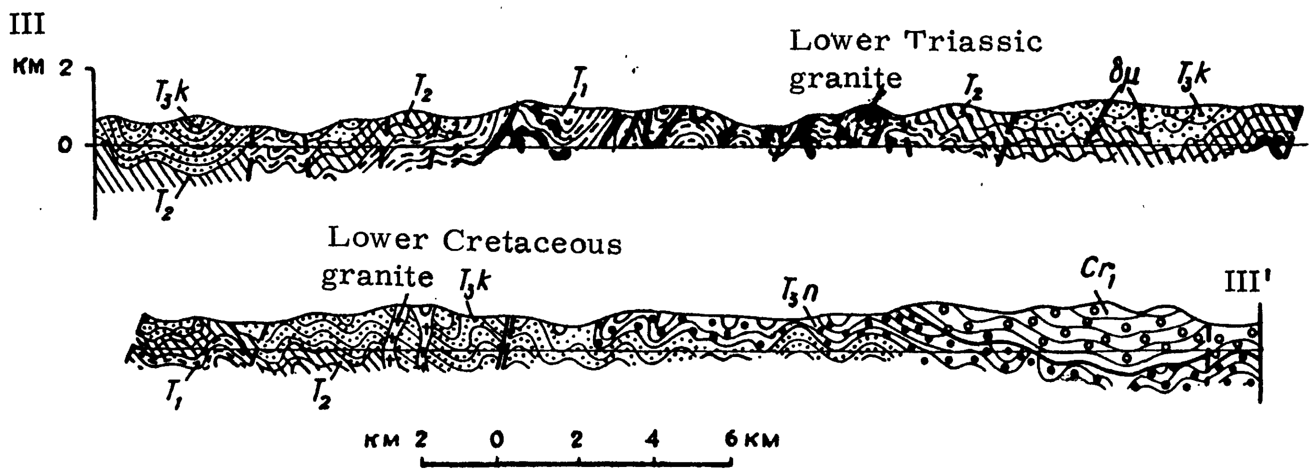

Figure 4. Cross section of the Anyuy zone of the Chukot fold system along line III-III' of figure 1 (after Til'man and others, 1969).
The original Russian illustration does not carry an explanation of the symbols. This cross section is presented to show structure.

on the northwest by the Okhotsk-Chukotsk volcanic belt. Two systems of different age are recognized within this folded region, the Anadyr-Koryak and the Olyutor-Kamchatka.

The peak of orogenic activity in the Anadyr-Korysk system was from the end of the Cretaceous to the Eocene; only in some zones did it extend into the Miocene. The Olyutor-Chukotsk system is still in the orogenic stage except for some interior zones where folding was pre-Pliocene.

Anadyr-Koryak system. This system is located in the northern part of the Korak-Kamchatka region (3a of fig. 1) and is superimposed on a basement composed of Paleozoic and Early Mesozoic rocks. This basement is distinct from the Paleozoic rocks of the Verkhoyansk-Chukotsk folded region, to which it may have been accreted during the Hercynian orogeny.

The Paleozoic basement consists of two structural stages, an Early-Middle Paleozoic geosynclinal stage and a Late Paleozoic orogenic stage. In some places the last stage began as early as in the Early Carboniferous (fig. 2).

The rocks of the geosynclinal stage are largely clastic deposits. Devonian reefs are present in some places. These are deformed intensively and invaded locally by ultramafic rocks. These ophiolites may indeed mark a collision zone of Carboniferous age. The Upper Paleozoic rocks rest discordantly on the Lower-Middle Paleozoic rocks. The Carboniferous is generally absent. The Permian rocks are clastic and volcanic deposits and are folded and faulted. The Paleozoic rocks of the Anadyr-Koryak system are part of a Paleozoic belt that extends into the interior parts of the Pacific Ocean region (Til'man, 1969, p. 32).

The Lower Mesozoic rocks of the basement are Middle and Upper Triassic and Lower and Middle Jurassic volcanic and clastic quasi-platformal sediments. They are gently folded and rest with angular unconformity on the underlying Paleozoic rocks.

Three structural stages are recognized in the geosynclinal development of the Anadyr-Koryak system: initial, middle, and late. The first two are geosynclinal, and the third is orogenic. The initial stage consists of Upper Jurassic, Valanginian and Hauterivian rocks. The middle stage includes the Barremian-Senonian deposits. These two stages are combined as pattern 9 in figure 2 and as patterns 1 and 2 of figure 5. The third or orogenic stage is Danian-Eocene and locally Oligocene-Miocene (pattern 3 of figure 5). Note that the Soviets place the Danian in the Upper Cretaceous.

The Anadyr-Koryak system is a complex assemblage of eugeosynclinal and miogeosynclinal deposits. Trends are generally northeast. The miogeosynclinal portion is in the northwest, outer zone of the system adjacent to the Okhotsk-Chukotsk volcanic belt, whereas the eugeosynclinal portion is in the southeast, inner part of the system (fig. 5).

The miogeosynclinal rocks of the initial structural stage are various volcano-clastic sandstones and siltstones, rarely shales or conglomerates. Tuffs of intermediate composition are also present. These rocks have been thrown into folds up to a few hundred kilometers long and 20-30 km wide. The eugeosynclinal equivalents are volcanic and volcano-clastic rocks, which have

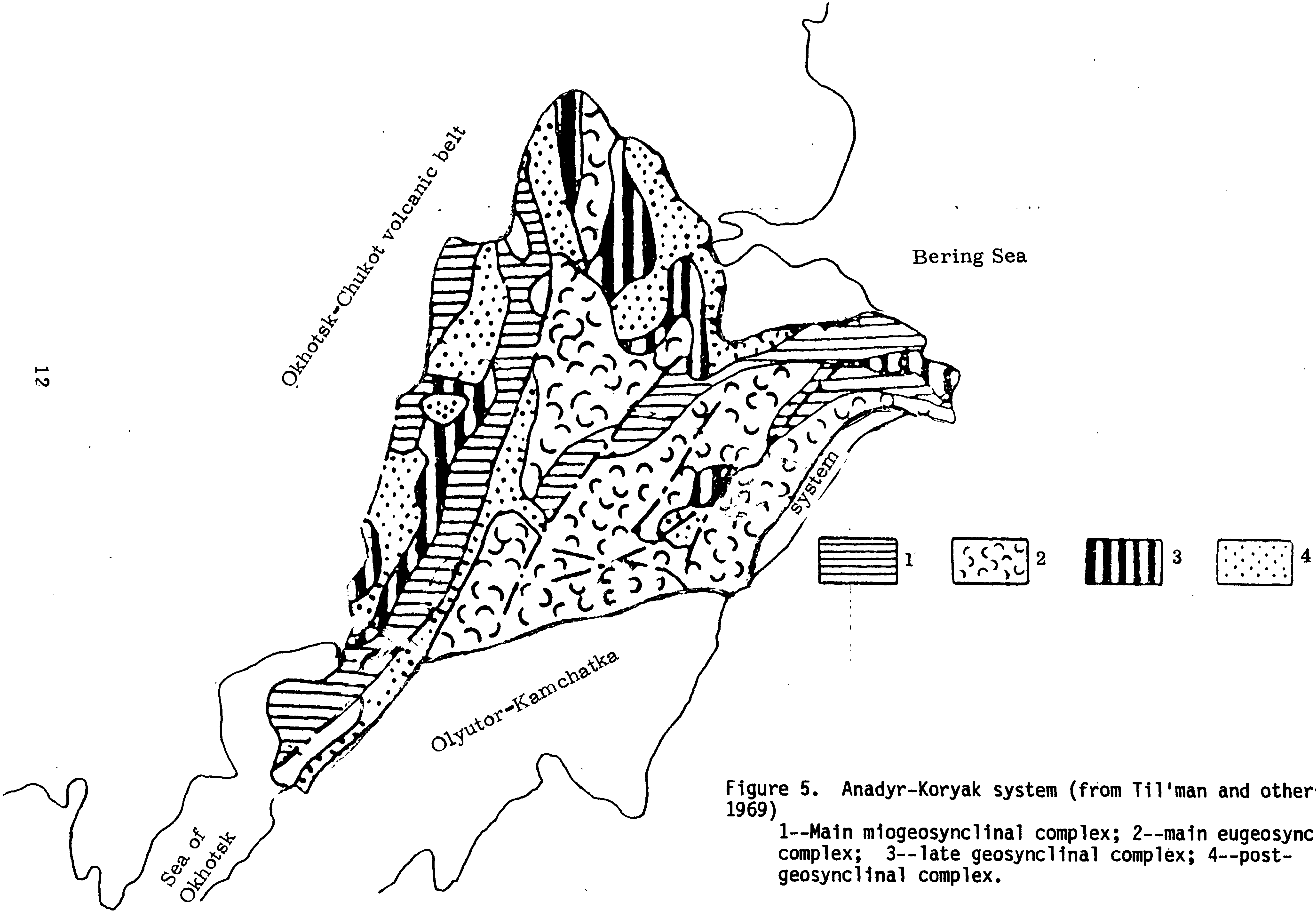

Figure 5. Anadyr-Koryak system (from Til'man and others, 1969)

1--Main miogeosynclinal complex; 2--main eugeosynclinal complex; 3--late geosynclinal complex; 4--post-geosynclinal complex.

been strongly folded and metamorphosed to greenschist-amphibolite, glaucophane, and rarely eclogite facies.

The middle structural stage is divided into two sub-stages: Barremian-Turonian and Senonian. The Barremian-Turonian sub-stage consists of tuffs, siltstone, sandstone, and argillite and is up to 5,500 m thick. It rests conformably on the rocks of the initial stage. Some of these rocks are marine, and others are continental.

The Senonian sub-stage rests unconformably on the Barremian-Turonian sub-stage. It consists of flysch deposits up to 5000 m thick as well as volcanic rocks including lava flows.

In the peripheral parts of the Anadyr-Koryak system the rocks of the middle structural stage have been mildly folded, whereas those of the interior parts have been deformed intensively.

The third or orogenic stage (also called late geosynclinal) was a time of early Tertiary formation of downwarps and depressions. These are filled by coal-bearing molasse and volcanics. The Senonian flysch passes gradually into this molasse.

The structure within these orogenic depressions is simple. The anticlines are gentle, and some domal uplifts are caused by intrusions. The borders of the depressions are commonly bounded by faults.

<u>Olyutor-Kamchatka system</u>. The Olyutor-Kamchatka and Anadyr-Koryak systems were a single geosynclinal region up until the end of the Cretaceous and the Paleogene when they reacted differently tectonically to become two separate systems. At this time the Anadyr-Koryak system experienced general uplift and folding, whereas the Olyutor-Kamchatka continued as a geosyncline into the early Miocene (fig. 2).

The lower structural stage of the Olyutor-Kamchatka system consists of Upper Cretaceous Senonian rocks (Til'man, 1969, p. 38). Note that this system is shown to begin in the Late Jurassic in figure 2. The outer, miogeosynclinal zone on the northwest (fig. 6) consists of thick flysch deposits, and the inner, eugeosynclinal zone to the southeast is composed of volcanics alternating with siltstone and sandstone. Total thickness of this Senonian stage is not less than 9000 m.

The next structural stage of this geosynclinal complex consists of Oligocene-lower Miocene volcanic and clastic deposits. Three formations are present in the inner, eugeosynclinal zone. The Vochvin is a pile of spilites, which alternate with shales and basic tuffs; thickness is about 4000 m. Overlying this is the Goven Formation, which consists of coarse tuffs, basalts, and clastic sediments 3500-4000 m thick (fig. 8a). The Il'pin Formation is a clastic unit 4000 m thick and is a facies equivalent of the Goven volcanics.

The geosynclinal complex is deformed into linear anticlines up to 200 km long and 25 km wide. Angles of dip are 20-80°. Some clastic units are isoclinally folded and overturned.

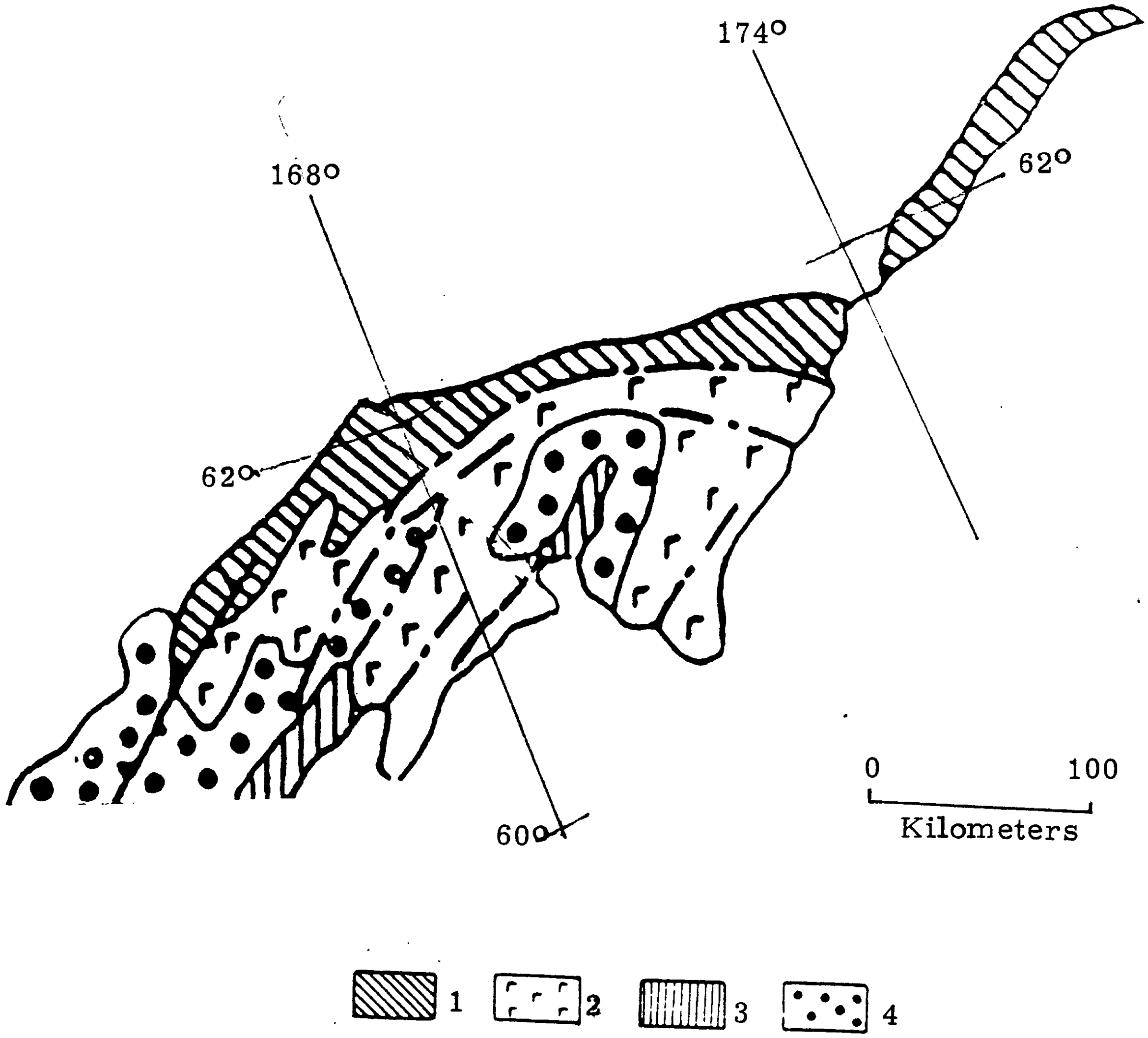

Figure 6. Olyutor-Kamchatka system (from Til'man and others, 1969)
1--Main miogeosynclinal complex; 2--main eugeosynclinal complex; 3--late geosynclinal complex; 4--Pliocene-Quaternary deposits.

The upper, orogenic stage includes middle-upper Miocene and, in places, Pliocene deposits. These occur in depressions that developed on the folded geosynclinal rocks of the lower two stages. These depressions are filled by marine and continental molasse. The lower molasse is middle and late Miocene in age and consists of conglomerate and tuffaceous sandstone. Thickness is 800-2500 m. The upper molasse is conglomerate, sandstone, shale, and brown coal. It is Pliocene in age and 1600-2800 m thick. Volcanic rocks are also present.

It is unclear whether the Olyutor-Kamchatka zone has passed completely through the geosynclinal cycle. The process is certainly still continuing in Eastern Kamchatka where subduction is presently active.

Okhotsk-Chukotsk volcanic belt

This belt extends 3000 km along the north coast of the Sea of Okhotsk and thence northeastward to the Chukotsk Peninsula (2 on fig. 1). The southwest, Okhotsk segment of the belt is 1400 km long and is different in some ways from the Chukotsk segment, which is 1600 km long.

Throughout its entire length the belt is composed of subaerial volcanics. Rhyolite, andesite, and basalt are the principal types. Volcanoclastic rocks are much less abundant.

The belt began its development in Aptian time and continued through to the end of the Paleocene. Three stages are recognized: Aptian-Turonian, late Senonian-Danian, and early Paleogene.

The lower stage is largely andesite, except in the Central Chukotsk region where liparites predominate. Individual units are characteristically not persistent laterally. This stage is shown as Aptian-Albian, Cenomanian-Turonian, and lowermost Senonian in figure 7.

The middle, late Senonian-Danian stage (all in the Cretaceous) is mainly lipariate ignimbrite. A stratigraphic hiatus is present between the lower and middle stages.

The upper stage is everywhere basalt except in the East Chukotsk region where liparite and andesite are present. There is no break between the middle and upper stages.

The relationship between the Okhotsk-Chukotsk volcanic belt and the adjacent fold systems is more clearly apparent in the northeastern, Chukotsk segment. Here the belt is rectilinear, separating the Chukotsk Mesozoic fold belt on the northwest from the Anadyr-Koryak Cenozoic fold belt on the southeast.

