RUSSIAN ACADEMY OF SCIENCES
GEOLOGICAL INSTITUTE

Look the Map

INTERNATIONAL TECTONIC MAP OF THE CASPIAN SEA REGION

Scale 1 : 2 500 000

EXPLANATORY NOTES

NAUCHNYI MIR
2005

International Tectonic Map of the Caspian Sea Region
Scale 1:2 500 000
Explanatory Notes

Annotation

Main geological structures, characteristic features of tectonic evolution, oil and gas potential, and seismicity of the Caspian Sea region are described. The Explanatory Notes are intended for specialists in regional geology, tectonics, oil and gas prospects, as well as for graduate and post-graduate students.

Editors-in-chief: V.Ye. Khain
N.A. Bogdanov

Editorial Board: Ak.A. Ali-Zadeh (Azerbaijan)
M. Gassemi (Iran)
Kh.A. Bespaev (Kazakhstan)
V.Ye. Khain (Russia)
O.A. Odekov (Turkmenistan)

Authors: F.S. Akhmedbeyli, Yu.M. Berlin, N.A. Bogdanov, P.A. Chekhovich, A.N. Gadzhiyev, M. Gassemi, I.S. Guliyev, A.J. Ismailzadeh, T.N. Kengerli, V.Ye. Khain, V.V. Korobanov, N.V. Koronovsky, S.L. Kostyuchenko, L.E. Levin, A.V. Mamedov, M.M. Marina, D.A. Mirzoev, O.A. Odekov, V.M. Pilifosov, V.M. Pirbudagov, V.I. Popkov, D.A. Shlygin, L.F. Volchegursky, E.S. Votsalevsky, A.U. Zakhidov,

The Map was prepared for publication by the Institute of the Lithosphere of Marginal Seas of the Russian Academy of Sciences (RAS) in cooperation with the Geological Faculty of the Moscow State University, GEON Center, Ministry of Natural Resources of the Russian Federation (Moscow); “Aerogeologiya” State Enterprise (Moscow), Shirshov Institute of Oceanology RAS (Moscow), All-Russia Oil Research Institute (Moscow), Institute of Geology of the Dagestan Scientific Center RAS (Makhachkala); Branch of North Caucasian Technical State University (Georgievsk), Institute of Geology of Azerbaijan National Academy of Sciences (Baku); Institute of Geological Sciences of the Kazakhstan National Academy of Sciences (Alma-Ata); Geological Prospecting Research Institute under “Turkmengeologia” (Ashkhabad); Geological Survey of Iran (Tehran)

The English version of the Explanatory Notes is being published after passing away of Prof. Nikita Bogdanov, which occurred on December 14, 2003. The Editorial Board and authors dedicate this work to memory of our eminent colleague. In the early 1990s he initiated the preparation of a series of tectonic maps on marginal and inland seas of Russia. His colleagues continue to perform his project.

The Caspian Sea and its adjacent areas form the Caspian oil/gas-bearing megabasin, one of the largest in the world, that make up part of the Barents-Caspian oil and gas belt. The N-S-trending megabasin consists of three sedimentary basins, separated by latitudinal sills: North Caspian, Middle Caspian, and South Caspian basins. The granite-metamorphic basement of the basins becomes younger from north to south, from Early Precambrian in the north to Early Cimmerian in the south. It was formed in the transitional zone from the southern edge of the East European Craton (Paleozoic continent Baltica) towards the Tethys oceanic basin. Accordingly, the Caspian megabasin is superimposed on the East European ancient platform, Scythian-Turanian young platform, and Alpine-Himalayan mobile belt. Each tectonic province comprises structural zones of a subordinate character: the North Caspian depression within the first province; Karpinsky Ridge, Kuma zone, North Ustyurt block, Buzachi uplift, Mangyshlak-Central Ustyurt and South Mangyshlak zones, as well as Karabogaz arch, and Middle Caspian basin within the second province; the Greater Caucasus, Kopeh Dag, Kura and South Caspian Depression, West Turkmenian Trough, and Alborz Range within the third province. The age of the sedimentary cover embraces the entire Phanerozoic and, probably, upper parts of the Proterozoic in the North Caspian region; the Jurassic, Cretaceous, and the Cenozoic in the Middle Caspian; and the Oligocene-Holocene in the South Caspian. The Permian and Triassic deposits in the Middle Caspian; the Jurassic, Cretaceous, and lower Paleogene deposits in the South Caspian occupy partly both the folded basement of the basin and its sedimentary cover. The stratigraphic range of oil and gas occurrence varies accordingly: from the Devonian to Paleogene in the North Caspian, from the Triassic to Miocene in the Middle Caspian, and from the Cretaceous to Eopleistocene in the South Caspian. The Explanatory Notes describe oil source rocks and assess oil and gas occurrence prospects. Seismicity of the region is characterized.

Size of the Explanatory notes 140 pages, 28 figures, 159 references
The map and inserts are made on one sheet

CONTENTS

INTRODUCTION

Recently, the Caspian region has attracted close attention both in Russia and abroad. This is naturally explained by the proven hydrocarbon reserves of this megabasin, one of the largest in the world, and its highly promising potential for the discovery of new hydrocarbon fields. This potential is confirmed by recent discoveries of hydrocarbon accumulations both in the northern and southern parts of the basin.

The region is characterized by an intricate geological structure. This complexity is related to the peculiar formation history of the megaasin, related as it is to heterogeneous tectonic elements involving the southern marginal part of the East European ancient platform - the Scythian-Turan platform - and the Alpine Mediterranean belt

Much geological and geophysical data and information are available for the Caspian Sea and surrounding regions that have never been compiled and reviewed on a regional scale. The compilation of the present Tectonic Map and relevant Explanatory Notes was undertaken at the *Institute of the Lithosphere of Marginal Seas RAS*. This work continues investigations that were carried out by the Institute during the last decade. It follows the compilation of the recently published *"Tectonic Map of the Barents Sea and Northern European Russia (1996)"*, *"Tectonic Map of the Kara and Laptev seas and Northern Siberia (1998)"*, and the *"Tectonic Map of the Okhotsk Sea Region (2000)"*, all compiled at a scale of 1: 2,500,000. Unlike these other regions, which are entirely or almost entirely located within the Russian Federation state boundaries, the Caspian region involves territories of five independent states: Azerbaijan, Iran, Kazakhstan, Russia and Turkmenistan. In this connection, the Map compilation project became international in its scope and included specialists from these countries who accepted the invitation to contribute to this work.

The following scientific and applied organizations took part in compiling the Map and preparing the Explanatory Notes: *Institute of Geology of Azerbaijan, National Academy of Sciences (Azerbaijan); Tectonic Group of the Geological Survey of the Ministry of Ores and Metals (Islam Republic of Iran); Satpaev Institute of Geological Sciences of the Kazakhstan, National Academy of Sciences (Kazakhstan); Geological – Prospecting Research Institute of the State Corporation "Turkmengeologiya" (Turkmen Republic); Institute of the Lithosphere of Marginal Seas RAS; Shirshov Institute of Oceanology RAS; Institute of Geology of the Dagestan Scientific Center RAS; Center of Regional Geophysical and Geoecological Researches (GEON) and State Enterprise "Aerogeologiya" of the Ministry of Natural resources of the Russian*

Federation; Geological Faculty of the Lomonosov Moscow State University; All-Russian Oil Research Institute (VNIGNII); and the Branch of the *North Caucasian Technical State University in Georgievsk (Russia).*

All these organizations were represented by specialists whose names are listed in the Map legend and Explanatory Notes. The official representatives from these organizations formed the editorial board, which included Ak.A. Ali-Zadeh (Azerbaijan), M. Gassemi (Iran), Kh.A. Bespaev (Kazahstan), V.Ye. Khain (Russia), O.A. Odekov (Turkmenistan). V.E. Khain and N.A Bogdanov were editors-in-chief.

The Map legend accords in general with those on maps of the same scale that were published previously by the *Institute of the Lithosphere of Marginal Seas*, as well as with the legend of the *International Tectonic Map of Europe (Scale 1: 5,000,000).* The universally accepted plate tectonics concepts served as a theoretical basis for these legends and Maps.

Although different aspects of the Caspian region geology are discussed in many publications, only a single work is dedicated to the region in question as a whole – a monograph by L.I. Lebedev with colleagues (Lebedev *et al.,* 1987). Other publications used in this work are cited in the reference list..

In the Explanatory Notes, along with tectonic aspects of the region we discuss the hydrocarbon potential of the basin. The section dedicated to the Middle Caspian was prepared at the *Shirshov Institute of Oceanology RAS* and that on the South Caspian at the *Institute of Geology Azerbaijan National Academy of Sciences.*

The digitizing and layout of the Map were carried out under the supervision of P.A. Chekhovich. A.G. Oknova took part in preparing the Explanatory Notes and P.A. Chekhovich and M.A. Morozov compiled the figures. At the preparatory stage, this work was supported by the *Russian Foundation for Basic Research* (grant 99-05-64009) and by the *Ministry of Energy of the Russian Federation*. During the later stages of the work, substantial technical help was provided by the *Center of Information Technologies of the State Geological Museum RAS* (V.M. Ryakhovskii, head of the Center) and the Industrial – Cartographic Enterprise *"Kartografiaya"* (G.V. Pozdnyak, in particular). The Map was published with financial support from the *Ministry of Industry, Science and Technologies of the Russian Federation*. We express our sincere gratitude to all mentioned persons and organizations.

1. TECTONIC ZONING

The Caspian Sea extends in an almost N-S direction (Fig. 1) and crosses different major latitudinal structural elements. *(Note: All directions herein refer to present-day coordinates)*. These structural elements belong to the southeastern margin of the ancient East European platform (the North Caspian depression); the younger, mainly epi-Hercynian Scythian-Turan platform; and the Alps-Himalayas orogenic belt. Each of these tectonic regions includes lower-order structural elements described below (Fig. 2). Unlike the major tectonic structures that are traceable without any significant changes from the Ciscaucasia and Caucasus to the Transcaspian region, these subordinate structural units show substantial differences on either side of the Caspian Sea. It is therefore necessary to consider separately the successions of these subordinate structural units along the Caspian Sea's western and eastern coasts. The exceptions are the North Caspian depression to the north and the Alborz mountain system bordering the Caspian Sea to the south.

The North Caspian depression is represented within the Map boundaries by its southern segment, which includes, in addition to land areas, the extreme northeastern part of the Caspian Sea. The sedimentary fill of this basin is estimated to be about 22-24 km thick in its central part, where it comprises the entire Phanerozoic and, probably, uppermost Proterozoic sequences. Deep drilling has penetrated the section down to Devonian-age strata. Judging from the high seismic velocities, the basement of the basin along its periphery is Early Precambrian in age. In the deepest part, seismic velocities show values characteristic of sub-oceanic or even oceanic crust. This leads us to assume that the basin is riftogenic in origin. According to some researchers (Volozh *et al.,* 1975; Brunet *et al*., 1999), the basin formation commenced in Late Riphean times. This is inferred from the facts that (a) Middle Devonian rocks penetrated by boreholes in the basin's central part are underlain by a thick sedimentary sequence, and (b) the Pachelma aulacogen of Riphean age continues from the Russian plate into the northwestern part of the basin. There, the aulacogen is presumed to join two other rifts oriented in northeasterly and north-south directions. In the opinion of other authors (Zonenshain *et al.,* 1990; Aplonov, 1995; Volchegurov *et al*., 1995), riftogenesis in the depression commenced in Devonian times. If this is the case, the thick pre-Middle Devonian sequence should correspond to the Devonian synrift complex. It is probable, however, that as with the entire East European platform, two riftogenic phases occurred in this region: one during Riphean times and a later one in Devonian times.

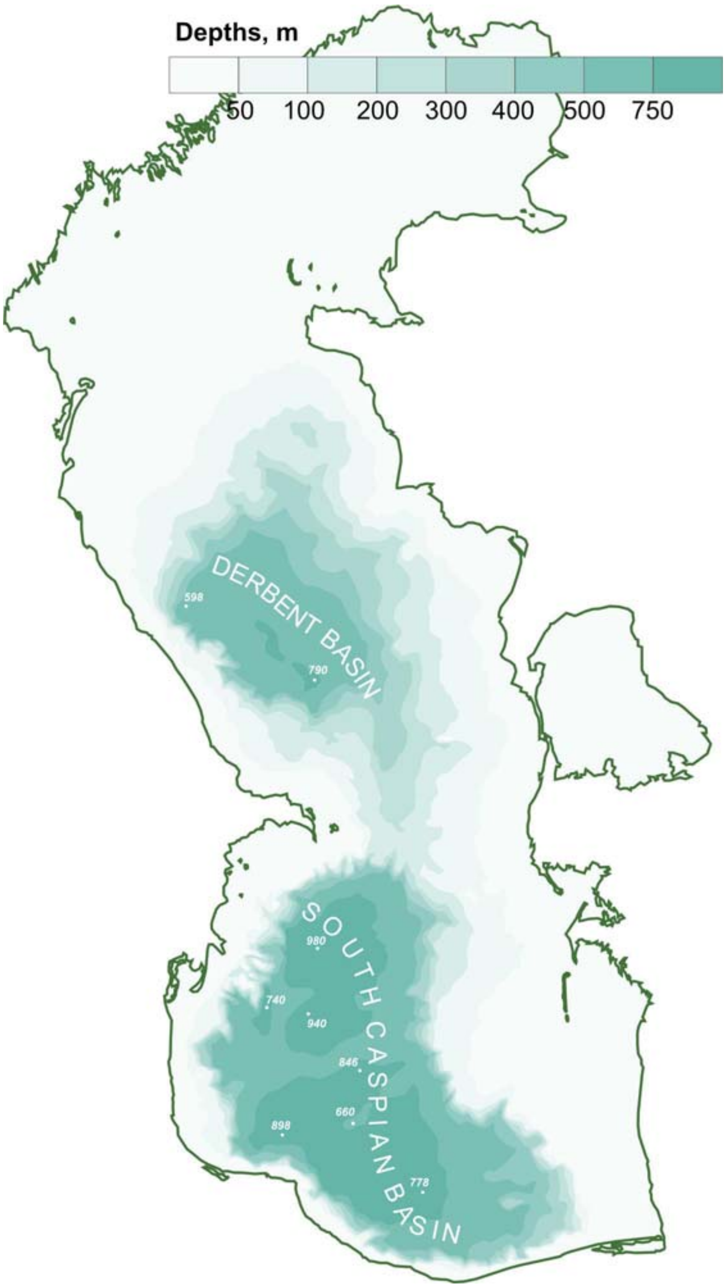
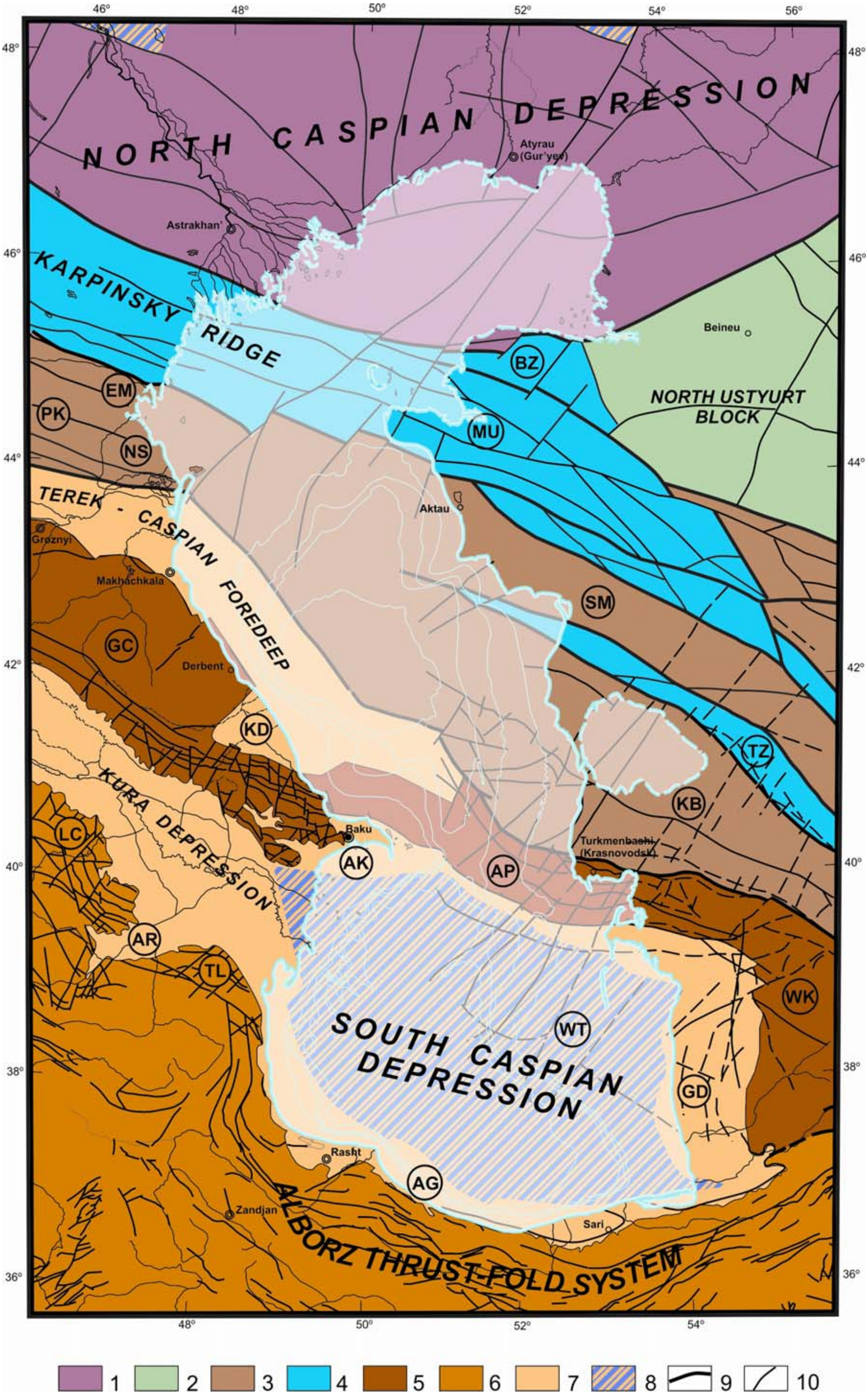


Fig. 1. Bathymetric chart of the Caspian Sea. Isobaths are according to *Atlas Mira* (1999) and the *General Bathymetric Chart of the World Ocean* (1975 – 1984).

Further south, the central part of the North Caspian depression is bordered by the Astrakhan-Aktyubinsk zone of uplifts where the Precambrian basement is raised up to depths of 7.0-8.0 km. This is overlain by a Middle Devonian sequence, which grades upward into thick and widespread Upper Devonian - Middle Carboniferous carbonate platform sediments. In the Permian (Kungurian and Kazanian ages), the North Caspian basin accumulated a thick salt sequence, which subsequently produced abundant salt diapirs penetrating the younger strata.

The Karpinsky Ridge. Along the western coast of the Caspian Sea, Paleozoic sequences comprising a fold zone, known in Russian geological literature as the Karpinsky Ridge, are thrust over the southwestern margin of the North Caspian depression. This structure is approximately 110-120 km wide and stretches in a NW-SE direction. It is bounded by thrusts both to the northeast and also to the southwest where it borders the East Manych trough (see below)**.** The Paleozoic sequence is characterized by an intricate internal structure. It consists of several fold and thrust elements, mainly north-verging. Beginning in the Middle Permian, the section's structure becomes progressively simpler. The basal Jurassic and younger layers form several parallel swells with gently dipping slopes. In its origin, the Karpinsky Ridge is a riftogenic structure that initiated in the Middle Devonian as a continuation of the Pripyat-Dnieper-Donets rift system and continues in turn into the Transcaspian region (see below). The rift was subjected to inversion in the mid-



International Tectonic Map of the Caspian Sea Region, 2005. V.Khain & N.Bogdanov (eds.)

Fig. 2. Main structural elements of the Caspian Sea region.
Basement of platform areas (1 – 4): (1) Early Precambrian, (2) Baikalian, (3) Hercynian, (4) Early Cimmerian; Alpine fold – thrust systems (5, 6): (5) Greater Caucasus and Kopeh Dagh, (6) Lesser Caucasus, Talesh, Alborz; (7) Foredeeps and depressions; (8) Depressions with oceanic-type crust; (9) Tectonic lineaments corresponding to boundaries of large structures; (10) other important lineaments. Main structures (letters in circles): (Bz) Buzachi arch, (MU) Mangyshlak – Central Ustyurt, (SM) South Mangyshlak – Ustyurt system of troughs, (TZ) Tuarkyr zone, (KB) Middle Caspian Karabogaz anteclise, (EM) East Manych trough, (PK) Kuma system of uplifts, (NS) Nogai scarp, (GC) Greater Caucasus fold system, (KD) Kusary – Divichi trough, (AP) Apsheron Balkhan zone, (WK) West Kopeh Dagh zone, (LC) Lesser Caucasus fold system, (AR) Lower Araks trough, (TL) Talesh zone, (AG) Alborz – Gorgan foredeep, (WT) West Turkmen trough, (GD) Gograndagh – Okarem zone.

Early Permian to Triassic-Jurassic boundary period. The last event resulted in the formation of a gently sloping uplift with subsequent accumulation of a thin, discontinuous sequence of shallow-marine Jurassic-Quaternary sediments.

The East Manych trough is associated with the Karpinsky Ridge, being separated from the latter by the previously mentioned thrust-type fault that initiated in the Early Cimmerian folding epoch (Triassic – Jurassic). The basal part of the sedimentary section in the trough is composed of Permian-Triassic rocks up to 2 km thick. Toward the Caspian coast, the trough's depth increases from 5.5 to 6.5 km. Low-amplitude folds disturbed by fractures complicate its structure. As with the Karpinsky Ridge, the East Manych trough represents a riftogenic structure, although in the south it grades smoothly into the Kuma system of uplifts, the structural element of the eastern part of the Scythian platform.

The Kuma system of uplifts trends in a similar east-west direction to the East Manych trough. The Kuma uplifts subside generally eastward toward the Caspian coast. In the west the Paleozoic basement is at a depth of 3.5 km or less; further east, the basement is at a depth of 6.5 km. The Paleozoic basement is composed of Devonian-lowermost Permian dark shales intruded by Late Paleozoic granitoids.

The sedimentary cover of the East Manych trough, comprising Permian-Triassic to Quaternary sediments, is slightly deformed in its lower part. These deformations reflect block faulting of the basement. The faults trend east-to-west, accompanied by transcurrent faults mainly with a northeast strike. In the south, the Kuma system of uplifts (a complex swell) joins, via the Nogai structural scarp and fault, the Terek-Caspian foredeep of the Greater Caucasus.

The Terek-Caspian trough starts in the Kabarda and Osetiya areas and stretches in a latitudinal direction up to the Sulak River. Here it turns southeastward and then continues in Dagestan along piedmonts, coast and the adjacent Caspian shelf, terminating approximately at the latitude of Derbent. The width of the trough is at maximum 75 km and its basement, most likely of Paleozoic (coupled with rocks of Triassic age?), is buried to depths of 12-14 km (as inferred from scarce boreholes). The thickest part of the sedimentary section is represented by the Upper Paleogene-Neogene molasse complex. This complex consists of the lower Oligocene to lower-middle Miocene (Maikop Group) and upper, Sarmatian-Akchagylian molasse complex. This molasse complex is underlain by Upper Jurassic-Early Paleogene shelf sediments with evaporitic sequences in the Upper Jurassic part, and by a Lower-Middle Jurassic black shale sequence that accumulated on the continental slope of the Greater Caucasus basin.

The entire sequence of these deposits was subjected to deformation in late Pliocene-Quaternary times. This deformation was particularly intense within the so-called Dagestan wedge, and also involved only the southern (southwestern in Dagestan) flank of the trough. Its external flank is characterized by almost horizontal platform-type bedding. In addition, this deformation epoch was marked by the formation of the rootless inversed linear Terek and Sunzha ridges, which were detached along the Upper Jurassic evaporites and Maikop clays, dividing the western part of the trough in two separate basins. Folds of these ridges continue into the maritime Dagestan and adjacent shelf.

The large buried uplift – the Yalama - Samur uplift – occurring in the Dagestan–Azerbaijan boundary area and continuing seaward is responsible for the closure of the Terek – Caspian trough in the south. A borehole penetrated at a depth of approximately 5 km the metamorphic basement of Permian- Triassic age, overlain by a Middle Jurassic terrigenous sequence, which is in turn overlain by sediments of Neogene age. This Yalama – Samur uplift separates the Terek – Caspian trough from the Kusary – Divichi trough, an echelon-like, approximately latitudinal continuation of the Terek – Caspian trough.

The Kusary – Divichi trough is filled by Oligocene – Quaternary molasse deposits, with the lower Pliocene hydrocarbon-productive formation unconformably superimposed on the southern continuation of the Limy Dagestan zone. In the north, this zone joins the anticlinorium of the Bokovoi (Lateral) Ridge of the eastern Greater Caucasus (see below). In the south, the continuation of this anticlinorium and its northern flank are thrust over the trough.

The southeastern plunge of the Greater Caucasus. The axial zone of the Greater Caucasus in the Chechnya, Dagestan and western Azerbaijan area is composed of the Lower-to-Middle Jurassic sand-shale sequence that is intensely deformed, eutomous, and divided by steep thrusts into nappes that have flowed in a southerly direction.. Two anticlinal zones of the Bokovoi and Glavnyi (Main) ridges distinguished here are separated by a synclinal trough. Both these structural zones submerge in an easterly direction under younger sediments. The Bokovoi Ridge zone continues in Dagestan as the moderately deformed Limy Dagestan zone composed of an Upper Jurassic-Lower Paleogene sequence, whereas in Azerbaijan its continuation is represented by a syncline formed mainly of Upper Jurassic reefal carbonate rocks. Further northeast along the thrust, this syncline joins the Kusary – Divichi trough and reaches the Caspian Sea shore.

In the east, the Main Ridge zone is separated from the Bokovoi Ridge by a trough and passes into the northern limb of an eastwards-widening synclinorium. This synclinorium represents an element of the southern slope zone of the Greater Caucasus. It is filled with a thick per Jurassic-Eocene flysch sequence, conformably underlain by Lower-Middle Jurassic shale-sand rocks. All these rocks represent together the sedimentary fill of the Tethyan marginal sea. In the northern limb, widespread slope and foot sediments alternate with olistostromes at different levels. The flysch zone is characterized by a highly intricate structure with low-angle thrusts and tectonic nappes displaced southward over dozens of kilometers.

The Kakhetiya – Vandam zone of uplifts corresponding to the Jurassic-Eocene volcanic arc that formed at the northern edge of the Transcaucasian microcontinent borders the flysch zone to the west. In the east, this zone of uplifts submerges under younger deposits. In the south it is bordered by the Adzhichai – Alyaty thrust that stretches up to the seashore and serves as a limitation for the entire Greater Caucasus system in this area. West of the Girdymanchii River, the Kakhetiya – Vandam zone is partly overlain by the Pliocene-Quaternary Alazan – Agrichai molasse-filled trough.

Along the northwestern periphery of the South Caspian depression, ***the Apsheron – Kobystan periclinal trough*** filled with shallow-water marine sediments during Pliocene-Quaternary times and is superimposed on the southeastern submerged part of the Greater Caucasus. The sedimentary section of the trough includes the Lower Pliocene hydrocarbon-productive formation representing deltaic sediments of the Paleo-Volga. The sequence structure shows the presence of variably oriented brachyaxial folds complicated by clay diapirs and mud volcanoes.

Within the limits of the Map, the Greater Caucasus is separated from the Lesser Caucasus and Talesh (located on the northwestern plunge of the Alborz Mountains) by the wide intermontane Kura depression that opens, like the Apsheron – Kobystan trough, into the southern Caspian Sea.

The Kura depression is filled with a thick sequence of molasse deposits of Oligocene-Quaternary age, of which up to 8 km are composed of sediments of Pliocene-Quaternary age. Upper Jurassic-Eocene carbonate–volcanogenic rocks and Middle Jurassic volcanogenic rocks of island-arc origin underlie the molasse complex. These were penetrated by the Saatly super-deep borehole. Exposures of granite-metamorphic basement along the western and southern peripheries of the depression imply its presence in the deeper part of the depression. The top of the acoustic basement of the depression corresponds (most likely) to the base of the molasse complex or uppermost Cretaceous-lowermost Paleogene carbonate sequence. In the southwestern part of the depression, the basement is substantially elevated to form the Kyurdamir – Saatly zone of buried NW – SE extending uplifts. These are immediately overlain by horizontal strata of Upper Miocene age. The minor Evlakh – Agdzhabeda trough separates this zone of uplifts from the northeastern slope of the Lesser Caucasus and its submerged continuation is traceable in geophysical records eastward up to the seashore.

The molasse complex was subjected to folding in the Quaternary and is intensely deformed only in the northern part of the depression, resulting from the compression induced by the Greater Caucasus motion. In the west, there is a system of latitudinal south-verging linear folds accompanied by thrusts. These folds grade in the east into a narrow system of chain-like brachyform uplifts complicated by faults and mud volcanoes. This system widens southeastward and submerges under waters of the Caspian Sea. In the axial zone of the depression and along its southern (southwestern) periphery, molasse deposits occur as almost horizontal layers, and only gravity and magnetic data imply faults near the boundary with the Lesser Caucasus and Talesh.

The northeastern slope of the Lesser Caucasus. The Lesser Caucasus is represented within the Map boundaries by the southeastern submerged part of its northern Somkhit – Karabakh zone. The Paleozoic metamorphic basement of this zone is exposed in the west in erosional windows and its sedimentary cover is mainly composed of a thick Middle Jurassic volcanogenic sequence of the island-arc type, overlain by Upper Jurassic reefal carbonates, thin Middle Cretaceous tuffogenic (sedimentary), Turonian-Lower Senonian volcanic, and Upper Cretaceous-Lower Paleogene carbonate strata. All these rocks were moderately deformed in the late Eocene.

In the southeast, the Lesser Caucasus submerges under the superimposed NE extending Lower Araks trough, which is filled with Oligocene-Quaternary molasse deposits. The base of this trough base presumably corresponds to a large fault with the dextral strike-slip component. The trough separates the Lesser Caucasus from the small Talesh mountain structure in southernmost Azerbaijan.

The Talesh Mountains are largely composed of thick Eocene alkaline basalt and riftogenic – island-arc sequences, underlain by Paleocene flysch and Upper Senonian carbonate deposits and overlain by Oligocene-Miocene molasse sequences. This northeast-verging structure is of a fold–thrust type and is moderately deformed. In the northwest, the Talesh structures submerge under younger deposits of the Lower Araks trough. In the east they are bordered by the Caspian Sea shoreline.

The Alborz mountain fold-thrust system is located entirely in the Iranian territorial borders the Caspian Sea to the south. Most of the Alborz mountain system is likely to be underlain by Late Proterozoic (Baikalian) basement similar to that underlying the Central Iranian micro-plate. This can be inferred from the similarity between the Vendian – Triassic shallow-water marine terrigenous – carbonate deposits of the Alborz mountain system and the sedimentary cover of the latter. However, in the northwestern submerged part of the Alborz Mountains, the Paleozoic deposits are characterized by a quite different composition: they include ophiolites and are metamorphosed to greenschists. These rocks presumably belong to the Paleo-Tethys and mark the suture along which Gondwana collided with the southern margin of Eurasia in the Early Cimmerian epoch. At that time, or slightly later on, the Alborz zone that was amalgamated with the Eurasian margin (the Transcaucasian microplate) could have been separated from Central Iran along this suture. This suture is traceable along the Central – Lesser Caucasus ophiolite zone, continuing in the Iranian Karadagh and Sabzevar ophiolites south of the eastern extremity of the Alborz – Aladag system.

In Late Triassic- Early Jurassic times, the Alborz area accumulated a thick continental detrital, coaliferous, molasse-type sequence composed of material likely derived from the eroded Early Cimmerian orogenic structure that formed in the north. The overlying, younger sequence consists mainly of Middle Jurassic-Upper Cretaceous carbonate rocks with subordinate (island-arc?) volcanics. During Eocene times, the Alborz system, particularly its southwestern part, was subjected to intense sub-aerial volcanism of debatable origin. Orogenic processes followed this in Oligocene times. The Alborz structure shows the presence of divergent thrusts and duplex folds, presumably reflecting detachment of this complex from the basement. Since that time, a molasse foredeep started to form along the Caspian coast and shelf north of the orogene.

Northwest of the western Alborz extremity (southwestern corner of the Map), widespread volcanics of Late Miocene-Quaternary surround the large Sakhend and Savalan strato-volcanoes; the Alborz structure-proper hosts the single Demavenda volcano.

The eastern fringes of the Caspian basin comprise two large regions: the young West Turan platform and the Alpine belt. The former is located in Kazakhstan territory, except for its southernmost part, and the Alpine belt, with the southern Turan area included, is in Turkmenistan. The North Ustyurt block represents the northernmost structural element of the West Turan platform.

The North Ustyurt block represents a syncline with the top of the basement occurring at depths of 10 – 11 km in the central part. The basement here is presumably of Precambrian age, most likely Late Proterozoic, i.e., Baikalian in age. Pre-Upper Permian deposits occur at depth of 8 km and are unconformably overlain by Upper Permo-Triassic strata, which are in turn overlain, with an insignificant unconformity, by Jurassic and younger sediments. These two lower complexes of the sedimentary cover, particularly the lower one, experienced slight deformation, creating several internal uplifts and depressions.

In the northwest, the North Ustyurt block is linked to the Trans-Volga – Tugarakchan system of troughs (up to 12 - 14 km deep) fringing the marginal Astrakhan - Aktyubinsk zone of uplifts (carbonate platforms). The buried South Emba uplift is thrust over the Astrakhan - Aktyubinsk zone of uplifts, within the North Caspian depression. Further south, the North Ustyurt block is, in turn, thrust by the Buzachi arch. This arch is an element of the Central Ustyurt zone of uplifts and represents the eastern continuation of the Karpinsky Ridge. Westward, the North Ustyurt block wedges out where the Karpinsky Ridge joins the North Caspian depression and in the east (beyond the Map boundaries) it is bordered by N-S extending faults of the Aral region.

The Buzachi arch represents an immediate continuation of the Karpinsky Ridge and is composed of pre-Permian deposits characterized by a similarly intricate north-verging fold-thrust structure. The fault and South Buzachi trough (with its basement submerged up to 9 km deep) separate the arch from the Mangyshlak – Central Ustyurt fold zone.