The volcanic belt is in contact with the Mesozoic rocks on the northwest along faults, flexures, and unconformities. The relationship is the same with the Precambrian and Paleozoic massifs. The faults have a northeast trend and are 50-100 km long.

The belt is in contact with the Anadyr-Koryak belt largely along faults, and these faults parallel internal structure within the system itself. Granites have been emplaced along these faults. In some places the volcanic belt is unconformable on the Anadyr-Koryak system.

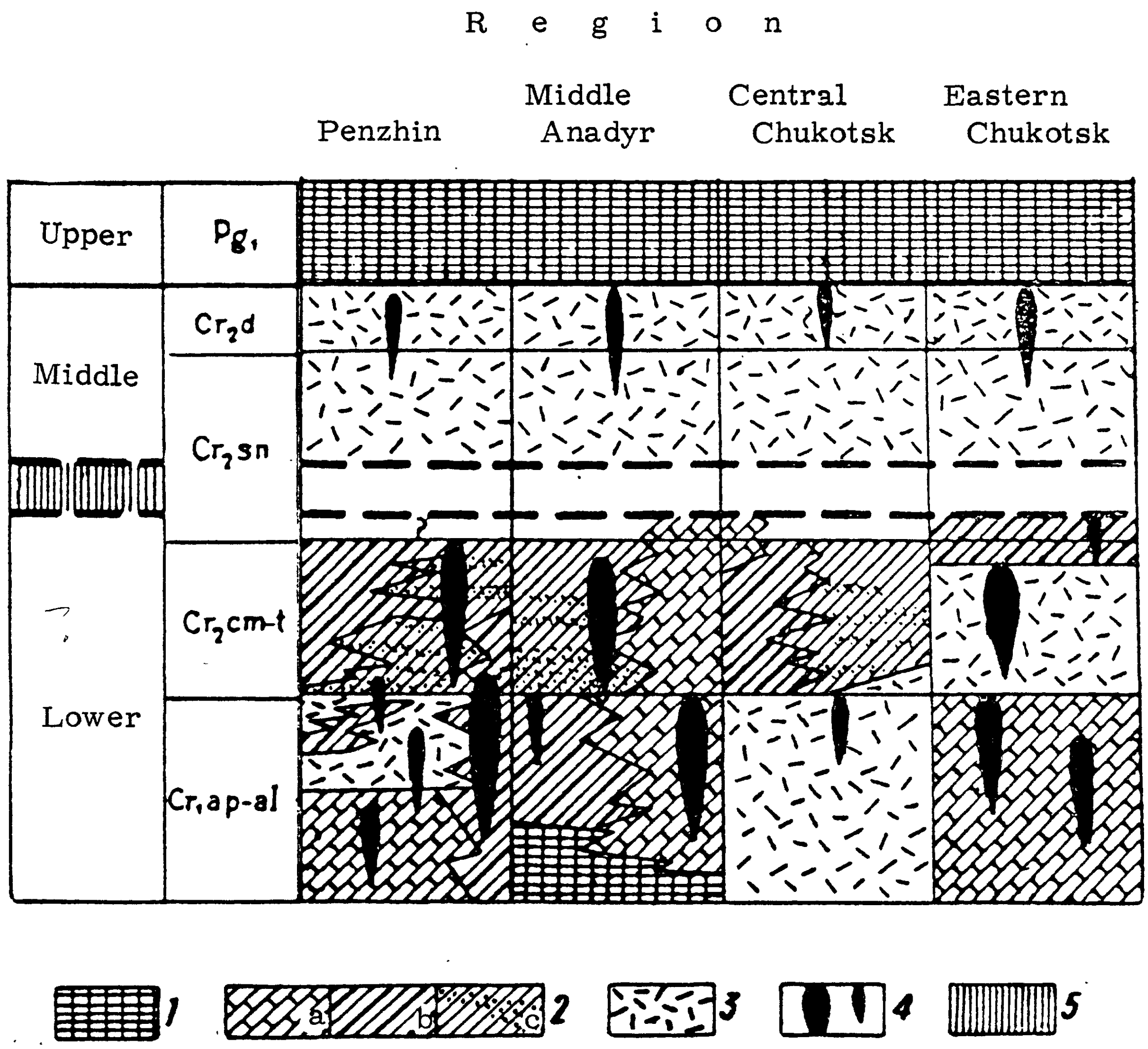

Figure 7. Structural stages in the Ohkotsk-Chukotsk volcanic belt 1 - Basalt; 2 - Andesite (a - andesite proper, b - two-pyroxene andesite basalt and andesite, c - andesite ignimbrite); 3 - ignimbrite; 4 - intrusions; 5 - stratigraphic break and structural discordance. (From Til'man and others, 1969)

Pg_1-Lower Paleogene
Cr_2d-Upper Cretaceous, Danian
Cr_2sn-Upper Cretaceous, Senonian
Cr_2cm-t-Upper Cretaceous, Cenomanian-Turonian
Cr_1ap-al-Lower Cretaceous, Aptian-Albian

In the southwestern, Okhotsk segment the relationship to the Yana-Kolyma belt is much the same as in the Chukotsk segment except that there are much fewer longitudinal faults. In places the rocks of the volcanic belt extend into the Yana-Kolym belt in fault-bounded troughs. One of these is on the eastern margin of the Balygychan massif (fig. 1).

The internal structure of the volcanic belt is more fully displayed in the Chukotsk segment than in the Okhotsk segment. The outer zone of the belt is on the northwest and the inner zone is on the southeast. These zones are nearly everywhere in fault contact. The inner zone is downdropped in relationship to the outer zone.

The inner and outer zones are characterized by different magnetic signatures. In the outer zone the magnetic anomalies are identical in size, shape, and orientation to those of the Mesozoic rocks on the northwest, whereas in the inner zone the anomalies are larger and sharper and trend northeast at an angle to those of the outer zone.

Dips are very gentle to horizontal in the outer zone. Monoclines may dip as much as 5-10° to the southeast. Depressions of isometric form are also present. In the inner zone the rocks of the lower stage (Aptian-Turonian) have been deformed into discontinuous short folds, whereas those of the middle and upper stages have the gentle attitudes of the rocks of the inner zone.

Development of the Okhotsk-Chukotsk volcanic belt was related closely to the geologic history of the Anadyr-Koryak belt. This relationship is manifest both in correspondence of their structural plans and in strict synchroneity of the main geological events in both regions. The ignimbrites of the second structural stage appear to have formed as a result of collision and underthrusting of the Anadyr-Koryak plate beneath the Verkhoyansk-Chukotsk plate. Such volcanic activity on the upper plate of a suture zone is expected.

SEDIMENTARY BASINS

Il'pin and Olyutor basins

These basins are located in the Olyutor-Kamchatka belt of Cenozoic folding (figs. 1 and 8). They are similar in age and in the composition of the sedimentary and volcanic fill.

General geology. Clastic and volcanic rocks of Late Cretaceous and Cenozoic age form the section of these basins (Ivanov, 1985, p. 33). The basin boundaries are drawn either along faults or along zones of abrupt facies change from clastic rocks of the basin to volcanic rocks outside the basin. The Pylgin high separates the two basins (3 in fig. 8).

These basins are classified as geosynclinal types (Ivanov, 1985, p. 33) and include the sedimentary and volcanic rocks of the middle and upper structural stages of the Olyutor-Kamchatka system. Til'man (1969, p. 39) designates only the upper structural stage as basin fill. (See section Olyutor-Kamchatka system in this report.)

The economic basement for oil and gas in these basins is composed largely of silicic volcanic of Late Cretaceous and early Paleocene age, although rocks

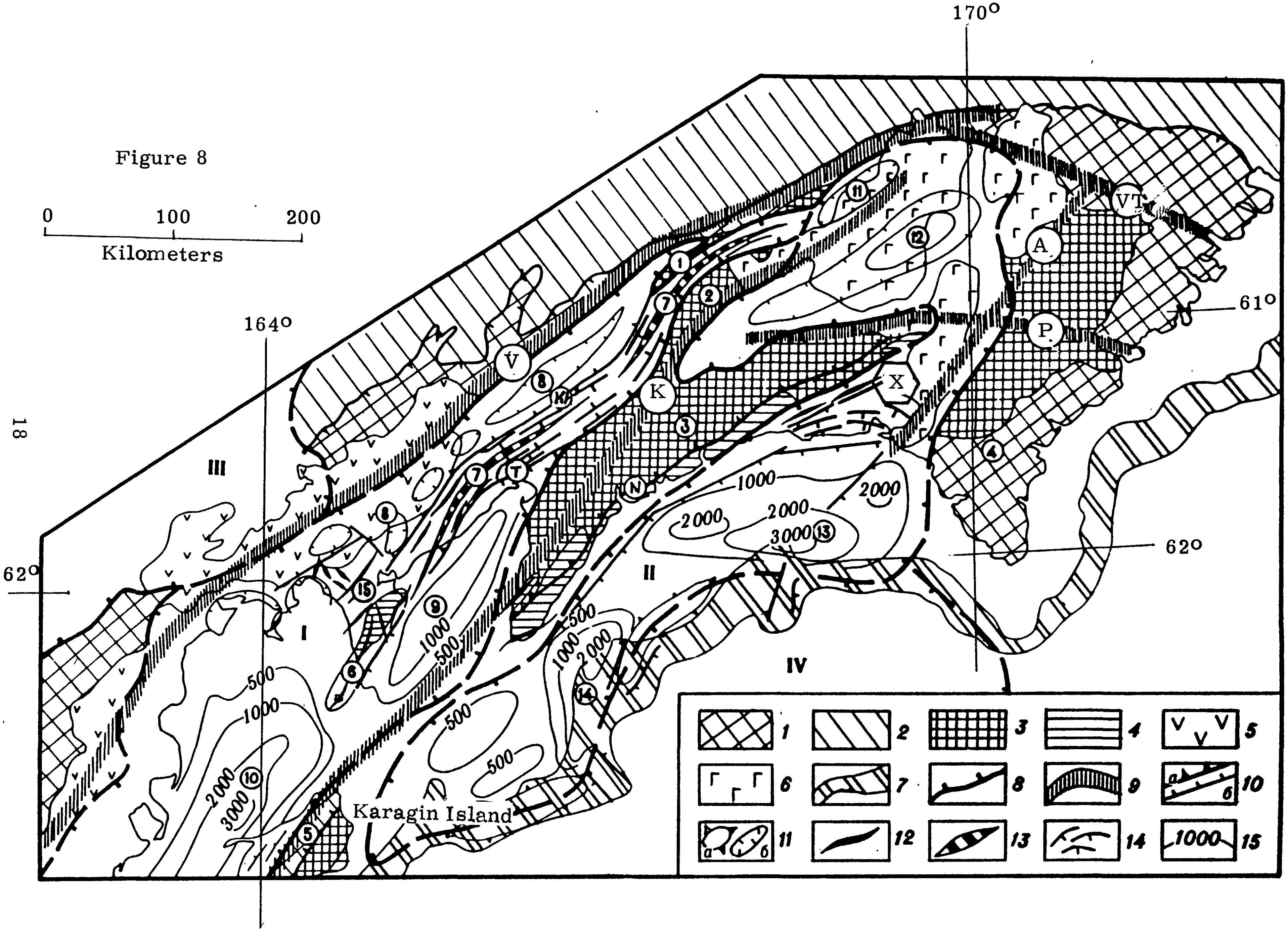
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Figure 8

Figure 8. Tectonic map of Il'pin and Olyutor basins of the southern part of the Koryak Highlands (after Ivanov, 1985).
1--Cenomanian silicic volcanic rocks; 2--Cenomanian clastic flysch sediments; 3--Maastrichtean-Paleogene silicic volcanic and sedimentary rocks; 4--Maastrichtean-Paleogene tuffs and clastic sediments; 5--Miocene extrusive rocks; 6--Miocene-Pliocene extrusive rocks; 7--continental slope; 8--boundaries of basins; 9--deep faults based on geophysical data; 10--large faults: a - overthrust, b- normal; 11--structures of the second order: a - highs, b - basins; 12--axes of local anticlines; 13--axes of synclinoria; 14--strike and dip; 15--structure contours on reflector in the Miocene section, m.

Basins: I-Il'pin, II-Olyutor, III-Pustorets, IV-Komandor. Deep faults: V-Vyven, VT-Vatyn, A-Achayvayam, P-Pylgovaya, K-Karagin-Pakhachin. Large faults: Kh-Khakin, T-Tilichen, N-Navayen. Anticlinoria and highs: 1-Khakin, 2-Ivtygin, 3-Pylgin, 4-Olyutor, 5-Central Karagin, 6-Vostochno-Il'pin, 7-Av'in, 8-Vyven, 9-Korfov, 10-Litken, 11-Echyayam, 12-Apukvayam, 13-Severo-Olyutor, 14-Vostochno-Goven, 15-Zapadno-Il'pin terrace.

X Approximate location of section shown in figure 8a.

of this same age are part of the sedimentary fill in other parts of these basins. On the northwest in the Il'pin basin the lower part of the basin fill consists of upper Paleocene-Oligocene sedimentary rocks. They are clay units, which contain beds of siltstone, sandstone, and tuff. They are rhythmically bedded in places, beginning with sandy or tuffaceous beds and ending with clay beds. To the southeast volcanic rocks are the major component of the lower portion of this lower part of the basin fill, and the upper portion is rhythmically alternating argillite, siltstone, and sandstone. Thickness of this lower part of the basin fill ranges from 2000 to 8000 m.

The upper part of the basin fill is Miocene in age and consists of the Pakhachin and the overlying Korfov Formations (fig. 8a).

The Pakhachin Formation in the central parts of both the Il'pin and Olyutor basins is composed of clays, siltstones, and sandstones. Coal beds are present in the uppermost part of the section.

The Korfov Formation consists of continental and near-shore marine coal-bearing sediments. Sandstone, conglomerate, tuff, and to a lesser extent, siltstone, argillite, and brown coal are present.

The Il'pin and Olyutor basins are narrow downwarps controlled to deep faults.

The Il'pin basin is characterized by a clearly expressed tectonic zonality. Along its northwest border, which is the Vyven fault, is the Vyven graben-depression (8 in fig. 8), which is filled by Neogene and Quaternary clastic and volcanic deposits. The Khakin high to its northeast is composed of Maastrichtian-lower Paleocene volcanic rocks. The Av'in synclinorium next on the east is filled by upper Paleocene-Oligocene flysch. Angles of dip here are up to 40 - 60°. Campanian-Paleocene silicic volcanics are present on the Vostochno-Il'pin horst-high. Anticlines on this high have various orientations (6 in fig. 8).

In the central part of the Il'pin depression are the Korfov and Litken depressions (9 and 10 of fig. 8), which are filled by gently dipping Neogene and Quaternary sediments. Seismic surveys show their thickness at 3 km in the Litken depression and 1.5 km in the Korfov.

The Olyutor basin has an irregular shape and is separated from the Il'pin by the Ivtygin, Pylgin, and Tsentral'no-Karagin anticlinoria (2, 3, and 5 of fig. 8). Within the basin are several troughs (Echvayam, Apukvayam, Severo-Olyutor - 11, 12, and 13 of fig. 8), which are filled by Neogene deposits. In the north continental and near-shore marine coarse clastic coal-bearing deposits up to 2000 - 2500 m thick are present. The section thins abruptly to the south along the Apuka River. (This river coincides approximately with the Achayrayan deep fault - A of fig. 8). Several other troughs are present off-shore in the south. Narrow elongate highs on the continental slope separate the Olyutor basin from the Komador basin to the east.

Petroleum geology. The silt-clay facies of these basins rarely contain as much as 1.5 percent organic matter, except for the coal beds. The most abundant organic matter in the Il'pin basin is found in the upper Paleogene and lower-middle Miocene. Organic matter here is 0.88 percent. Content

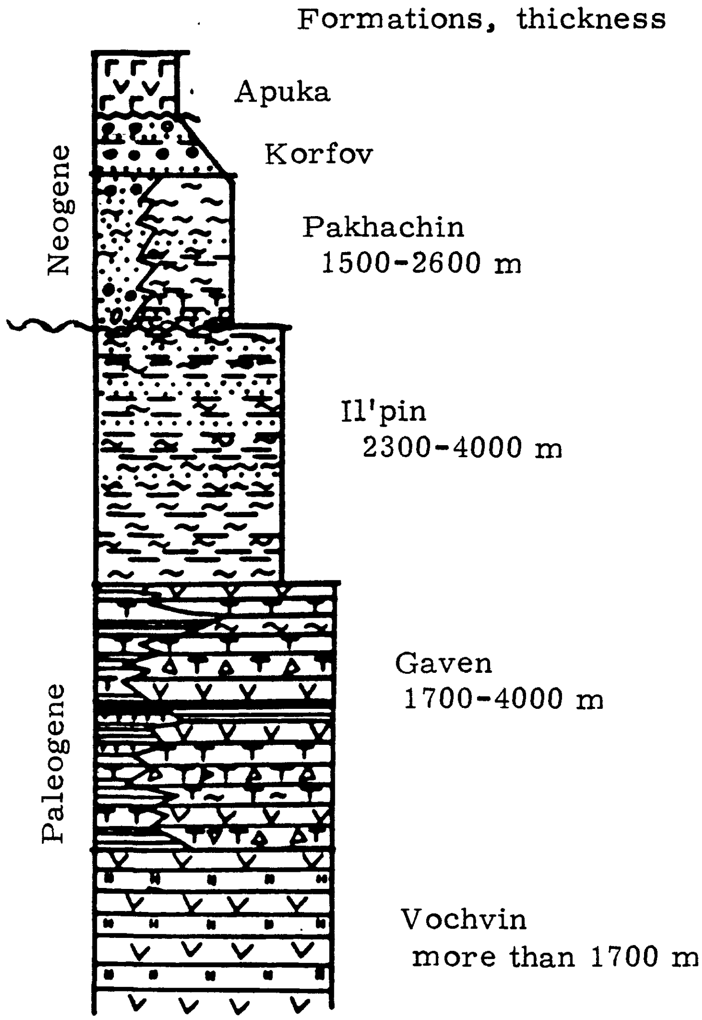
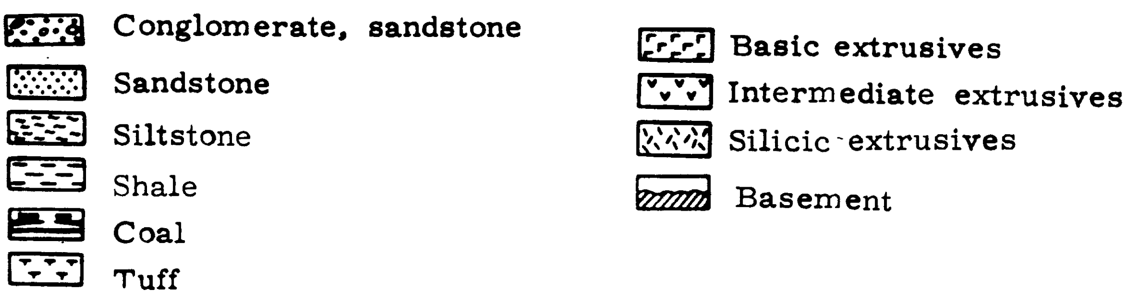


Figure 8a. Stratigraphic section along lower reaches of the Pakhacha River (from Ivanov, 1985). See figure 8 for location.



decreases downward along the section. The situation is much the same in the Olyutor basin. The best source rocks here are Eocene-Oligocene and early Miocene age.