The Mangyshlak – Central Ustyurt zone. In the most uplifted part of the zone that corresponds to the mountainous Mangyshlak, the thick Permo-Triassic sedimentary complex, which was deformed during the Early Cimmerian orogeny, is exposed at the current day surface. It forms a linear system of en-echelon-like steep folds complicated by abundant thrusts, strike-slip faults and normal faults of varying strike directions. This deformation zone continues into the eastern Mangyshlak and Tuarkyr Rise where it is separated from the main Mangyshlak zone by an oblique transcurrent fault, probably with a strike-slip component. In the opinion of Popkov (1992), the Tuarkyr Rise is an eastern element of an autonomous fold zone extending parallel to the Mangyshlak zone and continuing offshore. The central part of the Tuarkyr Rise is composed of Lower-Middle Paleozoic rocks, including ophiolites.

The South Mangyshlak –Ustyurt system of troughs replaces the Mangyshlak – Central Ustyurt zone in the southern direction. Within the South Mangyshlak – Ustyurt zone, the Permo-Triassic complex is buried to depths of 5.5 to 6.0 km, is characterized by a substantially lower angle bed attitude, and is overlain with an insignificant unconformity by Jurassic and younger strata of the platform sedimentary cover proper. This system comprises the South Mangyshlak trough, Cape Peschanyi– Rakushechnoe uplift, and Kazakh graben, opening into a synonymous bay of the Caspian Sea. The individual elements of this system are distinguished by the relief of their basement surface and structure of the Permian-Triassic strata**.** The Cape Peschanyi– Rakushechnoe uplift terminates the zone of gently sloping uplifts of northeastern strike that begins in the northeastern extremity of Azerbaijan and crosses the Middle Caspian (see below).

The southernmost element of this zone is represented by the Karaaudan scarp or swells, considered by Popkov (1992) to be a buried continuation of the Tuarkyr Rise, although other researchers do not share this viewpoint.

The Middle Caspian – Karabogaz anteclise *("anteclise" - a Russian term for a positive or uplifted structure of the continental platform)* is the largest structural element of the southern part of the West Turan platform. It occupies the Kara-Bogaz-Gol Gulf, northern part of the Krasnovodsk Peninsula and a significant area of the eastern Caspian shelf. The basement surface is uplifted here to depths of 0.8 to 1.5 km and overlain by almost horizontal uppermost Lower Cretaceous strata. Older horizons of sedimentary cover are developed only on anteclise slopes. The basement is mostly composed of Lower- Middle Paleozoic metamorphosed sedimentary - volcanogenic rocks and Middle-Late Paleozoic granitoids. More compact and more intensely metamorphosed rocks underlie this complex, whose age, Baikalian, has been determined from borehole evidence. In the north, the Karabogaz arch is separated from the Karaaudan zone by a major fault that coincides with a band of intense positive gravity and magnetic anomalies. These anomalies imply the presence of an ophiolitic rock association similar to that exposed in the Tuarkyr uplift.

In the south, the Karabogaz arch is also bordered by faulting that is considered by the Turkmen authors of the Map to represent the southern boundary of the West Turan platform. The southern limb of the arch coincides with the narrow Kubadagh – Greater Balkhan zone of uplifts that separates the platform from the Alpine belt. It consists of three chains separated by transcurrent faults. Along the westernmost of them (Kubadagh), the Paleozoic basement immediately overlain by Middle Jurassic rocks is exposed at the current day surface. The eastern chain (the Greater Balkhan Rise) represents a large northward-tapering anticline composed of Middle Jurassic and Upper Jurassic-Neocomian deposits. The basement in this area occurs at depths of 1.5 to 2.0 km. Both to the south and to the north, the Kubadagh – Greater Balkhan zone is bordered by large faults. Westward, these faults cross obliquely the Middle Caspian and join the fault that forms the northern boundary of the Terek – Caspian trough. It thus represents the boundary suture between the Scythian – Turan platform and Alpine mobile belt.

In the Turkmenistan territory, the latter structure comprises two main tectonic units: the western subsided part of the Kopeh Dagh fold system and West Turkmenian molasse-filled depression that serves as the eastern slope of the larger South Caspian depression.

The Kopeh Dagh folded mountainous structure is defined by the westernmost part of its linear frontal zone and by western submerged folds composing the internal zone and forming the northwestward convex arc. The Kopeh Dagh is composed of thick Jurassic-Paleogene shelf carbonates and terrigenous deposits underlain by the Paleozoic (coupled with Triassic?)

basement. This rock complex was deformed during Oligocene-Miocene times into moderately compressed folds, complicated by steep thrusts and strike-slip faults. In the north, the Kopeh Dagh structure subsides in a step-like manner along N-S trending faults. The Mesozoic-Paleogene rocks of the complex are submerged along them and buried under Neogene-Quaternary molasse deposits toward the South Caspian depression.

The West Turkmenian depression is filled with a sedimentary complex up to 20 km thick, 8 – 10 km of which are composed of Pliocene-Quaternary sediments and a lower Pliocene red-colored sequence (3 – 4 km thick), with an analogue of the hydrocarbon-productive formation of Azerbaijan included. The northern part of the depression shows the structural zoning of the Caucasus – Kopeh Dagh strike. The depression comprises three zones located in the western continuation of the Kopeh Dagh foredeep and Frontal Ridge: (1) the ***Kelkor trough,*** associated in the south with the Kubadagh – Greater Balkhan zone of uplifts and representing eastern continuation of both the North Apsheron (offshore) troughs and the Kusary – Divichi troughs, (2) the ***Balkhash zone of uplifts,*** a chain of brachyanticlines continuing the Apsheron sill, and (3) the wider ***Kyzyslkum zone*** with the deepest basement (20 – 22 km).

Southward along the coast, the ***Gograndagh (Okarem) zone*** extends in a N–S direction parallel to the fault separating it from the Kopeh Dagh ; and another fault of the same strike that extends along the seashore borders the zone on the west. The Neogene-Quaternary sediments composing this zone are folded. These folds trend predominantly N–S and rest unconformably upon the Cretaceous-Paleogene complex of the subsided part of the Kopeh Dagh. In the south, the zone joins the eastern termination of the Alborz foredeep. Further south of the centriclinal closure of the Alborz foredeep is situated the Gorgan block. This block has pre-Devonian metamorphic basement, a homologue of the Paleozoic uplift in the Reshta area of the northwestern subsided Alborz area. The Paleo-Tethys suture that is exposed at the current day surface near Meshkhed beyond the eastern boundary of the Map presumably continues in this area.

Local folds complicating the internal structure of the West Turkmenian depression are relatively uniform. They represent arch-shaped brachyanticlines with diapirs of pre-Pliocene clays and widespread mud volcanism that also involve sediments of Lower Quaternary age.

The Caspian sedimentation megabasin proper consists of three basins separated by approximately latitudinal zones of intra-basin uplifts. The northernmost of them, the *North Caspian basin* is located mostly on land and occupies only the extreme northeastern shallowest part of the Caspian Sea, with the western end of the North Ustyurt block and structures located between the block and the North Caspian depression.

The North Caspian basin is separated from the Middle Caspian basin by structures of the Karpinsky Ridge, Buzachi arch and Central Mangyshlak fold zone. These features have almost no distinguishing expression on the sea floor topography. According to seismic data, the Buzachi arch and Central Mangyshlak fold zone are traceable seaward over a distance of approximately 60 – 70 km. As with the North Ustyurt block, these structural zones of the Transcaspian region do not extend west of the Astrakhan – Gur'ev fault that crosses the North Caspian and northern Middle Caspian basins in a northeasterly direction.

The central main part of the Middle Caspian basin hosts the Derbent Basin, with a maximum sedimentary thickness of approximately 790 m. Its deepest part is located northeast of the axis of the Terek – Caspian trough, whose offshore continuation extends along the Dagestan coast.

Most of the Middle Caspian basin is occupied by the continuation of Turan structures plunging toward a system of Caucasian foredeeps, from the Terek – Caspian trough to the North Apsheron trough. The thickness of Jurassic and Cretaceous sedimentary cover on the Turan platform decreases in the same direction, partly because of their erosion and hiatuses at the Jurassic-Cretaceous and Cretaceous-Paleogene boundaries, and partly (near the Mangyshlak and Buzachi structures) due to replacement of shallow-water facies by thinner, deeper-water sediments. Even more reduced is the thickness of the Oligocene-Lower Miocene section in the zone of Ciscaucasian troughs, again because of their deeper water sedimentation settings. This thickness deficiency was compensated for by the accumulation of younger sediments, although the presence of a relatively deep basin in the central Middle Caspian after it completely dried out in the early Pliocene indicates an intermittent resumption of non-compensated sedimentation conditions.

The following Turan structures continue in the northern and eastern parts of the Middle Caspian basin: the Central Mangyshlak zone of uplifts is traceable over a distance of 60 – 70 km westward and continues as the West Mangyshlak undersea rise, some 150 km long; the West Mangyshlak scarp developed southward and is considered by Kazakh geologists to be a continuation of the Kuma zone of uplifts, a structural element of the southern Scythian platform (Ismagilov *et al.*, 2003); the Samur – Cape Peschanyi Mys saddle, located further to the south and separating the Terek – Caspian trough from the Kusary - Divichi trough in the western part of the sea; and an offshore continuation of the Kazakh trough opening into the North Apsheron trough that, in its turn, continues the Kusary – Divichi trough. The easternmost structural element of the Middle Caspian basin is a western part of the Karabogaz anteclise, separated from the latter by an N–S trending fault.

As expressed in the sea floor topography, the Middle Caspian Basin is separated from the South Caspian Basin by the ***Apsheron – Balkhash zone of uplifts,*** which bridge the fold systems of the Greater Caucasus and Kopeh Dagh. It consists of two chains of brachyanticlines, the western of which is located immediately north of the Apsheron Peninsula. Eastwards from the seashore there is a poorly traceable arch expression of the structure up to Eocene-Miocene deposits. Cretaceous strata occur here at a depth of approximately 2 km and are locally overlain by Pliocene sediments. This area represents a submerging continuation of the Greater Caucasus axial zone. The latter submerges sharply further eastward with simultaneous increase in the thickness of the lower Pliocene hydrocarbon productive sequence (red-colored in the Turkmenian segment).

The South Caspian basin in the broad sense includes not only the offshore South Caspian Basin, but its on-land flank zones as well: the Apsheron – Kobystan periclinal trough, Lower Kura intermontane trough, West Turkmenian trough, and Alborz foredeep. The water depth in the central part of the basin exceeds 1,000 m. The thickness of the consolidated earth crust beneath the basin is as much as 15 – 20 km and velocities of compressional seismic waves of 6.5 – 7.0 km/sec indicate that it is oceanic crust. The crust is underlain by the mantle, with boundary velocities of V_p= 8.0 – 8.4 km/sec. The thickness of sedimentary cover in the basin amounts to the extreme value of 25 km, 10 km of which is represented by Pliocene-Quaternary sediments. Miocene and Oligocene strata most probably underlie them because abundant clay diapirs and mud volcanoes are most likely rooted in the clayey Maikop Group. Rocks underlying the latter can be different in age and composition in different parts of the basin since it includes different submerged structural elements and formed only in the late Miocene into its present-day configuration.

The internal structure of the Middle Caspian basin is heterogeneous and comprises four segments: western, central, eastern, and southern. The western segment corresponds to the Azerbaijan shelf. It encloses continuations of anticlinal zones of the Apsheron – Kobystan and Lower Kura troughs that form a system of southeastward-diverging chains of brachyanticlines with diapir cores and mud volcanoes, the largest and most active of which form islands of the Baku Archipelago. The eastern segment coincides with the Turkmenian shelf (Turkmenian structural terrace) and is characterized by a substantially different structure. Its basement and all horizons of sedimentary cover occur at shallower levels compared with neighboring zones. The top of the basement - undoubtedly continental crust - is as deep as 15 – 16 km. Folds are gentle, vaguely outlined and variably oriented, slightly fractured, and only sometimes complicated by mud volcanoes. The central segment occupies the deepest part of the basin. Folds in this segment are characterized by larger amplitudes and strike in almost N-S or NNE directions. In the southern segment, the fold strike become approximately latitudinal, parallel to the general Alborz trend and the segment almost joins the Alborz foredeep. On the Turkmenian shelf, it corresponds to the Chikishlyar – Gryaznovulkanicheskaya zone with almost latitudinal strike and with linear anticlinal zones highly complicated by faults. The thickness of sedimentary cover increases again, amounting to 20 km and more in the Alborz foredeep.

The origin and age of the Middle Caspian depression remain debatable and we will discuss this topic in the relevant summarizing chapter of these Explanatory Notes.

2. NORTH CASPIAN DEPRESSION

The North Caspian depression occupies the southeastern part of the ancient East European platform and is characterized by a long development history. The initiation of this structure is related to formation of a triaxial rift system (the Aralsor, Khobda, and Pachelma rifts) in the late Precambrian that predetermined a subsequent long-term and stable subsidence of the central part of the depression, whose basement, in the opinion of many researchers, is lacking a "granite layer." South of the central part of the North Caspian depression, there is a preserved block of continental crust (Astrakhan – Aktyubinsk zone of uplifts). This block occupied a raised position during the Early Paleozoic and separated central areas of the depression from a system of deep troughs that formed along its southern periphery at that time.

None of the boreholes drilled in the northern part of the Caspian Sea adjacent to the North Caspian depression and in coastal areas have reached basement. Thus inferences on the basement structure in the northern part of the Caspian Sea region can be made based only on geophysical (gravimetric, magnetic, and seismic) data.

The gravity field of the North Caspian depression is characterized by a relatively large maximum anomaly corresponding to the zone of elevated basement blocks that extends from Astrakhan eastward and further northeastward up to the Aktyubinsk area. This zone is defined as the Astrakhan – Aktyubinsk system of uplifts. To the south, where the South Emba Rise and North Ustyurt Plateau converge, a zone of negative anomalies correspond to the Trans-Volga – Tugarakchan system of troughs and are related to basement subsidence of up to 12 – 13 km.

The magnetic field of the North Caspian region and adjacent territories is characterized by intricate patterns and represents a system of differently oriented linear and isometric positive and negative anomalies with relative amplitudes ranging from dozens to several hundreds of nT. The southern part of the North Caspian depression is underlain by the Achaean – Early Proterozoic basement, reworked by subsequent tectonic processes (Fomenko, 1972;

Tektonicheskaya karta…, 1981). This is confirmed by high boundary velocities registered in the basement by refraction seismic (from 6.3 to 6.7 km/sec). The magnetic and gravity field patterns point to a high concentration of blocks containing igneous material. Over 30 intrusive bodies with different characteristics are recorded in southern parts of the Astrakhan – Aktyubinsk and North Caspian zones alone, within the Map boundaries**.**

The southern boundary of the North Caspian depression is marked in the regional magnetic field by large positive and negative anomalies, slightly isometric or slightly elongated without any visible regularity in the strike of the anomalies' long axes. This is in contrast to the Karpinsky Ridge, which corresponds to a band of positive magnetic anomalies.

The basement of the southern termination of the North Caspian depression is substantially variable in the depth, dimensions, configuration, strike of structural elements, and by the density of tectonic fractures. Among the most characteristic features of the structures of the basement surface in the southern part of the North Caspian depression, worthy of mention are: the Astrakhan and North Caspian uplifts (with minimal depths of 7.5 – 8.0 km) that represent elements of the Astrakhan - Aktyubinsk system of basement uplifts; and the Trans-Volga – Tugarakchan system of troughs, up to 9 – 13 km deep and bordering, together with other marginal troughs in the basement, the North Caspian depression to the southeast.

The present-day southern boundary of the North Caspian depression coincides with the frontal portions of the Karpinsky Ridge structures, which are thrust over this depression on the west and along the North Ustyurt fault separating the South Emba and North Ustyurt block to the east.

Three boundary surfaces are recognized from geophysical (mainly seismic) methods within the basement: the upper mantle (surface "M"), the "basaltic" and the "granite" layers (Kunin, 1997; Tsimmer, 1997; and others). The surface "M," a refractive horizon with a boundary velocity of 8.0 – 8.2 km/s, occurs at maximum depths of approximately 47.5 km in the interfluve of the Volga and Ural rivers' lower courses in the southern part of the depression. Outside of this area, this boundary rises in all directions to reach a depth of approximately 35 km near the Mynsualmas fault in the northeastern coast of the Caspian Sea.

The surface of the "basaltic layer," a refractive horizon with a boundary velocity of 6.8 – 7.2 km/s occurs at the depth of approximately 15 km in the northern part of the area and approximately 20 km near the boundary faults. Distribution patterns of the depth of this layer surface are opposite to those that characterize the surface "M."

Northward in the Central North Caspian Depression and its western continuation (the Sarpin trough), the rocks of the geophysical "basaltic layer" compose the uppermost part of the crystalline basement (boundary velocities of 6.8 – 7.2 km/s). The surface layer of crystalline basement in the southern part of the depression is composed of granite-gneissose rocks, a refractive horizon with $V_r = 6.2 – 6.6$ km/s (penetrated in the interval of 5,836 to 5,843 m by Borehole 5 in the East Akzhar uplift).

Several reference reflectors (P_3, P_2d, P_2^1, P_2, and P_1) corresponding to boundaries between structural stages of the region are distinguished within the Paleozoic sequence of the North Caspian Depression (Pilifosov, 1986; *Sedimentatsionnye modeli*…, 1986; Pilifosov *et al.,* 1996; and others). In the southern part of the North Caspian depression (which includes the northern Caspian Sea), the deepest continuous horizon within the sedimentary cover is reflector P_3. According to the seismic refraction measurements, the basement surface in this area occurs, however, several kilometers below the reflector P_3. As established by the reflection and refraction methods, the sediment thickness between reflectors P_3 and “F” is 8 -9 km in the central part of the North Caspian depression. In the arch of the Astrakhan – Aktyubinsk block these sediments are missing and the reflector P_3 virtually coincides with the F refractive surface. Southward, these horizons diverge again, which indicates an increase in the thickness of sediments, the age of which can be arbitrarily estimated to be Early Paleozoic, at depths of 4 – 5 km.

The surface structure of the pre-Middle Devonian complex (reflector P_3) inherits the basement structure, although in slightly smoothed form. Three large structural elements are distinguished along the reflector P_3: the southern edge of the Central North Caspian depression; the Astrakhan – North Caspian – Aktyubinsk zone of uplifts; and a southeastern zone of marginal troughs.

The depression segment under consideration comprises three positive structures with a generally latitudinal strike: the Astrakhan arch, approximately 200×100 km in size; the North Caspian arch (80×50 km); and the Gur’ev arch (100×50 km), with minimal surface depths of 6.6, 7.0, and 6.6 km respectively. South of these uplifts, the base of the Upper Paleozoic complex dips sharply, with an average gradient of 25 – 30 m/km toward the flanks of the depression. The peripheral part of the depression hosts the relatively narrow Trans-Volga – Tugarakchan system of troughs with maximum depths of 8 – 10 km.

The Devonian – Artinskian structural stage of the North Caspian depression is subdivided into five rock complexes: Eifelian – lower Frasnian (between reflectors P_3 and P_2d); Upper Devonian – Lower Visean (between P_2d and P_2^1); Upper Visean – Lower Bashkirian (between P_2^1 and P_2); Moscovian – Kasimovian (between P_2 and P_1); and Gzhelian – Artinskian.

The thickness of the Eifelian – Lower Frasnian complex typically ranges between 0.5 and 0.7 km over most of the territory under consideration. In the North Caspian uplift, its thickness decreases to 0.2 – 0.4 km; southward it increases sharply to 1.2 – 1.4 km. The peripheral part of the depression shows the convergence of reflectors P_3 and P_2d, thinning to 0.15 – 0.20 km. In general, the structural pattern of the Eifelian – Lower Frasnian complex surface follows closely that of the reflector $P_{3,}$ being located 0.4 – 0.8 km higher in the section. This value corresponds to the average thickness of this complex.

The roof of the Bashkirian deposits and roof of the sub-salt complex (reflectors P_2 and P_1, respectively) correspond in general to the Astrakhan – Aktyubinsk system of monoclines and the North Caspian terrace, with depths varying from 7.0 – 8.0 km to 6.0 – 6.5 km along different horizons and with a general slope toward the central parts of the North Caspian depression. The surface of the sub-salt complex in the deepest part of the depression is as much as 9 km.

The most striking structural elements of the Upper Devonian – Lower Visean interval (between P_2d and P_2^1) and Upper Visean – Lower Bashkirian (between P_2^1 and $P_{2)}$ complexes are the high-standing Astrakhan and Kashagan – Tengiz carbonate massifs (platforms). These can rise to depths shallower than 5.2 – 5.8 km (reflector P_2) and are crowned by both Bashkirian and Lower Permian complexes**.** The carbonate platforms are characterized by gentler slopes in their basal parts. Their surfaces are complicated by isolated high-amplitude reef buildups with depths of 3.8 – 4.0 km in their shallowest regions. The largest of such structures are the Astrakhan, Kashagan, Kairan, Aktota (Southeastern Kashagan), Karaton, Korolevskaya, Tengiz, and Yuzhnaya massifs. The Kashagan, Kairan, and Aktota (Southeastern Kashagan) carbonate platforms are located offshore under the Caspian Sea. In the south, carbonate platforms of the northern Caspian Sea are separated from peripheral parts of the depression by a system of troughs with maximum depths of 6.2 and 6.6 km along the reflectors P_1 and P_2, respectively.

Shallower in the section of the North Caspian depression are widespread salt-bearing deposits whose initial sedimentation thickness amounts to 4.5 km in central areas of the depression and varies from 2.0 to 2.5 km in its southern peripheral part. The age of the salt-bearing formation spans the Early Permian to latest Kazanian of the Late Permian epoch. The thickest salt-bearing sections were deposited during Kungurian and Kazanian times.

The Upper Permian and Triassic sediments fill inter-dome zones in the southern part of the North Caspian depression, with total thicknesses of 3 – 4 km and more. The thickness of the Permian-Triassic sequences is 0.5 to 3.0 km in the peripheral parts of the depression, increasing toward its central area. The Upper Permian deposits are mainly represented by terrigenous red beds with separate salt and anhydrite intercalations. The Lower Triassic section in the eastern part of the depression is composed of continental red beds; in the southwest, gray-colored marine deposits are present, composed of thinly alternating clays and limestones with subordinate sandstone and siltstone interbeds. The Middle Triassic interval is characterized by a development of marine, gray-colored terrigenous–carbonate rocks, widespread in the interfluve of the Ural and Volga rivers, the Maritime zone and in the southern part of the North Caspian depression. To the east, gray-colored sediments are replaced by molassoid sands, sandstones, siltstones, and clays. The Upper Triassic sediments rest upon the underlying strata, usually on an erosional unconformity surface. They are represented by variegated, exclusively continental terrigenous rock varieties. The distribution of the Upper Permian-Triassic sedimentary complex was determined by sedimentation rates and terrigenous material influx into separate small inter-dome depressions as well as by the intensity of salt tectonics.

The Jurassic-Neogene sediments are generally characterized by sub-horizontal bedding and abundant seismic reference reflectors that subdivide the sedimentary sequence into seismic complexes whose lithology and composition are well studied using cores from many boreholes.

The Jurassic- Paleogene complex of the North Caspian depression is usually composed of coastal-marine, shallow water, but mainly terrigenous sediments with a subordinate quantity of carbonate types in the Upper Jurassic, Upper Cretaceous, and lower-most Paleogene portions of the section.

The Paleozoic (pre-Kungurian) structures common to platforms are replaced upward by intricate structural forms related to salt tectonics.

The morphology and genesis of salt-induced structures are variable and depend sometimes on their location and on their evaporitic composition and volume (Konishchev, 1984; Abdulin *et al.,* 1995). In the peripheral parts of the depression, salt domes and anticlines are usually instigated along scarps and faults in the sub-salt formations, which determine their morphology and spatial orientation. The reduced thickness of salt in these zones and its partial - or, sometimes, substantial - replacement by sulfate-carbonate and terrigenous sediments is responsible for their simpler structure: fault abundance decreases, central grabens are absent, and compensatory synclines become less common.

Toward the central parts of the depression, the surface of the sub-salt complex dips very gradually and domes become larger. They are complicated by central grabens as well as compensatory and subsidence synclines. Distribution of these complicating structures is determined by the presence of tectonic fractures in the sub-salt complex and by development of closely spaced domes with similar subordinate bodies. The area contains several different types of salt domes: e.g. arched; complicated by grabens; complex (branching); and rudimentary structures that terminated their development at different levels within the Jurassic and Lower Cretaceous section because of the complete redistribution of the available plastic matter (salt).

The regional structure of the segment of the depression that existed prior to salt tectonism is partly reconstructed using seismic reflectors corresponding to the surfaces of Middle Triassic (“K”), Triassic (V), pre-Cretaceous (III), and pre-Paleogene (I) complexes.

The seismic reflectors “K” and “V” dip southward from a depth of 1.2 km down to 2.6 km. Against this background, positive (2.0; 0.8 km) and negative (3.0; 3.4 km) structures are readily distinguishable.

The reflector III indicates a homoclinal southward dip of the surface of the pre-Cretaceous complex, from 0.6 km down to 2.0 km. There are several negative and positive structures recognizable against this background: local deeps (1.5 to 2.0 km) registered in the Lake Baskunchak area; relative elevation from a depth of 1.0 km observed in the Volga River lower courses; a wide structural terrace at a depth of 0.6 km traceable from the Ural River lower courses to the eastern boundary of the depression; and a low-amplitude positive structure in the Karaton sub-salt uplift area.

The base of Paleogene deposits in the eastern part of the region dips in a homoclinal manner southward from depths of approximately 0.1 km down to 0.8 km. In its western part, depth contours of the base of the Paleogene outline a large trough in the Volga River valley (depth 1.2 km) whose flanks rise toward the depression boundaries to reach depths of 0.6 to 1.0 km at its periphery.

The geological history of the depression has been variously interpreted (Garetskii *et al.,* 1972; Zhuravlev, 1972; Volozh *et al.,* 1975; Zonenshain *et al.,* 1990; Volozh, 1991; Artyushkov, 1993; Aplonov, 1995; Volchegurskii *et al*., 1995; Brunet *et al.,* 199; Artyushkov *et al.,* 2000). Consolidation of the crystalline basement occurred during the Baikalian tectogenesis, which resulted in the formation of the two-layer continental crust. Formation of a sedimentary cover commenced in Riphean times. The Riphean - early Paleozoic history of the North Caspian depression remains poorly studied so far. It probably represented an uplifted part of the Russian plate until Silurian times, separated from the Voronezh and the Volga – Ural syneclises by large faults. The uplift created graben structures. During the Riphean-Vendian period, terrigenous material was derived from the Pachelma aulacogen and accumulated in the main central graben (rift), as well as in smaller similar structures.

During Ordovician, Silurian and Early Devonian times, peripheral areas of the depression underwent subsidence. While remaining relatively elevated, its central part underwent rift formation. Middle Devonian rifting is inferred from the following facts:

- The absence of pre-Middle Devonian deposits north- and south-ward;
- The almost universal occurrence of Devonian deposits on the crystalline basement;
- The structure of the peripheral scarps of the depression, the linear distribution patterns of carbonate and terrigenous sequences indicating the existence of a deep elongated basin in the central part of the depression;

- The indications of Middle Devonian rifting in the neighboring Voronezh and Volga – Ural anteclises: the Sernovodsk – Abdulinsk; Kazan – Kazhim; and Don – Medveditsa aulacogens.

Rifting resulted in destruction of the "granite layer" in the Central depression, the Sarpin trough and the Novo-Alekseevskii graben. More precisely, the triaxial rift is responsible for the formation of the North Caspian depression in its present expression. Thus, it can be interpreted that the Riphean and Middle Devonian rifting phases occurred as part of the depression's history. The last phase resulted in formation of the passive margin with all the typical elements, such as a shelf edge with reefs, continental slope complicated by faults and clinoforms, and a deep-sea basin along the northern and western boundaries of the depression.

The passive margin accumulated alternating terrigenous and carbonate sediments. In contrast, the deep-sea basin sediments are typified by clayey-siliceous sediments. Coarse detrital sequences composed of material derived from eroded mountain structures that formed in the east as well as clayey-siliceous and sandy fan sediments were deposited on the basaltic layer in the rift valley.

Subsidence in the Middle-Late Paleozoic deep-sea basin was not compensated by thicker sedimentation. It filled with sediments only at the subsequent stage of depression development with the accumulation of thick Kungurian salt sequences and Upper Permian–Lower Triassic (mainly) terrigenous red beds.

Termination of the deep-sea development stage of the depression is related to the Permian-Triassic collision of the East European platform with the Scythian and Turan plates and accretion of their blocks. The relic oceanic crust is preserved in the central part of the platform. The deep-sea development stage gave way to the typical platform regime, characterized by relatively shallow-water marine sedimentation with intermittent subaqueous and continental hiatuses.

3. KARPINSKY RIDGE

The Karpinsky Ridge (or the Donets – Caspian fold zone) is a relatively narrow, buried, NW trending fold zone, thrust over the southwestern margin of the North Caspian depression. It is a continuation of the Donets Basin, being separated from its eastern buried termination by the Sal'sk transcurrent fault. This fault crosses the entire Ciscaucasia and even the western Caucasus. In the east, the Karpinsky Ridge dips under the Caspian Sea and then continues into the Transcaspian region. There the ridge is best expressed in the Buzachi Peninsula, although the

Astrakhan – Gur'ev oblique transverse fault that crosses the Caspian Sea separates it from the Buzachi Peninsula.

By origin, the Karpinsky Ridge is closely connected with the Donets Basin. Both of them belong to a large rift system initiated at the end of Middle Devonian times on the southern (in present-day coordinates) passive margin of the East European platform facing the Paleo-Tethys. The Early Precambrian crystalline basement subsided in this area to depths of 12 – 13 km on the west (Fig. 3) and to 16 –18 km on the east (closer to the Caspian Sea), whereas the Moho discontinuity occurs everywhere at a depth of 40 km and is horizontal (Fig. 4).

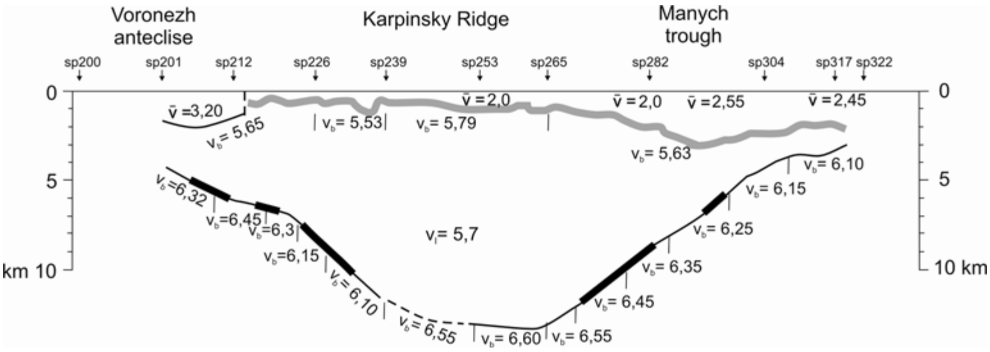


Fig. 3. Seismic refraction cross-section of the Karpinsky Ridge (CMP/DSS Data, GEON Center, 2000).

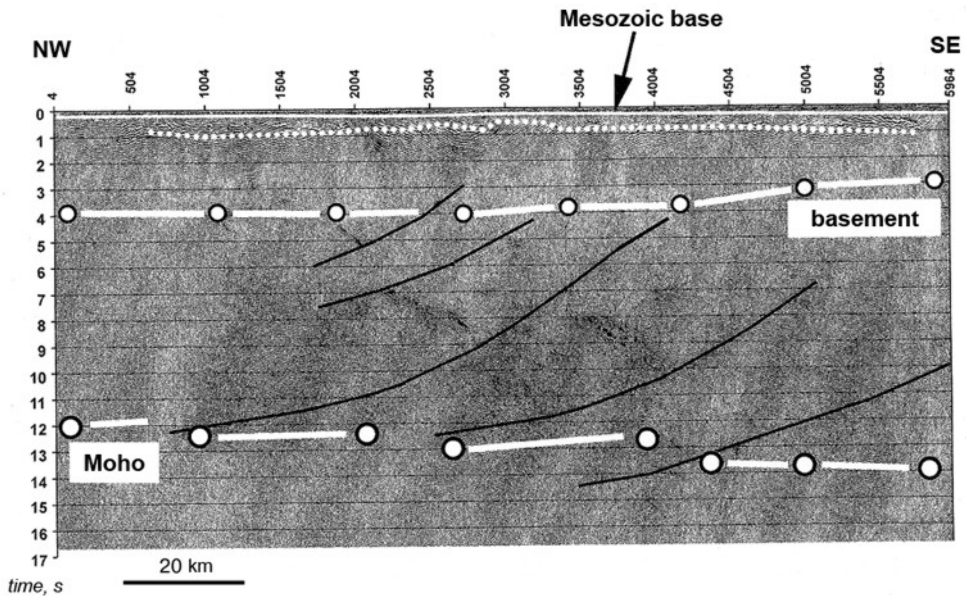


Fig. 4. Structure of the earth crust in the Karpinsky Ridge (CDP/DSS/CMP data along the seismic reflection profile Morozovsk – Elbrus, the Volgodonsk – Manychskoe area, GEON Center, 2001). (Vertical scale: Seconds, Two-way-time)

The development history of the Karpinsky Ridge differs from that of both the Donets Basin and main part of the Scythian platform. After the Frasnian initial rifting stage, the ridge zone experienced gradual subsidence during Famennian–Tourneisian times. This subsidence was not compensated by relatively deep-water clayey sediment infill. Subsequently, in the Visean–

Asselian period, subsidence accelerated and the trough was filled with coarse-grained and (at the terminal subsidence stage) flyschoid sediments. The first deformation phase was followed by inversion of the trough and its thrusting over the margin of the North Caspian syneclise. This occurred in Early Permian times, after the Sakmarian Age but prior to the Kungurian Age. In the Triassic, the ridge zone again experienced slight subsidence. In the Triassic-Jurassic boundary period, the Early Cimmerian deformation phase resulted in formation of its present-day north-verging fold-thrust structure (Fig. 5). The displacement of this thrusting over the North Caspian syneclise amounted to several dozens of kilometers. After some period of erosion, the Karpinsky Ridge was overlain by sediments of Jurassic and younger age. This sedimentary cover is characteristic of adjacent older and younger platforms representing the northernmost structural element of the Karpinsky Ridge.

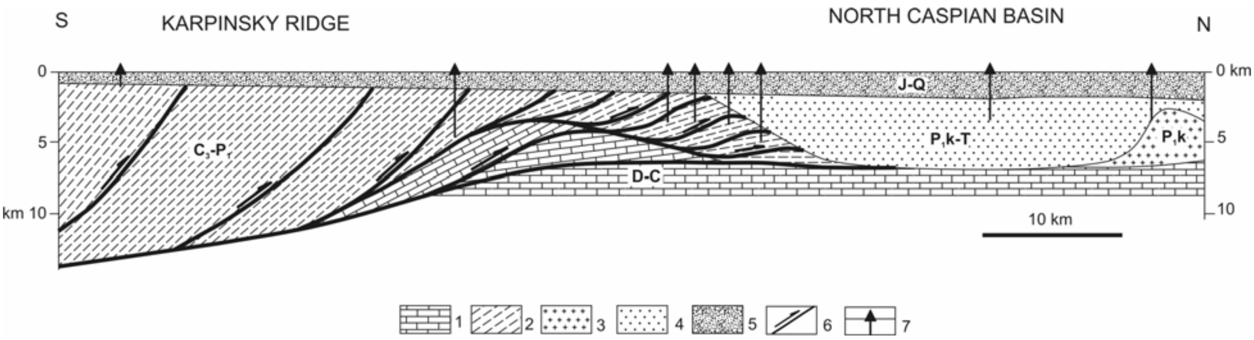


Fig. 5. Geological cross-section of the conjunction zone between the Karpinsky Ridge and North Caspian depression (Sobornov, 1996). (1) Devonian – Carboniferous complex in the North Caspian depression fringes; (2) Carboniferous and Lower Permian rudaceous and flyschoid sediments; (3) Kungurian salt; (4) Permian red beds; (5) Jurassic – Quaternary platform sedimentary cover; (6) thrusts and direction of relevant displacements; (7) boreholes.

In the Triassic the Scythian platform was flooded by a transgression that resulted in the accumulation of shallow-water marine and lagoonal carbonate-terrigenous sequences of sediments. Simultaneously, the platform was subjected in some areas to rifting with initiation of parallel, approximately latitudinal, graben-shaped troughs filled with deeper-water clayey sediments incorporating beds of varying volcanic types. This development phase was followed in late Triassic-initial Jurassic times by the epoch of deformations that occurred in two phases. The first phase was represented by an inversion of rifts with the formation of linear uplifts (Tarkhankut in the Crimea, Central Azov and Eisk – Berezan in the Ciscaucasia), affecting the younger sedimentary cover. The second phase occurred at the very end of the Triassic, when an Andean-type volcanic belt related to subduction of the Neo-Tethyan crust formed on the Scythian platform.

Since Jurassic times, the Scythian platform accumulated its own sedimentary cover, the basal part of which is composed of paralic sediments grading upwards into Lower- Middle Jurassic shallow-water marine sediments, with terrigenous formations occurring only in some areas. The thickness of post-Triassic, mainly shallow-water marine deposits in the ridge zone, does not exceed 1 – 2 km. During the period of their accumulation, the ridge was elevated in the form of a gently sloping uplift with several local low-amplitude anticlines typical of platforms.

The internal structure of the Paleozoic-Triassic complex includes several north-verging tectonic nappes. It is assumed that surfaces of these thrusts initially represented (at the rift stage) listric faults. Several low-angle swell-shaped, approximately latitudinal uplifts are distinguished within the Mesozoic sedimentary cover of the Karpinsky Ridge: the Promyslovskoe – Oleinikovskoe, Achiner – Caspian, and Krashokamyshinskoe uplifts.

4. EAST CISCAUCASIAN REGION

The Late Paleozoic (Hercynian) folded basement of the East Ciscaucasian region is composed of intricately deformed and metamorphosed rocks intruded by granites and granodiorites. The platform sedimentary complex is represented by Jurassic-Quaternary deposits whose thickness increases in the N-S direction. The Paleozoic basement and overlying platform sequences sandwich locally distributed Triassic terrigenous-carbonate and volcanogenic deposits referred to as the “transitional taphrogenic complex” (Krylov, 1971; Letavin *et al.,* 1975; Letavin, 1978; *Geologiya i neftegazonosnost…,* 2001).

The main structural elements of the Scythian plate in the Ciscaucasian region are the buried Karpinsky Ridge, the East Manych trough and the Kuma system of uplifts. The structural differentiation of the plate is best manifested in the structure of the Paleozoic basement and Triassic transitional complex. The deformation degree of the Jurassic-Quaternary plate sedimentary complex is insignificant and decreases upward. The Karpinsky Ridge is characterized by its fold-thrust structure (see above, Chapter 3). Its southern slope dips southward in a step-like manner across the Paleozoic basement from depths of 1.5 – 2.0 km to 4 km.

The East Manych trough, located in the southern part of Kalmykia and northern areas of the Stavropol and Dagestan regions, extends in an approximately latitudinal direction and coincides with the Kuma River’s lower course. It comprises several depressions and intervening arch-shaped uplifts. Depths of the Paleozoic basement surface increase eastward from 5.5 km, reaching 6.5 km in the Caspian Sea coast (Maritime depression). The latter is separated from the southern slope of the Karpinsky Ridge by the North Manych fault (a thrust), which coincides with a sharp 2 - 3 km change in depth of the basement surface and with seismic reflectors in the transitional tectonic complex. Borehole Adra-Ata-1 penetrated Lower Triassic terrigenous rocks at 3.8 km under granodiorites that in turn underly Mesozoic depositional complexes. Seismic profiles crossing this area confirm the presence of thrusts. This thrusting could have occurred under intense tangential stress during Late Triassic-Early Jurassic times. During these times, the Karpinsky Ridge experienced inversion accompanied by volcanism, evident from the development of volcanogenic rocks within the Upper Triassic section of the East Manych trough and in the area of its conjunction with the Karpinsky Ridge. Geophysical data indicates that the thickness of the Permian-Triassic complex in the eastern part of the Manych trough exceeds 2 km. The structure of this complex is affected by discrete folding, which becomes more intense northward. It is further complicated by abundant fractures, mainly with a northeastern strike.

The Permian-Triassic complex contains linear and isometric folds with amplitudes up to 100 m and more, as well as faults with throws of up to 1 km. Uplifts distinguished by geophysical methods within the Permian-Triassic sequences north of the Kuma River are referred to as the Arabli – Artesian swell.

The southern slope of the East Manych trough grades into the northern slope of the Kuma system of uplifts that are identified in the Paleozoic basement and Permian-Triassic complex. This system has an approximately latitudinal strike and dips in a westerly direction beneath the Caspian Sea, at depths from 3.5 to 6.5 km.

The latitudinal ***Kuma complex swell*** (system of uplifts) extends over a distance exceeding 200 km and is distinguished as a large structural element that unites uplifts of the Paleozoic basement: the Ozek-Saut, Sukhaya Kuma, Talovsk, and Kochubei – Tyulenii uplifts. The shallowest depth of the basement surface is registered in the Ozek-Saut block (3.35 km). Southeast of the Ozek-Saut block, a swell-shaped structure is traceable, against the background of the regional subsidence, as far as Kizlyar Bay where the basement surface occurs at 5 km, dipping toward the East Manych (5.5 km) and Terek – Caspian (9.0 km) troughs. The Sukhaya Kuma and Talovsk uplifts are the most studied by deep drilling and geophysical methods. The basement, with its main structural elements distinguished in the Kuma Plain, also determines the structure of the entire overlying Mesozoic-Cenozoic sedimentary section and controls distribution of individual lithologic - stratigraphic complexes. The stratigraphic range of two stages defined in the platform cover (the lower folded and upper folded stages of the homoclinal structure) directly depends on the degree of relief differentiation and the tectonic activity of blocks. In the west, folding in the sedimentary cover is traceable up to the Oligocene, whereas eastward the boundary of the lower structural stage is limited to the Lower Cretaceous above the

Talov uplift, and to the base of the Jurassic sequence in the Kizlyar Bay area. It is noted that the shallower the surface of the Paleozoic basement, the wider the stratigraphic range of the lower structural stage, and vice versa.

Basement elements show an approximately latitudinal strike, while the folding in the platform cover is characterized by the formation of intricate structures (Mavrichev et al., 2001). The structural patterns of the cover are influenced by near-N-S trending faults. Tectonic movements in two main directions (almost latitudinal and N-S trending) were responsible for the principal structural expression of the area under consideration. While the Ozek-Saut block is mainly characterized by latitudinal anticlinal zones closely connected with faults of the same direction, the Sukhaya Kuma and Talovsk blocks show development of anticlinal zones representing morphological reflection of northeast-oriented fractures in the basement. The Talovsk block has a general northeastern strike and is notable for the specific lithologic-facies composition of the Triassic complex that, in part, determines its enhanced oil and gas potential. Most of hydrocarbon accumulations discovered in the Triassic formations of the Dagestan territory are connected with this uplift.

The Kuma system of uplifts extends southeastward up to the Caspian Sea shore where it is separated from the Kochubei – Tyulenii uplift by the small Chernyi Rynok trough. In the area of the Kochubei – Tyulenii uplift, the basement surface is at depths of 5.5 to 6.0 km.

According to geophysical records and data obtained from some parametric boreholes (Kochubei, Severnyi Kochubei), the thickness of the Permian-Triassic sequence increases in this area up to 2.5 km and their upper surface (reflector “D”) is complicated by local small-scale structures up to 100 m in amplitude. In Kizlyar Bay, gravimetric studies have revealed the North and East Tyulenii uplifts. These uplifts are confined to the Dagestan wedge and are responsible for the curved shape of all latitudinal tectonic elements near the Agrakhan meridian. The recent seismic investigations carried out by the Closed Joint-Stock Company *Geo-Khazar* in Kizlyar Bay revealed a middle Miocene zone of stratigraphic truncation and an upper Miocene erosion outlier 35 km long and 500 m high. This substantially improves the hydrocarbon prospectivity of the upper Sarmatian limestones (similar to the Chervlenoe accumulation) and middle Miocene formations (Chokrakian and Karaganian horizons).

The southern slope of the Kuma swell grades into the gently sloping Krainov or Nogai (after Letavin, 1978) tectonic scarp. The width of this scarp increases northeastward to 30 km at the Caspian Sea coast. The southern boundary of the Kuma swell corresponds to the suture zone between the epi-Hercynian plate and Terek - Caspian foredeep.

In general, the Paleozoic basement is characterized by a block structure determined by development of a system of orthogonal faults, most important of which are those of approximately latitudinal strike.

As was noted above, the structure of the Triassic complex shows the presence of transitional features which differentiate it from the underlying Paleozoic basement and overlying Jurassic-Cretaceous platform strata. It is characterized by a wide distribution of volcanogenic – sedimentary formations and plicative-disjunctive deformations on the one hand, and by absence of any indications of regional metamorphism, development of intermittent folding, and by carbonate sediments mostly of the platform type on the other.

Within the Jurassic-Cretaceous strata, structural differentiation decreases and the regional structural style acquires a homoclinal character. Local structures are represented by low amplitude (up to 20 m) dome-shaped uplifts with low-angle slopes in their peripheral parts. Eastward, from the central part of the Kuma swell to the Caspian Sea, the local uplifts of the Jurassic-Cretaceous surface become less intense and are virtually indistinguishable in the seismic records. This can partly be related to an increase in the regional southward dip of the monocline caused by formation of the Terek – Caspian trough. Under these conditions, some uplifts turned into poorly defined structural elements (noses, terraces, and others). Downward, closer to the sharply differentiated Paleozoic basement, the structures become well developed. In the west, local uplifts within the Cretaceous-Paleogene sequence are expressed as very low-amplitude (5 – 10 m) complex structures. The overlying Neogene-Quaternary sediments are characterized by their horizontal homoclinal attitude.

In the Kuma system of uplifts under the Caspian Sea, some 38 oil, gas, and gas condensate fields have so far been discovered in the Permo-Triassic, Jurassic, Lower Cretaceous and Oligocene formations. The continuation of the Kuma system is represented by the Tyulenii area, which has been poorly studied by geophysical methods to-date. The Paleozoic basement presumably plunges in coastal areas up to depths of 6 – 7 km (Kizlyar depression). Further northeast- and eastward, it raises up to 4 – 5 km. Gravimetric, electrical prospecting and seismic research has revealed local uplifts of the Paleozoic basement near the Tyulenii and Chechen' islands. It is assumed that there is an anticlinal zone at the latitude of Tyulenii Island, which could contain oil and gas accumulations within the Triassic, Jurassic and Lower Cretaceous formations. Hydrocarbons are expected to be dominated by oil (up to 70%). Most promising for hydrocarbon accumulations is the northern elevated part of the Tyulenii area where the Paleozoic basement and Mesozoic deposits occur at depths of 4 – 5 km and the Triassic-Lower Cretaceous formations might have local uplifts. The Paleozoic rocks composing the basement beneath this part of the Caspian Sea are also believed to have promising potential for hydrocarbon accumulations. The hydrocarbon potential in the Paleozoic section could be comparable with those on land in the adjacent part of the Kuma system of uplifts, with a productivity that could amount to 30,000 tonnes/km^2.

5. TURAN PLATE

In the eastern coast of the Caspian Sea, direct data on and the composition of basement and its depth are limited. They are available only for the Cape Peschanyi – Rakushechnoe uplift where boreholes penetrated Devonian-Carboniferous granites and for the northern part of the Karabogaz arch where Precambrian (Baikalian?) metamorphic schists are known to occur. For the remainder of this territory, the structure of the basement surface is interpreted based only on geophysical evidence (Kunin and Korobkin, 1971; Dimakov and Tamarov, 1973; Popkov *et al.,* 1993; Pilifosov *et al.,* 1996).

The analysis of geophysical data allows several blocks of the earth crust with specific geophysical characteristics to be distinguished. Boundaries of these blocks coincide with large regional faults. The following structural elements of regional scale can be outlined:

- Karpinsky – Buzachi fold- thrust zone;
- Western termination of the North Ustyurt – Buzachi system of troughs and uplifts;
- Western termination of the South Mangyshlak – Ustyurt system of troughs and uplifts;
- Karabogaz – Middle Caspian system of uplifts;
- North Caucasus – Mangyshlak system of troughs.

All these elements are readily recognizable in the basement structure. They are separated from each other by a system of approximately latitudinal faults. An important element in the formation of the basement surface structure is the approximately N-S trending fractures with horizontal strike-slip deformations that create intricate block patterns.

The regional structural elements comprise several smaller positive and negative structures. These are reliably established on land and continue offshore. They are the intricately deformed Buzachi uplift; the extended South Buzachi zone of troughs; the deformed Central Mangyshlak system of uplifts; the West Mangyshlak scarp; and the Cape Peschanyi uplift. Among important structural elements of second and third orders in the basement surface are the North Caucasus – Mangyshlak system of troughs and their constituting elements, such as the Kazakh depression.

In the ***North Ustyurt block*** adjoining the Tugarakchan trough, the depth to the basement surface decreases from 10 – 12 km in the north to 6 – 7 km in the central areas.

The structure of Upper Paleozoic deposits developed in the western part of the Turan plate is characterized by the reflector "b", interpreted as corresponding to the sharp angular unconformity between the Paleozoic and overlying Permian-Triassic complexes.

The reflector "b" in the North Ustyurt block outlines the Koltyk depression in the north, where it is buried at depths of 7 – 8 km, and the Kyzan - Tokubai uplift in the south (at a depth of 4.0 – 4.5 km).

The Permian-Triassic sequences of the western Turan plate compose the so-called transitional, or taphrogenic, tectonic complex and are to be found everywhere except for the Karabogaz arch. They form the upper stage of the pre-Jurassic section bounded by the reflector "b" at the base and reflector V (V_1) at the top. The interval between these reflectors encloses several additional reference reflectors, the main ones being VI, V_3 and V_2.

The Upper Permian-Triassic sequence of the North Ustyurt block is composed of red-colored, variegated, and gray-colored lithologic-stratigraphic complexes. The red-colored complex is subdivided into the lower (Upper Permian) and upper (Lower Triassic: Induan – Olenekian) parts with the boundary between them corresponding to reflector VI. The Upper Permian rocks rest with angular unconformity upon Paleozoic strata and are represented by gritstones, massive sandstones and siltstones. The Lower Triassic part of the section is composed of alternating sandstones, siltstones, and tuffaceous siltstones of reddish and brownish coloration. A Middle Triassic variegated complex up to 1 km thick occurs on the eroded surface of the red-colored complex and consists of sandy-clayey sediments (mudstones, siltstones, sandstones). The Upper Triassic gray-colored sequence transgressively overlies different age sediments and fills the deepest depressions. It is composed of sandstones, gritstones, mudstones, and siltstones.

The basement of the ***Karpinsky – Buzachi zone*** comprises several large- and middle-scale uplifts and troughs of isometric and intricate outlines. They resulted from intense thrust deformations that involved both the sedimentary cover and basement. Against the background of average depths of the basement surface of approximately 4.5 – 5.0 km, the amplitude of individual positive and negative structures can amount to 1.0 – 2.5 km.

The surface of the Upper Paleozoic units is characterized by rather intricate structures. In the Karpinsky Ridge area, the reflector "b" corresponds to the surface of undivided Upper Carboniferous-Lower Permian strata. There, the surface of the Paleozoic sequence occurs at depths of 1.5 to 3.0 km, dipping southward.

In the Buzachi uplift of the eastern Caspian Sea coast, the reflector "b" is interpreted to correspond to the surface of the Paleozoic sequence. This sequence is composed of shallow-water carbonate–terrigenous and terrigenous–volcanogenic deposits of Late Devonian–Early Permian age. The Paleozoic surface in the Buzachi uplift is registered at depths of approximately 6 km. Its southern slope is truncated by the almost latitudinal Karazhanbas – Zhamanorpin fault, beyond which the surface of Paleozoic deposits dips steeply toward the South Buzachi trough up to depths of 9 km. The southern slope of the Buzachi uplift and the South Buzachi trough form distinct linear structural elements with a northwestern strike and are likely to be of relatively simple structure. In composition and attitude patterns, the Upper Permian and Triassic sequences of the Buzachi Peninsula are similar to those in the North Ustyurt. The Upper Triassic layers are missing from the Buzachi arch, being developed only in its termination area. Here they rest unconformably upon different age strata and fill the deepest depressions. They are represented by sandstones, gritstones, mudstones, and siltstones.

The Karpinsky – Buzachi system of thrusts is characterized by the intricate structure of the Upper Permo-Triassic complex, which is explained by the influence of fold-thrust dislocations. The entire section shows block structures with steeply dipping layers. It can be assumed that only its Upper Triassic gray-colored part in subsided areas is deformed to a lesser extent. The platform cover of the western Turan plate is characterized by uniform structural features and lithologic-stratigraphic characteristics over the largest part of the region under consideration. The regional structure of the Jurassic-Paleogene complexes is simpler than that of the Permo-Triassic sequence. Over most of the region, Jurassic- Paleogene sediments compose a single sub-horizontal blanket complex, with insignificant or only moderate signs of "platform" tectonics (Fig. 6.).

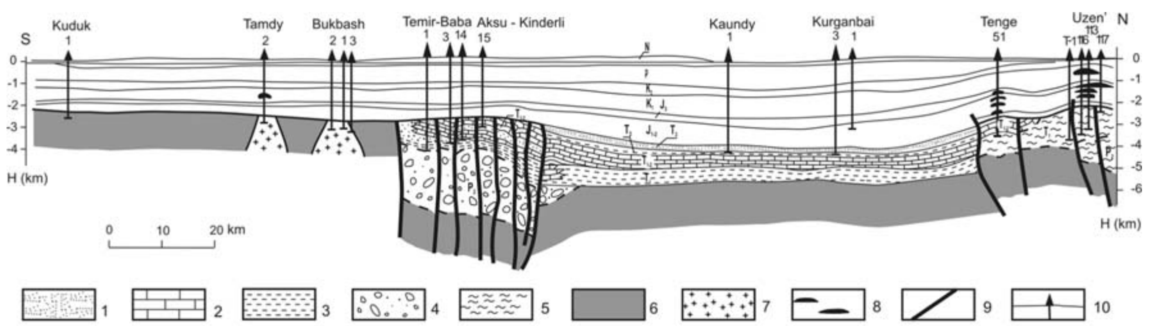


Fig. 6. Geological cross-section through the western part of the Turan plate (compiled by V.I. Popkov).
(1 - 7) Pre-Jurassic complexes: (1) Upper Triassic terrigenous (gray-colored) complex, (2) Lower-Middle Triassic carbonates, (3 – 4) Upper Permian-Lower Triassic terrigenous (red beds): rudaceous (3), sand – clay (4), (5) Permian-Triassic volcanogenic – sedimentary, (6) Paleozoic, (7) Devonian-Carboniferous granitoids; (8) hydrocarbon pools; (9) faults; (10) boreholes.

The structure of the Jurassic sequence is readily traceable using reflector V on the seismic data, corresponding to the base of the Jurassic complex. This reflector outlines large, distinct structural elements which form the western termination of the North Ustyurt – Buzachi system of troughs and uplifts, and which includes the Koltyk and Beineus troughs and Buzachi uplift.

The tectonic zoning of the Jurassic-Paleogene platform complex is best distinguished on the structural map compiled using seismic reflector III, corresponding to the base of the Lower Cretaceous sequence. The regional structure of this surface is typical of platforms.

Three large structural elements are recognizable in the western termination of the North Ustyurt – Buzachi region structures. These are (from north to south): the North Buzachi terrace; the Buzachi uplift; and the South Buzachi trough.

The North Buzachi terrace represents a structural element that occupies a transitional position between the North Caspian salt-bearing basin and the Buzachi uplift. The terrace has approximately a latitudinal strike and is about 160 x 10 – 80 km in size, being narrowest near the eastern termination of the Buzachi uplift and south of the Astrakhan arch.

The Buzachi uplift retains almost latitudinal orientation. It is about 260 x 55 – 90 km in size and approximately 900 m in amplitude. Local smaller-scale structures and disjunctive dislocations complicate the uplift. Its arched part is located on land and its western termination is presumed to be bordered by a regional fault under the Caspian Sea. The base of the Cretaceous sequence dips from the highest part of the uplift westward, from 0.5 to 1.2 km. The uplift is generally symmetrical and only in the conjugation area with the South Buzachi trough does its southern flank become steeper. The thickness and completeness of the Jurassic-Cretaceous section increases from the central part of the uplift outward. Among abundant fractures affecting this uplift, one of the largest is the Karazhnbas – Zhamanorpin approximately latitudinal fault, with vertical throw of about 250 m.

The South Buzachi trough, approximately 190 x 20 - 35 km in size and about 900 m deep, also extends in a broadly latitudinal direction. The trough is characterized by its symmetrical shape, with a flattened eastern slope and deeper western offshore centrocline. The base of the Cretaceous sequence occurs at depths of 1.7 km on the eastern slope and 2.4 km in the centrocline. The central part of the trough has a greater thickness and a wider stratigraphic range of the Jurassic-Cretaceous sequence than does its peripheral parts.

The ***Ciscaucasia – Mangyslak block*** is characterized by an intricate and regular structure. The Mangyshlak – South Buzachi segment of this block shows a distinct linear orientation of relatively narrow uplifts and troughs with generally northwestern strike. The basement surface in the troughs occurs at depths of 8 to 10 km (10.5 km in the North Karatau, 9.0 – 9.5 km in the Chakyrgan, and 8.5 km in the South Mangyshlak troughs). The troughs are 250 – 300 km long and 25 – 50 km wide. The system of faults, the largest among which are the South Karatau, North, and South Beke-Beshkuduk faults, separates deep troughs from narrow (approximately 20 km wide) and extended (up to several hundreds of kilometers) uplifts (meganticlines).

The linear Mangyshlak – South Buzachi basement structures come abruptly to an end at approximately meridian 40^o E. They are truncated by the Astrakhan – Gur'ev regional transform fault, emphasized by its associated gravity and magnetic anomalies.

The main structural elements of the Mangyshlak basement and associated geophysical anomalies are displaced along this fault in a northeasterly direction.

The most intricate structures of the reflector "b" are observed in the Mangyshlak block area. The large structural elements of this zone are the North Karatau trough with reflector "b" at depths up to 7 km, as well the Karatau and Beshe-Beshkuduk meganticlines separated by the Chakyrgamn trough. These are characterized by extremely variable reflector depths along linear NW-extending zones more then 300 km long.

Least substantiated and, thus, most debatable is the interpretation of depths in the Mangyshlak system of dislocations. Here, Paleozoic deposits might occur at deeper levels. Therefore the map of the basement surface compiled for this area characterizes the most likely depth of rock complexes with density of 2.7 g/cm^3 and P-wave velocities of approximately 6.0 km/s (typically: 'intensely deformed and partly metamorphosed sedimentary sequences').

The Paleozoic deposits are intensely deformed, so much so that their internal structure cannot be unraveled, which make them similar to some extent to basement complexes. They differ only in the degree of deformation and metamorphic alteration. In southern Mangyshlak, the area with a recognizable reflector "b" is limited by the South Beke-Beshkuduk fault.

In a similar manner in the East Ciscaucasia region, the Permian-Triassic terrigenous-carbonate section of the Mangyshlak begins with rudaceous red beds. Their basal layers are dated as Late Permian-Early Triassic (*Trias*…, 1981; Popkov, 1992). Following an insignificant hiatus, terrigenous rocks are overlain by Induan-age carbonate strata. These consist of light to dark gray massive dolomitic and organogenic limestones over 800 m thick.

The Lower Triassic sequence is unconformably overlain by Middle Triassic deposits interpreted as being of the Anisian and Ladinian Stages. The Anisian Stage is composed of calcareous siltstones and mudstones with limestone and marl interbeds. The Ladinian Stage is represented by variegated sandstones, siltstones and calcareous mudstones, with an admixture of tuffaceous material with substantially reduced carbonate content. The integral thickness of the Middle Triassic sequence exceeds 1,000 m.

Upper Triassic rocks form a volcanogenic-sedimentary complex up to 1,000 m thick, which transgressively overly Paleozoic to Triassic strata. The complex is composed of alternating variegated conglomerates, gritstones, sandstones, siltstones and mudstones with members of tuffs and lavas of acid, intermediate, and, less commonly, basic compositions. Some researchers believe that the volcanogenic-sedimentary complex is as old as Late Triassic-Early Jurassic. Thus, the Upper Permian-Triassic deposits are characterized by a rather complex distribution.

This pre-Jurassic structural stage is noteworthy because of the wide development of terrestrial volcanism that accompanied the rifting in the Scythian – Turan platform. Based on gravimetric and magnetic data, two areas differing in volcanic complexes are distinguishable:

The Mangyshlak – Ciscaucasia block is characterized by wide distribution of acid, intermediate and, less commonly, basic lavas in large depressions filled with Upper Permian-Triassic sediments.

In the south, the Middle Caspian – Karabogaz block contains basaltoid lavas distributed along the North Karabogaz fault. This fault was responsible for the formation of the one-sided Kazakh graben in Early Triassic times.

The age of volcanism in this region is ambiguous. In the Ciscaucasia, South Mangyshlak, and Buzachi areas, volcanogenic rocks (tuffs, lavas, and others) are widespread in the Lower (Olenekian Stage) and basal Upper Triassic sequences. However, periodic outbursts of volcanic activity accompanied the ongoing accumulation of (probably) carbonate-terrigenous sedimentation throughout the entire Triassic development history of the Ciscaucasia – Mangyshlak crustal block.

The interpretation of the structural – tectonic zoning of Upper Permian Triassic deposits is to a large extent arbitrary because of their very intricate structure.

Taphrogenic complexes of the Central Mangyshlak fold system and South Buzachi trough differ substantially from those developed in the South Mangyshlak and offshore Karabogaz area, mainly in their intensity of deformation. The regional structural patterns of the Central Mangyshlak fold system are remarkable for their intricate relationship of isometric and linear depressions on the one hand, and intervening uplifts (horsts) on the other, as well as for the highly variable thickness of the Permo-Triassic rocks that ranges from several hundreds of meters to 3.0 – 5.0 km.

The aforementioned elements are complicated by contrasting second-order positive and negative structures, most of which have been studied in detail on land. In the Kazakh coast, these are the Tyub-Karagan – Karatau and Beke-Beshkuduk meganticlines, Chakyrgan trough, and others.

South of the Mangyshlak linear fold system is the South Mangyshlak – Ustyurt system of troughs and uplifts. This zone comprises several structural elements (Cape Peschanyi uplift, North Karabogaz anticline) that were previously outlined on land by geological – geophysical research. The largest part of the Cape Peschanyi uplift, the most dominant structural element, is located offshore where the West Mangyshlak – Kuma scarp, a large tectonic element unknown on land, is also distinguishable.

The Upper Permian-Triassic sequences in the western part of the South Mangyshlak – Ustyurt system of troughs are also characterized by a having a more intricate structure than their overlying Jurassic formations.

The Kazakh trough is a semi-graben, bounded on the northeast by a fault with a vertical throw exceeding 1 km. Permian-Triassic deposits, 1 – 4 km thick, fill in this one-sided NW-trending trough, which extends for more than 200 km, with a width of 30 – 40 km. On the southwest and east, the thickness of sediments sharply decreases, finally pinching out in the arch of the Karabogaz basement uplift. Seismic data show the presence of the same three-membered sequence as in the well-studied South Mangyshlak trough: Upper Permian-Lower Triassic terrigenous, Lower- Middle Triassic carbonates, and Upper Triassic gray-colored terrigenous material.

The Cape Peschanyi uplift separates the South Mangyshlak and Kazakh troughs. This saddle represents the northwestern termination of the Tuarkur zone. The Permo-Triassic sequence here is 0.50 – 0.75 km thick and retains its three-member structure. Slightly deformed Jurassic deposits within these structural elements overly almost continuously the older rocks.

The orogenic Karatau and Beke-Beshkuduk arch structures as well as their offshore continuations are characterized by substantially more intense tectonic deformations than is observed in surrounding Jurassic- Paleogene platform cover. This is reflected in the much steeper dip angles of the stratigraphic units composing the orogenic structures (up to 5 – 15^{o}). The thickness of the Jurassic-Quaternary complex is highly variable, ranging from several hundreds of meters in the arches of anticlinal structures to several kilometers in the troughs, although this shallower section inherits to some degree the structural features of the underlying complexes.

The Tyub-Karagan anticlinal zone is about 100 x 200 km in extent and is largely located on land. It represents an element of the Tyub-Karagan – Karatau meganticline that terminates 30 km northwest of the seashore. Its northern and southern slopes are steep and complicated by fractures at deeper levels. The western periclinal part is noticeably flattened.

Offshore, this structural zone is seemingly a continuation of the West Mangyshlak uplift, a three-arched structure of complex configuration. However, the West Mangyshlak uplift is separated from the Tyub-Karagan – Karatau meganticline by an approximately N-S trending fault and in fact is not an immediate offshore continuation of this structure. The West Mangyshlak uplift is up to 120 km long, with a vertical expression of up to 500 m.

The Chakyrgan trough, located south of the Karatau meganticline, has no offshore continuation and has subsided the most in its western part, where the Lower Cretaceous deposits occur at depths of approximately 2.5 km. The total length and maximum width of this trough are 280 km and 15 km, respectively. On land, the trough separates the Tyub-Karagan – Karatau meganticline from structural elements located to the south.

The West Mangyshlak – Kuma scarp that is expressed in the structure of the Mesozoic sequence is a structural element that was outlined only recently by marine geophysical surveys. The scarp is only recognizable offshore and is divided by an approximately N-S trending fault into an eastern and a western area: the approximately latitudinal western area and the N-S extending eastern area.

The southwestern slope of the scarp dips toward a deep depression that is part of the Middle Caspian Basin. The scarp crosses the Caspian Sea and passes into the Kuma zone of uplifts and, partly, into the Nogai scarp in Russian territory. The offshore part of the West Mangyshlak – Kuma scarp is 320 km long and the maximum depth to its up-dip limit is 2.7 km.

The Cape Peschanyi uplift is east of the N-S extending part of the West Mangyshlak scarp. This uplift is located partly on land and largely offshore. The uplift is of almost isometric outlines, 190 x 120 km in size, and up to 700 m in amplitude. It is complicated by several local structures and a long, approximately latitudinal fault.

On the south and southeast, the Cape Peschanyi uplift is bordered by the almost latitudinal Kazakh trough. This trough is bounded in turn by an extended fault in the north. The Kazakh trough opens in the west into the Ciscaucasian system of troughs, and it is this feature that provided the grounds to term the entire region as the Ciscaucasia – Mangyshlak system of troughs.

The regional structure of Paleogene deposits (outlined by seismic reflector “I”, interpreted as corresponding to the base of the Paleogene sequence) inherits morphological peculiarities of older, deeper structures. The deeper structures include all the most important structural-tectonic elements defined within the Jurassic and Cretaceous complexes as well as most of the structures of the Triassic and pre-Triassic portions of the cover. A remarkable feature is the absence of these structural elements in the arched parts of the Buzachi and Cape Peschanyi uplifts as well as in the Beke-Beshkuduk and Karatau meganticlines.

The ***Central Turkmen region of uplifts*** includes the Central Karakumy and Middle Caspian – Karabogaz zones of arched uplifts, separated by the large Tuarkyr zone of linear uplifts and troughs. They comprise the eastern part of the Middle Caspian Basin, Karabogaz-Gol Bay, Krasnovodskii Peninsula, Chil-Mamedkumy, Tuarkyr, and adjacent areas of the Karashir, Uchtagan, and Cherkezlin Sands. The region is bounded by the Tuarkyr and Kaplankyr faults in the north and by the North Kubadagh – North Balkhan fault in the south. It is characterized by an anomalous gravity field and sharply reduced thickness of the earth's crust. The base of the crust here is at depths of 28 – 30 km dipping steeply north- and south-ward up to 49 km and 35 km respectively. Linear zones of substantially different thicknesses of the earth crust usually correspond to large faults that also represent boundaries of the entire region in question. The latter comprises four large tectonic zones: Middle Caspian – Karabogaz, Tuarkyr, South Karabogaz, and East Karabogaz.