Level of maturation is based on vitrine reflectance, composition of the coals, density, porosity, and secondary alteration. In the central parts of both basins the Paleogene flysch and lower-middle Miocene sand-clay molasse have reached the MK_2 (80° C) catagenic stage. Rocks of the same age and older in the frame of the basins have matured as high as the AK_1 (180° C) stage.

The sandstone and siltstone reservoirs of the basins are largely polymict (graywacke), volcanic, and tuffaceous varieties. They have been subjected to considerable alteration. Where Paleocene sandstones are at the MK_3 - MK_4 (115 - 135° C) catagenic stage, average porosity hardly reaches 10 - 12 percent, and gas permeability has a median value of 0.01 md. It can be said that the MK_3 stage is the limit for reservoirs of commercial value for these rocks. The sandstones and tuffs of the overlying Eocene, Oligocene, and, in particular, the Neogene have quite satisfactory reservoir properties.

Thick clay seals are present in the Paleogene section. The best of these are clays of the Oligocene and Eocene.

Traps for hydrocarbons are the local anticlines of the central part of the basin; these are large and their structure is simple. Toward the borders of the basin the folds are more open.

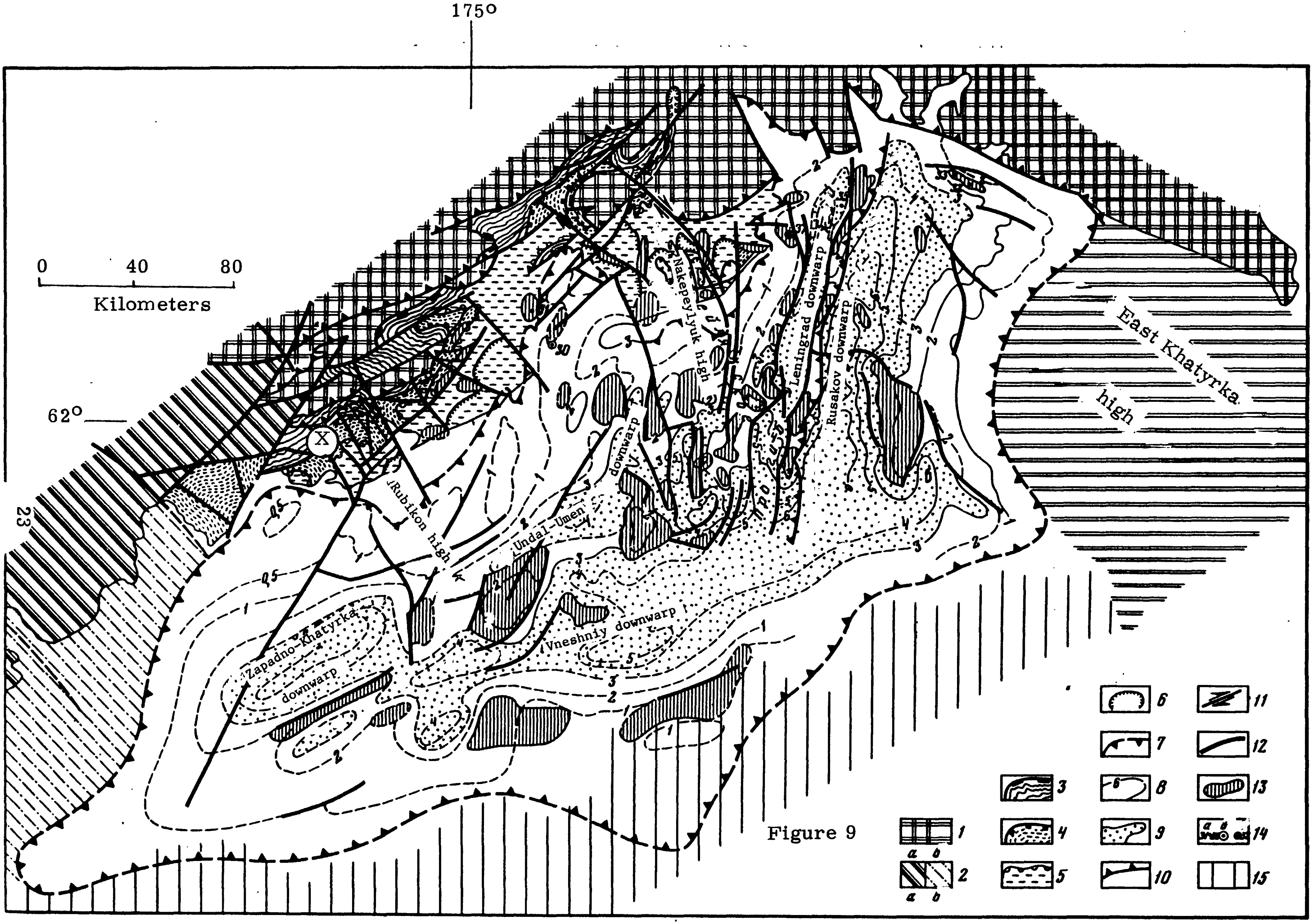
The best play is the middle part of the Cenozoic section in the Pakhachin Formation and upper half of the Il'pin Series. Thickness and stratigraphic range of these units increased toward the middle of the basins. The most favorable areas for exploration are the Litken, Korfov, Vostochno-Goven, and Severo-Olyutor troughs and the Zapadno-Il'pin tectonic terrace. The region is gas-prone.

Khatyrka basin

The Khatyrka basin is a para-geosynclinal type and occupies a coastal belt on the southeast flank of the Koryak Range (figs. 1 and 9). Tectonically it is located on the suture between the Anadyr-Koryak and Olyutor-Kamchatka Cenozoic fold systems but is more akin to the latter (Ivanov, 1985, p. 44).

General geology. The basement for the Khatyrka basin consists of Paleozoic and Mesozoic rocks. The upper age limit is not everywhere the same. In the north and south this complex includes Upper Cretaceous Senonian rocks. In the central part of the basin the Senonian rocks are part of the basin fill.

The Senonian of the basin fill is regarded as the lower part of an intermediate or buried stage. It consists of conglomerate, sandstone, siltstone, argillite, and tuff of Santonian, Campanian, and early Maastrichtian age. It is the El'ginmyn Formation and is 400 - 1200 m thick. Above an unconformity at the base of the upper Maastrichtian are clastic and volcanic deposits of late Maastrichtian-middle Eocene age (Bystrorechen and other formations); these are the upper part of the buried stage and are 200-1500 m thick.


175°
62°
0
40
80
Kilometers
East Khatyrka
high
Nakepeylyuk high
Leningrad downwarp
Rusakov downwarp
Rubikon high
Undal-Umen
downwarp
Vneshniy downwarp
Zapadno-Khatyrka
downwarp
X
1
2
3
4
5
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7
8
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14
15

Figure 9

Figure 9. Tectonic map of Khatyrka basin (after Ivanov, 1985). 1,2-Structures of the frame (a-at surface, b-beneath unconsolidated sediments): 1 - Anadyr-Koryak system, 2 - Olyutor-Kamchatka system; 3-9 - features within the basin: 3-4 lower (buried) stage; 3 - Coniacian-Maastrichtean substage, 4 - Maastrichtean - Eocene substage, 5-9 - upper (main) stage; 5 - Eocene-Oligocene substage, 6, 7 - structure contours on the base of: 6 - Neyvytv Fm and its analogs, 7 - Neogene-Quaternary substage; 8 - structure contours on seismic marker approximately at base of Neogene (km); 9 - zones of deepest subsidence (more than 3 km); 10-12 - faults: 10 - overthrusts and upthrusts, 11 - strike-slip, 12 - normal; 13 - local anticlines; 14 - deep wells; a - dry, b - gas, c - oil; 15 - zone of marginal uplift.

(X) Approximate location of section shown in figure 9a.

The upper or main stage of the sedimentary fill of the Khatyrka basin consists of deposits of Eocene-Quaternary age. Three sub-stages are recognized: Eocene-Oligocene, Miocene, and Pliocene-Quaternary.

The lower part of the Eocene-Oligocene sub-stage consists of argillaceous rocks (Ionay Formation), which range in thickness from a few hundred to 2000 m and more. The overlying Oligocene sediments (Neyvytvyr, Anol, and Mallen Formations) are alternating members of deltaic siltstone, argillite, and sandstone up to 6 - 8 km thick.

The middle or Miocene sub-stage is present onshore only in the coastal areas. The section begins with coarse clastic rocks (Imlikin Formation), and next are sandy facies along the margins of the basin and argillaceous facies in the central part (Vaamochkin Formation). Thickness is up to 1000 m. The upper Miocene consists of two units. The lower (Trekhrechen Formation) is polymict sandstone, and the upper (Yanrakoim Formation) is coarse sandstone with clay beds, brown coal, and fanglomerate. Maximum thickness of the upper Miocene is 2 km.

At the top of the basin fill are the upper sub-stage, upper Pliocene argillaceous sediments 30 - 40 m thick, and Quaternary clastic rocks 20 - 70 m thick.

Total thickness of the basin fill is 13 - 15 km. The rocks of the lower, buried stage and the lower sub-stage of the upper stage comprise a geosynclinal complex deposited in relatively deep water on the outer shelf and continental slope; they are turbidites. The Neogene deposits are a marine molasse, part of which may be submarine canyon facies.

The Khatyrka basin is asymmetric. Maximum thickness of Neogene-Quaternary sediments is in the east and southeast, whereas the Upper Cretaceous-Paleogene deposits are concentrated in the northwest. This asymmetry is also expressed in the character of the northwest and southeast borders of the basin. The northwest border of the basin is along overthrusts and upthrusts in a zone 5 - 7 km wide, whereas on the southeast the Cenozoic sediments rise and pinch out against a high.

Within the Khatyrka basin are several highs and lows (fig. 9). These are 50 - 150 km long and 5 - 40 km wide and are at all angles to the northwest trend of the basin. Highs such as the Rubikon and Nakepeylyak are composed of Paleogene rocks which are warped into folds with dips of 20 - 70°. The argillaceous rocks of the Ionay Formation have formed diapirs.

The Zapadno-Khatyrka, Undal-Umen, Leningrad, Vneshniy, and Rusakov downwarps occupy the central part of the basin. Here the thickness of the Neogene-Quaternary sediments reaches 5 - 6 km. Along the borders of these depressions are numerous local highs, and these may serve as traps for oil and gas. Most of them have a complex structure and are faulted. The Uglov oil-gas field is on one such structure. Along the gentle southeast border are other, more gentle folds.

A very unusual structure is the Maynopyl'gin ridge. It is a horst 3 - 5 km wide and 100 km long between the Leningrad and Rusakov downwarps. It is bounded by high angle normal and reverse faults on which displacement has been 2 - 3 km.

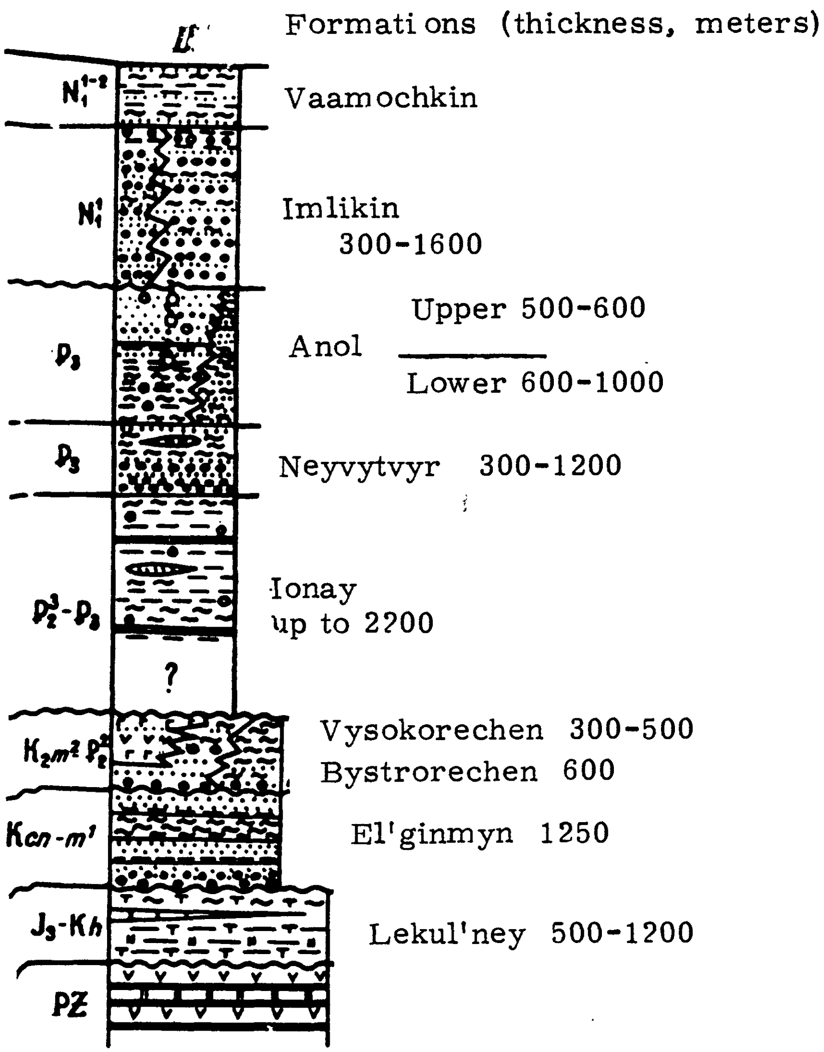
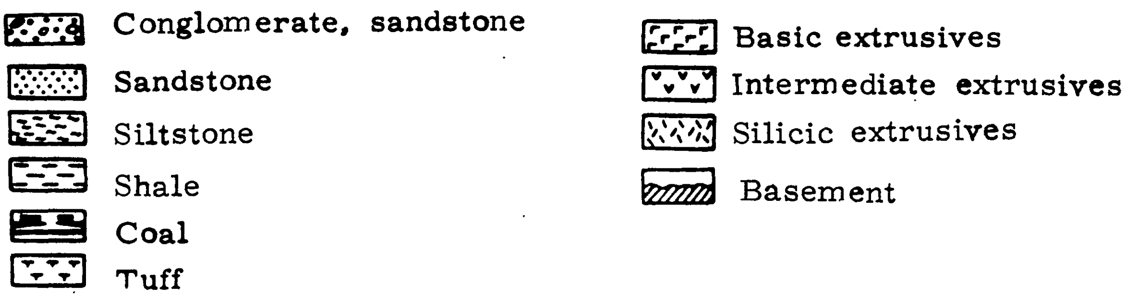


Figure 9a. Stratigraphic section in northwest part of Khatyrka basin (from Ivanov, 1985). See figure 9 for location.
PZ - Paleozoic, J_3-Kh - Jurassic to Hauterivian, Kcn-m^1 - Conianian to lower Maastrichtean, K_2m^2-P_2^2 - Upper Maastrichtean to middle Eocene, P_2^3- upper Eocene to Oligocene, P_3-Oligocene, N_1^1- lower Miocene, N_1^{1-2}- lower-middle Miocene.



Faulting has been very active in the structural development of this basin. Wrench faults are abundant on the Nakepeylyak high.

Petroleum geology. Except for a few coal beds there are no rocks in the Khatyrka basin that are anomalously rich in organic matter. However, many of the argillaceous units are rich enough to have been source beds. Practically all units of the Maastrichtian-middle Miocene have entered the oil window in one part of the basin or other. In general, the age of the rocks in the oil window youngs to the east. Reservoir properties within the basin worsen downward along the section. Good granular reservoirs are present in the Neogene section and locally in the Oligocene but are practically absent in the Eocene-Oligocene rocks. The latter contain some fracture reservoirs. Seals are widely distributed along the section.

The presence of extensive faulting, disharmonic folding, and clay diapirism limits the extent of simple anticlinal traps. They are found only along the borders of downwarps and on the southeast border of the basin. Fault traps and stratigraphic traps are the most likely to be found. The oil and gas pools that have been discovered in the Anol and Uglov areas are probably in combination-type traps.

Four plays are recognized: Senonian-Eocene, Eocene-Oligocene, lower-middle Miocene, and upper Miocene-Quaternary.

The Senonian-Eocene play may be productive only in local areas.