The Middle Caspian – Karabogaz tectonic zone occupies the almost entire Kara-Bogaz-Gol Bay and eastern part of the Middle Caspian. It is a large structural element of the platform, with relatively shallow basement (1.0 – 2.5 km). During Paleozoic, Triassic and Jurassic times it represented a permanent outcrop that served as a provenance for sediments accumulating in the surrounding troughs. The sedimentary cover of this zone is immediately underlain by a seismic reference reflector, with widely variable boundary wave velocities ranging from 5.8 to 6.6 km/s. It corresponds to the surface of heterogeneous basement. The reflector outlines the East Caspian, Central Karabogaz, and Omchala uplifts. Most remarkable of them is the East Caspian uplift characterized, according to geophysical data, by its N-S strike, which is atypical of surrounding areas and corresponds to elements of the Precambrian fold system. This feature allows it to be related to the oldest uplifts of the West Turan plate. The Central Karabogaz and Omchala uplifts represent large basement blocks. According to drilling data, the Omchala uplift is lacking Upper Paleozoic-Triassic, Jurassic and Neocomian rocks. Sediments of Aptian age directly overly deeply eroded folded basement.

The Tuarkyr tectonic zone corresponds to a large area bounded by concealed faults: the Kaplankyr faults in the north and northeast and the Tuarkyr faults in the south and southwest. The present-day structural outline includes the following elements: the Tuarkyr swell; Kubsemshen ledge; Karashor swell; Uchtagan trough; and Sakar – Gyadyn ledge. Almost all these structures are elongated and oriented in a northwest direction.

The South Karabogaz tectonic zone occupies an area of the Krasnovodsk Peninsula, the Chil-Mamedkum Sands and the North Balkhan piedmont plain. On the north and south, it is bordered by regional faults. The eastern boundary corresponds to a N-S trending fault that passes east of the Greater Balkhan. The zone's section is lacking Upper Paleozoic-Triassic and Jurassic rocks. The Lower Cretaceous strata rest immediately upon the heterogeneous basement, which is composed of metamorphic and igneous rocks. The Lower Cretaceous occurs at depths ranging from 1.2 – 1.5 km in the north and west to 2.5 km in the south and east. Jurassic sediments occur only in the eastern part of the zone. Distribution patterns and thicknesses of the sedimentary cover imply that the formation of the platform sedimentary sequence was controlled by the pre-Jurassic basement dipping stepwise in a southerly direction. The present-day structural outline of the zone includes the Krasnovodsk and Chil-Mamedkum anticlines and Kasnovodsk – North Balkhan trough.

The East Karabogaz tectonic zone is located east of the Middle Caspian – Karabogaz zone. It is separated from the Middle Caspian – Karabogaz zone by the N-S trending Belek-Koshoba fault. The thin sedimentary section of this zone is composed of Jurassic and Cretaceous rocks, which are exposed at the present-day surface. Their combined thickness does not exceed 1,200 m. The zone is complicated by the Kemal, Beineus, and Keldzhik swell-shaped uplifts and Ubyk group of local structures.

6. TEREK – CASPIAN TROUGH

The western half of the Terek – Caspian trough is superimposed at its outer slope on the southern part of Scythian epi-Paleozoic plate. Its inner areas overly outer zones of the Alpine Greater Caucasus structures. In the west (beyond the Map boundaries), the trough is bounded by the Mineral'nye Vody ledge. The surface of the Paleozoic basement occurs at depth ranging from 2 – 6 km, down to 12 km in the Terek – Sulak depression.

The boundaries of the Terek – Caspian trough with the Scythian plate and Greater Caucasus correspond to the Terek – Caspian and Vladikavkaz faults respectively. In general, the trough is asymmetrical: a northern gentle slope with dip angles of approximately 10^{o} and a southern steep, intensely deformed slope complicated by fractures and diapiric structures.

The deep structure of the trough is little explored, particularly by drilling. Because of its great depths, the nature of the basement remains almost unknown so far. By analogy with the neighboring Scythian platform, it is assumed that the latter is Paleozoic in age and composed of highly metamorphosed and deformed sedimentary and igneous rocks. Boreholes 37 and 42, drilled in the arch of the Varandino anticline in the northern flank of the Greater Caucasus, penetrated an intensely deformed carbonate sequence of Permian age; its apparent thickness exceeds 1,000 m. In the Benoi (Chechen Republic) and Burunnaya (Stavropol region) areas in the western part of the Terek – Caspian trough, boreholes recovered a thick (over 1,200 m) sequence of volcanogenic-sedimentary rocks of Triassic age. The Miatly parametric borehole drilled in the Dagestan Piedmont penetrated deformed clayey-carbonate rocks in the interval

2,144 to 2,380 m, arbitrarily dated as pre-Jurassic. Metamorphosed Permo-Triassic rocks were penetrated at a depth of approximately 5,000 m by Borehole 1 in the Agzybirchala area of northeastern Azerbaijan.

The trough is filled with Mesozoic and Cenozoic sediments. Its section usually begins with Upper Jurassic carbonates and salt-bearing rocks up to 1,500 m thick. These are overlain by Lower Cretaceous sandy-clayey sediments and Upper Cretaceous carbonate sequences of 1,400 m and up to 1,000 m thick respectively. Higher in the section, there are thin (up to 200 m) Paleocene-Eocene marly-clayey sediments overlain by the clayey Maikop Group, from 1,800 to 5,000 m thick.

The Lower-Middle Jurassic black shale complex is drilled in several uplifts of the Dagestan Piedmont (Irgartbash, Berikei, Dagestanskie Ogni, and others) where it is represented by shales, mudstones, and siltstones with sandstone interbeds and carbonaceous inclusions. The parametric borehole Mugri 1 drilled in the frontal part of the Greater Caucasus folded structure at the boundary with the Terek – Caspian trough reached Jurassic layers at a depth of 4,303 m. The thickness of the Lower-Middle Jurassic complex in the Mugri anticline area exceeds 6,000 m. The penetrated thickness of this complex in the folded side of the trough is usually less than 3,000 m. In southern Dagestan, its section is lacking the Bathonian and, partly, the Bajocian stages. The thickness of the Jurassic terrigenous sequence decreases westward to zero in the Burunnaya, Benoi, and other boreholes, and increases in thickness in the northerly direction.

It is beyond doubt that Lower-Middle Jurassic, thick (1.5 km) Upper Triassic volcanogenic, Lower Triassic (over 1 km thick), and Upper Permian (0.5 km thick) rocks are widespread in the trough, although their detailed distribution is difficult to interpret because of insufficient drilling data and the discontinuous nature of seismic reflectors defining these sequences.

The Upper Jurassic – Hauterivian carbonate complex composed of limestones, dolomites, terrigenous rocks, gypsum layers and anhydrites is developed only locally in the Terek – Caspian trough. This complex is missing from the areas located south of the Talgino and Dmitrov uplifts as well as in the Caspian Sea adjacent to South Dagestan. Westward and northward where saliferous sediments and reefal buildups are probably developed, their thickness amounts to 600 m.

The Barremian-Eocene complex consists of three lithologically different sequences: mostly terrigenous (Barremian-Albian), limey (Upper Cretaceous), and terrigenous-carbonate (Paleocene-Eocene) sequences. In some areas, sections are lacking Albian sediments (in South Dagestan) or Paleocene-Eocene sediments (Babayurt, Karabudakhkent). The thickness of this complex ranges from 500 to 1,200 m, decreasing southward away from the axial part of the trough.

The Maikop (Oligocene-lower Miocene) complex is up to 5 km thick and is characterized by a clinoform structure, frequently complicated by secondary folding and irregular thickness distribution. In the arched parts of folds (Sernovodsk, Malgobek – Voznesensk, and others) and also in northern slopes of some structures (Zamankul, Karabulak – Achaluk, and others), the thickness of this complex is 1.5 – 2.0 times higher than its average values, which has likely resulted from a thrusting-related doubling of the sequence.

The near-horizontal Pliocene-Quaternary molasse complex is at least 2 km thick and rests everywhere with an insignificant angular and stratigraphic unconformity upon middle-upper Miocene deposits. This older complex is characterized by narrow asymmetrical fan-shaped anticlines complicated by thrusts and up-throws with displacements of up to 2.5 km, which become low-angle in the plastic Maikop clays (the Terek and Sunzha anticlinal zones). In the Dagestan Piedmont, the middle – upper Miocene complex occurs as a homocline.

The most remarkable structural features of the western half of the Terek – Caspian foredeep are the two narrow en-echelon-like Terek and Sunzha anticlinal zones (Fig. 7). They are separated by relatively narrow depressions filled with horizontally bedded sediments. Anticlinal zones are probably rootless and composed of sheets detached and thrust along bed surfaces in plastic Upper Jurassic and Maikopian sediments. According to geophysical data, anticlinal zones correspond to a trough in the Paleozoic basement, not uplifted Paleozoic basement. Folding occurred in Pliocene-Quaternary times, caused by N-S compression. During the late Pliocene, the western part of the trough accumulated the thick (over 2 km) volcanogenic-sedimentary Rukh-Dzuar Formation, now forming the slopes of the Sunzha anticlinal zones.

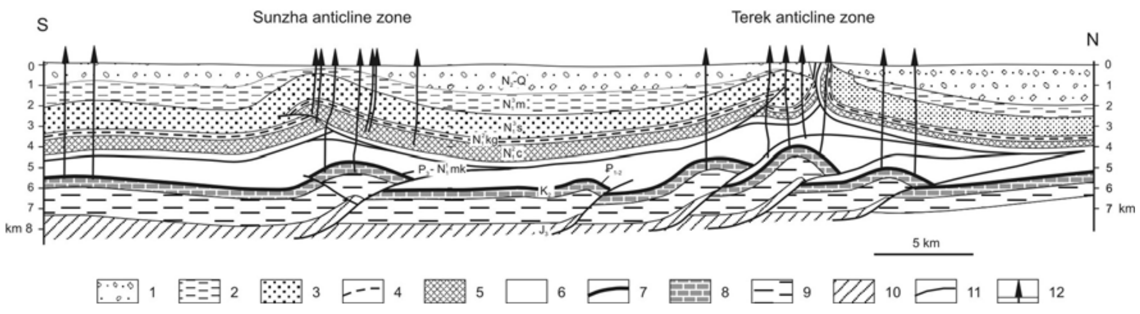


Fig. 7. Geological cross-section of the Terek – Sunzha fold zone (Sobornov, 1996).
(1 – 10) Stratigraphic complexes: (1) Pliocene-Quaternary (sandstones and siltstones), (2) upper Miocene (clays and shales), (3) upper Miocene (sandstones and siltstones), (4) middle Miocene (clays), (5) middle Miocene (sandstones and clays), (6) Oligocene-lower Miocene (clays and shales, Maikop Group), (7) Paleocene-Eocene (marls), (8) Upper Cretaceous (limestones), (9) Lower Cretaceous (dolomites, sandstones, shales), (10) Upper Jurassic (evaporites); (11) detachment surfaces; (12) boreholes.

Two narrow anticlinal zones within the Chechen and Dagestan republics are separated by the so-called Dagestan wedge, a peculiar tectonic element that complicates the structure of the southern side of the trough and juts into its axial part. The approximately latitudinal strike of fold zones within the wedge changes to a southeasterly trend. The Dagestan wedge is comprised of the Sulak and Irgartabash ledges, Talgin dome and intervening depressions. All these structures are intricate folded elements that are composed of lower-order structural forms, characterized by large amplitudes (up to 5,000 m), and complicated by fractures. In the Jurassic-Eocene portion of the sedimentary section, they are represented by thrusts forming the Dagestan belt of north-verging thrusts (Sobornov, 1996) (Fig. 8).

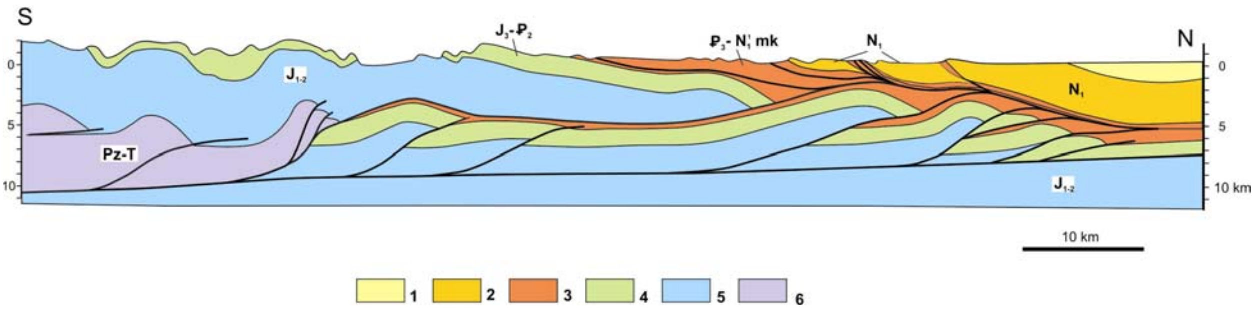


Fig. 8. Geological cross-section of the Dagestan wedge (Sobornov, 1996).
Stratigraphic complexes: (1) Pliocene-Quaternary; (2) middle-upper Miocene; (3) Oligocene-lower Miocene (Maikop Group); (4) Upper Jurassic-Miocene; (5) Lower – Middle Jurassic; (6) Paleozoic=Triassic.

The frontal part of the Dagestan wedge corresponds to the Narattyuba fold-thrust zone that extends over a distance of 150 km. The upper part of its section is composed of Chokrakian and Maikopian sediments forming a homocline and exposed at the present-day surface. They are crossed by the Gilyan uplift (with amplitudes of 500 – 1,500 m) that terminates in deposits of Oligocene age. Intense folding and fractures are characteristic of the Jurassic-Eocene complexes that make up buried uplifts: the Dimitrov, Shamkhalbulak, Novolakskoe uplifts, amongst others. A large thrust with amplitude up to 2,000 m is developed in the Eastern anticline and in one of the offshore anticlinal zones.

The slope of the Terek – Caspian trough adjacent to the platform corresponds to a low-angle, southward dipping homocline composed of molasse complexes and obscuring the structure of underlying complexes. Only single small (both in size and amplitude) uplifts are distinguishable (Aksai, Babayurt, and others), the internal structure of which remains unclear. Based on geomorphological and geophysical data, the East Sulak anticline can be outlined offshore in the Caspian Sea.

Different structural patterns are observable in the folded slope of the trough in Dagestan where the complexes are intensely deformed, crossed by regional and local faults, and complicated by various secondary structures and diapirs with cores composed of Miocene clays (Selli, Dagestanskie Ogni, and others). The defined complexes are substantially variable in their structure, which results in different spatial position and configuration of folds in different complexes, displacement of uplift arches, intricate conjugation of folds within anticlinal zones, and in a downward increase in intensity of structural elements.

The western (Osetiya – Chechen) and eastern (Dagestan) parts of the Terek – Caspian trough are substantially different in structure. In the former, echelon-like narrow anticlinal uplifts are prevalent and form two zones: the Terek and the Sunzha. In the south, the trough is bordered by the Vladikavkaz fault, which dips steeply southward. The Dagestan segment is lacking these zones. All thrusts within the Mesozoic part of the section dip southward; in its youngest portion, they dip northward (Shatsky thrusts).

Most widespread in the entire trough are sinistral strike-slip faults joining into the 30 – 40 km wide Agrakhan – Tbilisi zone. As a result of this sinistral fault movement, folded structures of the Dagestan wedge in the Varandino anticline area acquire a northeastern trend. Small dextral and sinistral strike-slip faults determine the present-day structureof the Terek – Caspian trough. Being bordered by a dextral strike-slip fault zone on the east along the Caspian Sea coast, the Dagestan wedge advanced northward, which determined the high seismicity at its apex where the compressional stresses could be released.

The Terek – Caspian trough started forming in the post-Khadumian time. An important component in its formation can be related to the plastic clays of the Maikop Group. It should be noted that the Miatly times were marked by the formation of olistostrome sequences both in the northern (platform) and southern peripheral parts of the Maikopian trough.

In the later Pliocene, the trough hosted the volcanic center located immediately to the west of Groznyi where the region's deepest earthquake foci (up to 100 km deep) are registered. The buried Pshekish – Tyrnyauz and Khasaut faults that continue into this area from the Central Caucasus region became activate in late Pliocene-Quaternary times, serving as paths for fluids and heat. Narrow anticlinal zones of the Terek and Sunzha ridges formed precisely above these faults in the Quaternary period.

7. MIDDLE CASPIAN DEPRESSION

The Middle Caspian Depression is oval, extending in a NNW direction over a distance of 450 km, being 100 – 200 km wide. It is characterized by a slightly steeper near-Caucasian slope, with the deepest part (Derbent depression) also shifted towards the Caucuses. The depression is filled with Jurassic-Quaternary sediments up to 8 – 10 km thick (Fig. 9) with a maximum thickness registered in the band adjacent to the Dagestan coast. The sedimentary cover is underlain by a partly deformed Permo-Triassic rock complex and metamorphosed basement of Paleozoic and, probably, older age. The crust beneath the Middle Caspian Basin is approximately 40 km thick, whereas the thickness of the lithosphere is 150 km (Levin and Fedorov, 2001).

The sedimentary cover includes several structural complexes. The uppermost of them is composed of upper Pliocene and Quaternary shallow-water marine sediments: Akchagylian, Apsheronian and younger ages, represented by clays, sands, and slightly subordinate coquina layers. The thickness of Akchagylian – Apsheronian sediments amounts to 1.3 km and that of the Quaternary sediments, 1.4 km. They are characterized by almost horizontal bedding, slightly repeating the local structures of the underlying deposits. They are frequently reflected in the Caspian Sea floor topography, for instance as a continuation of the Karpinsky Ridge, Kuma zone of uplifts, Buzachi, and Mountainous Mangyshlak features.

The basal layers of this complex are composed of alluvial-deltaic sandy-clayey sediments accumulated in the Paleo-Volga valley and delta. The valley incision is well seen in seismic records. Its depth varies from several hundreds of meters in the south to 0.7 km south of Makhachkala, and to 3.0 km in the delta, which begins south of the latitude of Derbent. Accumulation of these lower Pliocene sediments was preceded and accompanied by intense erosion, which eliminated completely the upper-middle Miocene, the partially underlying Oligocene-lower Miocene, and even the Paleocene-Eocene and Cretaceous deposits over most of the Middle Caspian depression.

The composite thickness of the Pliocene-Quaternary sediments exceeds 2 km in the Kizlyar Bay area in the northwest of the region and is less than 1.5 km east of the Paleo-Volga valley. The thickness gradually decreases toward the Kazakh coast of the Caspian Sea.

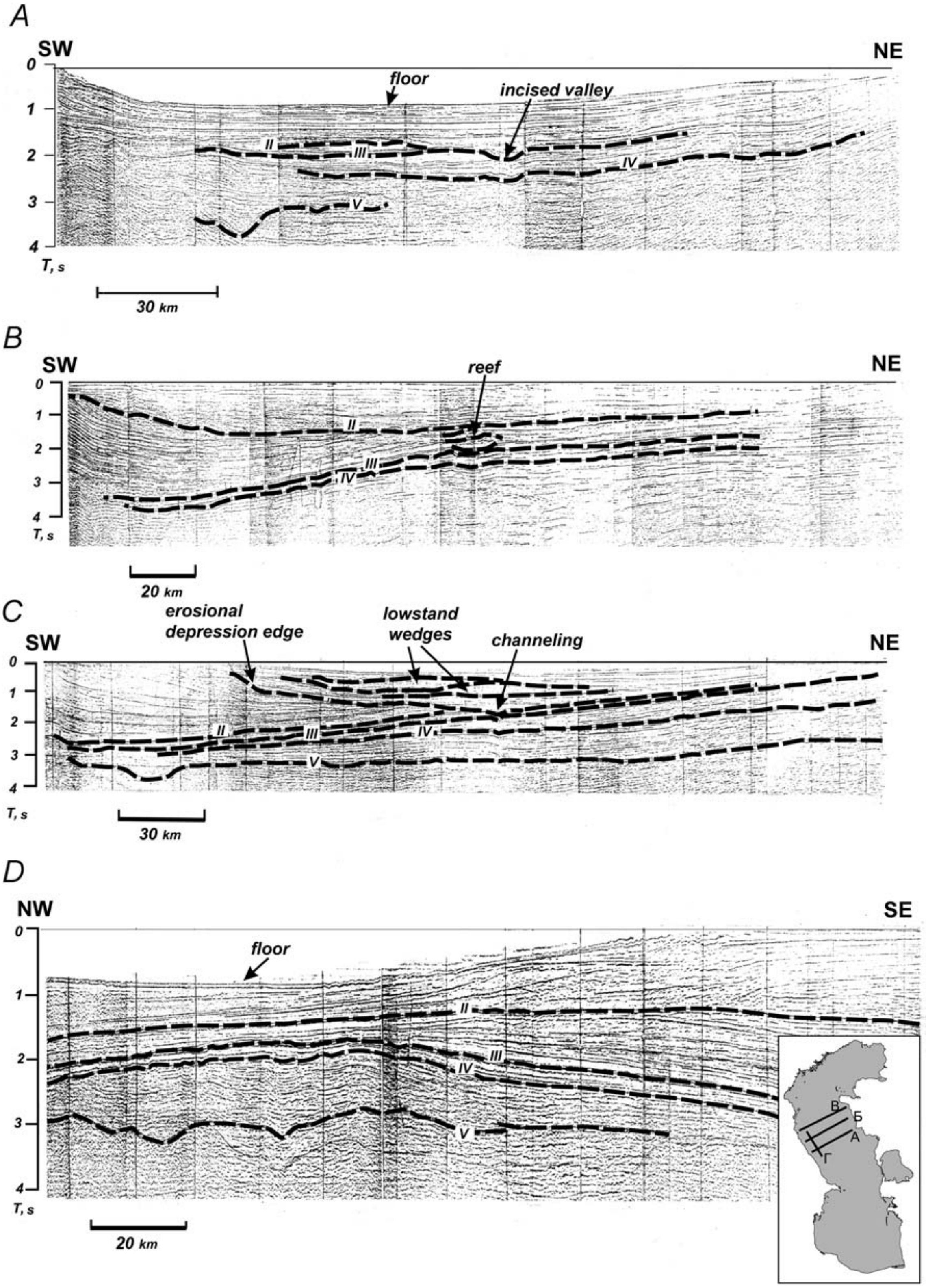


Fig. 9. The structure of sedimentary cover in the Middle Caspian depression (Gadzhiev and Popkov, 1988). The inset shows location of seismic reflection profiles. Main reflectors: (II) within the Neogene sequence; (III) near the Cretaceous-Paleogene boundary; (IV) near the Jurassic-Cretaceous boundary; (V) the base of the Jurassic.

The next structural complex is composed of Oligocene-Miocene sediments represented by the Oligocene-lower Miocene Maikop Group in the lower part of the section. These sediments mostly accumulated in the offshore continuation of the Terek - Caspian foredeep of the Greater Caucasus. Maximum thicknesses are recorded in the Terek - Sulak depocenter north of Makhachkala, the only area with preserved uppermost Miocene (Maeotian and Pontian) sediments. The thicknesses of the Sarmatian, Karaganian - Konkian, Tarkhanian - Chokrakian, and Maikopian sections, which are preserved only in this area, are, respectively 1.2 - 1.4, 0.5 - 0.6, 1.0, and up to 2.0 km. In seismic records, all horizons of Oligocene-Miocene and Pliocene sediments show the presence of scarps at the edge of prograding complexes composed of clinoforms. Except for the Sarmatian sediments, which contain detrital material derived from the Caucasus, these complexes point to their prevalent northern provenance. They are largely composed of clays, pure varieties of which accumulated in relatively deep settings of the central part of the depression. Upward in the section and northward, an admixture of sandy-silty material increases.

The Oligocene-Miocene sediments along the eastern Caspian Sea coast are represented by thin, shallow-water facies with oolitic and coquina limestones. The thickness of these sediments is usually only several dozens of meters. The Oligocene sequence rests on underlying complexes that locally have undergone intense erosion (erosion incision and other features). The lower Paleogene, Cretaceous and Jurassic rocks compose a single structural complex that is represented by a succession of lithostratigraphic units: Lower-Middle Jurassic marine, partly paralic, sandy-clayey (up to 2 km thick); Upper Jurassic carbonate (up to 3 km thick); Lower Cretaceous terrigenous, locally with subordinate limestones (up to 1 km thick); Upper Cretaceous marly -limey (up to 0.5 km thick); and lower Paleogene carbonate-terrigenous (up to 0.5 km thick) formations.

The structural patterns of the accumulation period of the Jurassic-Eocene complex differed substantially from that which existed during formation of the Oligocene-Miocene complex. The Oligocene-Miocene complex is characterized by a sharply asymmetrical structure: in the western part of the Middle Caspian depression it fills the deep Terek – Caspian trough and in the remainder of the depression it forms virtually a homocline grading into the northeastern slope of the trough. The Jurassic-Eocene complex shows different patterns: the eastern coast of the sea (approximately from the Samur River mouth to the Cape Peschanyi) is occupied by a NE-trending zone of uplifts that is depressed in the middle and crosses diagonally the Middle Caspian Basin. Most of the Jurassic-Paleogene sequence is missing from this zone. North of this zone, isopachs of the complex outline a low-angle isometric depression termed the Middle – Caspian syneclise (Ismagilov *et al.,* 2003) and in the east, some troughs developed in the Mangyshlak and Ustyurt (the Segendyk depression, which continues the South Mangyshlak system of troughs) open into the zone.

Southeast of the Samur – Cape Peschanyi zone of uplifts (saddles), there are two principal structural elements that continue structures of the Transcaspian region: the Kazakh trough and the Karabogaz arch, the latter represented by the West Karabogaz uplift. Its western dipping part and the Kazakh trough join the almost latitudinal North Apsheron trough that continues in an echelon-like manner with the Kusary – Divichi periclinal trough of the southeastern Caucasus. This extends further onto land, grading eastward into the Kelkor trough of Turkmenistan. These structures are referred to as the Alpine mobile belt. They fringe, on the north, the Apsheron – Balkhan zone of uplifts, a structural bridge between the Greater Caucasus and Kopeh Dagh, bordering the Middle Caspian depression in the south. The Alpine belt is bordered by a narrow zone located north of the Makhachkala - Turkmenbashi line and continuing offshore as the northern boundary of the Terek – Caspian and then North Apsheron troughs.

All these previously mentioned structural elements are complicated by local dome-shaped uplifts best manifested in the topography of the boundary surface between the Jurassic and Permian-Triassic complexes, although they are traceable even on the present-day sea floor (Kas'yanova, 1998). The largest of them are shown on the Map and almost all of them are promising with respect to hydrocarbons, accumulations of which have already been discovered in one of such structures, the Khazarskoe dome.

8. SOUTHEASTERN CAUCASUS

The Southeastern Caucasus is an eastern segment of the Greater Caucasus mountain fold-thrust structure. Its northeastern and southwestern slopes grade into the Kusary – Divichi and Alazan – Agrichai foredeeps. Structural – lithological complexes composing the Southeastern Caucasus and troughs bordering this structure on the north and south dip under younger sediments of the Caspian Sea.

When the superimposed structures of the orogenic stage are removed, the following main tectonic units can be distinguished in the region (from north to south):

1. The southern part of the Scythian platform involved in the pericratonic subsidence caused by initiation and development of the marginal-sea trough of the Greater Caucasus. At the present-day surface, it corresponds to the Bokovoi (Lateral) Ridge, the northern flank of which forms a flexure dipping under the Pliocene-Holocene sediments of the Kusary – Divichi superimposed trough. In the south, its boundary is represented by the Akhty – Nyugedi – Kilyazy buried fault reflected at the present-day surface by the Shakhdag – Termian thrust.

2. The trough of the Southern slope of the Greater Caucasus is a linear tectonic unit corresponding to the axial part of a marginal sea basin, the consolidated crust of which was

subjected to destruction and thinning. At the surface, it is represented by the Vodorazdel'nyi Ridge (Tufan tectonic zone) and Zakatala - Kovdag - Sumgait trough, with different age thrusts, compressional folds and foliation being characteristics of both structures.

3. The Balakan – Vandam tectonic zone corresponds to the northern margin of the Transcaucasian plate, a fragment of the Gondwana passive margin that separated from the latter during the Paleo-Tethys opening and was incorporated into the Eurasian plate as a result of the Hercynian tectonic movements. From the north, the lithological - structural complexes composing the trough of the Southern slope are thrust over this zone along the Zangi – Kozluchai fault. During the Alpine stage, the Transcaucasian plate represented an island arc system that separated the marginal sea of the Greater Caucasus from the Lesser Caucasus segment of the Meso-Tethys. In the present-day structure, the central part of the plate corresponds to the Kura intermontane trough and its northern part is involved in the structure of the Greater Caucasus.

Every one of these structural units represents, in turn, a stack of several sub-zones successively thrust over each other in a N-S direction. This resulted in the formation of different age nappes that form the main structural elements of the region (Fig. 10).

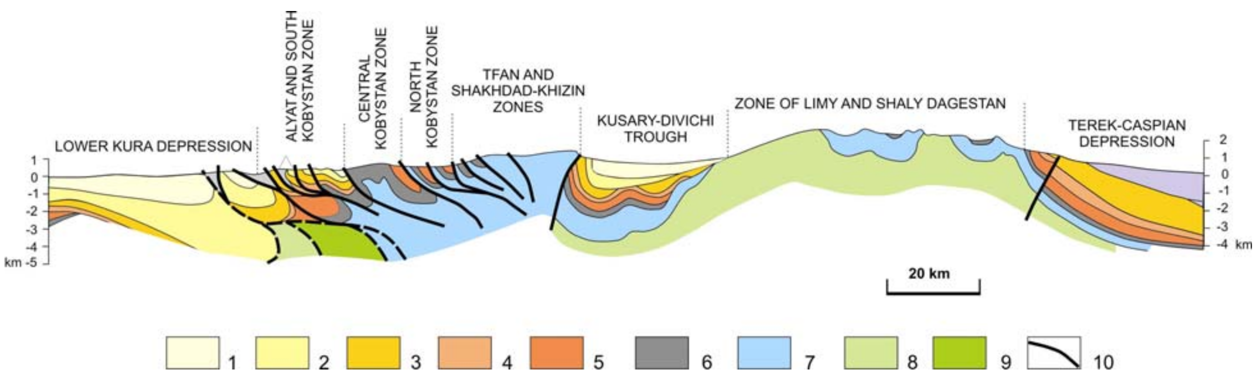


Fig. 10. Paleotectonic cross-section of the Greater Caucasus from Makhachkala to Saatly (terminal Apsheronian - initial Bakuan time) (Kopp and Shcherba, 1985).
(1) upper Pliocene-Quaternary; (2) Pontian-lower Pliocene; (3) middle=upper Miocene; (4) lower Miocene; (5) Oligocene;(6) Paleocene-Eocene; (7) Paleogene-Miocene, undivided (Vandam zone); (8) Cretaceous: (a) flysch and carbonate, (b) volcanogenic (Vandam zone); (9) Jurassic.

The Bokovoi Ridge uplift is located at the southeastern continuation of the Central uplift of the Greater Caucasus. Toward Azerbaijan, the Mesozoic structures composing the arch and northern part of the Bokovoi Ridge uplift submerge, forming a steep flexure accompanied by the Samur transcurrent fault, to depths of 3 – 5 km under the southeasterly-located Kusary - Divichi superimposed trough. The Kusary – Divichi trough formed in the middle Pliocene and represents the western termination of the large North Apsheron depression in the Middle Caspian (Khortov and Shlezinger, 1999).

The structure of the pre-Jurassic basement beneath the Kusary - Divichi trough and Bokovoi Ridge uplift includes three tectonic terraces of a general Caucasian strike. These are, from the north southward: (1) Khachmaz, corresponding to an elevated slope of the Scythian platform where a 200 m-thick sequence of andesites resting on Paleozoic (Permo-Triassic) metamorphic rocks was penetrated by a super-deep borehole at depths exceeding 5 km; (2) Kuba, representing the subsided, broken Terek – Caspian segment of the platform; (3) Tufan, corresponding to the basement of the trough of the Southern slope. The boundary between the two last terraces coincides with the Akhty – Nyugedi – Kilyazy fault, along which the basement and the structural – lithological complex of the Bokovoi Ridge uplift are thrust over the Southern slope, with maximum overlapping displacement of 32 – 35 km. At the present-day surface, this fault is manifested as several nappes, the external of which corresponds to the Shakhdag – Germian thrust, bordering at the south the exposed Mesozoic complexes of the Bokovoi Ridge uplift.

The Mesozoic complexes composing the Bokovoi Ridge tectonic zone are exposed within three sub-zones:

(1) The elevated Usukhchai – Tairdzhala sub-zone that represents a southward sloping meganticline, complicated on its limbs by small-scale folds, and composed of Lower-Middle Jurassic, relatively shallow-water, sandstones and mudstones;

(2) The transitional Sudur sub-zone located at the southern slope of the previous sub-zone and characterized by its synclinal structure; the sub-zone is complicated by linear box folds and composed of Upper Jurassic-Neocomian evaporites and carbonate facies of a continental shelf and barrier reef environment;

(3) The subsided Shakhdag – Khyzyn sub-zone representing the southernmost element of the Bokovoi Ridge and composed of Upper Jurassic-Cretaceous carbonate-terrigenous-clayey sediments accumulated in continental slope and rise settings.

During the Austrian orogenic phase (Early-Middle Cretaceous), the Sudur limestones were thrust along the Siazan thrust over the Shakhdag – Khyzyn sub-zone, separating the latter from the Sudur sub-zone. The Siazan thrust represents one of main elements of the Akhty – Nyugedi – Kilyazy fault. These limestones rest, as allochthonous chains of carbonate sheets and klippes, on Hauterivian-Barremian argillites. They are overlain by an Upper Cretaceous neoautochthonous complex of gently dipping synclines. The Upper Jurassic section of the autochthon is mostly represented by re-deposited psammitic-psephitic material from eroded shelf limestones; the Lower Cretaceous sequence contains abundant olistostromes with olistoliths of these limestones. A remarkable feature of the autochthon structure is the ridge-like anticlines extending obliquely to the strike of the Shakhdag – Khyzyn sub-zone, with cores composed of Jurassic rocks.

The trough of the Southern slope is represented at the present-day surface by the Vodorazdel'nyi Ridge in the north and Zakatala – Kovdag – Sumgait sub-zones in the south. The Vodorazdel'nyi Ridge (or Tufan) sub-zone is a continuous band of Lower- Middle Jurassic rocks overlain by Upper Jurassic flyschoid sequences in the southern part of the sub-zone. The sub-zone is intensely deformed and consists of linear, strongly compressed, frequently isoclinal folds, which are overturned southward along its southern periphery.

In the southeast, the sub-zone pinches out along the West Caspian fault and is thrust over the northern part of the Zakatala – Kovdag – Sumgait sub-zone along the Malkamud fault.

The Zakatala – Kovdag – Sumgait sub-zone begins in the westernmost Azerbaijan part of the southern slope of the Greater Caucasus and is traceable in the form of a widening zone up to the Caspian Sea coast. This sub-zone is a flysch-filled trough and is composed in its western segment by Upper Jurassic-Neocomian sandy-carbonate-clayey deposits deformed into small-scale, strongly compressed isoclinal folds overturned southward. In the east, this section is covered by Upper Cretaceous flysch and Paleocene-Miocene sediments (in the coastal area). Ridge-like folds with abundant fractures are prevalent in this area.

The narrow suture zone of the Zangin fault that extends along the southern slope of the western Zakatala – Kovdag – Sumgait sub-zone is marked by the Durudzha tectonic nappe. This nappe is composed of Jurassic rocks that were thrust in Late Senonian times over the Upper Cretaceous complex of the southerly-located Balakan – Vandam – Gendob tectonic zone. The overlapping displacement of this nappe complex is approximately 30 km.

East of the Girdymanchai River, the Durudzha nappe is overlain (with tectonic contact) by the Baskal – Pirekishkul allochthonous complex of the Stirian and Attic orogenic phases. It is composed of Barremian-Miocene rocks and was thrust along the Zangin fault over Tertiary sequences of the Shemakha – Dzheirankechmaz trough, with a displacement of 25 km and more. In the east, the allochthonous complex dips under Pliocene-Quaternary sediments of the Apsheron – Kobystan periclinal trough.

The eastern continuation of the trough of the Southern slope of the Greater Caucasus opening in the Southeastern Caucasus is generally traceable as the Apsheron – Balkhan zone offshore.

The Balakan – Vandam uplift represents the northern near-slope structural element of the Transcaucasian plate and is exposed at the base of the southern slope of the Greater Caucasus. The basement (Vandam tectonic terrace of the pre-Jurassic basement) and overlying

Alpine volcanogenic-sedimentary complex of the uplift are thrust far northward under the southern part of the Southern Slope trough. This results in the para-autochthonous position of the Zakatala – Kovdag – Sumgait sub-zone of the trough.

The Balakan – Vandam tectonic zone represents in its western part an uplift, with the Bajocian volcanogenic and Neocomian flysch formations exposed in the arch area and Upper Cretaceous volcanogenic – sedimentary complex complicated by ridge-like folds developed in its peripheral parts. Most of the arch and southern slope, which are overlain by Quaternary continental sediments of the Alazan – Agrichai depression, are marked by geophysical anomalies interpreted as corresponding to buried intrusions and paleovolcanoes.

The uplifted and ruptured arch of the Balakan – Vandam zone in the Vandamchai – Akhokhchai area is complicated by a large volcano-tectonic structure composed of a thick Maastrichtian-lower Paleocene volcanogenic-sedimentary sequence. It contains intrusive and subvolcanic bodies of middle Eocene age. The Late Senonian volcanogenic complex is recognized by potassic trachytic basalt, whereas Paleogene igneous rocks belong to the gabbro – syenite association that is part of the larger Late Senonian-Paleogene volcano-plutonic rock association.

In the interfluve area between the Girdymanchai and Akhsuchai rivers, the Mesozoic core of the Balakan – Vandam uplift dips in a flexured manner along the Girdymanchai dextral strike-slip zone of transcurrent faults. Its southeastern continuation is occupied by the wide Shemakha – Dzheirankechmaz depression filled mainly by Oligocene-Pliocene sandy-clayey sediments. They form small-scale tapered and isoclinal folds, frequently overturned southward. Low-angle thrusts of the Rodanian orogenic phase (middle Pliocene) complicate the internal structure of the trough, resulting in doubling of the Cenozoic section. During the Valakhian orogenic phase, the southern slope of the trough was thrust, along the Adzhichai – Alyaty fault, over the slope of the Lower Kura trough, a distance of 15 – 20 km and more.

9. KURA DEPRESSION

The Kura depression is approximately 450 km long and is part of a system of intermontane troughs of the Alpine belt. It is located, along with the Rioni depression, between folded structures of the Greater and Lesser Caucasus. The boundary between these two troughs corresponds to the Okrib – Dziruli uplift, west of which the Rioni depression opens toward the Black Sea and east of which the Kura depression opens toward the Caspian Sea. The Okrib – Dziruli uplift represents a projection of the crystalline basement underlying these depressions.

East of the Dziruli uplift, the surface of the basement in the Kura depression dips steeply. The Kura depression consists of three smaller structures: the Upper, Middle, and Lower Kura troughs separated by the Martkobi and Talesh – Vandam transcurrent uplifts. Geophysical data indicates that the thickness of the crust decreases eastward because of a thinned "granite layer" and correspondingly the thickness of Oligocene-Neogene molasse sequence increases (up to 7 – 8 km). The Upper Kura trough and the corresponding Kartali depression are located in Georgia where the trough is 125 m long and filled with Mesozoic-upper Eocene sediments overlain by molasse. The sedimentary sequence is characterized by narrow linear folds along the general Caucasian strike and complicated by thrusts, along which northeastern limbs are thrust over southwestern ones. The trough is bounded by thrust flysch sequences of the southern slope of the Greater Caucasus to the north, and by rocks composing the Adzharia – Trialeti Ridge to the south.

The Middle Kura trough, 370 km long and up to 130 km wide, is the largest and most complex structural element of the Kura depression. Uplifts of the crystalline basement have played a substantial role in its formation. These uplifts are have retained their elevated position throughout Mesozoic-Paleogene times. The structural scheme and surface topography of the Mesozoic complex is shown in Fig. 11.

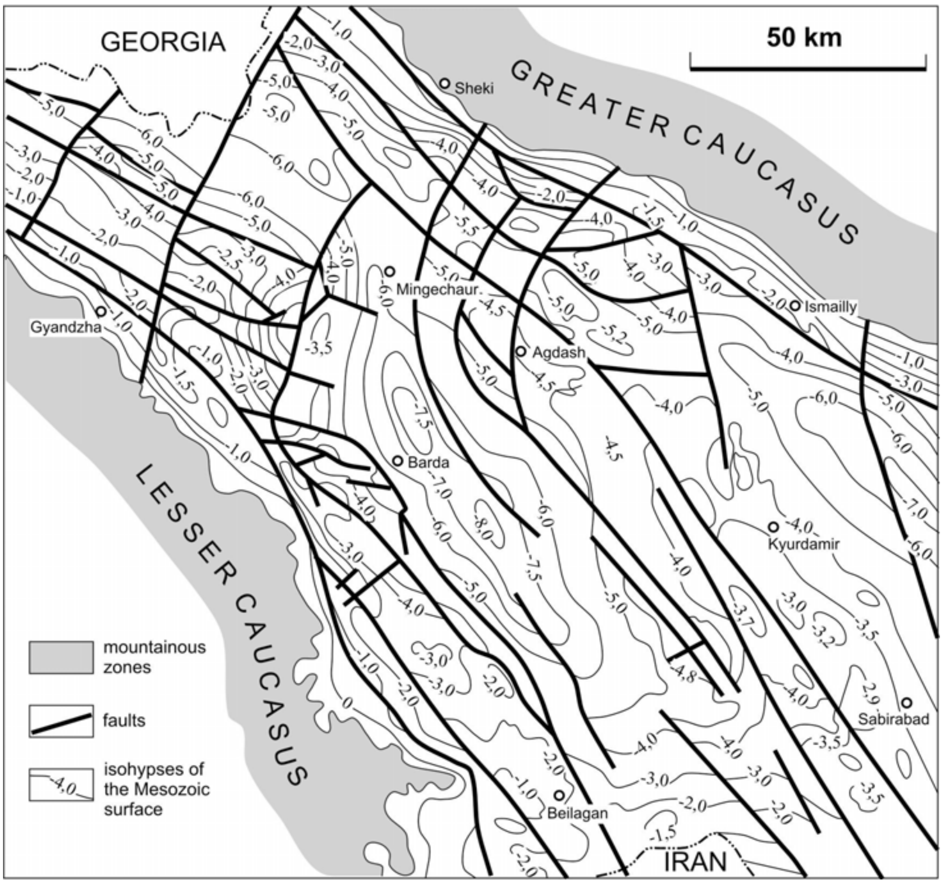


Fig. 11. Schematic structure of the Middle Kura depression along the surface of Mesozoic complexes (compiled by N.S. Kastryulin, C.B. Mamedov, and A.Z. Mustafiev). (Hatched – Mountains; Heavy lines – Faults; Contours – Surface of Mesozoic sediments, km)

The Alazan – Agrichai trough is an extreme northwestern structural element of the Middle Kura trough and is superimposed on structures of the southern slope of the Greater Caucasus. It is composed of almost horizontal Pliocene-Quaternary continental sediments underlain, according to drilling and seismic data, by folded Paleogene and Mesozoic strata. These older rocks are overturned southward and complicated by thrusts. On the north and south, this trough is separated from positive structural elements by regional faults, i.e., it is characterized by a graben- synclinorium structure. Its southwestern slope grades into the Dashyuz – Amirvan zone, representing the southeastern buried continuation of the Dzhava – Kakhetiya uplift. Linear and strongly compressed folds overturned toward the neighboring depression are replaced within the uplift by less compressed folds of this zone. These folds are complicated by thrusts and overturned mainly southwestward.

The zone is composed of Pliocene-Quaternary sediments underlain by Eocene olistostromes enclosing blocks of Middle Jurassic porphyrites and Upper Jurassic limestones. A thrust can be traced along the entire zone. This thrust has forced rocks from the northeastern part over those in the southwest, with a lateral displacement of 1.5 – 2.0 km. Seismic and gravimetric data indicate that this low angle thrust grades downward into a large fault that also cuts the pre-Alpine basement. To the southwest, the Mirzaan trough represents the structural continuation of the Kartali trough. The Neogene-Quaternary sediments filling the trough are deformed into folds, overturned or inclined southward and complicated by up-throws and thrusts (with northern limbs thrust over southern ones). Small brachyanticlines are present, separated by wide and low-angle synclines. Southward (the Alazan River lower course), all fold hinges steeply dip, whereas to the east the structure of this zone becomes simpler, evident from the smaller dimensions of the folds and their less asymmetrical shapes. An observed angular unconformity (5–6^{o}) between the Akchagylian strata and lower Pliocene hydrocarbon-productive sequence implies that the first folding phase occurred in pre-Akchagylian time and formation of folds and faults terminated during the Quaternary (Valakhian) orogeny. Seismic investigations have revealed two high-velocity and high-density bodies that are independent from each other and any other bodies (Krasnopevtseva, 1984).

In the south, the Middle Kura trough is bounded by the narrow Chatma - Geokchai zone of uplifts extending along the path of the Iori River. This zone is the most intricate tectonic element of the Middle Kura trough. It is a continuation of a thrust passing along the northern part of the Trialeti zone. Farther southeastward, this zone is traceable as a system of echelon-like up-throws and thrusts known as the Udabno – Erikdar and Geokchai thrusts. These thrusts are separated by the aforementioned approximately N–S trending flexure of the Mirzaani trough in the Alazan River valley. The latter divides the zone in two sub-zones: the western Udabno –

Chatma sub-zone and the eastern Geokchai sub-zone. The western Udabno – Chatma sub-zone has complex and large folds frequently overturned and complicated by south-verging thrusts, with up to 2.0 – 2.5 km in displacement The eastern Geokchai sub-zone has relatively low-angle folds in upper Pliocene-Quaternary sediments. The Bozdag – Karadzha – Karam-Yar anticlinal belt composed of Akchagylian and Apsheronian sediments represents a southernmost structural element. Here, folds with northwestern to almost latitudinal strike are characterized by their en-echelon-like distribution and asymmetrical form, with low-angle north-eastern and steep southern limbs. The folding intensity and fracture intensity decrease eastward. Folds become gentler in the same direction and in the lower Pliocene interval they join in a common uplift.

The Dzheiranchel zone occupying the Kura and Iori river interfluve is the southernmost structural element of the Middle Kura trough. The zone is composed of upper Pliocene-Quaternary sediments resting with angular and azimuthal unconformities upon lower Miocene-lower Pliocene strata. Folds are mostly of gentler patterns than in the northern areas of the zone, although they retain distinct southern vergence. Folds developed in upper Pliocene sediments are substantially different to those in the Miocene and Mesozoic-Paleogene intervals of the section. Brachyanticlines in Miocene sediments are represented by linear folds larger than in the upper Pliocene portion of the section. In seismic records, the surface of the Mesozoic sequence, with its local uplifts and structural terraces, is characterized by homoclinal patterns. The surface dips in a SW-NE direction from a depth of 1.0 km to 5.6 km. Mesozoic and Paleogene deposits show no structural differences.

Seismic data observed at different structural stages indicate that folding commenced in the early-middle Miocene time and was most intense during the pre-Akchagylian and post-Apsheronian orogenic phases (Agabekov and Mamedov, 1976; Mamedov, 1996).

The boundary between the Middle Kura trough and Lesser Caucasus slope is marked by the large South Kura fault and further westward is traceable along the distribution area of Miocene sediments. There, Pliocene-Quaternary layers with a sharply reduced section of molasse sediments (60 to 400 m thick) transgressively overly the Paleogene and Mesozoic deposits. The remarkable feature of this zone is the structural discordance between upper Pliocene-Quaternary and Mesozoic-Paleogene sequences. The former is characterized by low-angle homoclinal northeastward dip with development of anticlinal folds at the base of the Akchagylian regional stage. The latter also shows a homoclinal form complicated by hemi- and brachy- anticlinal asymmetrical uplifts. However, the southwestern slopes are limited in extent and are gently dipping, while the northeastern slopes are relatively wide and crossed by normal faults. Folds in the southwestern slope of the trough formed during the pre-Pliocene phase of tectonic development of the region.

The southeastern part of the Middle Kura trough contains the smaller Evlakh – Agdzhabeda trough. This is recognized in the Mesozoic-Paleogene and, partly, Miocene intervals. In contrast, only low-angled northeastward dip of layers is observed in the Pliocene sequence.

The Middle Kura trough is bordered by the Kyurdamir – Saatly zone of buried Mesozoic uplifts on the northeast and by the distribution boundary of pinching-out Miocene sediments on the southwest. Seismic data shows that the structural patterns of the Mesozoic and Paleogene intervals correspond to each other and are characterized by the development of local uplifts of the brachyanticlinal type.

Two anticlinal belts are defined in the northeastern slope of the trough: the Zardob – Muradkhanli and Shakhsunny – Mil anticlinal belts. The first of these incorporates the large high-amplitude Muradkhanli uplift, which is complicated by two longitudinal and several transcurrent faults. The second anticlinal belt is characterized by low-amplitude uplifts composed of Cretaceous complexes. The Pliocene-Quaternary strata filling the trough dip gently north-eastward. Geophysical data indicates that the surface of the pre-Alpine basement occurs at depths of 15 km and the latter contains a high-velocity, high-density body 15 km thick, similar to that in the Mirzaan trough to the north..

Three gravitational maxima are recorded in this area. The first of these, the Mingechaur – Geokchai maximum has a northwestern orientation and the second, the Kyurdamir – Saatly maximum is oriented in an almost north-south direction. The third, the Mugan gravitational maximum is the largest anomaly (120 mGal). It is located in the Karadoilu – Belyasuvar area of the Talesh foothills. This gravity anomaly decreases in a NNW direction down to 40 mGal in the Saatly area and 10 mGal near Kyurdamir. This anomaly continues in the northwesterly direction toward the Mingechaur – Geokchai maximum where it is separated from the Vandam maximum (of 10 mGal) by the Adzhinuori minimum. Through this connection, the traditionally defined Talesh – Vandam gravitational maximum is considered as a single gravity anomaly or continuous Talesh – Vandam N-S trending uplift. In the highest part of the Kyurdamir – Saatly zone, most of the Cenozoic sediments pinch out and the hydrocarbon-productive sequence rests upon the Sarmatian layers, which in turn overly Lower Cretaceous rocks. In sections to the south (Belyasuvar, Novogolovka), the Paleogene sequence is overlain with angular unconformity by gently deformed Sarmatian and upper Pliocene strata, whereas the lower-middle Miocene layers pinch out.

The Lower Kura trough is the deepest of all the Kura troughs. The thickness of the sedimentary fill in this trough exceeds 15 km, most of which is represented by Pliocene-Quaternary sediments. The trough is bordered by the Adzhichai – Alyaty fault on the north and by the West Caspian fault on the southwest. The Alyaty – Kyzylagach transcurrent fault separates it from the Baku Archipelago.

The most significant of these is the Adzhichai – Alyaty fault, along which the base of the Pliocene-Quaternary sequence composing the northeastern slope of the trough slopes from 1.5 km down to 2.0 km. The Lower Kura trough is subdivided by degree of deformation into the Shirvan and Mugan zones. The Shirvan zone corresponds to the northeastern part of the trough. It has two echelon-like systems of anticlinal uplifts: one extending almost east-west along its northeastern slope and another trending southeast along the Kura River lower courses. Folds in the sediments in both zones, characterized by synsedimentary growth in the early Pliocene and folding in Quaternary times, are represented by elongated brachyanticlines. These are complicated in their arched portions by faults, thrusts and abundant mud volcanoes. The Mugan zone occupies the southwestern part of the trough. It is located between the Kyurovdag – Neftechaly anticlinal zone and the Mugan homocline. A remarkable feature of the northeastern part of this trough is a sharp thickness increase (up to 3,000 m) of upper Pliocene-Quaternary sediments, undeformed in most of the trough (Gasanov and Alyeva, 2001; and others). The Padar group of folds revealed by seismic profiling in the southwestern slope of the trough is represented by low angle anticlines forming a single zone up to 35 km long.

The southerly located Mugan – Salyan trough is characterized by its asymmetrical structure, with steeper northeastern and low angle southwestern slopes. The southwestern slope is known as the “Mugan homocline.”

10. LESSER CAUCASUS AND TALESH

The northeastern Lesser Caucasus. The northeastern part of the Lesser Caucasus mountain system is separated form the southwestern slope of the Middle Kura trough by the deep fault corresponding to piedmonts of the Lesser Caucasus. The Artvin – Karabakh tectonic zone extends southwest of this fault. It corresponds to the southern marginal part of the Transcaucasian plate that developed in Jurassic and Cretaceous times as a volcanic island arc. The Artvin – Karabakh uplift corresponds to the Mrovdag and Karabakh ridges of the northeastern Lesser Caucasus. The uplift dips in a southeasterly direction under Oligocene-Quaternary sediments of the Lower Araks superimposed transverse trough. In the west, this zone continues, via northern Armenia and southern Georgia, toward the East Pontian Mountains (Artvin) of Turkey.

The Artvin – Karabakh uplift is comprised of three sub-zones: the Loki – Karabakh, Geicha – Akerin, and the Kafan sub-zone.

The first of these sub-zones is characterized by a fold-block structure and consists of several echelon-like, relatively simple anticlines (Shamkir, Geigel, Murovdag, Agdam) and synclines (Kazakh, Dashkesan, Agdzhakend, Agdarin). They are developed in Mesozoic volcanogenic and sedimentary-volcanogenic sequences.

The second sub-zone is characterized by the development of relatively simple compressed folds composed mainly of Jurassic and Cretaceous (Albian-Upper Senonian) sedimentary-volcanogenic sequences. The sub-zone is notable for the occurrence of the southwestern segment of the extended Amasiya – Geicha – Akerin allochthonous ophiolitic belt (Gasanov, 1996) represented by several intricate tectonic nappes. The neoautochthonous upper Santonian-Eocene sedimentary-volcanogenic sequences truncate the structure of autochthonous and allochthonous nappes.

The third sub-zone is located beyond the Map boundaries.

The Talesh fold zone in the territory of the Azerbaijan Republic is represented by its eastern slope, which is composed of Upper Senonian-Quaternary sediments. The Upper Cretaceous carbonate rocks exposed in the southwestern part of the region are unconformably overlain by Paleocene sedimentary and Eocene volcanogenic-sedimentary complexes that give way northeastward to an Oligocene-Miocene molasse sequence and further northeastwards to Quaternary sediments that reach up to the Caspian Sea coast.

The Paleogene complexes of the region form two horst-anticlinoria – the Astara and Burovar - separated by the Yardamly and Dzhilalabad graben-synclinoria, the former filled with lower rudaceous molasse and the latter with the upper finer-grained detrital molasse complex. The South Mugan uplift lies to the east of these structures, with its eastern slope overlain by Pliocene-Quaternary sediments, dipping toward the South Caspian depression.

The slopes of these uplifted structures are complicated by northeast-verging thrusts. In the Astara horst-anticlinorium, the Upper Cretaceous complex is thrust over the Paleocene sequence and the latter, in turn, is thrust over the Eocene layers. The Burovar horst-anticlinorium is represented only by its southwestern limb, where upper Eocene rocks are thrust over the Oligocene-Miocene molasse complex. The northeastern limb has subsided and is buried under the Paleogene complex.

These structures dip in a northwesterly direction toward the Lower Araks superimposed trough. In the southeastern direction, fold axes rise and simultaneously change strike to a sub-meridional direction. They then bend, following the southwestern slope of the South Caspian depression to join the Alborz system.

The basement of this zone is represented by a crystalline complex 36 – 38 km thick. Its surface dips to the east in the direction of the town of Astara, from 5 – 6 km down to 10 km. The Moho discontinuity simultaneously rises from 37 to 31 km. These features point to the continental crust thinning toward the South Caspian Basin. The Eocene volcanogenic complex is more than 3,500 m thick and is characterized by an intricate structure. It is composed of two thick sequences (Azizbekov *et al*., 1979). The lower-middle Eocene and upper Eocene volcanogenic sequences are represented by sub-alkaline rock associations: differentiated trachybasalt – trachyandesite – trachyte and contrasting trachybasalt – leucite – troctolite. The magmatic processes terminated in the late Eocene–early Oligocene with the formation of alkaline and ultramafic intrusions.

Sub-alkaline basic igneous rocks incorporating a significant portion of volcanic complexes are characterized by their low alkaline content, prevalence of K over Na, elevated Al_2O_3, Ba, Rb, Sr, light Rare Earth elements, Cr, and Ni concentrations, observed against a background of depletion in Mg, Ti, and heavy Rare Earth elements.

Two successive (pre-collision) extension phases expressed in the eastern slope of the Talesh trough resulted in prevalent sub-alkaline potassic volcanism that terminated with alkaline associations. Thus, the tectonic peculiarity of volcanics in the Talesh zone is determined by their connection with extension zones in the crystalline basement, with reduced sialic crust and with positive gravity anomalies, typical of riftogenic troughs of marginal back-arc sea basins.

11. ALBORZ MOUNTAIN SYSTEM

Geological setting and tectonostratigraphic history. The oldest exposed rock unit in the Alborz Mountains is the Kahar Formation of Late Proterozoic age. Its deformation style is very similar to that of the younger to Paleozoic, Mesozoic, and Cenozoic rock units in the system, except for subsidence-related metamorphism. This indicates that the entire section is detached along a basal decolement from an unexposed basement. The Upper Proterozoic-Middle Triassic complex is largely composed of carbonate rocks, clays, and sandstones that were deposited on a continental basement, which is unexposed in the Alborz system. By analogy with Central Iran, its age is presumably Late Precambrian.

Exposures of rocks affected by low- to middle-grade greenschist metamorphism occur in the northern part of the Alborz Range. They are composed of Paleozoic rocks deformed and metamorphosed during the Paleo-Tethys closure (Alavi, 1996). Gneisses and phillites sampled in the Kalekh Rudkhanek area of the Talesh region are dated back to 382 ± 47 and 375 ± 12 Ma

(Crawford, 1977). Some sedimentary and ultramafic rocks from this metamorphic sequence formed presumably in the Paleo-Tethys ocean (Shahpasand-Zadeh, 1993). It is likely that the orogene that formed as a result of the Paleo-Tethys closure existed for a long period, as is evidenced from its transgressive overlapping by Jurassic- and Cretaceous-age sediments.

The post-orogenic Shemshak Formation is Late Triassic–Early Jurassic in age. This coal-bearing formation is mostly composed of alternating sandstones and clays. Carbonate sediments accumulated in the Middle Jurassic–Late Cretaceous period. Some volcanic activity occurred in the Alborz region in the Early–Late Cretaceous boundary period and in the Late Cretaceous. The Late Cretaceous volcanic activity was more intense in the western Alborz and Iranian Talesh, as well as in Azerbaijan where volcanics and volcaniclastic rocks compose the Chalus Formation. Flysch deposits of Late Cretaceous age are also developed in Iran across the Araks River from Azerbaijan.

The Paleogene time was marked by intense accumulation of volcanogenic and volcaniclastic facies. Their thickness is maximal in the western Alborz. In this region, their sections begin locally with conglomerates and limestones and include volcaniclastic (mostly green tuffs) and intermediate-to-acidic volcanic rocks several kilometers thick. The causes of this volcanic activity are debatable. Different geodynamic settings are proposed for its explanation, such as subduction and rifting (Adamia, 1975; Adamia et al., 1977), back-arc environments (Zonenshain and Le Pichon, 1986), and the creation of oceanic crust. Some authors believe that similar oceanic crust of the Middle Caspian Basin represents a relict of the ancient Tethys ocean (Kornev et al., 2962; Dewey et al., 1973), whereas others (Rezanov and Chamo, 1969; Shikalibeili and Grigoriants, 1980) consider the basin as representing an eroded rigid continental massif and a zone of repeated rifting. Berberian (1983) assumed that the South Caspian Basin represents a compression-related depression underlain by trapped and modified oceanic crust.

The lack of sedimentation in the Alborz during Oligocene time and development of sedimentary basins filled with material derived from the Alborz Range north and south of the Range in Neogene and Quaternary times point to formation of the Para-Tethys, a predecessor of the present-day Caspian Sea. During this period, the rising Alborz Mountains accumulated sediments in some intermontane depressions. In the northern Alborz region, the sedimentary sequences of the Para-Tethys include conglomerates, sandstones and pelites, known as the Khazarian (Caspian) sediments (Yassini, 1981). Tertiary granitoid intrusions with unclear tectonic relationships occur in different areas of the Alborz Range. They probably resulted from tectonic processes in Oligocene and Neogene times.

The magmatic activity continued in the Neogene and Quaternary in the form of volcanic extrusions. These are mostly developed in northern Iran, adjacent to Azerbaijan. The highest summits of the mountain range represent volcanic remnants of that time. The tectonic setting of the volcanic activity remains poorly understood.

Loess sequences of the northern Alborz Range occurring east of the South Caspian depression represent eolian sediments accumulated during the Quaternary cold (glacial) periods.

Structure and main faults of the Alborz Range. The Alborz Range represents a fold–thrust belt that forms a large uplift south of the South Caspian Basin. Thrusts of this belt are divergent (Fig. 12): northern thrusts are inclined southward and southern thrusts are inclined northward (Stocklin, 1974). Most of the large faults probably begin at the detachment surface along the roof of the Precambrian basement of the ridge. Strike-slip faults play an important role in the ridge structure. Most folds in the Alborz Range are connected with fault development and are evident in many areas.

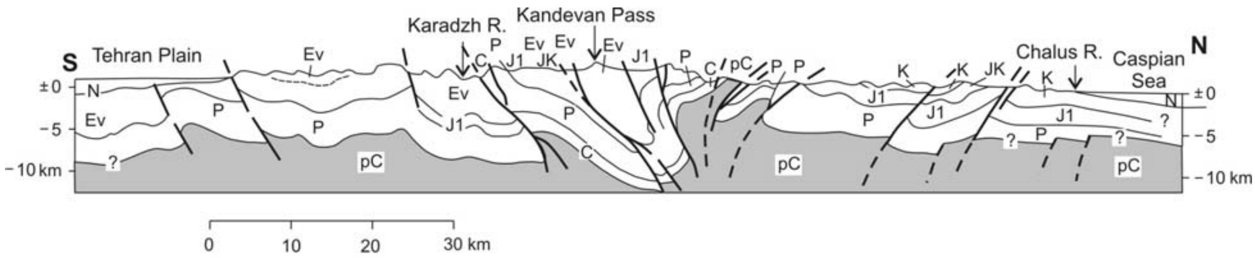


Fig. 12. Generalized cross-section of main structures in the Alborz fold system (Stocklin, 1968; Alavi, 1996, with modifications).

pЄ - Precambrian; C - Carboniferous; P - Permian; J_1 - Lower Jurassic; JK - Jurassic-Cretaceous; Ev - Eocene volcanics; N - Neogene.

The North Alborz fault, a south dipping thrust, is one of the largest features of the mountain range. Its strike changes from east-northeast to west-northwest in the central part of the ridge and is parallel to that of the entire orogene. The fault became active in Neogene or (probably) earlier times. In some places, Neogene deposits are thrust under the fault.

The Shahrood fault is another major south-dipping thrust in the eastern part of the Alborz Range. The Khazar fault represents a south-dipping thrust that is best observed in the eastern part of the Range. Paleozoic metamorphic sequences and Mesozoic to Neogene rocks in its hanging wall are thrust northward over Neogene and Quaternary sediments. Geomorphologic and neotectonic data indicate that this fault is still active (Allen *et al.,* 2001; Vincent *et al.,* 2001).

The Moshi fault, with its intricate geometry and movement history, is also a very important structural feature of the Alborz Range. In some areas, it is interpreted as a major north-dipping thrust. Deep stratigraphic levels present in the hanging wall of the fault support this interpretation in many places. Field observations and neotectonic evidences indicate, however, that the major component of movement along the Mosha faults at the present time is sinistral strike-slip. The North Tehran fault is probably a branch of the Mosha fault. This latitudinal and south-dipping fault zone is characterized by both thrust and strike-slip movements.

The Astara fault is another major thrust that dips west- to southwestward and whose strike varies from almost N-S to west–northwest in the southern part of the range. The focus of earthquake activity in the vicinity of the Astara fault implies a low-angle westward-dipping thrust (Berberian, 1983).

The Lahijan fault represents a northeast-trending fracture in the western part of the Alborz Range. Its structure has not been observed in the field, although the analysis of geological maps allows the assumption that this structure might represent a sinistral strike-slip fault, along which different structures and lithological complexes were displaced.

Tectonic history and interaction between the Caspian Sea and Alborz Range. Structural studies carried out in the northern part of the Alborz Range (Axen *et al.,* 2001; Jackson *et al.,* 2002) indicate that faults and other structures at its border with the Caspian Sea are compression-related and dip to the north. This is consistent with the interpretation that the South Caspian Basin is undergoing subduction under the Alborz Range. The North Alborz, Khazar, Astara, and many other major faults dip southward.

The southward deflection of the Alborz Range in form of an orocline implies that the South Caspian plate has played an important role in development of the Range. Geophysical data and seismicity of the region provide grounds to consider that the South Caspian plate is more rigid compared with surrounding structures (Jackson *et al.,* 2002). Compression structures and uplifts in the Alborz Range probably resulted from collision between the South Caspian and Iranian plates. On the other hand, sediments eroded from elevated areas and transported to the South Caspian Basin provided a tremendous load that, in turn, accelerated subsidence of the Basin and its under-thrusting (Allen *et al*., 2002). Convergence between the South Caspian and Iranian plates was probably oblique relative to the intervening boundary, along which the former plate moved southwestward relative to the Iranian plate (Priestley *et al.,* 1994). This oblique convergence is likely to have commenced in Oligocene times and may explain the simultaneous thrusting and sinistral strike-slip fault activities in the Alborz Range.

Development of short wavelength folds without major seismic activity in the upper portion of the sedimentary cover in the South Caspian Basin indicates that this is “thin-skinned” tectonics. The parallel axes of folds in the slopes of the depression suggest that folds are produced by compression of the surrounding structures.

12. KOPEH DAGH AND WEST TURKMEN TROUGH

The Kopeh Dagh mountain system includes mainly approximately latitudinal folded Mesozoic structures and is composed of pre-Alpine, Alpine pre-orogenic and orogenic rock complexes. The pre-Alpine basement is represented by the Precambrian (Baikalian) metamorphic complex, which is exposed in the axial part of the Binalood anticlinorium (Iran). The basement is overlain, with regional angular unconformity, by Paleozoic-Triassic platform deposits. These deposits are exposed in the Mulgazar and Muzderan ridges in Iran. The Alpine pre-orogenic complex consisting of Upper Triassic to Paleogene (Oligocene excluded) rocks forms three tectonic sub-stages: the Upper Triassic-lower Barremian; upper Barremian-Danian; and the upper Danian-Paleogene. The orogenic complex is represented by Neogene-Quaternary sediments accumulated in the period of formation and development of late Alpine mountainous folded structures. In the north, the zone comprising two tectonic sub-zones (Kopeh Dagh proper and West Turkmen) is bordered by the South Turkmen suture fault.

In the Turkmen part of the region under consideration, the Kopeh Dagh mountainous fold zone, which resulted from inversion of the Late Triassic or Early Jurassic (?) miogeoclinal trough, consists of the Peredovoi Ridge rectilinear (outer) and Internal arcuate sub-zones. The horst of the Frontal Ridge is bounded by two large faults that cross the entire sequence of the basement. Their throw ranges from 4 km in the west to 8 km in the Central Kopeh Dagh area. The Internal sub-zone forms in plan a giant arc, arching northward and repeating the configuration of the older Ala Dagh – Binalood anticlinorium (Iran).

In the present-day structure of the Alpine pre-orogenic complex, the West Kopeh Dagh zone forms a large depression with highly differentiated topography and northeasterly strike. It is bounded by anticlines of the Frontal Ridge in the north and western dipping parts of anticlines of the Internal zone in the east. Available geophysical data allow the assumption that the Ala Dagh – Messerian zone (formerly defined as an autonomous swell) represents a western dipping part of the western Kopeh Dagh mountains, bordered by the Shordzha – Gekcha N-S trending fault. The zone contains both exposed and buried local folds that form an extended tectonic system. The following sub-zones can be distinguished, differentiated by their distribution of Pliocene structures: Shakhman; Ala Dagh – Messerian; and the dipping folds of the western Kopeh Dagh.