The Eocene-Oligocene play contains abundant argillaceous source beds and has almost everywhere entered the oil window, or even passed through it in places. Persistent granular reservoirs are not common, however.

The lower-middle Miocene has an optimum alternation of granular reservoirs and seals. The source-bed potential of this play is less than that of the underlying Eocene-Oligocene play; however, the combination of alternating sandy and argillaceous varieties is very favorable where the play is within the oil window.

The upper Miocene-Quaternary play in the eastern, coastal part of the basin consists largely of coarse-clastic sediments; however, they appear to be flushed of any oil and gas. Toward the central parts of the basin at a distance from the source area of the clastics this play may thicken and become more argillaceous. Upper Pliocene clays may prove to be effective seals.

On a basis of the distribution of plays, types of traps, and hydrogeologic conditions, the areas of the Rusakov, Leningrad, Vneshney, Undal-Umen, and Zapadno-Khatyrka downwarps are favorable for oil-gas exploration.

Pustorets basin

This basin is located on the west coast of northern Kamchatka, extending offshore. It is 450 km long and 50-100 km wide and is on the northwest margin of the Olyutor-Kamchatka system where the latter is in contact with the Anadyr-Koryak system (fig. 10).

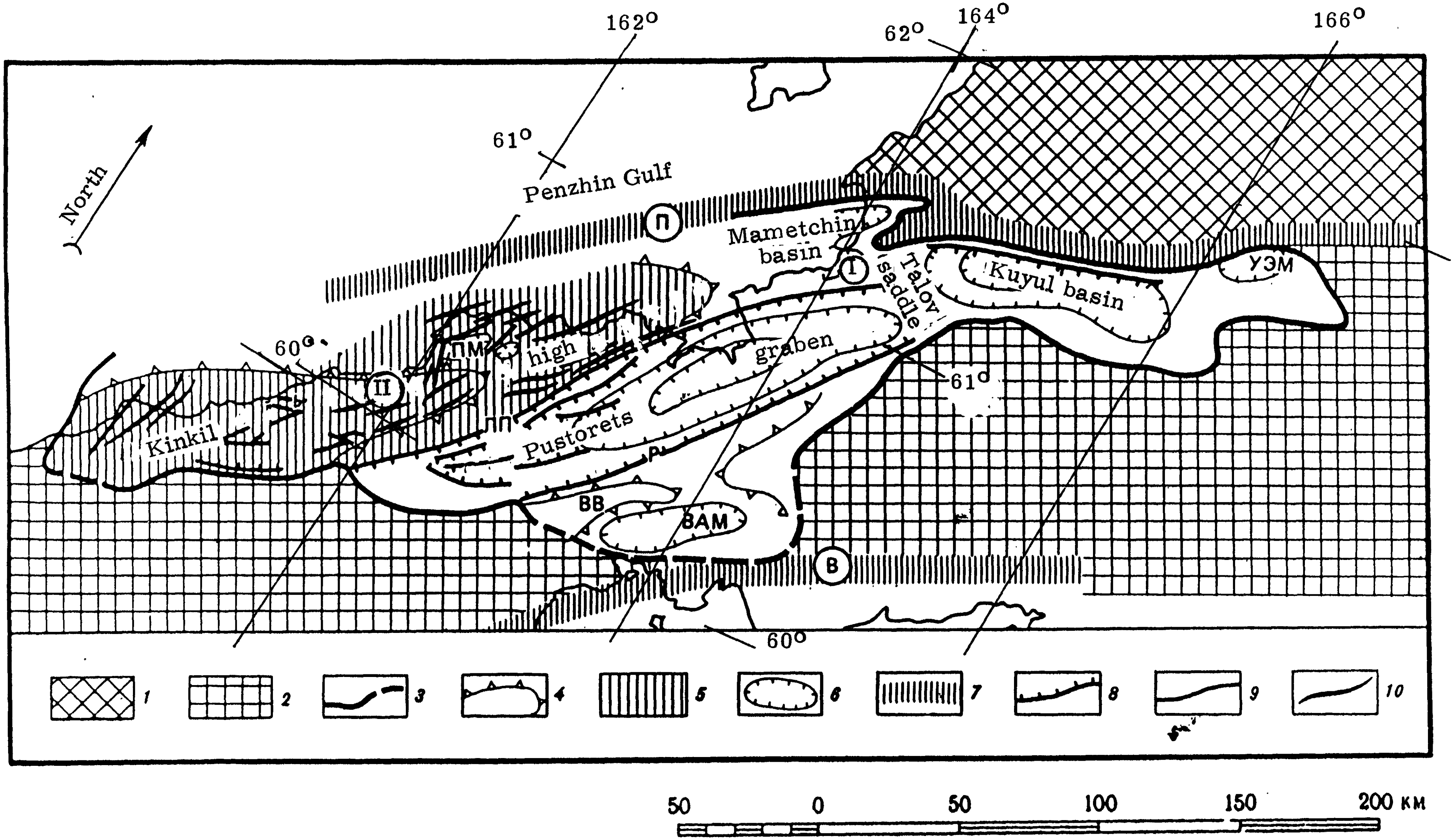


Fig. 10. Tectonic map of Pustorets basin. 1,2-Tectonic zones: 1-Penzhin, 2 - Kamchatka-Central Koryak; 3-boundaries of basin; 4-10 - tectonic elements: 4-positive (BB-Valovayam high), 5-Kinkil high, 6-negative (troughs: ПМ-Podkagernin, BAM-Verkhneanapkin, УЭМ - Ust-Enychavayam), 7-9 - faults: 7-deep (П-Penzhin-Parapol, B-Vyven), 8-large (ЛП-Levo-Pustorets, P-Rekinik), 9-local; 10-axes of local anticlines. (From Ivanov, 1985)

(I) (II) - Approximate positions of sections shown in figure 10a

General geology. The folded basement for this basin consists of Cretaceous rocks, and the basin fill is Cenozoic (fig. 10a).

All stages of the Cretaceous are present in the folded basement of the northwest border. A possible play here is the Aptian-Albian sediments, which contain the Tikhorechen and Kedrov Formations with thicknesses of 500-2200 and 200-3500 m, respectively. The Cretaceous rocks on the southeast border are metamorphosed to greenschist facies and intruded by granite and gabbro.

Practically all age subdivisions of the Cenozoic are represented in the basin fill. In the central part of the basin is the Paleocene-Eocene Tigil Series, which from the bottom upward is comprised of the Getkilnin, Kamchatka, and Tkapravaya Formations.

The Getkilnin Formation consists of members of sandstone and siltstone that are 15-300 m thick. Total thickness of the formation is 800-1200 m.

The Kamchatka Formation contains sandstone, carbonaceous clay, and siltstone members that are 10-60 m thick, and total formation thickness is 500-100 m.

The Tkapravayam Formation is comprised of alternating members of sandstone, conglomerate, clay, and siltstone, These members are 25-240 m thick, and total thickness is 1000-2000 m.

The Tigil Series is the lower molasse complex of the Pustorets basin and is characterized by abrupt facies change. The environment of deposition ranged from near-shore swamp and lagoonal to near-shore marine, inner shelf, and continental slope conditions.

Overlying the Tigil Series are subaerial volcanic deposits of late Eocene-Oligocene age (31-41 million years), which range in thickness from 200 to 3700 m. These deposits young from southwest to the northeast. In the northern part of the basin the Eocene-Oligocene is represented by the Unel (1100-1700 m) and Ommay (700-1400 m) Formations, which are composed largely of clays and siltstones.

The Cenozoic section is topped by the Oligocene-Miocene sediments of the Voyampol and Kavran Formations, which are largely sandstones and conglomerates. Their thickness is up to 2500 m.

The Pustorets basin is bounded on the northwest by the Penzhin-Parapol deep fault and on the southeast by the Vyven deep fault (fig. 10). Within the basin are several highs and lows, which are elongate parallel to the trend of the basin.

On the southwest along the shore of the Penzhin Gulf is the Kinkil high, which is 240 km long and about 40 km wide. Three structural stages are present on this high. The lower consists of Paleocene-Eocene sedimentary rocks, and dips are up to 60-70°. The second stage is comprised of Eocene-Oligocene volcanic rocks, and dips are up to 40°. The third stage is Neogene; it is locally distributed, and dips are 3-25°.

In the central part of the basin is the Pustorets graben, which is bounded by the Levo-Pustorets and Rekinik faults. This graben is 150 km long, and depth to folded basement is 2-3 km.

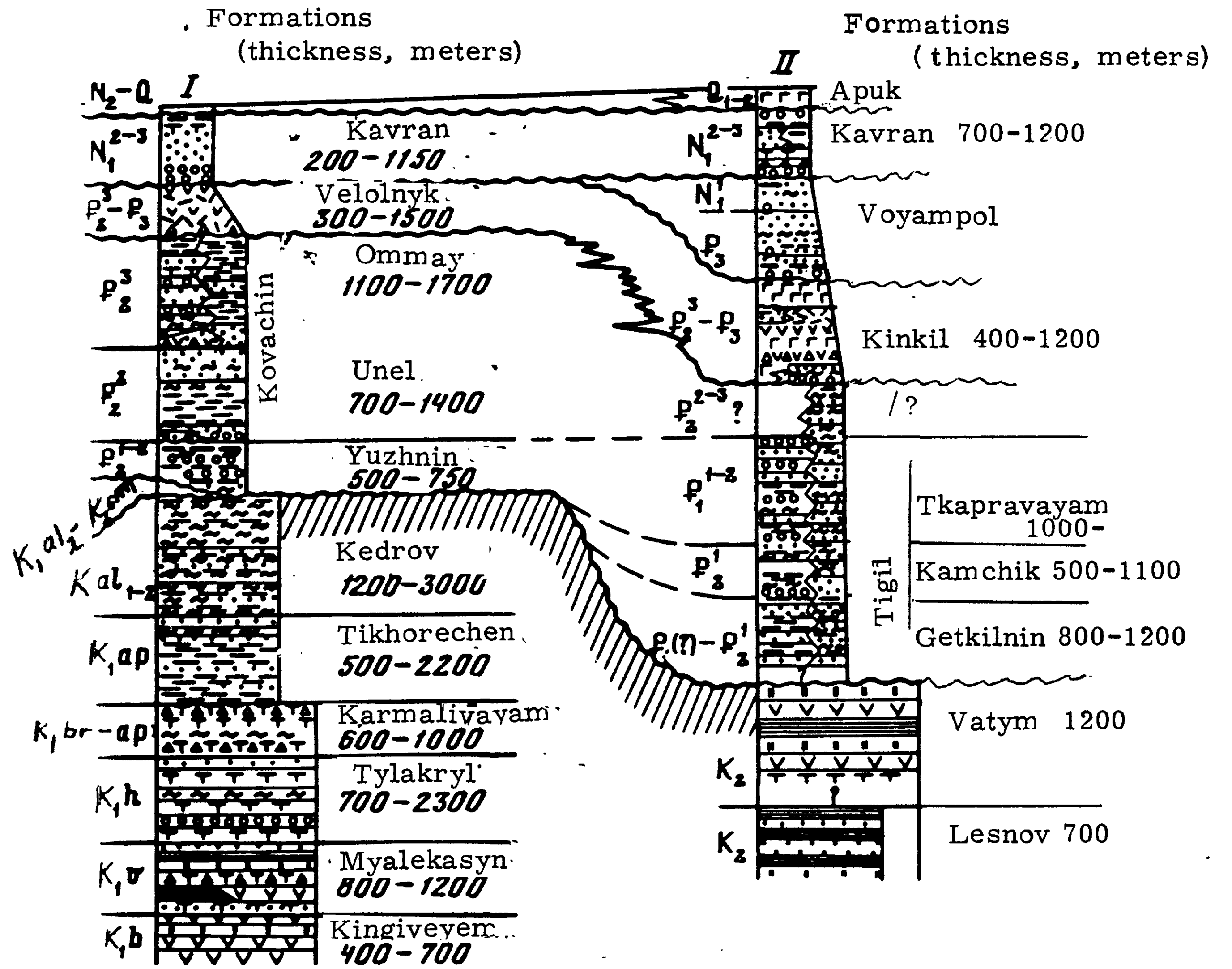
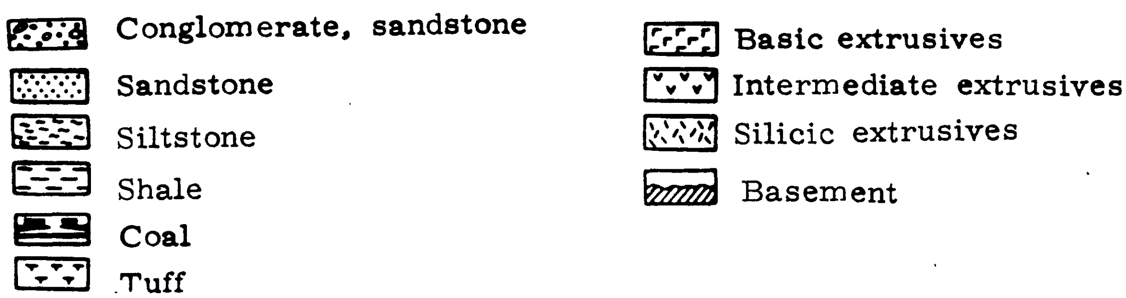


Figure 10a. Stratigraphic columns for the Pustorets basin (from Ivanov, 1985).
I- Mametch Bay, II- Podkager Bay. See figure 10 for approximate locations
K_1-Lower Cretaceous, b-Berriasian, v- Valanginian, h-Hauterivian, ap-Aptian, al-Albian, m-Maastrichtean, P-Paleogene, N-Neogene, Q-Quaternary.



To the northeast of the Pustorets graben and on line with it are the Kuyul and Ust'-Enychavayam troughs.

Petroleum geology. Content of organic carbon in the Cretaceous Tikhorechen Formation of the northwest folded frame of the Pustorets basin is 0.25-1.83 percent. These rocks have entered the oil window.

Of the rocks of the Tigil Series the Kamchatka Formation has the highest content of organic carbon, values being in the 1-2 percent range. These sediments have also reached the oil window. The igneous dikes and sills within these rocks have had little effect on their maturation, the width of the contact alteration not exceeding 1.5 m. Bitumens have been found in many places in sandstones of the Tigil Series.

The organic-carbon content of the clays of the Unel Formation is 0.4-0.9 percent. Bitumens are present in some places, but they appear to be the result of migration. The clays of the Ommay Formation are high in disseminated bituminous material.

The Pustorets basin appears to have sufficient reservoir rocks, seals, and traps for oil and gas pools. Good reservoirs are present in practically all stratigraphic subdivisions. Clay seals are widely distributed in the Tikhorechen, Kedrov, Kamchatka, Unel, and Ommay Formations. The clays of the Ommay Formation are an effective upper regional seal. Anticlines within the Kinkil high can serve as traps. Similar structures are probably present in the deeper, central part of the basin. Fault and stratigraphic traps are also expected.

The plays recognized in the Pustorets basin are the upper Tikhorechen and middle Kedrov Formations, the lower part of the Tigil Series, and the lower and middle Ommay Formation. Favorable exploration areas are the central part of the basin, the Mametchin basin, and the northeast flank of the Kinkil high. This favorable area is about 13,000 km^2.

Penzhin basin

The Penzhin basin is in the northwest part of the Anadyr-Koryak system of Cenozoids at its boundary with the Okhotsk-Chukotsk volcanic belt. It extends more than 700 km in a northeast direction.

General geology. The folded basement of this basin includes rocks of Precambrian, Paleozoic, and pre-Aptian Mesozoic age. The Precambrian is represented by Archean and Proterozoic metamorphic varieties. The Paleozoic rocks are volcanic, carbonate, and coarse-clastic deposits. The Mesozoic section consists of upper Jurassic-Barremian volcanic and sedimentary rocks.

The intermediate or lower-buried stage of the basin fill is Aptian-middle Albian in age. These rocks are present only in the southeastern part of the basin and consist largely of argillite and siltstone. They comprise the Tikhorechen Formation (1200-2200 m thick) and the overlying Kedrov Formation (1200-3500 m thick).

The upper structural stage of the basin fill begins with sediments of the upper Albian, at the base of which is an unconformity. The thickest Albian-Turonian section (up to 2.5 km) is along the northwest border of the basin. The sandstones here are generally volcanic-derived and graywacke, and the clays are polymineralic.

The overlying Coniacian and Campanian sediments are coarse-clastic and coal-bearing on the northwest and fine-clastic marine on the southeast. To the northeast these pass into volcanics. These deposits range in thickness from a few hundred meters to 2.5-3 km.

During late Campanian-Danian time subaerial volcanics and coarse-clastic, commonly coal-bearing sediments were deposited. Their maximum thickness is 1200 m .

The Paleogene section also consists of two main rock types, subaerial volcanics and coarse-clastic, commonly coal-bearing deposits. There were two periods of volcanic activity: Paleocene-early Eocene (72.5-50 m.y.) and late Eocene-Oligocene (47-32 m.y.). The first was along the periphery of the basin, and the second was in the central regions. Thickness of the Paleogene rocks is a few hundred meters.

The Neogene is represented by sands and gravels a few hundred meters thick.

The Penzhin basin is bounded on the northwest by the Murgal anticlinorium, in the core of which are Upper Jurassic-Barremian deposits that have been intruded by granites. The basin boundary here is along deep faults (fig. 11). On the southeast boundary are the Talov-Maynskiy and Pekul'ney anticlinoria. The basin is asymmetrical (fig. 12); the southeast has subsided to greater depths and the sedimentary fill is as much as 6-6.5 km thick. Within the basin is a line of depressions separated by saddles and highs. Local folds are present in both the basins and on the highs. Some of the highs are laccolithic.