The Shakhman sub-zone corresponds to the synonymous Neogene-Quaternary N-S trending trough. It serves as a western boundary of the West Kopeh Dagh zone. The Ala Dagh – Messerian sub-zone includes a tectonic scarp located in the dipping part of the Mesozoic sequences of the West Kopeh Dagh and occupies an intermediate position between the West Kopeh Dagh and West Turkmen tectonic zones. Within the sub-zone, which is bounded by faults both on the west and east, Mesozoic deposits show general dip in a southwesterly direction. The sub-zone of dipping folds of the western Kopeh Dagh corresponds to the area where linear northward dipping structures of the synonymous folded orogene are replaced by brachyanticlines and synclines. All sub-zones are complicated by local structural elements.

The West Turkmen tectonic zone is a part of the eastern slope of the South Caspian depression. The structure of its pre-orogenic (Alpine) complex is virtually unknown so far. The tectonics of the Alpine orogenic (Pliocene-Quaternary) complex are better understood. The zone represents an area of intense Alpine subsidence and is composed of Mesozoic-Cenozoic sediments up to 20 km thick. Approximately 8 – 10 km of this sequence are represented by Pliocene-Quaternary sediments: lower Pliocene Productive red beds (3 – 4 km thick), Akchagylian regional stage (0.2 – 0.3 km), Apsheronian regional stage (1.5 – 2.0 km), and Quaternary sediments (1.5 – 2.0 km). The present-day structure of these sediments consists of extended zones of intricate folds in the peripheral near-slope part, with differently oriented dislocations of the inner depression, controlled at a regional scale by approximately N-S trending faults. The easternmost of them, the Zirik – Chad fault, separates the zone of Alpine folds of western Kopeh Dagh from structures dipping under a thin orogenic complex. The Shordzha – Gekcha fault serves as a boundary for the next scarp in a subsided pre-orogenic basement. Each zone separated by these faults is characterized by near-surface dislocations of different origin, reflecting the heterogeneous block structure of the entire zone.

A remarkable feature of its deep structure is mud volcanism. This is widespread along the peripheral near-slope area. The West Turkmen tectonic region is subdivided into the following zones on the basis of the structural differences of the orogenic complex and the surface topography of the Alpine basement: (1) Kubadag – Greater Balkhan mountainous-folded zone; (2) Kelkor; (3) Near-Balkhan; (4) Kyzylkum; (5) Gograndagh – Okarem; (6) zone of the Turkmen shelf of the southern Caspian Sea; (7) Chikishlyar – Gryaznovulkanicheskaya; and (8) the Fore-Alborz – Gorgan zone.

The Kubadag – Greater Balkhan tectonic zone represents a system of Mesozoic folds aligned in and approximately latitudinal direction and extending over a distance exceeding 250 km along the boundary between the epi-Hercynian platform and Alpine mobile belt. It fringes the West Turkmen zone in the north and is characterized by a block structure composed of heterogeneous tectonic elements . In the north and south, the zone is bordered by the North Kubadag – North Balkhan and South Balkhan regional faults, respectively. Three large blocks are distinguished in its structure: Kubadag; Dardzha; and Greater Balkhan blocks. The first block corresponds to the synonymous almost latitudinal uplift extending over a distance exceeding 60 km, from the eastern Caspian Sea shore to the Bakla-Ada Peninsula. The block section is lacking Permian-Triassic and Lower Jurassic portions, and Middle Jurassic layers rest immediately upon different volcanics and igneous rocks of the basement. The Dardzha block is located east of the Kubadag uplift, being separated from the latter by an approximately N-S trending fault. Its basement is encountered at a depth of 465 m in Borehole 179. Akchagylian sediments immediately overlie the basement. In the east, the Dardzha block is separated from the Greater Balkhan meganticline by the Belek-Koshoba fault, trending approximately N-S. This meganticline represents a large, intricate, asymmetrical, approximately latitudinal fold with a narrow, steep, frequently overturned northern limb, dipping at 40 – 60^o, and a wide lower-dipping (10 – 15^o) southern limb. The fold is 100 km long, at maximum 50 km wide and over 2 km high. Its arch consists of Middle Jurassic sediments and its limbs are of upper Jurassic to Neocomian sediments. The basement surface occurs at depths of 1.5 to 2.0 km in the axial part of the fold, up to 3.0 km in the north and over 5 km in the south. The total thickness of the Jurassic, Cretaceous and Paleogene sedimentary sequence exceeds 8 km, of which 5.5 km are represented by Middle-Upper Jurassic and the remaining 2.5 km by Cretaceous rocks.

The Kelkor tectonic zone corresponds to the synonymous trough that represents the eastern part of the larger almost latitudinal Kusary – Apsheron – Kelkor trough extending parallel to the Kubadag – Greater Balkhan zone.

With respect to its origin, the Kelkor trough can be related to superimposed structures. Its sedimentary fill of Neogene-Quaternary molasse sequences overlies a deeply eroded and heterogeneous surface of the Alpine pre-orogenic basement.

The Near-Balkhan tectonic zone also represents the eastern part of the larger Apsheron – Near-Balkhan zone of Pliocene folds that extends parallel to the Kusary – Kelkor zone, from southeastern spurs of the Greater Caucasus to northwestern Kopeh Dagh. The Turkmen part of the zone is over 250 km long and up to 30 km wide.

Local structures of the Turkmenian part of the zone are grouped into two sub-zones: a western (Livanova – Near-Cheleken) zone consisting of offshore, strictly northwest-trending structures; and an eastern (Cheleken – Kara-Tepe) zone uniting on-land folds with predominantly almost latitudinal or near-southwestern trends. The latter folds are distributed in an echelon-like manner and form a single zone with relatively elevated Pliocene strata. They are divided by longitudinal and transcurrent faults into several autonomous blocks differentiated by the depth of the base of their individual red-colored sequences.

All structures are characterized by steep (30 – 40^o) southern and relatively low-angle (15 – 20^o) northern limbs, with intense deformations in their arched portions, and mud volcanism. With depth, the deformation intensity in the arched parts of structures decreases. The base of the lower Pliocene sequence dips from east to west, from a depth of 1.5 km in the Kara-Tepe area to 4.5 km on the Livanova Bank.

The Kyzylkum zone is represented by a synonymous trough bounded by the Near-Balkhan zone of uplift in the north and the Gograndagh zone of uplift in the south. Widening as it opens westward, the trough grades into a deep depression filled with deposits of the orogenic complex. In the east, the zone borders structures of western Kopeh Dagh, separated by an approximately N-S trending fault. Geophysical data indicates that the zone has a very thick sedimentary cover of the order of 20 – 22 km, of which 8 – 10 km are represented by the orogenic complex. Local dislocations are distinguishable, forming almost latitudinal structural zones against the background of the regional dip. Unlike the Near-Balkhan and Kyzylkum zones, the Gograndagh – Okarem tectonic zone corresponds to a heterogeneous, approximately N-S trending block of the earth's crust. It is located between two almost parallel faults: (presumably) the Gograndagh – Okarem fault in the west and Gekcha – Shordzha fault in the east. The former separates the Gograndagh – Okarem zone from the Turkmen shelf of the southern Caspian Sea and the Gekcha – Shordzha fault separates the zone from western dipping structures of the Kopeh Dagh. Two tectonic stages are distinguishable in the zone structure: Neogene-Quaternary and Cretaceous-Paleogene. The westwardly step-wise subsidence of different blocks determines the formation of approximately N-S trending folds in the later (upper) stage. Structurally, the zone is very heterogeneous and comprises several local folds different in spatial position and formational settings. It is assumed that on-land structures composing the western part of the zone continue offshore under the shallow part of the sea. Three sub-zones with different structural patterns can be recognized in the zone-: the Gograndagh – Kamyshaldzha; the Okarem – Chikishlyar and the Bugdaily sub-zones. Fold axes are orientated with a northeastern strike in the Gograndagh – Kamyshaldzha sub-zone, and with a southeastern strike in the Okarem – Chikishlyar sub-zone. The Bugdaily sub-zone is mainly characterized by almost N-S trending structures.

13. SOUTH CASPIAN DEPRESSION

The South Caspian depression occupies a southern part of the N-S trending Caspian Sea megabasin, but is characterized by the approximately latitudinal orientation of the major elements of the whole structure. This observation emphasizes its active participation in the Alpine tectogenesis. In the north, it is bordered by structures of the Greater Caucasus, which dip eastward under the Caspian Sea and continue further into the Transcaspian region as the Greater Balkhan – Kopeh Dagh mountain system. In the south, the Alborz structures (the Talesh zone included) envelop the southeastern and eastern parts of the depression.

The South Caspian depression is an autonomous tectonic unit that consists of: the southern part of the Caspian Sea; the West Turkmen depression adjacent to the latter; the northern lowland periphery of the Alborz system; the Lower Kura trough; and the Apsheron – Kobystan trough.

In the earth's crustal structure, the South Caspian depression differs significantly from both the northern part of the Caspian Sea depression and also the surrounding mountain systems. The deep seismic soundings carried out in the South and, partly, Middle Caspian Sea and on the adjacent land revealed principal features of the deep structure in the region under consideration, which includes two different zones. The first is the northern area, with platform sedimentary complexes resting upon basement (V_p = 5.8 – 6.2 km/s). The second is in the south, where the sedimentary cover is underlain by oceanic crust with V_p = 6.5 – 7.8 km/s (Fig. 13). The base of the earth's crust corresponds to the sharp sub-horizontal seismic boundary (Moho discontinuity) with V_p = 8.0 – 8.4 km/s.

The crust beneath the South Caspian depression is two-layered and consists of the sedimentary cover up to 25 km thick and a "basaltic layer" 15 – 20 km thick (V_p = 6.6 – 6.7 km/s).

The South Caspian mega-depression corresponds to a gravitational minimum complicated by positive anomalies in its southeastern and southern parts. On the northeast and west, gravitational gradients related to deep-seated faults border the depression.

Two gravitational maximums are defined in the offshore areas of the depression: the Alov – Atatyurk maximum in the central deep-water part, and the large oval-shaped South Caspian maximum elongated in a northwestern direction. The magnetic field in these areas is substantially less intense (many times) compared with anomalies over the mountain structures surrounding the depression. This is a result of the significant thickness of its virtually non-magnetic sedimentary fill. The Alov – Atatyurk zone extends transversely in the Caucasian direction over a distance exceeding 150 km. According to seismic and gravity data, this zone is characterized by high-amplitude structures that correspond to gravitational maximums, indicating its inherited development of Mesozoic and Cenozoic structural elements. The northeastern continuation of the Mesozoic Alov – Atatyurk zone of uplifts is traceable in the South Karabogaz zone in the form of gravitational maximums and transcurrent faults. The Alov – Atatyurk zone separates the largest part the South Caspian deep basin from the Turkmen shelf. The zone played a decisive role in the distribution of sedimentary facies in the South Caspian Basin, and also in the formation of structures including the Turkmen terrace and offshore part of the Lower Kura depression. In addition, the Alov – Atatyurk zone of uplifts connects the Apsheron – Near-Balkhan anticlinal zone in the north and the "massif" located in the Fore-Alborz domain.

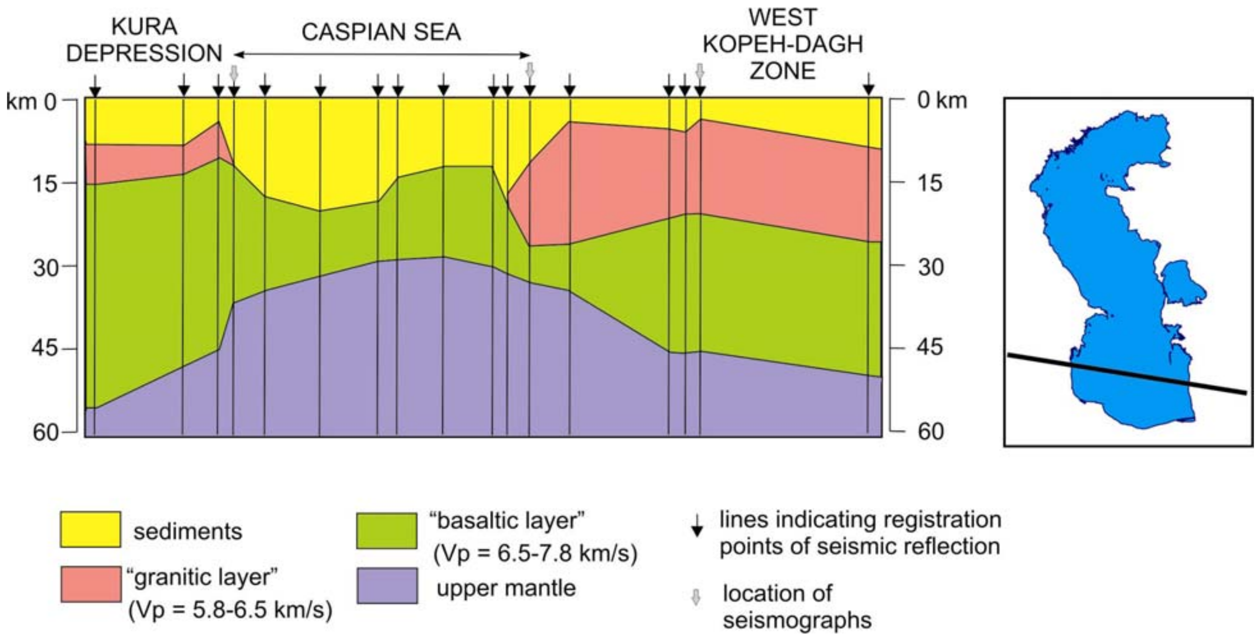


Fig. 13. Cross-section of the crust and upper mantle in the South Caspian depression (Jackson et al., 2002). The dashed line at depth level of 35 km denotes the approximate position of the Mohorovicic discontinuity (Moho). Inset shows profile location. (Yellow – Sediments; Red – "Granite" layer; Green – "Basaltic" layer; Purple – Upper Mantle; Arrows – Location of Seismic shot points and receivers).

The South Caspian depression is characterized by extremely thick Pliocene-Quaternary sediments as well as by neotectonic movements, mud volcanism and diapirism. A remarkable feature of the present-day South Caspian depression is the development of distinct structures in its peripheral part, in addition to those observed in inner areas of the depression. The peripheral zone is characterized by intensely deformed structures: upper and lower Pliocene sediments are exposed in arches of most local uplifts (Neft-Dashlary, Bulla, Cheleken, Nebit-Dag, and others) or locally completely eroded.

The Pliocene-Quaternary structural stage hosts several zones of uplift, tectonic scarps and troughs reflecting differences in the formation of structures in bordering zones: Kilyazi – Near-Kubadag; Apsheron – Near-Balkhan zone of uplifts; Apsheron – Kobystan and Lower Kura scarps; Turkmen scarp (terrace) and inner depression.

The Kilyazi – Near-Kubadag scarp represents an offshore continuation of the axial zone of the Greater Caucasus and is the most uplifted tectonic element of the southern Caspian Sea. This structure shows a decrease in thickness of Cenozoic sediments in the northeastern direction toward the Turan plate. The Cretaceous strata penetrated by boreholes at depths of 1,755 and 2,112 m (on the Apsheron-Kyupam and Gilyavar uplifts) dip in a southeasterly direction down to depths of 4,270 – 5,100 m (Agburun and Khazri uplifts) and further southeastward (toward Kubadag) the Mesozoic complex rises on a regional scale, with simultaneous reduction in the thickness of Pliocene and Oligocene-Miocene sediments. There, the lower Pliocene sequence comprises a spacious, extended, (up to 20 km wide and150 km long) slightly deformed zone of uplifts that dips eastward and incorporates several buried uplifts. Local structures of this zone are characterized by their small dimensions (5–10 x 2 km), low-angle slopes (up to 7 – 12^{o}), and echelon-like arrangement. They correspond to local gravitational maximums related to Mesozoic uplifts.

To the south, the Apsheron – Near-Balkhan zone of uplifts (Chilov – Neft-Dashlary – Gyuneshli – Chyrag – Azeri – Dayag – Livanova – Shenlik – Near-Cheleken dome) are aligned with a general Caucasian strike direction.

Widening westward, the Kilyazi – Near-Kubadag scarp involves southeastern terminations of the Terek – Caspian marginal trough, the axial zone of the Greater Caucasus, and the Apsheron folded region. It joins in an intricate manner the zone of the approximately N-S extending Apsheron – Kobystan gravitational minimum. The scarp is characterized by linear converging ridge-like anticlinal structures complicated by longitudinal and transcurrent faults, mud volcanoes and diapirs. As a whole, the zone is distinguishable as a deep trough in the basement and also as a zone of high-amplitude uplifts composed of the Miocene-Quaternary complex. A notable feature of local structures is their fan-like arrangement in the Upper Pliocene interval. The western part of the Apsheron – Near-Balkhan zone of uplifts is the most elevated, resulting in the arches of anticlinal structures being eroded so that Eocene-Miocene deposits are observed at the present-day surface. In the gravity field, most of anticlinal structures correspond to local minimums induced by diapirism, rock thinning, and other processes. Substantially less common are gravitational maximums corresponding to buried Mesozoic uplifts.

The Apsheron – Kobystan scarp is an offshore continuation of the synonymous tectonic element on-land. The South Apsheron Archipelago includes two large depressions: the

Dzheirankechmez and the Shakh – Gousan depressions. The Dzheirankechmez depression has an on-shore segment in its northwestern part that corresponds to the distribution of its hydrocarbon-productive sequence. The Shakh – Gousan depression is separated in its central part by the Gum-deniz – Bakhar – Shakh-deniz zone of uplifts. The latter shows the step-wise dip of the Pliocene folded complexes, probably related to Mesozoic transverse uplifts. The Sangachaly – Duvannyi – Bulla anticlinal zone continuing from the northwest separates the Apsheron – Kobystan and Lower Kura tectonic scarps. This area corresponds to the large Baku gravitational maximum that represents an offshore continuation of the on-land Yavandag – Sangachaly maximum. The Baku Archipelago is located in the junction area of the Apsheron – Kobystan and Lower Kura gravitational minimums.

The Lower Kura scarp comprises the zone of uplifts corresponding to the central and southern parts of the Baku Archipelago. The scarp is bordered on the southwest by the Talesh – Vandam gravitational maximum. According to drilling and seismic survey data, the thickness of lower Pliocene sediments decreases southwestward, as they progressively overlap different-age Mesozoic terrigenous-carbonate and volcanogenic strata. This volcanogenic material is reflected in the gravitational contours in the extreme southwestern part of the region.

The zone of the Turkmen shelf of the southern Caspian Sea (also known as the Turkmen structural terrace) is located west of the Gograndagh - Chikishlyar tectonic zone. The boundary between these two zones corresponds to a N-S trending band of sharp differences in the depths of occurrence of lower Pliocene sediments (that dip at an angle of 2 – 3^{o}). This N-S trending boundary band results from the presence of two faults, one of which coincides with the shoreline and another that passes (presumably) west of the South Ogurchinskii uplift. In its deep structure and degree of deformation, the Turkmen shelf zone sharply differs from the Gograndagh – Okarem shelf zone. The Gograndagh – Okarem shelf zone is characterized by large, approximately N–S trending structures, mud volcanoes and diapirs. The Turkmen shelf is marked by relatively low-amplitude folds of vague outlines and strike directions. These folds are complicated by rare disjunctive deformations and mud volcanoes. The zone is also characterized by the relatively elevated position of the basement surface and of all its sedimentary cover (Godina massif). The base of the Red-colored sequence occurs at depths of 6.0 – 6.5 km and the basement surface is as deep as 15 – 16 km. On the north and south, the zone is fringed by local structures with a northwestern strike.

The Chikishlyar – Gryaznovulkanicheskaya tectonic zone borders the Turkmen shelf on the south and is characterized by its strictly northwestern strike. It contains over 20 local structures that form mainly linear systems. Most distinct is the southern system known as the NIMGE swell. The latter complicates the northern slope of the Fore-Alborz – Gorgan trough. It is noteworthy that local structures of this zone are not expressed within the upper portion of the Quaternary sequence. With respect to their genesis, these structures include both inherited and cover folds. The zone is characterized by widespread development of disjunctive deformations. The base of the Red-colored sequence occurs at depth exceeding 6.0 km.

The Fore-Alborz – Gorgan tectonic zone extends along the northern slope of the Alborz meganticlinorium and corresponds to the Fore-Alborz – Gorgan trough. Seismic data shows a thickness of sedimentary cover of about 15 – 20 km and more. In a southern direction toward the slopes of the trough, it decreases to 5 – 10 km. The Fore-Alborz trough unites several genetically related second order troughs. They are (from west to east) the Mugan, Resht, and Mazandaran troughs. The Gorgan trough is the largest, and is bordered by the Kopeh Dagh spurs in the northeast and by the Nika ledge in the south. The Nika ledge forms with gently dipping slopes and pre-Devonian shales in its core. All of these troughs are complicated by folds oriented parallel to the Alborz meganticlinorium strike.

14. MAIN STAGES IN THE TECTONIC EVOLUTION OF THE CASPIAN SEA REGION

An intricate tectonic history of the Caspian Sea region can only be deciphered for the Late Proterozoic and younger eras because older rocks (assumed to occur only in its northernmost part) are unexposed and have not been penetrated by drilling.

The Late Proterozoic. According to widely accepted (although not undisputed) views, the Late Proterozoic was marked by the break-up of the Rodinia super-continent existing at that time. The East European platform (craton), known in paleogeographic publications as the Baltica continent, represents one of the Rodinia fragments. From seismic data, it can be interpreted that the southeastern margin of the East European platform formed the northern part of the region, including the North Caspian depression, Karpinsky Ridge, northern Ciscaucasia (the continuation of the Rostov ledge of the Ukrainian shield) and probably, the northern Ustyurt block. All other areas were probably part of the newly formed oceanic basin – the Proto-Tethys mobile belt. Rocks of corresponding age are exposed in the Mineral'nye Vody area of the southernmost Ciscaucasia and in the Dziruli massif of the Transcaucasian region. Two boreholes on the Karabogaz arch have also penetrated them. By analogy with Central Iran, the presence of rocks of this age is also assumed for the Alborz Mountains. Radiometric dates obtained for rocks of the Dziruli massif and basement of the Karabogaz arch correspond to the Vendian, i.e., to the period of the Proto-Tethys closure, which was accompanied by folding, metamorphism, and granitization. These events are part of the epoch of global tectogenesis known as Baikalian in this region, Cadomian in West Europe, and Panafrican in Africa and Arabia. It resulted in accretion of the northern part of the Gondwana mega-continent forming approximately at that time.

Oceanic crust could have been developed between the Gondwana and Baltica continents. A relict of oceanic crust is probably represented by the ophiolitic belt outlined by magnetic anomalies along the southern margin of the North Ustyurt block (Popkov et al., 1993). In the opinion of some researchers (Volozh et al., 1999), formation of the North Caspian depression (or more exactly, its “granite-free” central part) as a back-arc basin commenced as a result of rifting during this era.. This opinion is supported by the very thick pre-Middle Devonian deposits in the central part of the basin (interpreted from seismic data). These deposits presumably include Lower Paleozoic and even Upper Proterozoic rocks, although it is not inconceivable that they might be Middle Devonian synrift sediments. Another argument supporting a Riphean age for the depression is the continuation of the Pachelma aulacogen from the Russian plate to the North Caspian depression.

The Early Paleozoic. Data on the distribution of Lower Paleozoic deposits in the region are scarce and insufficient for adequate interpretation of concurrent tectonic developments. As mentioned earlier, sediments of this period are assumed to be present in the central part of the North Caspian basin. Southward, the continuation of the Sarmatian shield was probably sub-aerial. The Mineral’nye Vody area of the southern Ciscaucasia retains an outlier of the platform cover: a Silurian clayey sequence underlain by sandstones of presumably Ordovician age and enclosing conglomerates composed of limestone fragments containing fossils of Middle Cambrian age. The Transcaucasian region was probably characterized by a continental environment. In contrast, the Alborz system was accumulating marine carbonate – terrigenous sediments, commencing in the Vendian and continuing until the Middle Triassic, and forming a platform sedimentary cover common for this region and Central Iran.

Nevertheless, several important events could occur at this stage in the following two zones:

The first zone, the Frontal Ridge, extended across the Greater Caucasus and contains pre-Devonian and (probably) pre-Silurian (most likely Ordovician) ophiolites. It is assumed that this Ridge represents a continuation of the West European Rheicum basin, and is an expression of one of the Paleo-Tethys branches, and sutures related to its closure. The eastern continuation of this zone is traceable by magnetic anomalies along the Frontal Ridges of the eastern Caucasus and, on the other side of the Caspian Sea, along the northern periphery of the Karabogaz arch and in the Tuarkyr area.

The second zone is a southerly branch of the Paleo-Tethys that could have separated the Transcaucasian microcontinent from a similar epi-Baikalian microcontinent of Alborz and Central Iran, the former margin of Gondwana. Relicts of the crust underlying this basin are recorded in the Resht area of the extreme northwestern part of the Alborz system and in the Gorgan block south of the Turkmenistan – Iranian state boundary in the Transcaspian region. These relicts are undoubtedly pre-Devonian, although their precise age is so far unknown.

The Middle Paleozoic. In the Middle Devonian, the structure of the region was substantially reorganized. The most remarkable event of that period was the formation of a large intracontinental rift system in the southern margin of the Baltica continent. This rift extended from the Dnieper – Donets depression and Donets Basin via the Karpinsky Ridge to the Buzachi Peninsula and northern Mangyshlak and, according to some data (Volozh et al., 1975) even farther, into the Tuarkyr area. This system continued its development during the remainder of the Paleozoic and into Triassic times.

As with some aulacogens of the Russian plate, the North Caspian depression was subjected in the Middle Devonian to the next rifting phase, which is considered by some researchers to be the main or even the *only* rifting phase. From that time until the mid-Early Permian, the central part of the North Caspian depression represented a deep non-compensated basin, with limited deposits of siliceous – clayey sediments. This deep basin was surrounded on the southwest and southeast by the Astrakhan – Aktyubinsk zones of carbonate platforms. These platforms separated the depression from the Tugarakchan trough adjacent to the Turan plate.

In the second half of the Devonian, deposition of terrigenous sediments began in the central Ciscaucasia and on the Turan plate north and south of the Donets – Mangyshlak rift system, continuing in the latter rift system during Carboniferous and initial Permian times.

Meanwhile, in the Middle Devonian a volcanic arc appeared in the Greater Caucasus and terrigenous sediments started to accumulate in continental slope and rise settings of the marginal sea that separated the arc from the Transcaucasian microcontinent. This continental slope and rise were to become the future southern slope of the central segment the Greater Caucasus. Terrigenous sedimentation continued through Carboniferous, Permian and Triassic times. It is likely that this depositional basin extended to the Transcaspian region, which is evidenced from the occurrence of coeval sediments in the southern Kopeh Dagh of Iran (beyond the map boundaries). The southern basin of the Paleo-Tethys ocean might extend into this region as well, while the volcanic arc of the Greater Caucasus could continue as far as the Kara-Bogaz-Gol. The Alborz area still represented a Gondwana shelf margin during these times.

The Late Paleozoic to Triassic. New and drastic changes occurred in the region at the beginning of the second half of the Early Carboniferous (late Visean). This period corresponded to initiation of the orogenic phase in the Greater Caucasus, probably related to collision of the volcanic arc with the southern edge of the East European continent that became a constituent of the Laurussia super-continent. In the Late Paleozoic, the newly formed mountain system was marked by development of superimposed intermontane depressions filled with lower, Middle-Upper Carboniferous coal-bearing molasse, and upper, Permian rudaceous red-colored molasse. Simultaneously, marine sedimentation continued on the southern slope of the central Caucasus and in its eastern segment.

The Late Paleozoic orogeny also involved the Transcaucasian epi-Baikalian micro-continent, as is evidenced by formation of granitoid intrusions that resulted from subduction of the crust underlying the southern branch of the Paleo-Tethys ocean.

Important events occurred at this time in the northern half of the region. For instance, the rift of the Karpinsky Ridge and its Buzachi continuation underwent their first phase of tectonic inversion in the later stages of Artinskian times.

The Ciscaucasia and southwestern Turan plate were involved in orogenesis that advanced from the Greater Caucasus. It produced fold deformations and was accompanied by intrusions of granitoid plutons. As a result, the southeastern ledge of the East European platform appeared to be bordered in Kungurian times by a large mountain system that separated the East European platform from the Tethys. In the basin that occupied the present-day North Caspian depression the sea level fell under hot and arid climatic conditions. It subsequently filled with a thick salt sequence, fed by seawaters entering this restricted basin from the north via the Urals foredeep. Salt accumulation continued in the initial Permian.

During the remainder of the Permian and in the Triassic, the North Caspian depression was accumulating thick variegated detrital, mainly terrestrial sediments with interbeds of marine carbonates. Similar deposits were also deposited on the Scythian and Turan plates. The thick nature of these deposits is registered in the East Manych rift that formed south of the Karpinsky Ridge, in two lower-order rifts of the Ciscaucasia, and particularly in the Central Mangyshlak – Ustyurt zone of the Turan platform where sedimentary sequences also enclose various types of volcanic material.

The most intense Hercynian orogenic phase involved the present-day Main Ridge of the Greater Caucasus. Its sediments were subjected to amphibolite metamorphism and by several phases of intrusion of granitoid plutons. The eastern continuation of the Late Paleozoic volcanic arc of the Greater Caucasus can be seen in the Karabogaz arch where Middle Paleozoic and older rocks are also intruded by granitoid plutons and show signs of intense metamorphic alterations.

In the zone extending through Svanetiya, eastern Caucasus and Kopeh Dagh south of the Main Ridge of the central Caucasus, sedimentation continued almost throughout the entire Late Paleozoic and almost until the end of the Triassic. The Svanetiya basin probably represented a marginal sea of the Paleo-Tethys.

In the south, this basin is bordered by the Transcaucasian microcontinent where Upper Proterozoic-Lower Paleozoic (?) metamorphic rocks are overlain by a thin Carboniferous detrital-volcanogenic continental and shallow water marine deposits. In the east, this microcontinent could have included the so-called buried Godina massif in the Turkmen shelf of the southern Caspian Sea.

Farther southward, the central zone of the Lesser Caucasus and Iranian Kara-Dagh were probably occupied by the main basin of the Paleo-Tethys, with its eastern continuation in the Gorgan block and southern Kopeh Dagh of the Transcaspian region. It is not inconceivable that a continuation of the Svanetiya marginal sea joined this basin in the Kopeh Dagh region. Alternatively, the main basin of the Paleo-Tethys could diverge in the east into two branches separated by the Alborz microcontinent.

This stage of regional development was crowned with a major structural reorganization caused by the early Cimmerian orogenic phase. In the northern part of the region, this phase resulted in the following events:

- Final inversion of the rift in the Karpinsky Ridge area;
- Intense fold-thrust and strike-slip deformations and rise of the Central Mangyshlak – Ustyurt – Tuarkyr region;
- Closure of the Svanetiya basin as a result of collision of the Transcaucasian microcontinent with the southern margin of Eurasia that amalgamated the Main Ridge of the Greater Caucasus;
- Closure of the northern branch of the Paleo-Tethys main basin due to collision between the Alborz microplate and Transcaucasian microcontinent.

Deformations in the Donets – Mangyshlak intraplate rift system were probably repercussion of these collision processes. In the late Triassic, a marginal volcano-plutonic belt in the southern Ciscaucasia appeared, extending from the Dobrudja to Kubadag.

The Jurassic – Eocene. At the Triassic-Jurassic boundary, the entire region under consideration was subjected to desiccation and a break in sedimentation. This continued through the initial Jurassic period. Since that time, the northern half of the region developed as a platform (orthoplatform, after R.G. Garetskii). Its southern boundary crossed the Caspian Sea north of the Makhachkala – Turkmenbashi line, continuing in the Ciscaucasia and Transcaspian region. In Sinemurian times, the large Tethys marginal-sea basin began to form in the southern half of the region (the present-day Greater Caucasus and Kopeh Dagh areas). It developed through the entire Jurassic-Eocene period. The formation of this deep and at least 200 km wide basin commenced as a result of rifting. Its formation was undoubtedly accompanied by substantial destruction of the Late Paleozoic continental crust. The destruction degree remains debatable, however, and it is unclear, because of the absence of ophiolite exposures, whether the continental crust was ruptured completely and (as in the case of the Red Sea) replaced by oceanic crust.

At the initial stage of its development (Early-Middle Jurassic), the basin accumulated black shales with some volcanics. In the Middle Jurassic, transgression of this basin resulted in the accumulation of a thin sequence of shallow marine terrigenous sediments in formerly desiccated areas of the Ciscaucasia, North Caspian depression and Turan platform. In the Middle Jurassic, the northern slope of the basin was subjected to compression-related deformations accompanied by intrusion of small-scale granitoid plutons. These deformations resulted in the reduction of the deep-sea part of the basin and replacement of preponderant pelitic sedimentation by a similarly intense flysch deposition that continued until Eocene times. The flysch trough, occupying mainly the southern slope of the Greater Caucasus and both its western and eastern dipping parts, finds no continuation in the Transcaspian region where the basin was probably shallower. In Late Jurassic times, it was bordered on the north and south by barrier reefs with salt-accumulating lagoons behind them, the largest of which were located in the north, in the southern Ciscaucasia. The northern slope of the basin suffered a subsequent phase of compression-related deformations in the terminal Jurassic and mid-Cretaceous, which resulted in the formation of thick olistostromes on the northern slope of the southeastern Caucasus.

The eastern Ciscaucasia and western Turan regions accumulated shallow marine shelf sediments in Cretaceous and Paleogene times, with the Karabogaz arch remaining above sea level. The sediment composition was carbonate-terrigenous and then carbonate during the Early-Middle Cretaceous and carbonate-clayey in the Paleogene. Main structural elements developed under a slow, synsedimentary regime.

The Transcaucasian microcontinent was subjected in the terminal Early – initial Middle Jurassic to transgression accompanied by accumulation of a thin cover composed largely of terrigenous sediments. The Bajocian was marked there by the formation of a large volcanic arc, related undoubtedly to subduction of the basin located in the central part of the present-day Lesser Caucasus and inherited from the Paleo-Tethys. The rocks produced by this arc are exposed in the Mountainous Karabakh and drilled in the adjacent part of the Middle Kura depression. The intense volcanic activity continued throughout the Bathonian. During the remainder of the Jurassic, sporadic volcanic activity alternated with the development of reefal build-ups and the accumulation of shallow water marine detrital- pyroclastic sediments. In the Bajocian, the volcanic arc extended along the northern periphery of the Transcaucasian microcontinent, immediately adjacent to the flysch trough of the Greater Caucasus, to become the base for the barrier reef in Oxfordian–Tithonian times. The Albian-Cenomanian and then the Eocene were marked by new outbursts of volcanic activity, with the last one being of increased alkalinity (intra-arc rifting?). Island-arc volcanism in the Kura depression and northeastern slopes of the Lesser Caucasus continued until the mid-Senonian. Later on the entire territory was enveloped by an Upper Senonian carbonate formation. This was succeeded higher in the section by mainly marly sediments of Lower Paleogene age. The Lesser Caucasus volcanic arc extended in a southeasterly direction to the northern slope of the Alborz Mountains. Rifting within this volcanic arc in the Eocene was probably accompanied by intense alkaline basic volcanism, as it is evident in the Talesh area. Simultaneously, similarly intense volcanism of slightly different petrochemical composition was a characteristic of the southern slope of the Alborz system. Its origin (supra-subduction or riftogenic) remains debatable so far.

The Oligocene – <u>Quaternary</u>. In the latest stages of the Eocene, the Caucasian segment of the Alpine belt entered a new phase of development. Thick olistostromes formed on both slopes of the Greater and Lesser Caucasus and represent first evidence of the inversion and uplifting of this region. The regional uplifting first involved the Lesser Caucasus. Here the uplift was more rapid than that in the Greater Caucasus, which resulted in thick accumulation of Oligocene-Miocene rudaceous sequences in the southeastern dipping part of the Lesser Caucasus and in the Talesh area. Formation of the rudaceous sequence in this area reflects a coeval onset of the Alborz uplifting. In the central part of the Lesser Caucasus, these events were preceded by intense deformation that resulted in closure of the oceanic basin and obduction of early Senonian ophiolites onto both its slopes.

The Greater Caucasus experienced only a slight uplifting during the Oligocene, and also in the early-middle Miocene, with the formation of a small low-topography island in its central part. Simultaneously, three troughs formed in this region: the Terek – Caspian trough located north of this island initiated on the slope of the Scythian platform and two others (Kusary – Divichi and North Apsheron troughs) appeared southeast of the island. The last two troughs were separated by the Samur transverse uplift. Depocenters of the Kura depression shifted to its peripheral parts, toward the slopes of the Greater and Lesser Caucasus and Talesh.

The South Caspian depression as a single large structure undoubtedly formed as early as Oligocene times. This conclusion is drawn from the fact that the widespread mud diapirs and mud volcanoes in this region are rooted precisely within the Oligocene-Miocene clayey sequence.

In the late Miocene, collision processes in the Caucasus sharply intensified and involved the Transcaspian region. This collision was caused by separation of the Arabian lithospheric plate from the African plate and its rapid northward movement. One result of this activity was the replacement of fine-grained sedimentation by coarser deposits in troughs along the periphery of the Greater Caucasus. Other effects were the formation of the transverse Mineral'nye Voy – Stavropol uplift in the Ciscaucasia region and the shift of peripheral troughs of the Kura depression. As a consequence of the latter, the Saatly uplift subsided and all troughs co-joined into a single structure. Under the pressure of the Arabian plate movement, the Transcaucasian microplate was thrust under the Greater Caucasus, forming a system of thrusts and nappes on its southern slope that verge towards the Kura depression.

The Transcaspian region was subjected to similar processes, probably related to the "squeezing out" of the Central Iranian microplate and advancement of the Lut block in the east. These processes resulted in the formation of the Turkmen – Khorasan mountainous arc (with the Kopeh Dag at its apex) and of the Fore-Kopeh Dagh molasse trough. The Caspian Sea occupied a transitional position between the apexes of the Arabian and Lut indenters and N-S extending zones of uplifts. As a consequence, the Caspian Sea turned into a single subsidence system extending in the same N-S direction.

In the Miocene-Pliocene boundary period, approximately synchronously or slightly after the Messinian 'crisis' in the Mediterranean Sea (when the Mediterranean Sea dried up), this system (except for the central part of the South Caspian depression) was subjected to compete or almost complete desiccation. This was accompanied by erosion of significant portions of the Cenozoic and Mesozoic sequence in the North and Middle Caspian. The northern part of the depression is crossed by the N-S trending Paleo-Volga River valley, whose incision is seen in seismic sections crossing the Middle Caspian Basin. This valley reached the latitude of Derbent and terminated in the Apsheron Peninsula area with a wide delta as it emptied into the South Caspian lake basin.

In the early Pliocene the Paleo-Kura and Paleo-Amu-Darya rivers flowed into this basin on the west and east, respectively. These and smaller rivers deposited a thick (up to 5 – 6 km) sequence of sands and clays in the South Caspian depression and in troughs located along its periphery (Kusary – Divichi, North Apsheron, Apsheron – Kobystan, Lower Kura, West Turkmenian). This sequence of sediments are known as the Productive sequence in Azerbaijan and as the Red-colored sequence in Turkmenistan. Its large thickness indicates that mountain structures of the Caucasus and Transcaspian regions were rising at that time. The unconformable contact between the upper Pliocene-Akchagylian age rocks and older layers implies that the older rocks were subjected to deformation, most intense at the orogenic stage.

At the beginning of the late Pliocene, sea waters flooded into the formerly closed Caspian basin, resulting in an expansive Akchagylian transgression. This transgression spreads far beyond contours of the present-day Caspian Sea, particularly in the north. The source of these sea waters is unknown, but most likely they came from the Mediterranean Sea and penetrated the basin via Anatolia and the Lower Araks strait that existed at that time.

The Akchagylian sediments overly almost conformably the Productive (Red-colored) sequence and grade upwards into the Apsheronian sequence, considered to be of Pleistocene (Eopleistocene) age. They point to strong desalination of the Apsheronian basin and reduction of its dimensions. All these sediments were deformed in the Quaternary, although in the Lower Kura trough and South Caspian depression, deformation has continued virtually up to the present day (Akhmedbeili *et al.,* 1991, 1999; Kengerli, 1996). In the Lower Kura trough and South Caspian depression, Quaternary marine sediments built on the Pliocene section and their total thickness amounts to approximately 10 km.

Flat areas of the Ciscaucasia and Turan plate have also been subjected, although slightly, to recent deformations. In the Ciscaucasia, this deformation reflects movements of basement blocks along WNW and NE trending faults (Kas'yanova, 1998).

The origin and age of the South Caspian depression. With its many peculiar features, the South Caspian depression is a unique structure. Its sedimentary fill amounts to 25 km and only low heat flow explains an absence of metamorphism in the lower part of the section. The sedimentary sequence is complicated by much mud diapirism and mud volcanism. The depression is underlain by basement with velocities of longitudinal seismic waves characteristic of the second layer of the oceanic crust and characterized by a lineation that fits into the linear structure of the Alpine – Himalayan belt. Several hypotheses were put forward since the 1960 – 1970s to explain all these facts. We will not dwell here on those hypotheses that consider the depression history from a fixism standpoint. They are discussed in an article by Berberian (1983). Some other possible scenarios proposed to explain the formation of the South Caspian depression were considered in several articles (Lebedev *et al*., 1987; Artyushkov, 1993; Artyushkov *et al.,* 2000). Nevertheless, even from a mobilistic viewpoint, its origin and age are still not unambiguously explained. Only the last stage of depression development (since the Oligocene) and its present-day geodynamics are sufficiently clear.

As mentioned previously, the structure of the Caspian Sea megabasin has acquired its N-S trend since the late Miocene, i.e. 10 Ma ago. This is usually ascribed to the commencement of rapid northward movement of the Arabian plate, a fragment of the African continent, which played the role of an indenter intruding the Mediterranean mobile belt. The Lut block that separated from the Central Iranian plate as early as in the Cretaceous and also moved northward played the role of another indenter. Its pressure resulted in formation of an arcuate structure of the Turkmen – Khorasan mountain system with the Kopeh Dagh in its northern part. The South Caspian depression appears to have been sandwiched between these two indenters, being separated from them by the dextral West Caspian and sinistral East Caspian strike-slip faults. In as much as the depression represented a deep-sea basin by that time, it was rapidly filling with detrital material derived from the surrounding rising folded structures. This process accelerated sharply since the Pliocene (5 Ma ago) with the sedimentation rate exceeded 2,000 m per million years.

During the Oligocene-Miocene, the South Caspian depression accumulated only clayey sediments. These sediments, including the deepest, the Maikop Group, give birth to mud diapirs and mud volcanoes. These are caused by anomalously high formation pressures. The clays are characterized by their high content of organic matter, which is responsible in turn for the generation of large hydrocarbon deposits that have accumulated within sands in the shallower Pliocene formations. By the Oligocene, the basement probably acquired its present-day structural style.

Thus, although the base of the Oligocene sequence occurring at depths of 8 – 14 km marks the upper age limit of deep-sea basin formation, the base of the Jurassic deposits associated with termination of the early Cimmerian orogeny should be considered as representing its lower limit. This boundary is of substantial importance for the history of the region. It resulted in the formation of a continuous continental crust beneath the region from the southern boundary of the East European craton to the Meso-Tethys oceanic basin in the central part of the Lesser Caucasus. This basin also extended southeastward along the Talesh periphery and southern slope of the western Alborz Mountains. In the Jurassic-Eocene time interval, a system of ensialic volcanic arcs that formed above the northward-dipping subduction zone existed in the southern foothills of the Greater Caucasus, in the Kura depression, the northern part of the Lesser Caucasus, in the Alborz and in the Talesh mountains. The oceanic lithosphere of the Meso-Tethys was thrust in this system under the Transcaucasian microcontinent, the Alborz and Talesh Mountains included. Following Berberian (1983) and Zonenshain and Le Pichon (1986), we may assume that rifting or, probably, spreading that resulted in formation of the South Caspian basin could occur immediately in the back of the Lesser Caucasus – Alborz volcanic arc. This assumption is supported by analogy with the Black Sea basin, which formed in the back of the Pontides volcanic arc – itself a continuation of the Alborz volcanic arc. The formation of the South Caspian Basin could have started in the Bajocian simultaneously with the onset of the Lesser Caucasus arc and Kakhetiya – Vandam zone system. Assuming that a hypothetical branch of this system could extend along the Greater Caucasus piedmonts, it can be assumed that rifting (± spreading, see below) could be of intra-arc character.

The Greater Caucasus – Kopeh Dagh marginal sea basin was actively developing at about the same time. This basin initiated in the Early Jurassic (Sinemurian) as a result of rifting between the Transcaucasian microcontinent and the Eurasian plate (which already included the Scythian – Turan plate at that time) and extended to the northern part of the present-day South Caspian Basin. Such a situation existed until the Early Senonian when the Central Iranian micro-continent collided with the southern margin of Eurasia in the Lesser Caucasus and northwestern Iran. This collision stopped extension in the present-day South Caspian Basin and its western periphery. The extension resumed in the Eocene, although in a substantially different geodynamic setting. After closure of the Meso-Tethys in the Early Senonian, the role of the main (and only) Tethyan branch passed to the southerly basin (Neo-Tethys), extending along the High Zagros Mountains. Its lithosphere subducted northward under Central Iran, where a volcanic arc existed. The Alborz, Talesh, and southern part of the Lesser Caucasus systems that were located behind this arc were marked by development of intense alkaline – basaltic riftogenic volcanism, indicating the onset of a new phase of rifting in the South Caspian region.

It is noted that all the aforementioned processes (subduction, volcanism, rifting) involved neither the eastern half of the Alborz mountain system nor the eastern slope and eastern fringes of the Southern Caspian Basin, the Turkmen shelf included. The Turkmen shelf is underlain by the so-called Godina massif, a block of continental crust overlain, according to some assumptions, by Paleogene sediments. No manifestations of post-Triassic magmatism are recorded in this shelf area and its sediments are exclusively epicontinental. The Jurassic-Eocene flysch complex, widespread in the Greater Caucasus, is missing even in the northerly-located Kopeh Dagh Mountains.Tthe Lesser Caucasus – Iranian Kara-Dagh ophiolitic belt is untraceable eastward, which could point to degradation of the Meso-Tethys in this region. Its western boundary is represented by a large fault separating the central part of the South Caspian depression from the buried Godina massif where the elevated continental basement was not subjected to substantial destruction. Rifting that resulted in formation of the South Caspian depression did not extend beyond the latter.

Seismic velocities in the uppermost part of the basement in the South Caspian depression correspond to those in the topmost oceanic crust, although the considerable thickness (15 – 20 km) makes this crust different from a typical oceanic one. It is known, however, that the crust of the Caribbean Sea is of a similar thickness. It is characteristic of blocks of oceanic crust that formed as a result of both normal spreading and plume magmatism. It is therefore possible that the basement of the South Caspian depression is a typical oceanic crust. Nevertheless, another interpretation is also possible. It was shown recently that passive margins, particularly those in the Atlantic Ocean, are underlain by a transition-type crust that represents a continental crust thinned in the course of rifting, intruded by abundant dolerite dykes and frequently overlain by flows of tholeiites, close (but not identical) in composition to MORB-varieties. The width of zones with such crust can be as much as 100 – 150 km, i.e., their doubled pre-spreading width could be 200 – 300 km, which is comparable with the diameter of the South Caspian depression, and it may be more correct to term this type of crust as oceanic. Consequently, the basement of the South Caspian depression can be classed with either oceanic or sub-oceanic crust. A similar dilemma also concerns the origin of the basement beneath the East Black Sea basin as well as the crust that underlays the Jurassic-Eocene marginal sea basin of the Greater Caucasus.

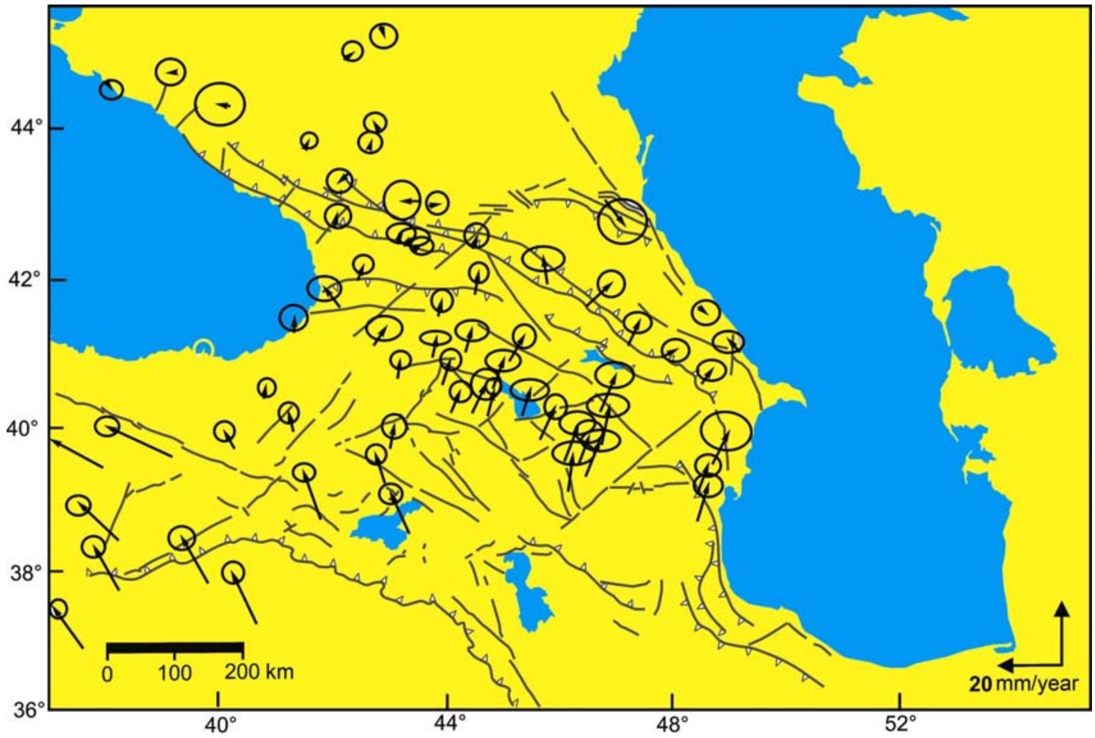


Fig. 14. Rates of horizontal movements and ellipses of their 95% confidence probability based on GPS measurements in the Caucasus and Caspian regions in the period of 1998 – 2000. (Eurasian coordinate system) (Guliev *et al*., 2002).

Recently, seismic activity (earthquakes) continues along the entire periphery of the South Caspian depression, being most intense along the Apsheron sill. GPS measurements (Guliev *et al.,* 2002) indicate that the northern periphery of the Arabian plate is continuing to move northeastward at a speed of 10 – 12 mm/year (Fig. 14). Based on the distribution of earthquake foci in the Apsheron sill area where they are registered at depth of 110 km, it was assumed long ago that the South Caspian microplate is accompanied by a present-day subduction zone (Khalilov *et al.,* 1987). This was confirmed by recent data (Khalilov, 2003). As is evident from the Rachinskoe earthquake in 1991, this subduction zone appears to continue along the southern slope of the Greater Caucasus. It is assumed that this subduction initiated 5.5 Ma ago (Allen *et al.,* 2002), probably due to the commencement of the rapid northward motion of the Arabian plate. It is not inconceivable, however, that this can be related to activation of an older subduction zone.

Mud diapirism and mud volcanism have also been intense. As noted in the special Internet-version of the geological bulletin of the *Geological Institute, the National Academy of Sciences of Azerbaijan* the beginning of the new millennium was marked by a sharp intensification of these processes. At present, the most active are the Lokbatan and Keireki mud volcanoes in the Apsheron Peninsula and the Shikhzagirli mud volcano in central Kobystan. A powerful eruption of the Lokbatan mud volcano located 18 km southwest of Baku occurred on October 24, 2001. It lasted 25 - 30 minutes. An associated erupted gas mixture ignited almost immediately and the flare column was as high as 30 – 45 m (Fig. 15). The volcano ejected a large volume of mud breccia, which contained fragments of deep-occurring oil-bearing rocks of Oligocene-Miocene age. A similar eruption of this volcano occurred in 1977 when it is estimated that up to 150 thousand m^3 of mud breccia and up to 30 million m^3 of natural gas were expelled.

On March 2001, an intense underwater eruption occurred in the Buzovninskaya Sopka mud volcano located 4 km north of the Apsheron Peninsula coast. This eruption resulted in the formation of a small island. Scientists from the *Laboratory of Mud Volcanism, Geological Institute of the Azerbaijan National Academy of Sciences* could observe remnants of this island some time later (Fig. 16). Residents of the coast observed bright flashes that accompanied volcanic eruption. An intense eruption of the Keireki mud volcano, although not accompanied by gas blowouts, occurred in June of the same year when flows of mud breccia up to 200 m long and 2 m thick appeared on the slope of the cone (Fig. 17). Signs of eruptions were recorded in 2001 in many other volcanoes as well. A detailed analysis of mud volcano relationships with tectonic faults, diapir folds and hydrocarbon deposits has recently been carried out by Kholodov (2002a, b).

In summing up all of this material, the following conclusions can be drawn for the South Caspian depression:

- The South Caspian depression is underlain by oceanic or sub-oceanic crust;
- The depression probably initiated in the Bajocian as a result of back-arc rifting that subsequently graded into small-scale spreading;
- After a break in Senonian-Paleocene times, this process probably reactivated in the Eocene;

Fig. 15. Burning gas in the Lokbatan mud volcano (Apsheron Peninsula, October 2001).

Photos (Figs. 15 – 17) taken by specialists from the Laboratory of the Mud Volcanism of the Institute of Geology, Azerbaijan National Academy of Sciences (Dr. Adil Aliev, head of the laboratory) are published due to the courtesy of I.S. Guliev.

Fig. 16. Remnants of the newly formed island in the eruption area of the underwater Buzovninskaya Sopka mud volcano (March 2001).

Fig. 17. Mud breccia flows at the slopes of the Keireki mud volcano (Apsheron Peninsula, Binagadi Village outskirts, June 2001).

- In the Oligocene, the depression entered a new phase of development when it was subjected, in addition to isostatic subsidence, to compression in the N-S direction, and thrusting under the continental crust of the Middle Caspian depression, a process that probably continues to the present day.

15. HYDROCARBON-BEARING POTENTIAL: NORTH CASPIAN BASIN AND NORTHERN CASPIAN SEA

With respect to its geology, the Caspian Sea and its on-land fringing areas are well studied. The region contains three established hydrocarbon-bearing sedimentary basins: North Caspian, Middle Caspian and South Caspian basins. Exploration for oil and gas has been carried out in this region over several decades, so far resulting in the discovery of over 200 separate hydrocarbon fields. Hydrocarbon accumulations are known to occur over a wide stratigraphic range within the sedimentary cover, but their number and volumes are irregularly distributed throughout the section (Alikhanov, 1964, 1977, 1978; Trukhachev, 1976; Ali-Zade *et al.,* 1985; *Atlas neftegazonosnykh…,* 1987; *Neftyanye i gazovye…,* 1987; Volozh *et al.,* 1989; Zolotov *et al.,* 1989; Corner *et al.,* 1993; Ismagilov *et al.,* 1999; Fedorov *et al.,* 2000; Voronin, 2001, *Barde et al.,* 2002; Lebedev, 2002).

More than 30 oil and gas accumulations are defined along the Kazakh coast of the Caspian Sea (Fig. 18). All of them are confined to large structural on-land elements continuing, in most cases, offshore. The accumulations are part of the North Caspian hydrocarbon-bearing province and are specifically within two more localized hydrocarbon-bearing regions: North Ustyurt – Buzachi and South Mangyshlak – Ustyurt.

Almost all oil and gas accumulations are confined to the large positive structural elements – anticlinal zones, uplifts, meganticlines, and scarps – adjacent to various long-developing negative structures – troughs, depressions, grabens and synclines.

The wide stratigraphic range of oil and gas accumulation is characteristic of the North Caspian basin. These accumulations occur in Upper Devonian, Lower-Middle Carboniferous, Triassic, Jurassic, Cretaceous and Paleogene formations. A unique feature of this region are local traps within the pre-Kungurian carbonate sequence of the Tengiz – Kashagan (Maritime) carbonate platform that forms a continuous reservoir interval spanning from the Famennian Stage of the Upper Devonian to Bashkirian Stage of the Carboniferous.

The wide stratigraphic range of oil and gas accumulations in supra-salt deposits such as the Pustynnoe, Terenozek Zapadnyi, Korolevskoe, Tazhigali, Tazhigali Yugo-Zapadnoe,

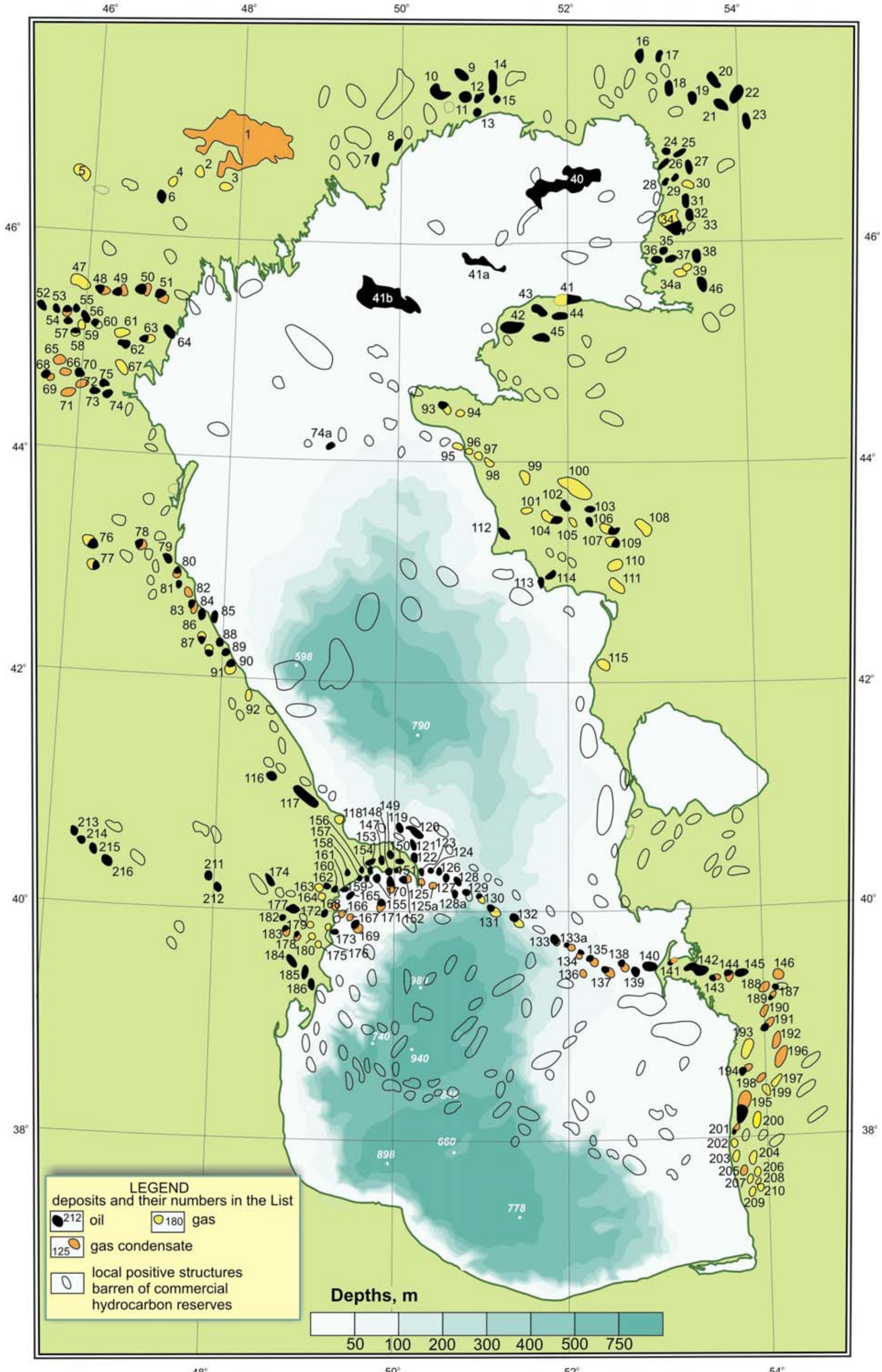

LEGEND
deposits and their numbers in the List
212 oil
180 gas
125 gas condensate
local positive structures barren of commercial hydrocarbon reserves
Depths, m
50 100 200 300 400 500 750

Fig. 18

Fig. 18. Distribution of hydrocarbon accumulations in the Caspian region. For the list of accumulations, see Appendix 1.

Karaton-Koshkimbet, Pribrezhnoe, and Karaarna fields indicates the importance of vertical hydrocarbon migration on their formation. These deposits show oil pools even in the Cenomanian Stage of the Upper Cretaceous, which is atypical of other deposits of the North Caspian basin.

Hydrocarbon accumulations of the Buzachi uplift are confined to its northern part and arch. The distribution of the arch-related accumulations is distinctly related to the almost latitudinal Karazhanbas – Zhamanorpin fault system. One of the most important features of the sedimentary section in the Buzachi uplift is an absence of salt-bearing members. In this style, structures and traps are different to those in the North Caspian basin and the stratigraphic range of the reservoir formations is narrower.

Large oil accumulations are capped by the widespread clayey sequence of the Aptian Stage and locally developed clayey members in the Jurassic and Neocomian sequences. All known deposits are confined to latitudinal and almost latitudinal anticlinal and brachyanticlinal folds variably complicated by tectonic fractures. Fields usually consist of several reservoir layers. The stratigraphic range of the reservoir formations spans from rocks of Middle Jurassic to Lower Cretaceous age. These general characteristics of the distribution of hydrocarbon accumulations provide guidelines for the prognosis of the hydrocarbon-bearing potential of other offshore structural – tectonic zones of the Caspian Sea.

The North Caspian depression (offshore part). Several zones of oil and gas accumulation are defined within the Paleozoic and Mesozoic parts of the section in the southern portion of the North Caspian depression. Their presence was originally established and studied on land and they have distinct offshore continuations. These are, first of all, the Palaeozoic reservoirs in the Tengiz – Kashagan and North Caspian zones and the Cenozoic reservoirs of the Zhambai – Zaburunskaya, Martyshinskaya, Karaton – Tengiz, and Prorva zones.

Most promising among them with respect to oil and gas reserves is the *Tengiz – Kashagan zone*. According to marine seismic surveys, this zone of thick Famennian – Bashkirian carbonate reservoirs is capped by sealing rocks represented by the Lower Permian argillite and Famennian – Bashkirian salt sequences, similar to those studied on land. The carbonates are assumed to have good porosity and permeability properties where they occur within the localized structures of this zone.

Available data on the geology, reserves and production potential of the giant Kashagan discovery indicate that the other local structures of this zone will have similar geological and reservoir properties.

In geological parameters and hydrocarbon-bearing potential, various supra-salt formations can differ substantially from each other. They do not represent classical large positive structural elements (uplifts, anticlines, arches, swells, and others) and their boundaries are to a significant extent conditional on the nature of the underlying salt diapirism. Consequently, there tends to be an aerial confinement of these zones and only a weak connection with the structure of deeper sequences of the sedimentary cover.

The Karaton-Tengiz oil/gas-bearing zone. In this zone, several on-land deposits of mainly heavy oils formed by hydrocarbon migration from Paleozoic sediments are confined to salt-dome structures. Because of the specific type of traps confined to salt domes, the critical factor in the control of oil and gas distribution through the section of the Karaton – Tengiz zone is the presence or otherwise of the regional and local clayey rock seals overlying the reservoirs. These sealing clay zones are widespread in the Triassic, Middle and Upper Jurassic and Lower Cretaceous sequences. It is suggested that oil deposits might be discovered in the offshore part of the Karaton-Tengiz zone, sourced from hydrocarbons generated in the Paleozoic section. It is also suggested that oil accumulations can be expected in upper parts of the section (up to the Paleogene) above intensely developed salt diapirs that penetrate through the Triassic–Jurassic–Cretaceous sections. In zones with less intensely developed salt diapirs that terminate in the Triassic sediments, oil accumulations are most probable in the Triassic and Jurassic portions of the section.

The Prorva hydrocarbon-bearing zone differs substantially from the previous one. Judging from geochemical data, formation of the Prorva group of deposits is related to a different oil-generating source. In this zone, traps are confined to poorly developed salt-diapir structures that are referred to in the category of "deeply buried" salt domes. In such features, local structures are less tectonically disturbed than with conventional salt diapirs. They are further characterized by their brachyanticlinal shapes, and by their significantly larger dimensions than those found in typical salt diapiric structures. These large dimensions, coupled with high porosities, can accommodate substantial accumulations of hydrocarbons. The Prorva zone is characterized by the widely developed regional Callovian-Oxfordian rock that acts as a seal for oil and gas accumulations in reservoirs of the Callovian Stage of the Middle Jurassic. Other accumulations are sealed by rocks within the Middle Jurassic and Triassic. On land, this zone is characterized by the increase in gas content in a NE-SW direction as it dips and deepens toward the Caspian Sea.

In all aspects of its potential for accumulation of hydrocarbons, the supra-salt formations in the Prorva zone are amongst the most promising areas in the northern offshore part of the Caspian depression.

The Martyshinskaya zone is studied in detail on land where it represents one of the important areas of oil production. The area of its assumed offshore part is significantly smaller than the land part. The zone is known to contain mainly oil deposits; free gas in the form of small gas-caps is noted only in two accumulations.

All land deposits are confined to salt dome structures except for the Novobogatinskoe Yugo-Vostochnoe fields that occur within the Triassic sequence under the salt seal. The Yugo-Vostochnoe field is virtually the only fully explored and developed field in the North Caspian depression, and it is assumed that hydrocarbon accumulations are likely in other traps of a similar type.

Geological parameters in the offshore part of this zone are expected to be similar to those on land and thus discovery of additional oil accumulations is highly probable.

The Zhambai – Zaburunskaya zone in its land part is predominantly oil-bearing, although gas is noted as a component in the Oktyabr'skoe and Zaburunskoe accumulations. In its geological properties, the supra-salt complex in the land and offshore part of the zone are similar.

In summarizing the hydrocarbon-bearing potential of the northern part of the Caspian Sea as a whole, it is emphasized that this zone is amongst the most promising for the discovery of additional accumulations of hydrocarbons, particularly in the pre-Kungurian Paleozoic formations and in the supra-salt complex. It is characterized by many favorable features such as occurrence of different-style structures, reservoirs with sufficient-to-high porosity and permeability, good sealing rocks and proven oil and gas accumulations.

16. HYDROCARBON-BEARING POTENTIAL: MIDDLE CASPIAN BASIN

Three oil fields have so far been discovered in the offshore part of the Caspian depression (Fig. 18). One of them, the Inchkhe-more deposit, is located near the Dagestan coast. It has oil reserves of up to 10 million tonnes in reservoirs of the Chokrakian sequence. The Skalistoe-more discovery in Aptian-age reservoirs is near the eastern coast on the continuation of the Beke-Beshkuduk swell in the Mangyshlak zone of uplifts. In the Khvalynskoe accumulation, the reservoirs are of Jurassic and Cretaceous age. Other deposits occur in the Scythian and Turan plates and in the Terek – Caspian trough (areas adjacent to the western and eastern Caspian Sea).

The map (Fig. 18) shows the locations of 66 discoveries, in areas mostly close to the sea. In the Scythian plate, they are confined to the Karpinsky Ridge, East Manych trough, and Kuma – Tyulenii zone of uplifts where hydrocarbon-bearing formations are found within, variously, the Triassic, Jurassic and Cretaceous portions of the section. Oil accumulations occur most frequently within Lower Cretaceous rocks. In the Terek – Caspian trough, oil and gas deposits are found in Jurassic, Cretaceous, Paleogene and Neogene formations (Mirzoev and Sharafutdinov, 1986; Mirzoev and Pirbudagov, 2001). In the Turan plate, deposits have been discovered in the Mangyshlak zone of uplifts, in the South Mangyshlak system of troughs and in the Middle Caspian arc where they occur within Triassic, Jurassic, Lower and, less commonly, Upper Cretaceous sequences. Unlike the western fringes of the Middle Caspian, the most hydrocarbon accumulations occur within Middle Jurassic sand formations. The hydrocarbon prospectivity of the Middle Caspian depression is currently high because many of its structures have yet to be drilled.