<u>Petroleum geology.</u> The rocks of the Penzhin basin are low in organic carbon. Average content in the silt-clay varieties is 0.3-0.5 percent. The highest concentrations have been found in the Aptian-Albian Tikhorechen and Kedrov Formations, where values are 0.9-1.4 percent. The upper Cenonian-Danian and Paleogene sediments generally contain some coal beds. No trace of any migrated hydrocarbon has been found anywhere in the basin. The low content of organic matter is due to the abundance of volcanic rocks in the depression. The environment of volcanic deposition was not favorable for abundant life in the basin; further, this was also an oxidizing environment.

The sedimentary and volcanic fill of the basin is in the early stages of maturation. Along the northwest border these rocks are at most only in the brown coal stage, not yet into the oil window. On the southeast, however, the lower part of the section has entered the oil window.

The lower Senonian reservoir rocks in the southwest parts of the basin have a porosity less than 12 percent and permeability less than 0.2 md. On the northeast, however,the porosity is up to 16.5 percent, and permeability is up to 4 md. In general the reservoir properties are poor. In the upper

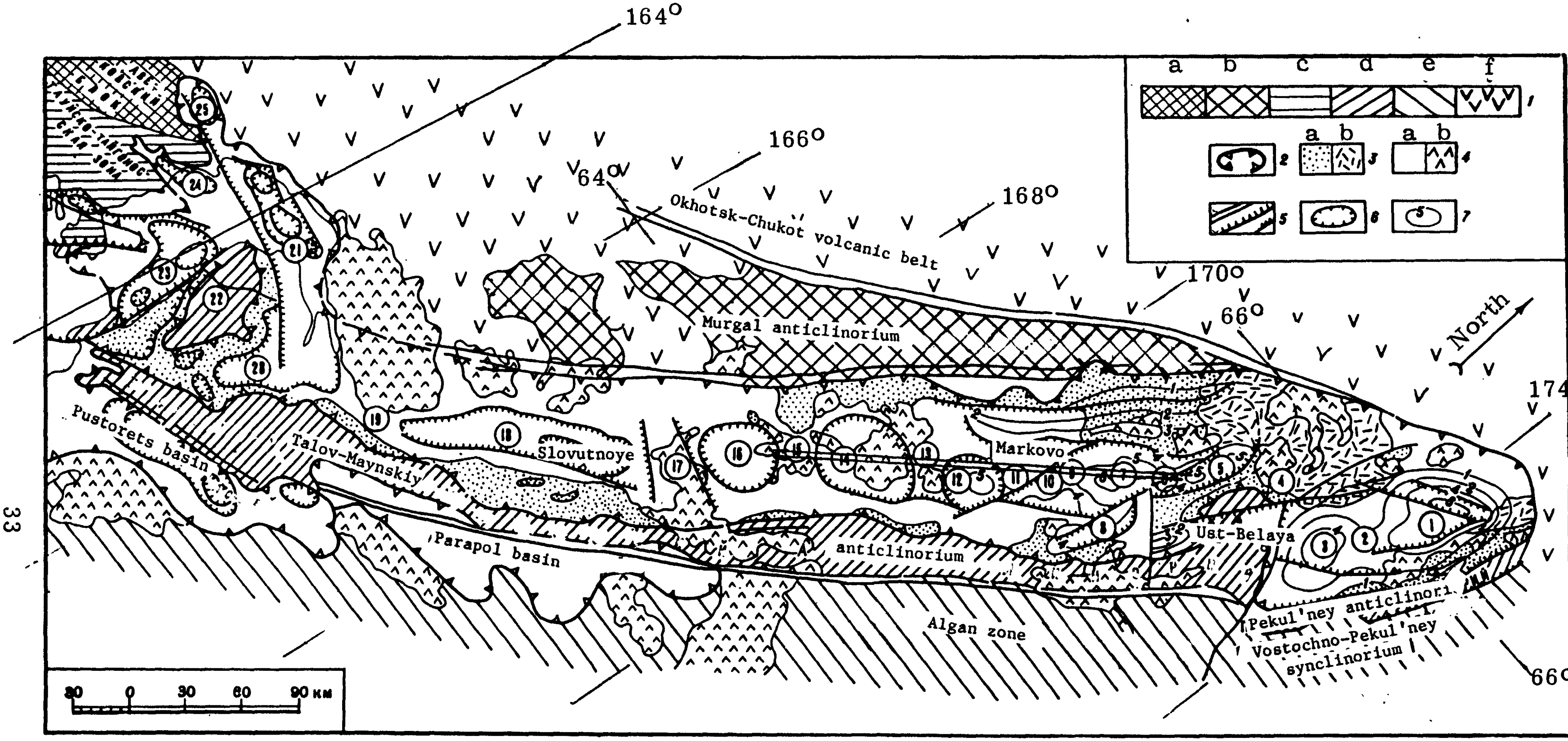


Figure 11. Structure map of Penzhin basin (after Ivanov, 1985).
Terranes surrounding the basin: a - Precambrian metamorphic rocks, b - upper Jurassic-Barremian clastic-tuffaceous deposits and granites, c - Permian-Hauterivian clastic and volcanic rocks, d - various Paleozoic-Barremian rocks, e - Cretaceous clastic and siliceous volcanic rocks, f - Albian-Cenomanian subaerial tuffs and effusive rocks.
2 - Basin boundaries. Rocks of basin fill; 3 - Cretaceous: a - clastic, b - volcanic; 4 - Cenozoic: a - clastic, b - volcanic. 5 - Large faults: a - deep, determined from geophysical data, b - normal faults; c - overthrusts.
6 - Second order negative structures. 7 - Structure contours on base (Aptian-Albian) of basin fill, km. Second order structures (numbers in circles) basins and depressions: 1 - Afon'kin, 3 - Levobel, 5 - Chineyveyem, 7 - Marakov, 8 - Bachkin, 10 Tarsuk, 12 - Mayor, 14 - Orlov, 16 - Chernorechen, 18 - Kondyrev, 10 - Aynyn,
21 - Ust-Penzhin, 23 - Mametchin, 24 - Kechichman, 25 - Paren. Transverse and diagonal highs: 2 - Bychin, 4 - Pastbishch, 6 - Ilistoye, 9 - Ubiyen-Mayn, 11 - Vakarev, 13 - Russkikh gor, 15 - Nalgim, 17 - Slovutnen, 19 - Oklan, 22 - Valizhgen. ══ Approximate position of profile of figure 12.

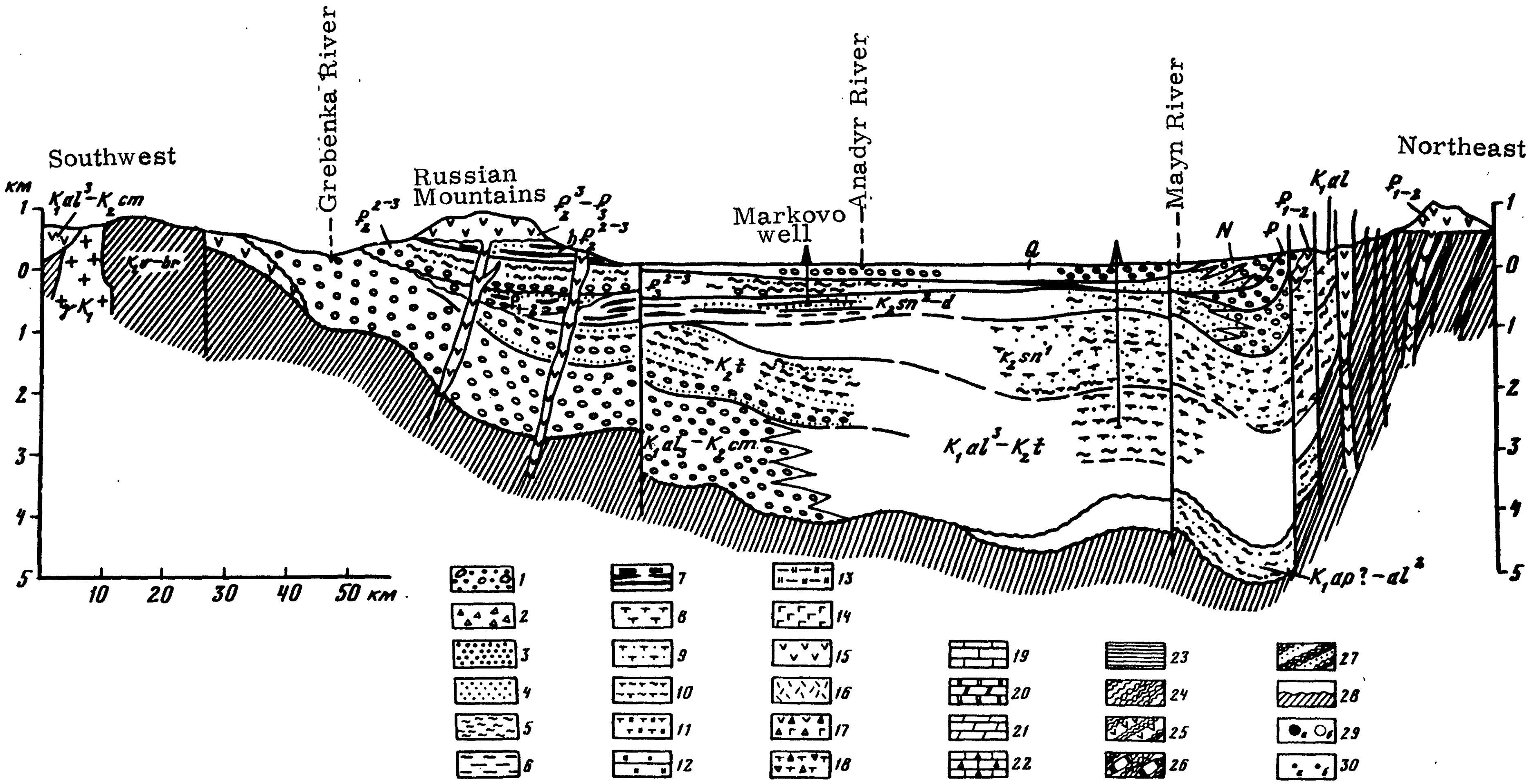


Figure 12 Schematic geologic profile through northeast part of Penzhin basin. See figure 11 for approximate location.

Legend (not all of these symbols are depicted in this illustration): 1-conglomerate, 2-breccia, 3-gravel, 4-sand, 5-silt, siltstone, 6-clay, argillite, 7-coal, 8-tuff, 9-tuffaceous sandstone, 10-tuffaceous siltstone and argillite, 11-siliceous tuff, 12-siliceous rocks (diatomite, opoka, etc), 13-siliceous aragillite, clayey diatomites, 14-basic effusives, 15-intermediate effusives, 16-silicic effusives, 17-lava breccia, 18-tuff breccia, 19-limestone, 20-dolomite, 21-marl, 22-limestone breccia, 23-shale, phyllite, 24-schist, 25-schist and amphibolite, 26-schist and marble, 27-schist and quartzite; 28-surface of folded sub-strat; commercial flows of 29 - a-oil, b-gas; 30-shows: a-oil, b-gas.

Senonian-Danian and Cenozoic reservoirs porosity is generally more than 20 percent, and permeability is 1-500 md.

Clay seals are present in the Aptian-Albian and Cenomanian-Turonian section of the southeast part of the basin. They appear to have a local distribution.

Anticlines that could serve as traps are present along the southeast border of the basin; however, they are faulted and eroded. Structural traps capable of containing pools are present only in the central, most subsided parts of the basin.

No oil plays are recognized in the Penzhin basin. There are practically no source beds; where reservoirs are good there are no seals; and where seals are present the reservoirs are poor. Gas pools may be present in the Aptian-Turonian and upper Senonian-Paleogene parts of the section in the deep parts of the basin.

Parapol basin

The Parapol basin is an intermontane depression 400 km long and 10-40 km wide on the southeast side of the Penzhin basin (fig. 11). The basement here consists of folded pre-upper Campanian or pre-Maastrichtean Cretaceous rocks, and the basin fill is upper Senonian-Danian and Cenozoic.

The sedimentary rocks of the basin are coarse clastic near-shore marine and continental deposits, among which are also silt-clay and coal-bearing varieties. They are late Senonian-Danian, early-middle Eocene, middle Eocene, and Oligocene in age. The Oligocene section contains some volcanics.

The basin is half graben with a steep border fault on the northwest. On the southeast are two small downwarps where molasse deposits are 1.5-2 km thick.

The Parapol basin is a young feature where the sediments are still in the diagenetic stage. The coarse-clastic nature of the sedimentary fill, its oxidized state, and small thickness suggest that no commerical oil or gas will be found here. The possibilities for the folded basement, however, remain open.

Anadyr basin

The basin occupies the Anadyr Plain and opens offshore into the Gulf of Anadyr (figs. 1 and 14), where it has been described by Kummer and Creager (1971) and Marlow and others (1983). It is on line with the offshore Navarin basin, but the two are separated by a high. Structurally the Anadyr basin is on the northeast margin of the Anadyr-Koryak fold system. Two gas pools and one oil field have been discovered here, and flows of hydrocarbons have been recovered at several places (Agapitov and others, 1983).

General geology. The folded basement of the depression is heterogeneous. Present are Precambrian metamorphic rocks; Paleozoic carbonate and clastic sedimentary rocks, which in places are metamorphosed; and Jurassic-Neocomian sandstones, shales, and volcanic rocks. On the north and northwest the basement consists of Albian-Cenomanian extrusive rocks and tuffs of the Okhotsk-Chukotsk volcanic belt. Granitic plutons of Early and Late Cretaceous age are present throughout the basement of the basin.

On the south and southwest in the regions adjacent to the Anadyr-Koryak fold system, upper Albian-Cenomanian and younger Upper Cretaceous rocks form the lower stage of the sedimentary fill. Two sub-stages are recognized here. The lower sub-stage consists of upper Albian-lower Campanian marine graywacke, tuffaceous sandstone, siltstone, argillite, and tuff. The upper sub-stage is continental coal-bearing sandstone, siltstone, and argillite. This latter unit is the Rarytkin Formation and is 800-1000 m thick (fig. 13).

In the north and northeast parts of the basin Paleocene-Eocene volcanic rocks rest directly on rocks of the Okhotsk-Chukotsk volcanic belt. Toward the south these volcanic rocks pass into coal-bearing clastic sediments. These are the Anadyr and Tanyurer Formations of figure 13.

The main stage of the sedimentary fill of the Anadyr basin consists of two lithostratigrahic complexes: upper Eocene-Oligocene and Neogene. The first has a limited distribution in the south and southwest parts of the depression and probably also in the East Anadyr downwarp (fig. 14). The second is extensive in its distribution with the area of occurrence increasing upward in the section.

The upper Eocene-Oligocene sediments are a fine-clastic, transgressive-regressive unit. The lower, transgressive part is combined into the Ust'-Chirynay Formation; it consists of shale and interbeds of siltstone and limy sandstone. The overlying Maynitsa Formation is subdivided into a lower argillite, middle siltstone, and upper sandstone-siltstone assemblage. The lower and middle subdivisions correspond with maximum marine transgression. The fine-grained character of these rocks suggests a peneplaned source area at great distance. Thickness of the Eocene-Oligocene section is as much as 3 km.

The Neogene sediments are near-shore marine clastic deposits: sandstone, siltstone, conglomerate, argillite, coal, and lignite. Based on lithologic differences the Sobol'kov, Gagarin, Avtatkul, Yeliseyev, Ozernin, Echin, and Aleksandrov Formations are recognized (fig. 13). Total thickness of the Neogene-Quaternary section is 3.5-5 km in the deepest parts of the basin.

In summary, the sedimentary fill of the Anadyr basin consists of: 1) upper Albian-lower Campanian marine tuff-clastic deposits; 2) upper Campanian-Danian coal-bearing continental deposits; 3) Paleocene-Eocene subaerial volcanic rocks, which pass laterally into coal-bearing and marine clastic material; 4) Eocene-Oligocene marine pelites; 5) Neogene near-shore marine clastic coal-bearing deposits; and 6) Quaternary continental coarse-grained deposits.

The Anadyr basin has a very irregular outline (fig. 14). It consists of several semi-isolated lows separated by highs, which are composed of folded Cretaceous rocks.

The basin is asymmetrical (fig. 15). Two zones are present: platformal and geosynclinal. In the platformal part on the north and northeast Neogene-Quaternary sediments rest directly on Paleocene-Eocene volcanic and older rocks. Dips here are gentle, and amplitude of folding does not exceed 300-400 m.

Structure in the geosynclinal south part is different from that of the north. The Neogene section is much thicker, and a thick section of upper

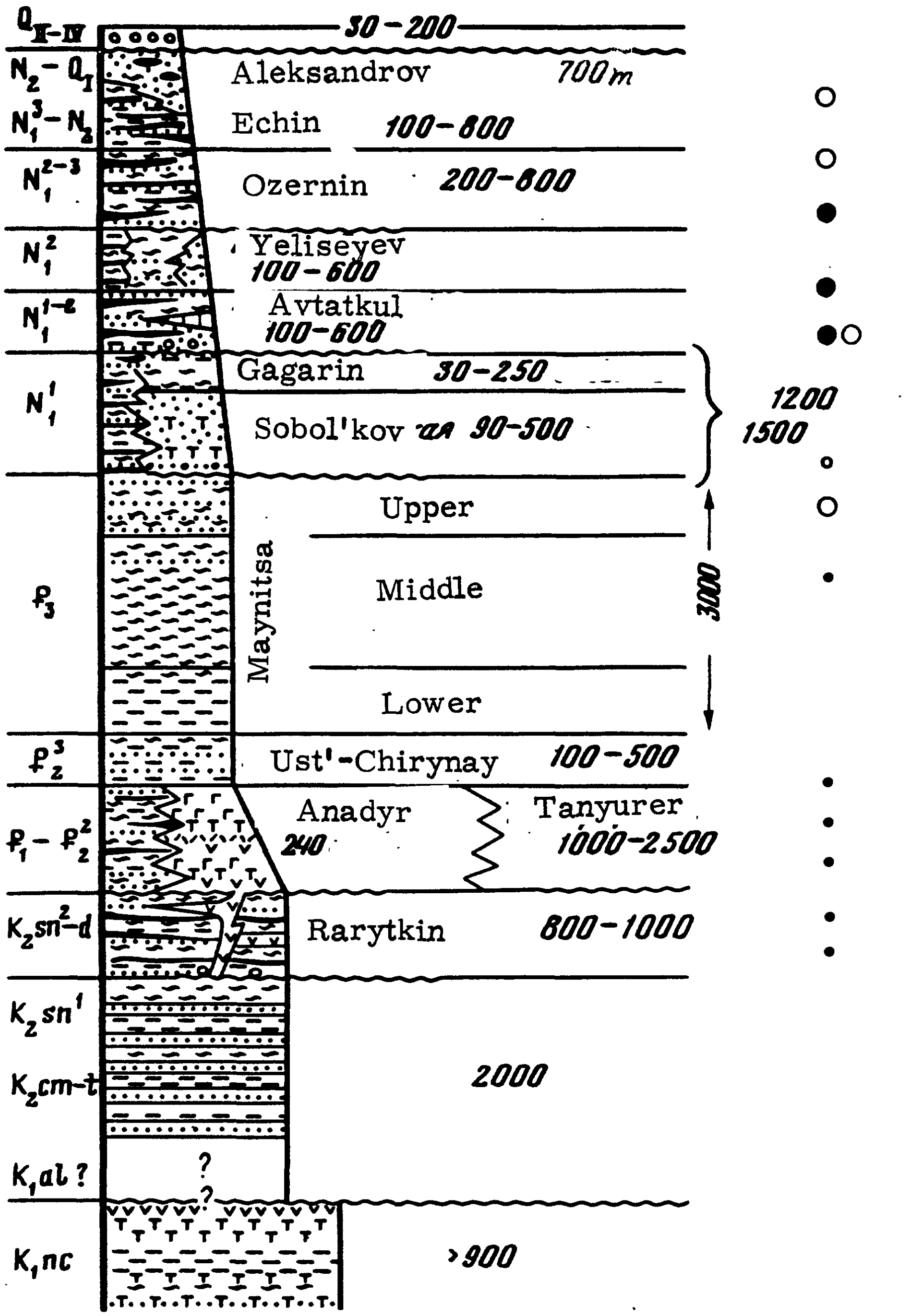


Figure 13. Composite stratigraphic column of Anadyr basin (from Ivanov, 1985)

Conglomerate, sandstone
Sandstone
Siltstone
Shale
Coal
Tuff
Basic extrusives
Intermediate extrusives
Silicic extrusives
Basement

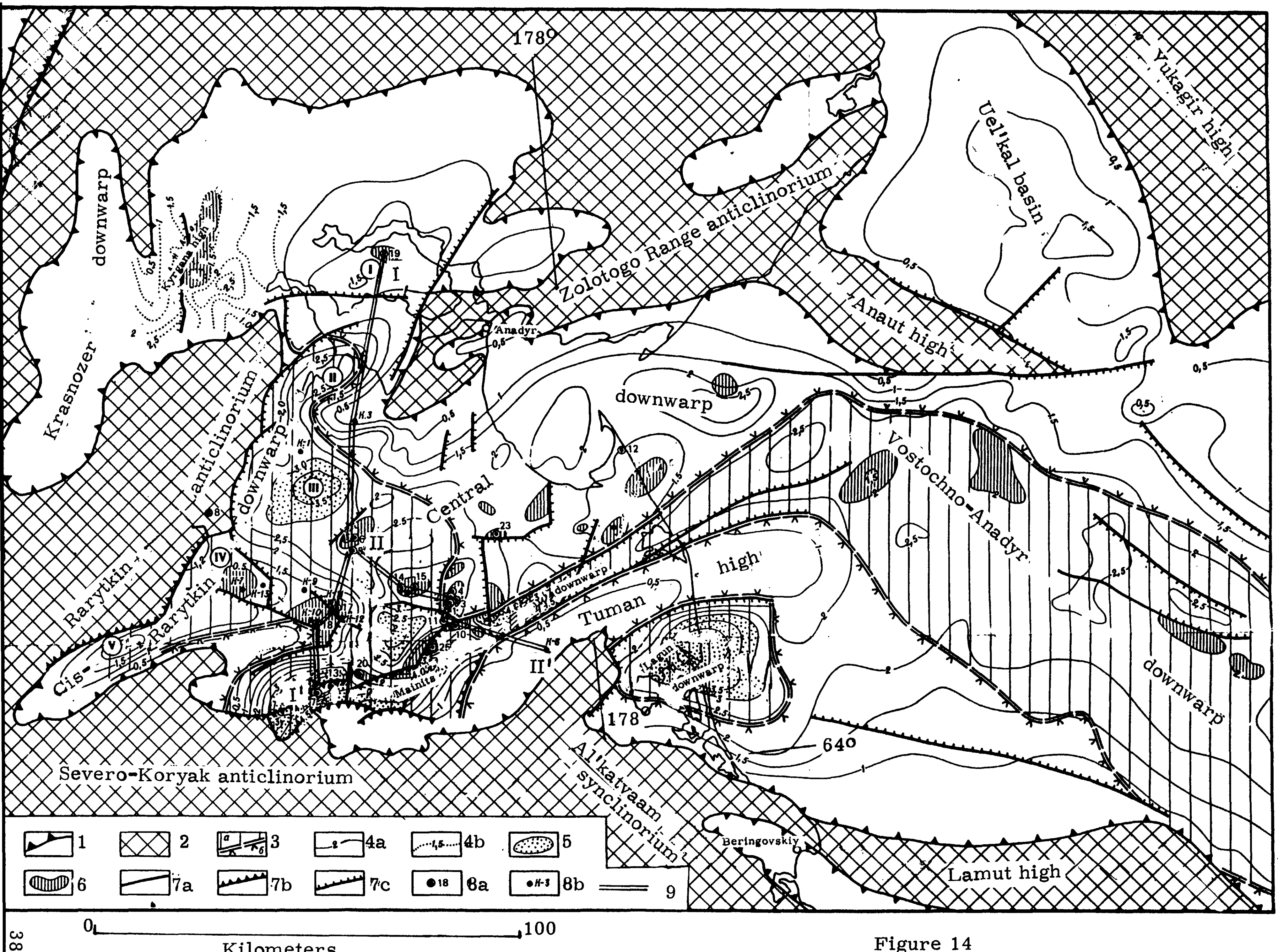
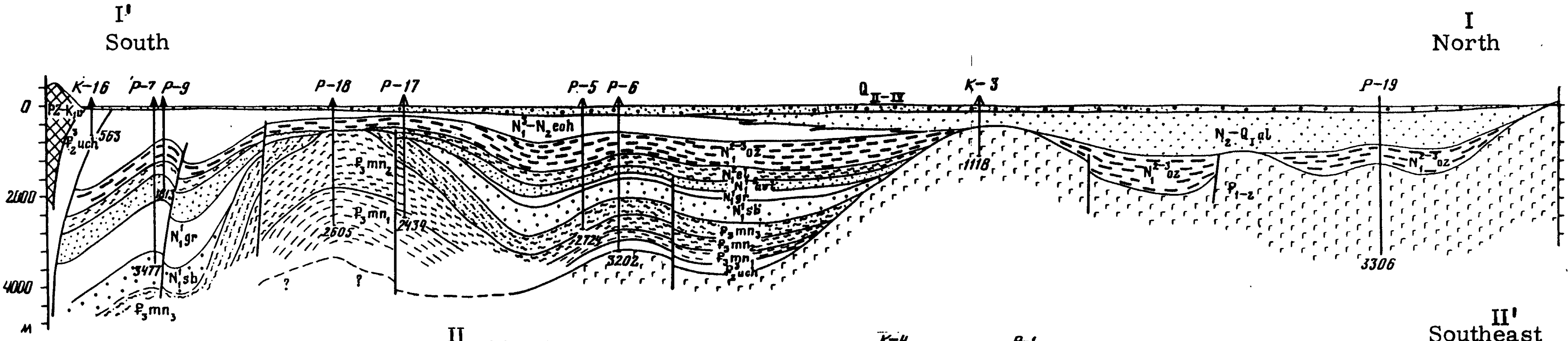
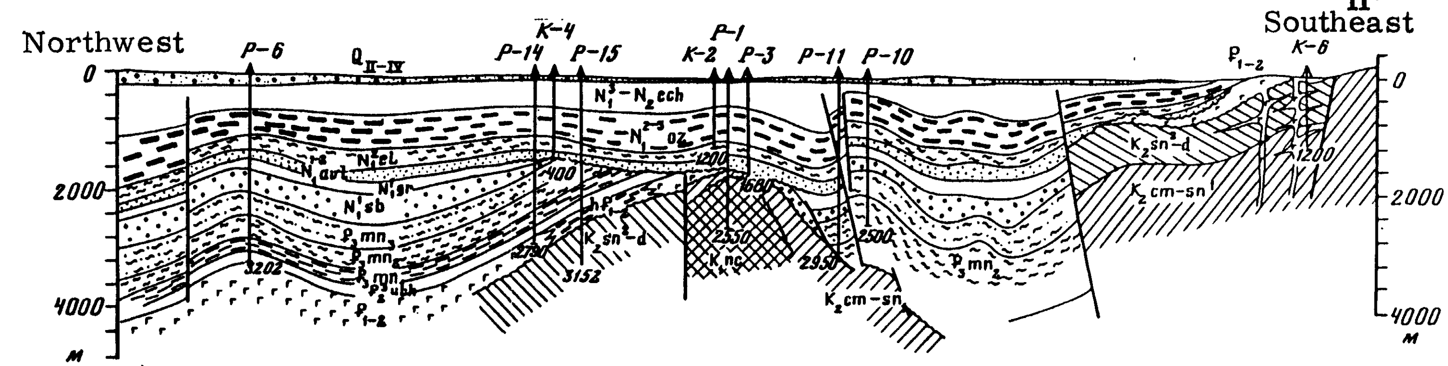

178°
Yukagir high
Uel'kal basin
Zolotogo Range anticlinorium
Anaut high
Krasnozer downwarp
Kyrgena high
Anadyr
downwarp
Central downwarp
Vostochno-Anadyr downwarp
Tuman high
Lagun downwarp
Mainits
Rarytkin anticlinorium
Cis-Rarytkin downwarp
Severo-Koryak anticlinorium
Al'katvaam synclinorium
Beringovskiy
Lamut high
178
64°
1
2
3
4a
4b
5
6
7a
7b
7c
8a
8b
9
0
100
Kilometers

Figure 14

Figure 14. Tectonic map of Anadyr basin (from Ivanov, 1985).
1-Boundaries of the basin; 2-structures of the frame; 3-boundary between sectors of the basin where Neogene sediments are underlain by: a-Eocene-Oligocene rocks, b-volcanics of the Paleocene-Eocene and/or sediments of the Upper Cretaceous; 4-structure contours (km): a-on base of Neogene, b-on reflector in Upper Cretaceous; 5-zones of downwarping with thickness of Neogene-Quaternary greater than 3 km; 6-local uplifts; 7-large faults: a-general, b-overthrusts and upthrusts, c-normal; 8-drill holes: a-deep parametric, b-core holes; 9-lines of profile of figure 15.





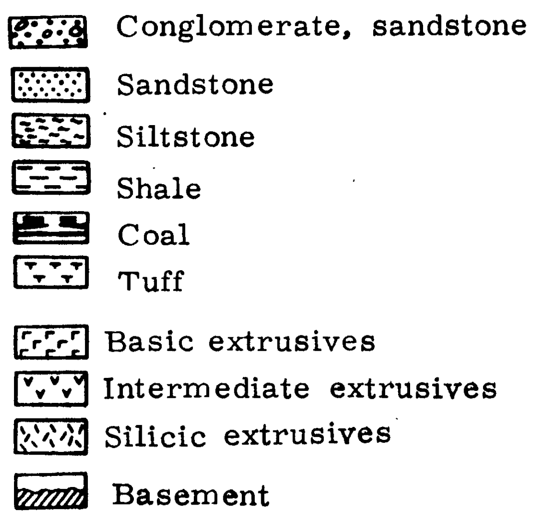


Figure 15. Geologic profiles through Anadyr basin (from Ivanov, 1985). Formations: N3/1-N_2 ech - Echin, N2/1-^{3}oz - Ozernin, N2/1 el - Oliseyev, N1/1-^{2}-avt-Avtatkul, N1/1gr-Gagarin, N_{1sb}-Sobol'skov, P_3mn-Maynits, P3/1 uch - Ust-Chirynay.

Eocene-Oligocene rocks is present. Upthrusts and overthrusts dip to the southeast. Anticlines with amplitudes of 1.5-2 km are associated with these faults.

The principal structural feature of the eastern part of the Anadyr basin is the East Anadyr downwarp, which is 250 km long and 120 km wide. Seismic surveys indicate that dips are gentle. Neogene deposits here are 2-2.5 km thick. Maximum sedimentary thickness including rocks of Cretaceous age is up to 9 km (Marlow and others, 1983).

Petroleum geology. The clays of the Albian-Cenomanian and upper Senonian-Danian in outcrop on the margin of the basin have average organic carbon contents of 0.64 and 0.97 percent, respectively. It is the humic type. Migrated bitumen is also found in these rocks. In the central part of the basin Santonian-Campanian argillites contain an average of 0.59 percent organic carbon.

Clays of the Ust'-Chirynay Formation of the upper Eocene have a background concentration of organic carbon at 0.2-1.2 percent. This material is regarded as a possible oil source bed. The organic carbon content of the argillaceous rocks of the lower and middle parts of the Maynitsa Formation of Oligocene age is the 0.56-1.05 percent range, increasing from the central part of the basin toward the southwest. These rocks are also regarded as oil source beds. The organic matter of these Eocene-Oligocene rocks is the humic type.

Average concentration of organic carbon in the Neogene rocks increases upward in the section from 0.63 percent in the Sobol'kov Formation to 3 percent in the Aleksandrov Formation, and also by area from the central part of the basin toward the west and south borders. It is the humic type. These Neogene rocks are not considered as being oil source rocks in the northeast, central and west parts of the basin because they are not mature enough. Here they may be gas sources, however. In the southern part of the basin the Neogene sediments are up to 4-4.5 km thick, and the lower parts are consequently in the oil window (fig. 16).

The main oil kitchen for the Anadyr basin was in the southwest part of the basin, and the main source beds were the upper Eocene-Oligocene argillaceous rocks. All oil shows found have been in this region. As of the end of 1983 shows or flows of oil had been recorded in four areas of the basin: Zapadno-Ozer well P-15, Ust'-Chirynay well K-7, Izmennoy wells P-10 and P-11, and Verkhne-Echin wells P-16, P-9, and P-13. The Ust'-Chirynay well K-7 is located in the Rarytkin downwarp in the southeast part of the basin (fig. 14). The location of these other wells could not be determined.

In Zapadno-Ozer well P-15 films of oil were recovered during testing of several intervals of the upper Senonian-Danian and Paleocene-Eocene coal-bearing sediments. Visually this oil is paraffinic and viscous. The source beds may be both interbedded sediments and Eocene-Oligocene rocks, which, on the flanks of the Zapadno-Ozer high, are hypsometrically lower than the beds with the oil shows.

Drops of oil in core samples of Ust-Chirynay well K-7 contains 91 percent oily fraction in which methane-naphthene fractions predominate. A considerable

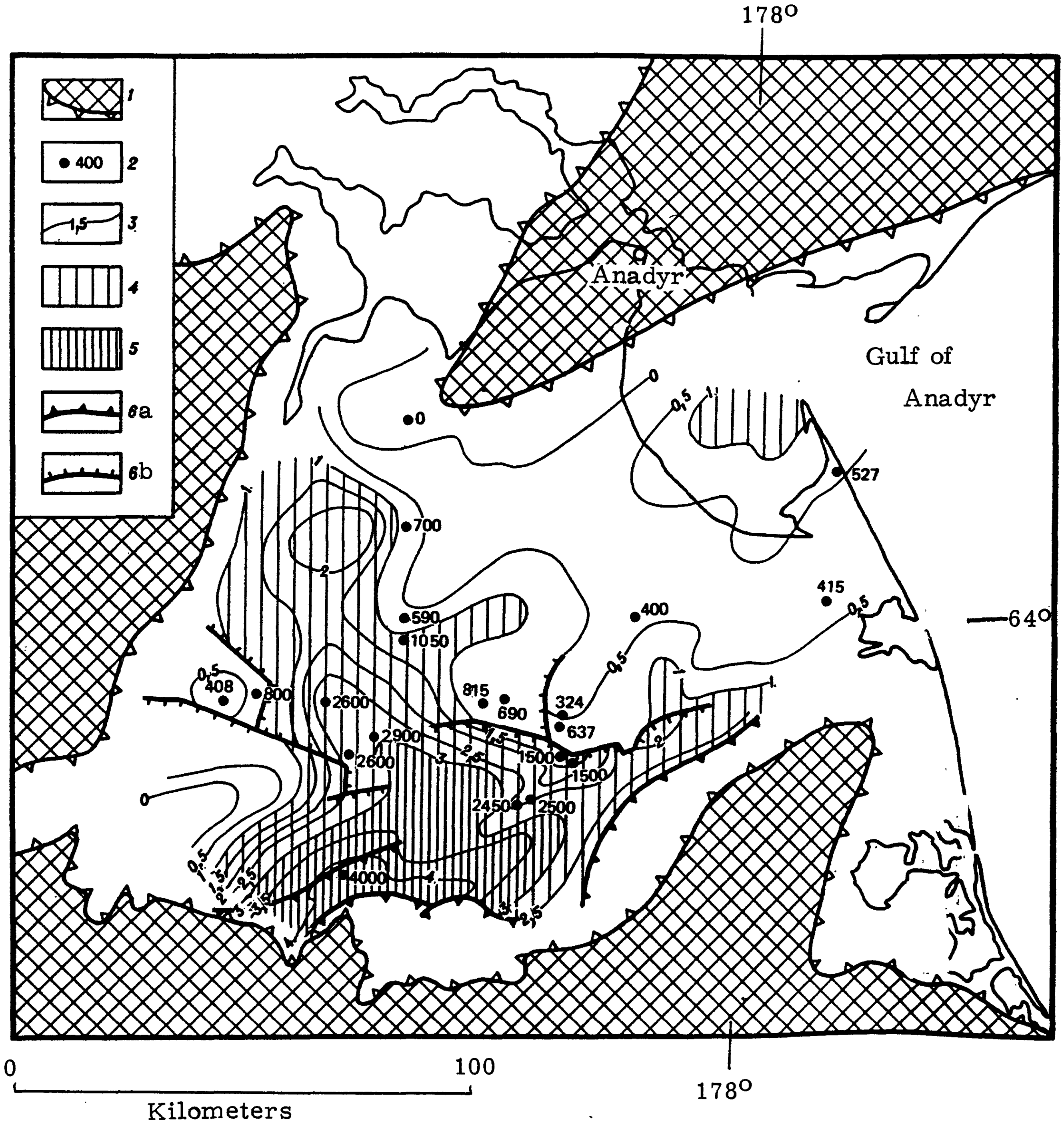


Figure 16. Map showing thickness of Cenozoic sediments of Anadyr basin occurring beneath the iso-reflectance surface 7R[a] (from Ivanov, 1985). 1-Boundaries of basin and its frame; 2-wells and thickness (m) of Cenozoic sediments beneath 7R[a] surface; 3-isopachs, km; 4-regions where thickness is 1-3 km beneath 7R[a] surface; 5-same, more than 3 km; 6-faults: a-upthrusts and overthrusts, b-normal.

quantity of solid paraffin is present. A genetic relationship between the naphthenes with the sandy-clayey rocks of the Ust-'Chirynay Formation seems certain.

In the Izmennoy area small flows of light oil and condensate have been recovered from two wells from fractured siltstone of the middle Maynitsa Formation. The oil is light, practically sulfur-free, low in tar, and is the methane-naphthene type. It appears to be related genetically to the Oligocene sediments.

Oil pools are present in the 1200-2000 m depth interval of the lower and middle Miocene in the Verkhne-Echin area. These oils differ from those of the Izmen area; they are somewhat lighter (0.81-0.83 g/cm^3), higher in tar, and contain more methane-type hydrocarbons. There is a greater content of odd-number carbon atoms in the chains, indicating a continental origin.

In summary, the oils of the Anadyr basin are in general the paraffinic type.

More than 100 shows and flows of gas have now been recorded in the Anadyr basin. These occur in eight areas. The composition of the gases is related directly to degree of catagenic alteration (fig. 17). As average values of maturation increase (down the first column of fig. 17), the gases first become richer in heavy hydrocarbons and then become poorer until none are present at all. In the Neogene sediments that have not reached the oil window, only methane has formed. In the lower parts of the Neogene the heavier hydrocarbons begin to appear in the gases, and this continues down into the Eocene-Oligocene sediments. Then in the older sediments, which have entered the thermal gas window, only methane has formed. Areally the gases with high concentrations of heavy hydrocarbons are in the central and south parts of the basin (figs. 18 and 19).

Very good granular reservoirs are present in the upper part of the Neogene section; they are well sorted polymict and volcanomict sandstones. Total porosity is 40-50 percent, open porosity is 35-40 percent, effective porosity is 20-25 percent, and gas permeability is 4-6 darcies. The best of these reservoirs are in the west, north, and east parts of the onshore area of the basin.

The reservoirs of the lower Miocene are not as good as those higher in the Neogene section because of greater catagenesis and a tuffaceous composition of the sandstones, and also because of intense zeolitization.

Good reservoirs are also present in the upper part of the Oligocene Maynitsa Formation. Total porosity here is up to 35 percent, open porosity to 30 percent, effective porosity to 10 percent, and gas permeability to 500 md. No satisfactory reservoirs have been found lower in the Maynitsa nor in the underlying Ust'-Chirynay Formation.

Although the rocks of the Upper Cretaceous, Paleocene, and Eocene have undergone much alteration, some good sandstone reservoirs are present. Open porosities of 25 and even 35 percent, and gas permeabilities of 70-80 md are found. Similar reservoirs are also present in the Lower Cretaceous.

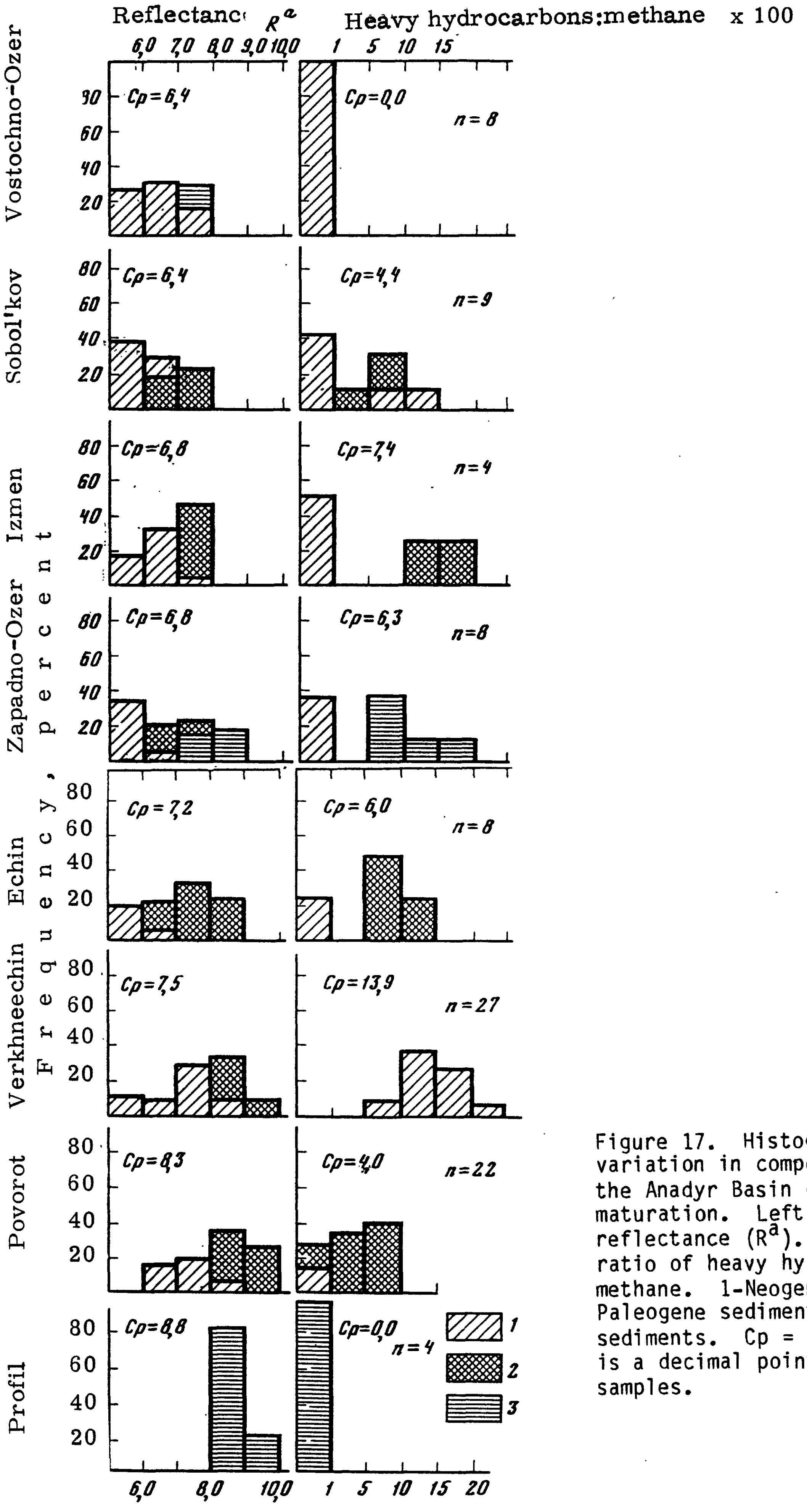


Figure 17. Histograms showing variation in composition of gases of the Anadyr Basin depending on maturation. Left column shows vitrine reflectance (R^a). Right column shows ratio of heavy hydrocarbons to methane. 1-Neogene sediments, 2-Paleogene sediments, 3-Upper Cretaceous sediments. Cp = average value (comma is a decimal point); n = number of gas samples.

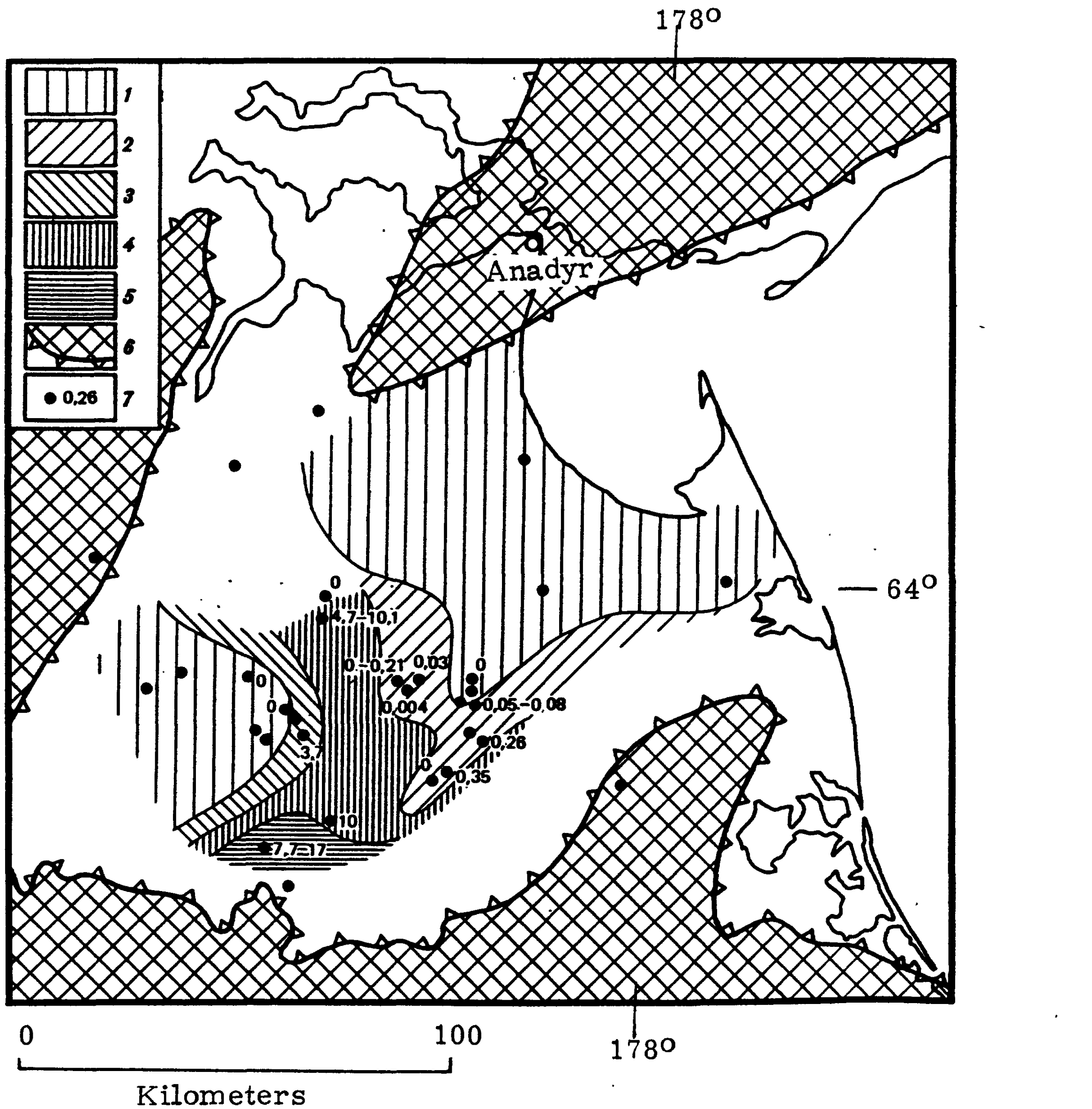


Figure 18. Variation in composition of gases by area in the Neogene sediments of the Anadyr Basin (from Ivanov, 1985).
1-5 - zones with content of heavy hydrocarbons (in percent): 1-less than 0.01; 2-from 0.01 to 1; 3-from 1 to 5; 4-from 5 to 10; 5-greater than 10; 6-boundaries of the basin; 7-drill holes and content of heavy hydrocarbons in percent.

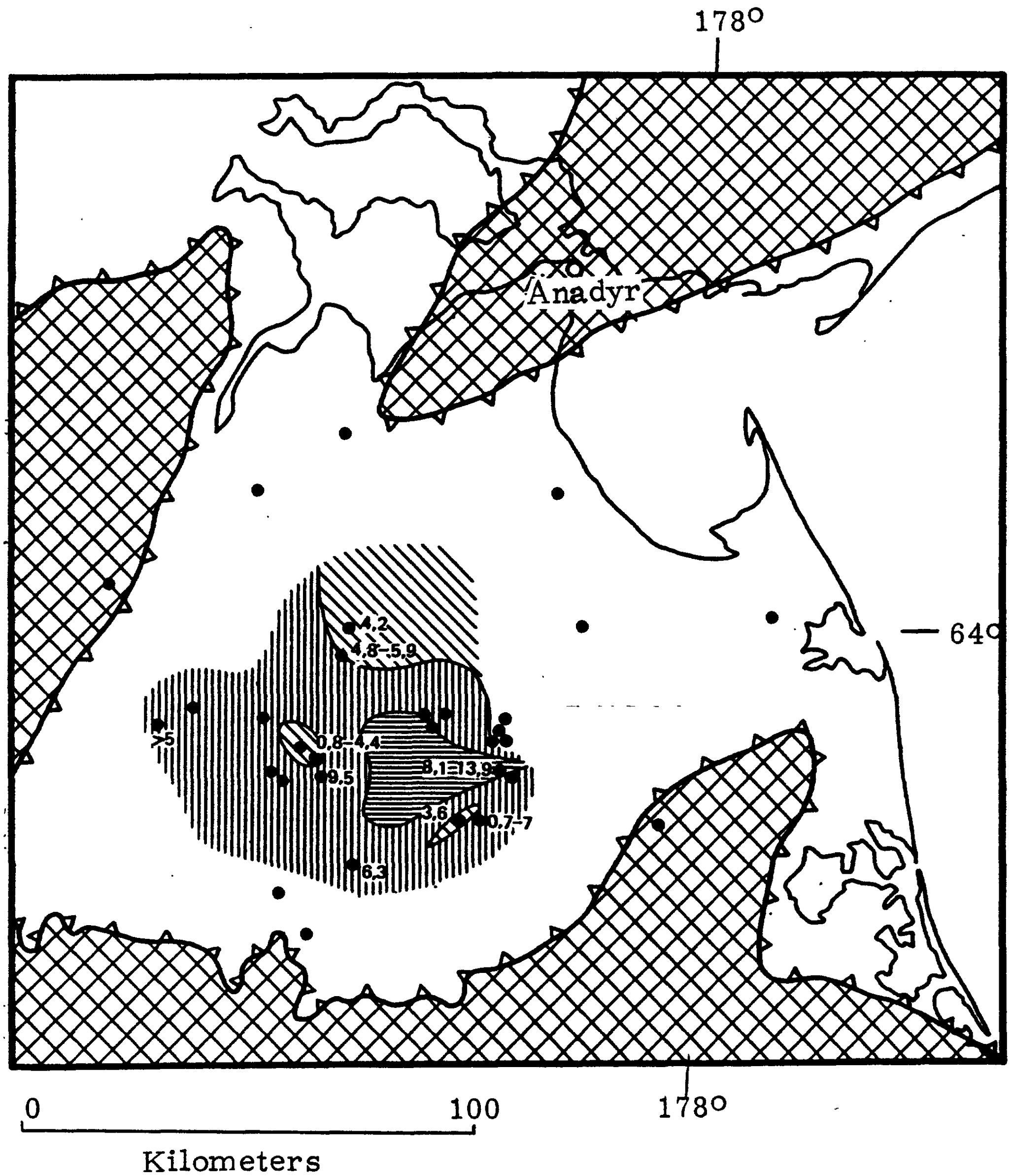


Figure 19. Variation in composition of gases by area in the Paleogene sediments of the Anadyr Basin (from Ivanov, 1985). Symbols same as in figure 18.

The clay seals of the Neogene section are in general not very good; however, they improve in the south part of the basin. Clays of the middle and upper Miocene are a factor in trapping in the Verkhne-Echin gas-oil field. The Eocene-Oligocene sediments except for the upper Maynitsa Formation are a thick seal for the entire basin.

In the platformal part of the basin the anticlinal traps are gentle structures with low closure. In the geosynclinal part the anticlines are more narrow, have greater closure, and are complicated by clay diapirism. Faulting is extensive. Local structures in the south of the basin form the Povorotno-Telekay zone of oil-gas accumulation. Stratigraphic traps may be present in the zone of transition where Eocene-Oligocene sediments pass from the geosynclinal zone to the platformal zone.

Earlier assessments by the Soviets held that in the Neogene section good granular reservoirs were common, but there were no effective seals to trap gas, and that good quality source beds were present in the Paleogene sediments as well as were seals; however, granular reservoirs were few. This assessment has now been revised toward the optimistic by the Soviets. First, in the south part of the depression pure argillaceous rocks have now been found in the upper part of the Neogene section. These serve as seals for the oil and gas pools of the Verkhne-Echin area. Second, it has now been established that a thick Cenozoic section is present here with thick source beds. Third, oil plays may have been missed in the Upper Cretaceous and Paleocene-Eocene sections of the Zapadno-Ozer area. The presence of paraffinic oil here indicates possibly the presence of an older, independent oil-gas play beneath the Paleogene volcanic and argillaceous section.

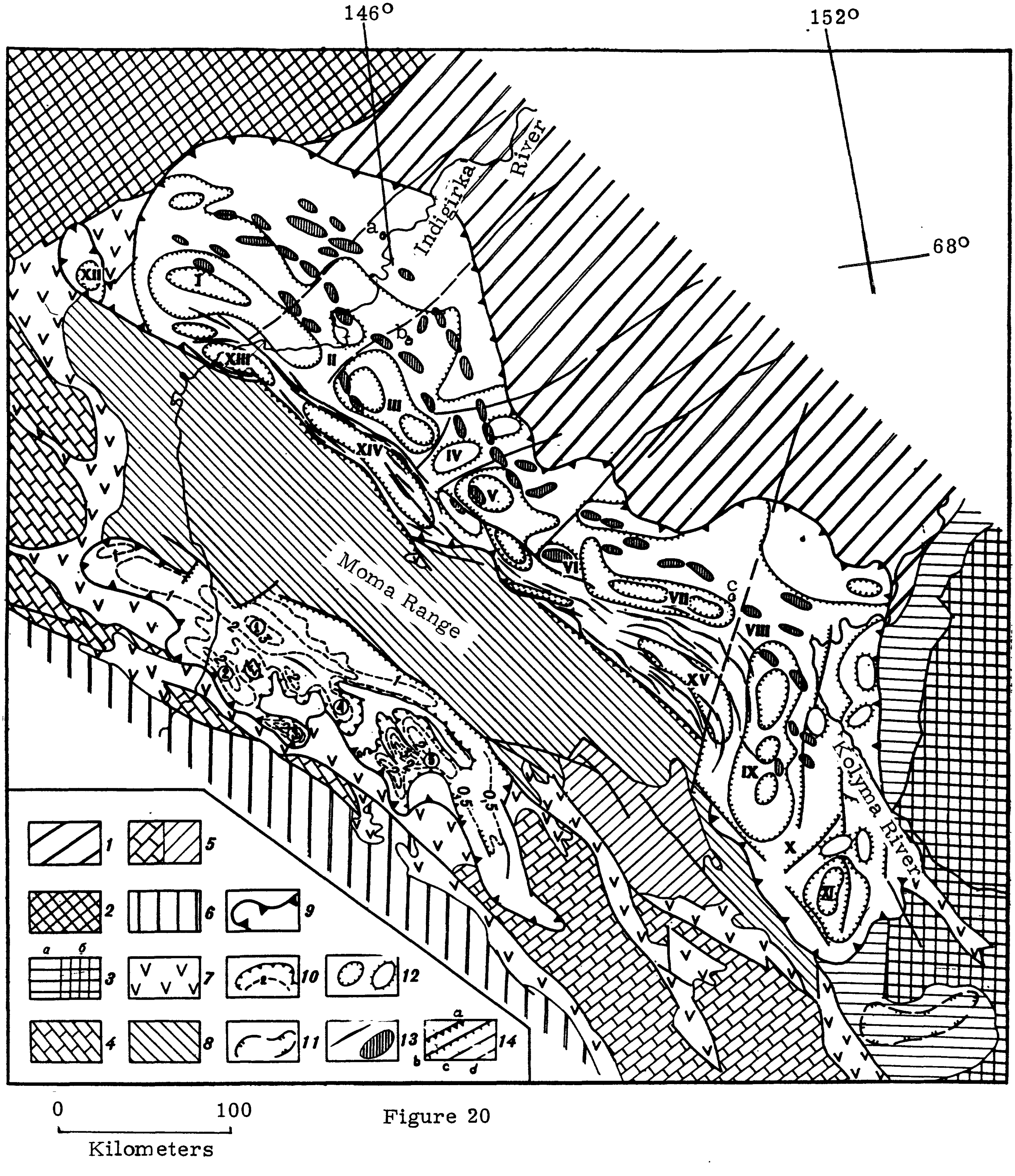
Yet other directions of exploration are open in the south part of the basin. Both reservoirs and seals appear to be present on the Povorotno-Telekay high. Stratigraphic traps may be present where granular reservoir rocks shale out. Then also along the southern border of the basin Neogene rocks are thrust over Paleogene and older rocks, thereby creating conditions for an overthrust play.

In addition to the above favorable areas of the south and southwest parts of the basin, conditions are also favorable for oil and gas in the Predrarytkin, Vostochno-Anadyr, and Lagun downwarps. In the northwest part of the basin only Neogene deposits are present, and only gas can be expected to be found.

Indigirka-Zyryanka basin

This is the largest of the sedimentary basins of northeastern Asia (figs. 1, 20). It covers an area of 70,000 km^2 along the northeast flank of the Moma Range, underlying the valleys of the Indirgirka and Kolyma Rivers. It is bounded on the northeast by the Alazey Tableland. The depression formed in the final stages of the Mesozoids and is filled by Upper Jurassic, Cretaceous, and Cenozoic sedimentary rocks.

General geology. The folded basement for the Indigirka-Zyryanka depression is exposed in several highs along its borders. On the Selennyakh block on the north (fig. 20) the section consists largely of lower and middle Paleozoic carbonate rocks. On the Alazey high, which corresponds with the Alazey Tableland, are Devonian-Permian and Triassic volcanics rocks. Then on the Kolyma high are Paleozoic carbonate and clastic rocks. The Omulev high on



146°
152°
68°
Indigirka River
Moma Range
Kolyma River
0 100
Kilometers

Figure 20

Figure 20. Tectonic map of Indigirka-Zyryanka and Moma basins (from Ivanov, 1985).
1-8 - Structures of the frame of the basin: 1-Alazey zone of the Alazey-Oloy eugeosynclinal system, 2-Polousnen high (Selennyakh block), 3-Prikolyma high: a-west flank where clastic-carbonate rocks of the Lower and Middle Paleozoic are present, b-central zone of metamorphic rocks, 4-Tas-Khayakhtas high, 5-Omulev high: a-Taskan, b-Rassoshin zone, 6-In'yali-Debin synclinorium, 7-Uyandin-Yasachnen interior volcanic belt and graben filled by Upper Jurassic volcanics, 8-Il'in-Tass anticlinorium (inversion regenerated downwarp); 9 - boundaries of basins; 10 - highs and downwarps of second order in Moma basin contoured on base of Cretaceous (km); 11 - Nyatven graben-syncline; 12 - downwarps (a) and highs (b) of second order in Indigirka-Zyryanka basin; 13 - local positive structures recognized from: a-geological data, b-structural-geomorphic data; 14 - main faults: a-overthrusts and upthrusts, b-normal faults, c-not subdivided, d-recognized from geophysical data. Structures of the Indigirka-Zyryanka basin: depressions: I-Selennyakh, III-Kyllakh, V-Badyarikh, VII-Arga-Yuryakh, IX-Bil'bet, XI-Cherbyn'yen, XII-Tommot, XIII-Krasnorechen, XIV-Myatis, XV-Silyap. Transverse highs and saddles: II_ Indigirka IV-Antyy, VI-Chechelyugin, VIII-Nizhneozhogin, X-Omulev. Main negative structures of Moma basin (numbers in circles): 1-Nizhnemomo, 2-Tikhon-Yuryukh, 3-Arga-Yuryukh, 4-Erikit, 5-Dolygdin.

the south is divided into two zones. The Rassoshin zone on the east consists of clastic, carbonate, and volcanic rocks, which are Ordovician to Triassic in age. The Taskan zone is composed of Paleozoic miogeosynclinal carbonate rocks. The latter contains bitumen; however, it is highly altered.

The sedimentary fill of the Indirgirka-Zyryanka depression begins with volcanic rocks of the Ilin'tas Formation of Oxfordian-Volgian age (fig. 21). Above this is the Volgian Bastakh Formation, which is up to 8 km thick. It consists of shale, argillite, siltstone, graywacke, and rare tuffaceous sandstone. On a basis of rock type the Bastakh is subdivided into lower, middle, and upper parts, and the upper is in turn divided into three subdivisions (fig. 21). At the top of this formation is a pelitic member 200-2000 m thick.

The Lower Cretaceous coal-bearing sediments are combined into the Zyryanka Series, within which three formations are recognized: Ozhogin, Silyap, and Buorkemyus. The Lower Cretaceous section is several thousand meters thick and consists of rounded and sorted sandstone, siltstone, argillite, conglomerate, and coal. Coal fields are present on the southwest border of the depression.

Upper Cretaceous sediments are present in some parts of the depression and are as much as 600 m thick. They are largely sandstone but contain beds of siltstone, conglomerate, coal, and silicic tuff. These rocks rest unconformably on the Lower Cretaceous and are in turn overlain by upper Eocene-Oligocene arenaceous sediments. At the top of the section are Neogene-Quaternary deposits, which contain brown coal and lignite.

Along the southwest border of the Indigerka-Zyryanka basin are three synclines or basins: the Krasnorechen, Myatis, and Silyap. They measure 25-50 km by 70-130 km (fig. 20) and are filled by Lower Cretaceous coal-bearing rocks. These rocks are folded gently.

To the northeast of the border synclines is a series of large basins separated by saddles and highs. These are designated I, III, V, VII, IX, and XI in figure 20. Recognition of these structures is based on gravity surveys. They form the axis of the depression. Then to the northeast of these axial basins are structural terraces, which extend along the northeast part of the depression. Both here and in the axial zone are small structures which have been recognized by their geomorphic expression.

Maximum thickness of the Bastakh series is 8 km, that of the Zyryanka Series is 5 km, and the Upper Cretaceous and Cenozoic is 1.5-2 km. Nowhere, however, is total thickness equal to the sum of these figures, because the depocenter migrated with time.

Petroleum geology. The most important source rocks in the Paleozoic section of the basement of the Indigirka-Zyryanka depression are clastic and carbonate sedimentary rocks, which are found in the Selennykh and Kolyma highs on the northwest and southeast margins of the depression, respectively (fig. 20). The Ordovician and Silurian carbonate rocks here contain only small amounts of organic carbon. The Devonian and Carboniferous, however, have good source-rock potential.
fig. 21

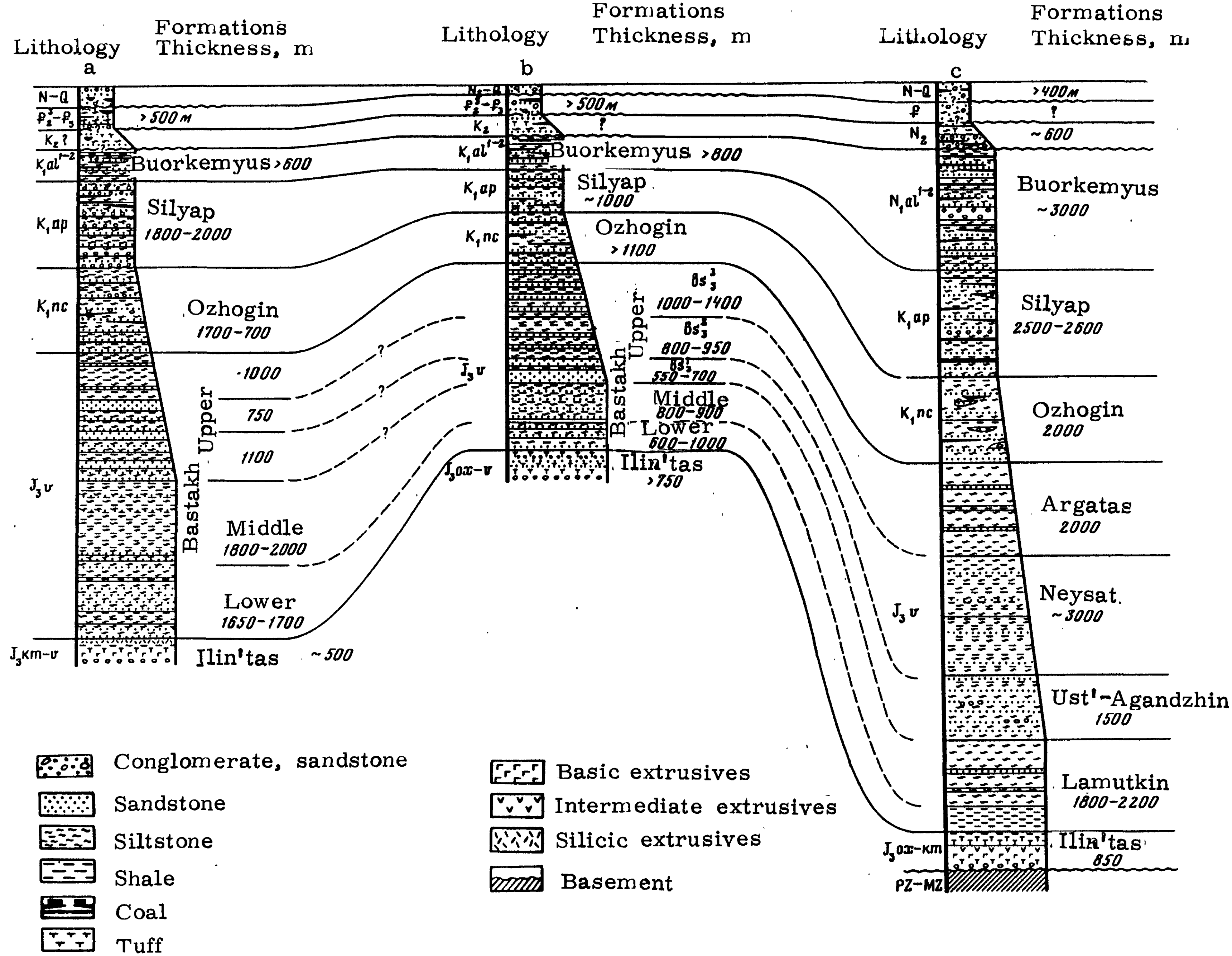


Figure 21. Composite geologic sections on Indigirka River (a), Myatis - Sulakkan Rivers (b), and Zyryanka-Silyap Rivers (c). See figure 20 for approximate locations of these sections.

On the Kolyma high are Devonian organoclastic and siliceous limestones that contain up to 1.6 percent organic carbon, and Middle Carboniferous siliceous tuffaceous argillaceous rocks here carry 3-4 percent organic matter.

On the Selennykh high a Domanik facies is present in the Middle Devonian. Combustible limy shales here contain 8-9 percent organic carbon, shaly detrital marls carry 4 percent, and organic limestones 1-5 percent. On a basis of conodont discoloration these rocks have entered the oil window in the 135-180° C range.

The siltstones of the Bastakh and Ilin-'Tas Formations of the Upper Jurassic contain about 1 percent organic carbon, and the Lower Cretaceous argillaceous rocks have similar concentrations. These rocks are generally in the oil window; however, the Lower Cretaceous will be more gas-prone because of a humic character of its organic matter.

Sandstones dominate among the Upper Cretaceous and Paleogene sedimentary rocks of the basin, and these are under-mature.

Possible reservoirs in the Paleozoic section are the fracture and cavity-fracture type in carbonate rocks. No reservoir rocks are present in the Upper Jurassic. In the Lower Cretaceous section sandstones and conglomerates of the Buorkemyus and Silyap Formations have good porosity and permeability.

The best seals are found in the upper half of the Lower Cretaceous Zyryanka Series where montmorillonite predominates among the clay minerals. Lower in the section the clays have gone to illite, and consequently their sealing capacity has deteriorated.

Traps in the Paleozoic rocks may be associated with biohermal and erosional highs. In the basin fill, in addition to anticlinal traps, there may be stratigraphic and fault traps.

Two plays are present in the Indigirka-Zyryanka depression: a lower, Paleozoic play and an upper, Lower Cretaceous play.

The upper, Cretaceous play is characterized by an optimum combination of siltstone-clay varieties and sandstone varieties that occur in the oil window. Reservoirs, traps, and seals are present. Conditions favorable for formation and preservation of pools should be best in the interior of the depression.

The lower, Paleozoic play is largely Devonian-Carboniferous in the southeast part of the depression. In spite of upper Paleozoic and Mesozoic seals, it may contribute hydrocarbons to the upper play.

Moma basin

The Moma depression is a graben, which is separated from the Indigirka-Zyryanka depression by the Ilin'-Tas anticlinorium (figs. 1 and 20). Practically the same rocks are present here as are in the Indigirka-Zyryanka. The Tas-Khayakhtas high at the northwest end and the Omulev high on the southeast are Paleozoic carbonates. Unconformable on these are Upper Jurassic volcanic and clastic rocks and Lower Cretaceous coal-bearing deposits.

The Cretaceous System is represented in the Moma depression by only the Neocomian-Aptian; analogs of the Albian Buorkemyus Formation of the Indigirka-Zyryanka depression are absent. These Lower Cretaceous rocks occur in semi-isolated basins separated by transverse highs on which the Upper Jurassic Bastakh and Ilin'-Tas Formations crop out. Maximum thickness of the Lower Cretaceous is 3 km. These rocks have been deformed into folds of various orientation, and the folds are deeply eroded. Younger depressions filled by Neogene-Quaternary deposits have formed along the southeast and northwest flanks of the depression.

The Lower Cretaceous rocks are in the oil window, and the Upper Jurassic and Paleozoic rocks have entered the gas window. Content of organic carbon is only at background. Porosity and permeability are low, porosity nowhere exceeding 5 percent and permeability being less than 1 md. Given the small area of the basin and the unfavorable conditions for oil-gas formation, the basin is assessed as having no prospects for finding commercial deposits.

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