Analytical methods. The oil and gas reserves of sedimentation basins in the Caspian Sea region have been repeatedly assessed. The estimates have mostly been based on an analysis of the geological – geophysical information that defines the occurrence of local uplifts in the offshore areas, the availability of reservoirs and rock seals, the similarity in the geological structure with other regions where accumulations have already been discovered, and other prerequisites that are usually used for the assessment of regional hydrocarbon prospectively. In this section, we assess the hydrocarbon-bearing prospects of the Mesozoic-Cenozoic section using the genetic method elaborated specifically for offshore areas (Geodekyan et al., 1980; Trotsyuk, 1982; *Neftegazogeneticheskie issledovaniya*…, 1984). The essence of the method is the successive solution of the following tasks:

- The study and quantitative assessment of a system of parameters characterizing geological-geochemical processes responsible for the generation of oil and gas in offshore sedimentary basins;

- Mapping of the hydrocarbon generating potential of deep horizons in the offshore areas, coupled with outlining the most promising trapping structures with respect to their oil and gas reserves.

In practice, the assessment procedure is further subdivided into several operations. The first of these includes the geological study of sedimentary cover in the region with the compilation of isopach and lithofacies maps, as well as paleogeographic, structural, and paleostructural maps for separate lithological-stratigraphic complexes. All available geological, geophysical and geochemical data represent the factual base for this stage. The second group of operations is connected with defining oil-generating formations within the sedimentary sequence and prediction of their lateral distribution. This work is coupled with in the compilation of maps demonstrating the distribution of organic matter (OM) content and types. This is followed by an assessment of the degree of heating (maturation) of the oil-generating formations in different parts of the basin with compilation of maps showing distribution of temperatures (paleotemperatures) at the top or base of the defined oil-generating formations. The final stage is to identify regions of oil- and gas-generation. This operation is performed by comparing maps of OM type and content distribution with maps of temperatures characterizing relevant lithological – stratigraphic sequences. In line with available concepts of zoning the oil- and gas-generating processes, several categories of hydrocarbon-generating zones have been defined (Table 1).

Table 1. Temperature characteristic of hydrocarbon generation zones

Kerogen type	Temp ^{o}C	Generation zones
III	70-180	Low-temperature gas generation
II	70-155	Initial oil generation
	135-180	Complete oil generation
II - III	70-135	Initial oil and gas generation
	135-180	Complete oil and gas generation
II – III with prevalent III	70-135	Initial oil and gas generation
	135-180	Complete oil and gas generation
III – II with prevalent II	70-135	Initial gas and oil generation
	135-180	Complete gas and oil generation
Any	180-220	Initial high-temperature gas generation
	>220	Complete high-temperature gas generation

The comparison of defined oil- and gas-generation areas with the other prerequisites for the accumulation and entrapment of hydrocarbons, as well as up-to-date information on discoveries of oil and gas deposits leads to further exploration planning.

Extensive drilling data obtained from land areas fringing the Middle Caspian basin, coupled with geophysical data from its offshore parts and abundant data on organic geochemistry of the Mesozoic-Cenozoic sedimentary cover beneath the entire Caspian Sea floor has made it possible to outline and trace separate oil- and gas-generating sequences, which are believed to provide the hydrocarbons for the main accumulations. These are the Bajocian-Bathonian (Middle Jurassic), Albian-Aptian (Lower Cretaceous), Oligocene-Miocene (Maikop) terrigenous lithological-stratigraphic complexes that are characterized by wide lateral distribution, significant thickness, and relatively high OM content. Lithological - paleogeographic maps coupled with isopach maps that characterize sedimentation settings and specifics of their organic matter have been compiled for each of these source-rock complexes, as well as structural maps for their top and base.

Distribution of organic matter. Two (extrapolation and modeling) methods were used to predict distribution of oil-generating formations. Extrapolation includes standard statistical operations with numerous geological – geochemical data from the surrounding land that were collected over many years. Average concentrations of organic carbon (C_{org}) were calculated, along with determination of kerogen type for every seismostratigraphic sequence within each separate structural zone. Extrapolation of these data to offshore areas has certain limitations.

This is a reasonable approach when seismostratigraphic data and data from offshore drilling reveal similar thicknesses and lithology within a single structural zone both on land and in its offshore continuation. However, when these parameters are different, the method of computational modeling (Trotsyuk and Marina, 1982) is used in un-drilled areas.

This modeling approach takes into consideration the combined influence of several geological parameters on the organic matter content: geomorphological and morphostructural setting of the region in question, age and lithology, sedimentation rates. The prognosis of the prevalent organic matter genetic type for each and every stratigraphic unit was based on combined analysis of the following data: calculated average sedimentation rates, seismostratigraphic characteristics of the sequence and predicted C_{org} concentration. Using this method, distribution maps of organic matter contents and types were compiled for three lithological–stratigraphic complexes defined as ‘oil generating’.

The Bajocian – Bathonian complex. Average C_{org} concentrations in the Bajocian-Bathonian complex range typically from 1 to 2%, values that are characteristic for most of the region under consideration. Only two local areas in the Kuma – Tyulenii zone of uplifts and eastern periphery of the Karabogaz arch show higher C_{org} concentrations, amounting to 3% and higher (Fig. 19). In addition to the areas mentioned immediately above, there are a further six small localities with average C_{org} content exceeding 2% in the Middle Caspian region: the subsided Karpinsky Ridge, the Yalama – Samur uplift, the northern flank of the Greater Caucasus, the southern flank of the Mangyshlak zone of uplifts, the western limb of the Karabogaz arch, and the Buzachi uplift that is only partly within the Middle Caspian region. The prognosis of local zones enriched in C_{org} is hampered because of the lack of drilling data and insufficient seismostratigraphic information. A low content of organic matter (0.5 to 1%) is characteristic of the flysch formations in the southeastern continuation of the Greater Caucasus.

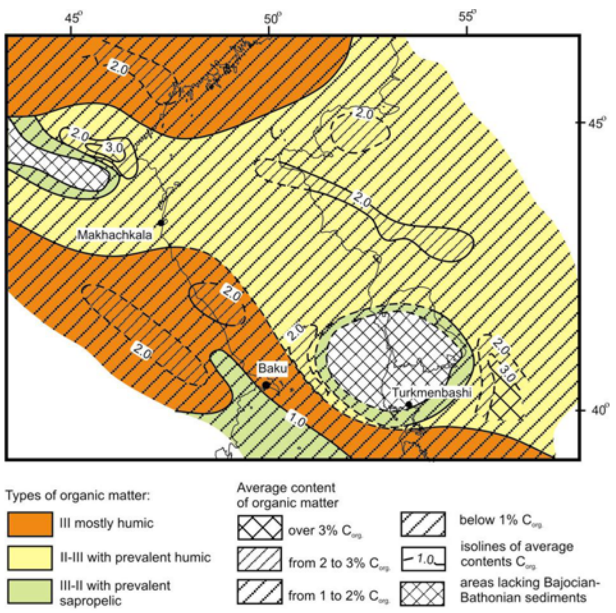


Fig. 19. Distribution of concentrations and types of organic matter in the Bajocian-Bathonian complex.

Three kerogen types are distinguished in the region: (1) mixed, with a prevalence of sapropelic (III – II); (2) mixed, with a prevalence of humic (II – III); and (3) mostly humic (III) organic matter. In Bajocian-Bathonian time, over 50% of the mapped territory represented a low-lying plain that was intermittently flooded by sea and accumulated marine - terrigenous sediments alternating with continental coal-bearing facies (Bagir-Zade *et al.*, 1988). These formations correspond to distribution area of the II – III kerogen type.

Pyrolysis examination of cores from boreholes drilled on the adjacent land characterizes organic matter in this zone by its relatively low hydrogen index (HI), only locally exceeding 250 – 280 kgHC/t C_{org}. (Appendix 2). During Bajocian-Bathonian times the north- and southwestern parts of the Middle Caspian region accumulated marine sediments, mainly under anoxic (reducing) conditions. These sediments are represented by alternating argillites, siltstones, and sandstones with abundant inclusions of pyrite, siderite, and glauconite (Okun'kova, 1971). The predominantly reducing environment favored fossilization of mixed organic matter with the prevalent sapropelic type of kerogen (III – II). Sediments containing kerogen of type III are distributed in narrow zones around the paleoland in the northwestern part of the region, around the Karabogaz arch, and in the zone of development of flysch sequences in the southeastern continuation of the Greater Caucasus.

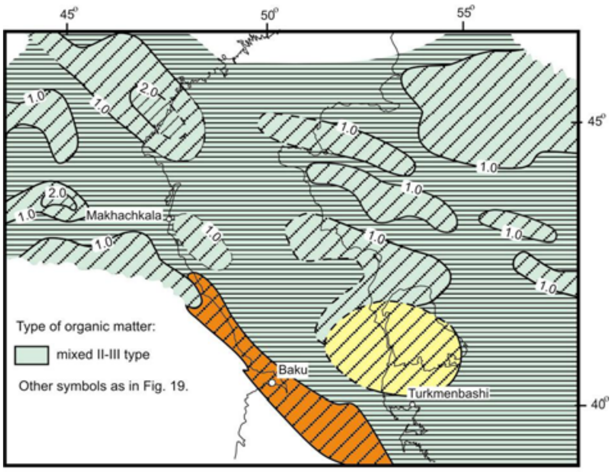


Fig. 20. Distribution of concentrations and types of organic matter in the Aptian - Albian complex. Other symbols as in Fig. 19.

The Aptian – Albian complex. Over most of the region, average C_{org} contents in sediments of this complex range from 0.7 to 2%. The mapped values vary within narrower limits and with lower gradient compared with those in the Bajocian-Bathonian source rocks. The background C_{org} content that is typical of less than half of the region decreases to 0.5 – 1.0%. Two areas with maximum C_{org} values (over 2%) are located in the western part of the region. One of them is confined to the Karpinsky Ridge and another, to the northwestern slope of the Terek – Caspian foredeep (Fig. 20). There are also several areas with elevated C_{org} content (from 1 to 2%) that occupy the most part of the Turan plate and approximately half of the Terek – Caspian foredeep. The formation of zones with the elevated C_{org} concentrations can be explained by accumulation of marine clayey sediments deposited under sub-oxidizing conditions combined with low sedimentation rates (Trotsyuk, 1982). Such environments occur usually near paleoslopes or in relatively deep-sea parts of the basin. In addition, faults that formed in the Karpinsky Ridge and Mangyshlak zone of uplifts could serve as conduits for fluid flows, which brought nutrients to the sea floor and stimulated bacterial synthesis and relevant fossilization of organic matter in these zones. Low-rate marine sedimentation, sometimes under oxygen deficient environments, was one of the characteristic features of the vast platform part of this region during Aptian-Albian times (Rodionova *et al.,* 1972). Such a paleogeographic setting, characteristic of most part of the Middle Caspian region at this time, was favorable for accumulation of mainly fine-grained sediments with organic matter of the mixed II – III type. The pyrolysis of core samples from boreholes drilled in areas adjacent to the Caspian Sea characterizes this organic matter as having relatively low hydrocarbon potential (Appendix 2). The Karabogaz arch includes small areas characterized by kerogen of type II – III with prevalent humic organic matter. Sedimentation in this area occurred under sub-oxidizing shallow-water conditions (Bagir-Zade et al., 1988). Accumulation of organic matter of type III is characteristic of the northern slope of the Apsheron sill where flyschoid sediments were deposited.

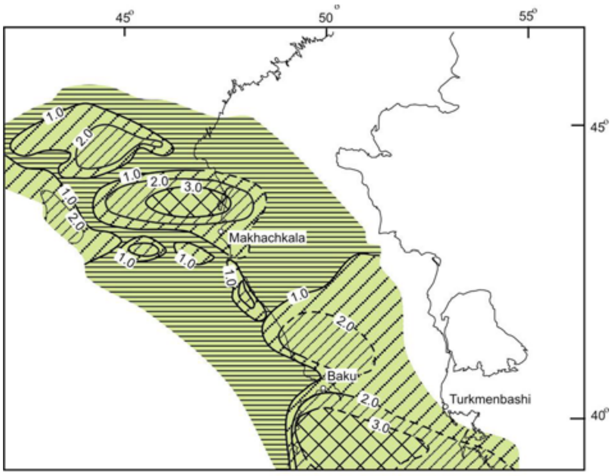


Fig. 21. Distribution of concentrations and types of organic matter in the Maikop complex. Symbols as in Fig. 19.

The Oligocene – lower Miocene complex (Maikop Group). Variations of the average C_{org} concentrations in Maikop sequences are sharper then in the underlying Mesozoic formations. Figure 21 demonstrates an intricate distribution of organic matter in the Middle Caspian region. This is probably related to the high orogenic activity of the Caucasus and the differentiation of sedimentary settings.

Nevertheless, the region as a whole was characterized by relatively stable sedimentation in reducing or almost reducing environments (Akhmet'ev and Zaporozhets, 1996). The region includes two zones with maximum C_{org} concentrations exceeding 3%, one of which is confined to the Terek – Caspian foredeep and another to the northern termination of the South Caspian depression depocenter (Fig. 21). In addition, spacious distribution areas of sediments with C_{org} contents exceeding 2% occur in the Kuma – Tyulenii zone of uplifts and North Apsheron depression. Geochemical examination of many drill cores from on-land boreholes imply a high hydrocarbon-generating potential from the organic matter contained in the Maikop Group, which has a high prevalence of sapropelic kerogen (III – II types) (Saint-Germes *et al.*, 2000).

Thermal conditions. The thermal regime of the Earth's interior is a main factor responsible for organic matter transformation. The assessment of temperatures at boundaries of defined lithological – stratigraphic complexes was carried out using the equation after Geodekyan et al., 1980, which takes into consideration data on heat flow, thermal conductivity of sediments, their thickness and their lithology. The geothermal and physical parameters of formations were taken from published and unpublished materials on the Caspian Sea and its fringes (Kisin, 1967; Ammosov and Sharkova, 1971, 1973; Sergienko, 1971; Lyubimova *et al.*, 1973, 1976; Kutas *et al.*, 1975; Novikov, 1975; Kraichik, 1983; Grechishnikov, 1984; Ognev and Zhylkaidarova, 1986; Chadovich and Polovnikova, 1989; Silant'ev, 1997; and others). It should be emphasized that offshore data on heat flow are extremely scarce and their values for the Middle Caspian Basin were therefore obtained by extrapolation from adjacent land areas. Because of the heterogeneous tectonic structure of the region, the heat flow is highly variable, ranging from 35 to 70 mW/m^2. The values above 55 mW/m^2 are characteristic of elevated parts of the Karpinsky Ridge and Kuma – Tyulenii zone of uplifts. The relatively low values (below 45 mW/m^2) are typical of the inner, both land and offshore, parts of the Terek – Caspian trough. In the North Apsheron depression the heat flow amounts, however, to 130 mW/m^2, probably because of the influence of convective heat exchange along a system of faults that were highly active during late Neogene and Quaternary times. Other areas of the Middle Caspian depression, except for the narrow band along the Mangyshlak zone of uplifts, are characterized by moderate heat flow values from 43 to 45 mW/m^2. In calculations, the heat flow values are usually averaged for a particular structural – formational zone. The values of thermal conductivity for sediments are taken from a plot demonstrating distribution of this parameter with depth compiled for different types of terrigenous rocks, and from the plot of thermal conductivity against density of particular sedimentary types. It should be noted that temperatures were calculated for several reference sections, the location density of which was selected depending on the geological structure of the area and the availability of geothermal data. The available and relatively numerous results of direct temperature measurements in deep holes were also taken into consideration. As a result, maps demonstrating distribution of present-day temperatures at the top of the Bajocian-Bathonian, Aptian-Albian and middle part of the Maikop complexes were compiled. These maps, combined with maps of distribution of organic matter content and type, served as a basis for compilation of distribution maps of oil- and gas-generation in these formations.

Hydrocarbon-generation centers. Four centers of oil and gas generation are defined in the Bajocian-Bathonian hydrocarbon-generating formation (Fig. 22). It should be noted that a large zone of initial hydrocarbon generation (70 – 135^{o}C) occupying the most offshore part of the Middle Caspian depression and adjacent land areas is common for three centers considered below. These centers are separated from each other by a zone of complete generation of oil - gas and gas - oil hydrocarbons (135 – 180^{o}C).

The largest generation center corresponds partly to the offshore areas of the Middle Caspian depression and partly to adjacent areas of the fringing land to the west. It includes three

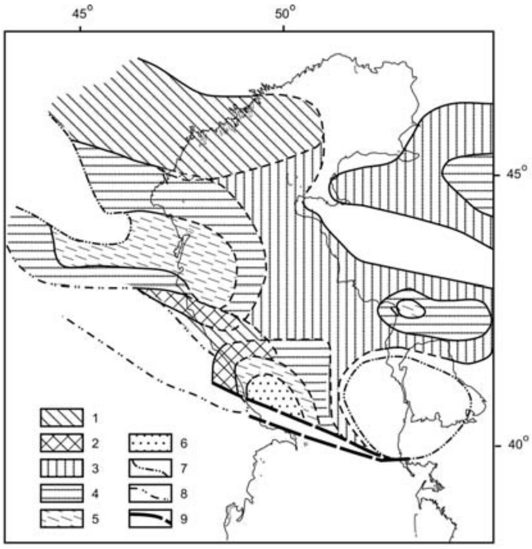


Fig. 22. Distribution of oil- and gas-generation centers within the Bajocian-Bathonian complex.
(1) zone of initial generation of gas - oil hydrocarbons; (2) zone of complete generation of gas - oil hydrocarbons; (3) zone of initial generation of oil - gas hydrocarbons; (4) zone of complete generation of oil - gas hydrocarbons; (5) zone of initial high-temperature gas generation; (6) zone of complete high-temperature gas generation; (7) boundary of the eroded area; (8) boundaries of the alpine Greater Caucasus structure; (9) main faults.

zones differing in heat flow values. Two of them (initial and complete generation) are, in turn, subdivided in two sub-zones each based on differences in the prevalent organic matter type. The first sub-zone of gas and oil generation (kerogen of the III – II type with prevalent sapropelic organic matter) is confined to the areas where Bajocian-Bathonian sediments accumulated in marine shallow-water settings. The second oil and gas generation sub-zone is located entirely in the offshore part of the depression where sedimentation settings were represented by a low-lying accumulative plain intermittently flooded by sea (kerogen of the II – III type with prevalent humic organic matter). The most deeply subsided part of the present-day Terek Caspian trough corresponds to the third zone of high-temperature (over 180^{o}C) gas generation.

With respect of tectonic structure, the second hydrocarbon-generating center corresponds mainly to the southern part of the Terek – Caspian trough and North Apsheron depression (Fig. 22). It includes zones of initial and complete (over 220^{o}C) high-temperature gas generation fringed by zones of complete and initial generation of gas - oil and oil - gas hydrocarbons. Their distribution is closely connected with the prevalent kerogen type (III – II or II – III) and depends on their paleogeographic sedimentation settings. In terms of the history of oil and gas generation in the two previously-discussed centers, it commenced locally at the end of Early Cretaceous, sharply increased by the end of Maikopian time, and continued, to a variable extent, into recent times. It is also worth noting that the sharp temperature rise and corresponding acceleration in catagenetic transformation of organic matter that occurred against the background of gradual subsidence of the Bajocian-Bathonian complex in the North Apsheron depression and adjacent areas was related to high heat flow values amounting to 130 mW/m^2.

Two other centers of oil and gas generation within the Bajocian-Bathonian complex are located in the eastern part of the Middle Caspian and, partly, North Caspian basins of the Turan plate (Fig. 22). Unlike those centres discussed above, these centers developed until the Eocene and then the temperature decreased gradually because of permanently low sedimentation rates in the Cenozoic. The Eocene paleotemperatures exceeded the present-day ones by 40%. This inference is confirmed by the data on vitrinite reflectance (Ammosov and Sharkova, 1971, 1973). In both centers Bajocian–Bathonian sediments accumulated in a low-lying accumulative plain, with intermittent sea ingressions. The sediments contain kerogen of the II – III type with prevalence of the latter, and generate oil and gas. The first of these two hydrocarbon-generation centers is bordered by the South Mangyslak trough and continues offshore. It comprises zones of initial and complete oil and gas generation and a small zone of initial high-temperature gas generation. There is a distinct genetic relationship between this center and the distribution of gas, oil - gas, and, to a lesser extent, oil deposits within the Bajocian-Bathonian complex. The second of these hydrocarbon-generation centers is almost entirely located in the North Ustyurt trough, and can also be subdivided into zones of initial and complete oil and gas generation. The discovery of only oil and oil - gas deposits in the immediate vicinity of this center, for instance in the Buzachi arch, can probably be explained by the uplift to shallow depths of the Bajocian – Bathonian complex, which possibly resulted in the escape of any pure gas accumulations.

Unlike the Bajocian-Bathonian complex, the Aptian-Albian sediments accumulated in shallow-water marine settings and contain kerogen mainly of the mixed II – III type (Fig. 23). In the North Ustyurt trough where rocks did not appear to reach the depth with temperature conditions of the main oil/gas-generation zone, a hydrocarbon-generation center is absent. The contours of generation areas are to some extent similar to those in the Bajocian-Bathonian complex, although there are differences concerning, first of all, their distribution areas. This is explained by changes in their outer boundaries corresponding to the isotherm of 70°C. Depending on the maximum temperature, the boundaries of generation zones within centers change their configurations. In the northeastern part of the Terek – Caspian trough (Terek – Sulak depression) corresponding to the zone of complete oil and gas generation in the Middle Caspian fringes, maximum temperatures at the top of the Aptian-Albian complex are as high as 160°C and a small zone of initial high-temperature gas generation (180°C) is located only in the offshore part of the trough. In the hydrocarbon-generation center confined to the South Mangyshlak trough, rocks are heated

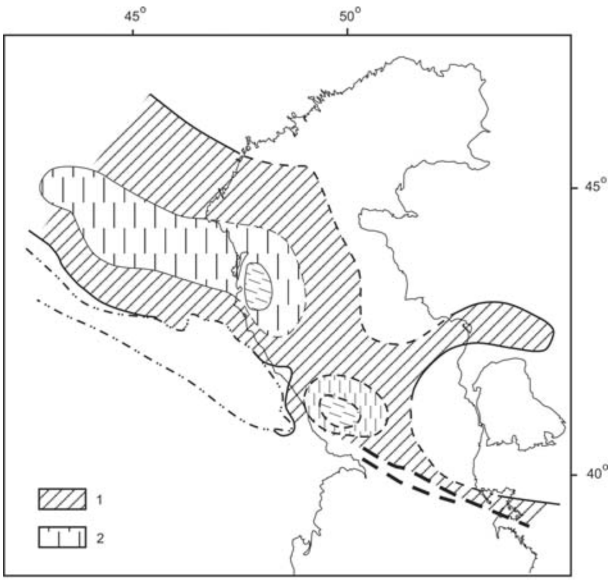


Fig. 23. Distribution of oil- and gas-generation centers within the Aptian-Albian complex.
Zones of oil and gas hydrocarbon generation: (1) initial, (2) complete. Other symbols as in Fig. 22.

only to temperatures characteristic of the zone of initial oil and gas generation (70 – 90°C). Zones of complete oil and gas generation (135 – 180°C) and initial high-temperature gas generation (below 200°C) are confined to the central parts of the North Apsheron depression.

As was mentioned, the Maikop hydrocarbon-generating sequence accumulated in a marine sedimentation setting and contains kerogen of type III – II with a substantial content of sapropelic organic matter. Two oil- and gas-generation centers differing in the heating temperature and characterized by a common outer contour of the initial oil- and gas-generation zone are defined in the middle part of this sedimentary complex (Fig. 24). They are confined to the western half of the Middle Caspian depression because the rocks of its eastern part did not reach sufficient temperature conditions for maximum oil-generation. One of these centers corresponds to the Terek – Sulak depression and, partly, northerly located Kuma – Tyulenii zone of uplifts. The second one is located in the North Apsheron depression. They are smaller in size compared with those confined to the previous complexes due to the narrower zone of initial gas and oil formation. The zone of high-temperature gas generation in the Terek – Sulak depression is mostly located in fringing land (Fig. 24). In the North Apsheron depression, temperatures exceeding 180°C are probably characteristic only of the lower part of the Maikop Group, while the middle part of this Group only reached zones of initial and complete gas and oil generation.

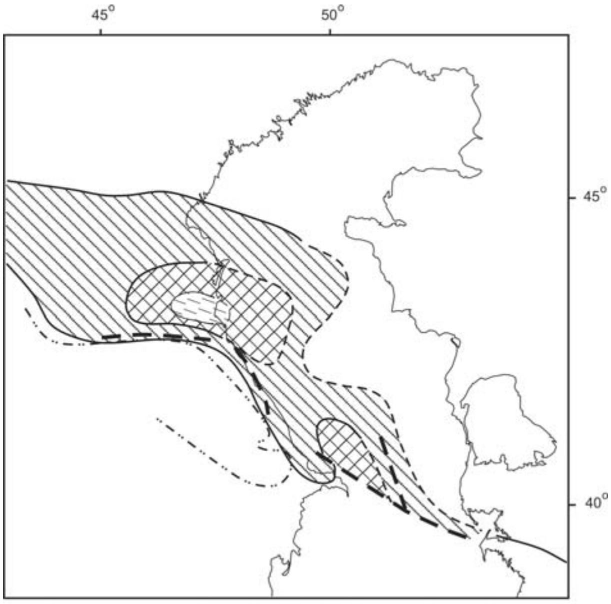


Fig. 24. Distribution of oil- and gas-generation centers within the Oligocene-lower Miocene complex. Legend as in Fig. 22.

The oil and gas generation mapping shows that the Yalama – Samur uplift, located in in the region of the Russian-Azerbaijan International boundary, is probably the largest hydrocarbon-prospective structure in the offshore part of the Middle Caspian depression. It is well defined in isopach maps of the Jurassic and Cretaceous formations and has been developing from Jurassic times up to the present. Hydrocarbons can migrate into the uplift from generation centers within the Terek – Sulak and North Apsheron depressions. Main prospects are most likely connected with Cretaceous formations. Significant oil and gas reserves could also be found in structural traps identified from offshore seismic reflection surveys. Such structures are located offshore within the previously described first generation centers of initial oil- and gas-generation zones in the Bajocian-Bathonian and Aptian-Albian complexes. This assumption is supported by the Khvalynskoe accumulation discovered in 2000. Also promising in the Russian offshore part of the Middle Caspian depression are structures revealed by seismic surveys in the Dagestan shelf, where zones of oil and gas accumulation are probably located on migration paths from oil- and gas-generation centers.

17. HYDROCARBON-BEARING POTENTIAL: SOUTH CASPIAN DEPRESSION

The south Caspian depression contains major hydrocarbon reserves and represents part of the large N-S extending Barents – Caspian belt (Khain, 2000) and also a part of the latitudinal Mediterranean belt of oil and gas deposits. The present-day views on the character and origin of oil and gas deposits in this region are based on many works (Baba-Zadeh, 1964; Bagir-Zadeh *et al*., 1978; Yassini, 1981; Gadzhiev, 1985a, 1985b; Guliev et al., 1991; and others). Oil and gas prospects of this region continue to attract attention and are widely discussed in recent publications (Bailey *et al.,* 1996; Abrams and Narimanov, 1997; Inan *et al.,* 1997; Tagiev *et al.,* 1997; Devlin *et al.,* 1999; Ismail-Zadeh, 1999; Kerimov *et al*., 1999; Huseynov, 2000; Katz *et al*., 2000; Abasov *et al*., 2001, Guliev and Ivanov, 2001; Dadashev, 20001; Lebedev, 2001; Levin and Fedorov, 2001).

Sedimentary system and formation of reservoirs. According to recent data, the sedimentary cover of the South Caspian depression is 22 – 25 km thick. Significant portions of sedimentary rocks occur at depths inaccessible to drilling and can be characterized only by comparing with sections from adjacent areas. In the composite section of the depression, oil and gas accumulations have been established over a wide stratigraphic interval, from the Aalenian Stage of the Middle Jurassic to the Apsheronian regional stage of the Eopleistocene (Ali-Zadeh, 2000). The main hydrocarbon-bearing potential is related to the Pliocene Productive formation, which formed under conditions of extreme geodynamic changes in the Caspian region.

The Jurassic complex is developed in the northern slope of the depression along the near-watershed part of the Greater Caucasus. The Middle Jurassic sequence (mainly Bajocian and Bathonian stages) is composed of substantially thick alternating sandstones, siltstones, limestones, clays, and shales. Similar sandstone members 25 – 30 m thick are drilled in neighboring areas of the Caspian – Kuba structure where they are sporadically saturated with gas and oil. The Upper Jurassic sequences are represented by two lithological – facies complexes; (1) the Callovian – Oxfordian – Lusitanian complexes composed of alternating flyschoid siliceous - calcareous siltstones and clays and (2) the Kimmeridgian Tithonian complex consisting of alternating hard pinkish fissured limestones, sandstones, siltstones and clays. The total thickness of Upper Jurassic rocks amounts to 2,000 m.

The Lower Cretaceous complex. Within this complex, hydrocarbon-bearing reservoirs are a sandy – limey formation occurring in the lower part of the Hauterivian Stage and represented by frequently alternating dense sandstones, siltstones and limestones and the Barremian sandy – silty – limey member. Commercial oil yields and oil-gas shows are proven in the Caspian – Kuba and Shemakha – Kobystan areas, as well as in the Middle Kura trough.

The Upper Cretaceous complex, represented mainly by Campanian-Maastrichtian rocks, is widespread in slope zones of the South Caspian depression. In its southern slope, along the northeastern piedmonts of the Lesser Caucasus, the complex is composed of fissured limestones and marls. According to drilling and geophysical data, these lithologies occur in all known geological structures of the Middle Kura trough. In some areas, drilling of Upper Cretaceous fissured carbonate rocks was accompanied by oil and gas inflows.

In the northern slope of the depression (Shemakha – Kobystan zone), the Upper Cretaceous (Cenomanian-Maastrichtian) complex is represented by 3 – 5 m thick calcareous sandstones and siltstones alternating with clays and limestones.

The Paleocene complex is widely developed in the South Caspian depression and represented mainly by a clayey sequence with thin interbeds of sandy – silty, carbonate, and tuffogenic rocks. Commercial oil accumulations are established in the Kura depression.

The Eocene complex is composed of calcareous clays, sandstones, and black clays with foraminifers, ostracods, and fish remains. Their thickness is 1,400 – 1,500 m in the Shemakha – Kobystan zone and they thicken southeastward. Drilling data has shown that the thickness of Eocene sediments in the Apsheron Peninsula amounts to 1,600 m. Commercial oil accumulations occur in the Middle Kura trough.

The Oligocene – lower Miocene complex (Maikop Group). The Maikop Group is composed of dark green and chocolate – brown clays with abundant fish remains and coalified tree trunks. The peculiar feature of the Maikop Group is its high pyrite content, which indicates reducing conditions during the entire Oligocene – early Miocene time. The thickness of the group is highly variable, ranging from 500 (and less) to 2,000 m.

Oil and gas accumulations in the lower Maikop sequence are established in the southwestern piedmonts of the Lesser Caucasus. The largest commercial deposits have been discovered in thin sandstones in the Kobystan area and in the southwestern Apsheron Peninsula.

The middle – upper Miocene complex in the South Caspian depression is subdivided into the middle (Tarkhanian, Chokrakian, Karaganian, and Konkian) and upper (Sarmatian, Maeotian, and Pontian) parts. Sediments of the Karaganian, Konkian, Sarmatian, and Maeotian regional stages are referred to as the Diatom Formation.

The Tarkhanian and Chokrakian regional stages (middle Miocene). The Tarkhanian regional stage is represented by greenish gray marls, massive clays, dark gray clays with sand interbeds, gray calcareous clays, and sandstones. Its thickness does not exceed 80 – 90 m. The Chokrakian regional stage is composed of sandy – silty sediments with interlayers of laminated black clays (approximately 100 m thick in total), dolomites, and sandstones. The thickness of Chokrakian sediments increases from the Apsheronian Peninsula to Kobystan area where it amounts to 500 m. Oil and gas accumulations in the formation are established to occur locally in southwestern Kobystan and Dzhalilabad areas. Intense hydrocarbon shows are recorded in the southwestern Apsheron Peninsula.

The Diatom Formation. The Karaganian – Konkian – Sarmatian sequence is composed of gray to grayish green laminated clays with thin intercalations of sand, yellowish brown siltstones, marls, and fissured dolomites. They include abundant fish remains and diatomites. The maximum thickness of the formation is 500 m. The largest commercial oil accumulations have been found in fields of the western Apsheron Peninsula, southern Kobystan, and in the Kura – Iori interfluve.

The Pontian regional stage is represented by alternating clays and marls from 110 – 200 m to 300 – 500m thick in the Apsheron Peninsula and Kobystan area, respectively.

The lower Pliocene (Productive and Red-colored sequences). The Productive Sequence and its analogue, the Red-colored Sequence, in the eastern periphery of the South Caspian depression represent its main reservoirs. The sequences are composed of rhythmically alternating sand – clay sedimentary bands and are up to 7 km thick in most subsided parts of the basin. The sediments accumulated in a closed marine basin whose formation was accompanied by intense uplifting in adjacent land areas, subsidence in the central part of the South Caspian depression, and a substantial Caspian Sea level fall of, according to some calculations, 600 – 1,500 m. The final isolation of the Caspian Sea from the Eastern Para-Tethys 5.5 Ma ago coincided with the Messinian 'crisis' and the isolation of the Mediterranean Sea. These events were related to global climatic changes and glacio-eustatic sea-level fall.

The Productive Sequence consists of nine formations (Kalinskaya, Podkirmanskaya, Kirmanskaya, Nadkirmanskaya Sandy, Nadkirmanskaya Clayey, Hiatus, Balkhan, Sabuncha, Surakhan) and is spread over a vast territory, including the Apsheron Peninsula, Apsheron and Baku archipelagos, Dzheirankechmez depression, Alyaty Ridge, and Near-Caspian region. The sequence comprises several facies types: the so-called Apsheron, Lower Kura, Kobystan – Near-Caspian, and South Caspian facies types.

Sediments of the Apsheron type are characteristic of the entire Apsheron Peninsula, Apsheron Archipelago and northern part of the Baku Archipelago. They are also distributed, in form of a wide gulf, in the Dzheirankechmez depression of the Shemakha – Kobystan trough. These sediments are represented by quartz sands and silts. Their peculiar features are the quartz composition and occurrence of distene and staurolite. The thickness of sand, silt and clay beds composing the section of the Apsheron type varies from several centimeters to several meters, in total amounting to approximately 700 m. The section encloses up to 40 – 50 productive gas-bearing silty – sandy beds . The main source of terrigenous material was carried into the basin by the Paleo-Volga, a large river flowing in the northern part of the basin.

Sediments of the Lower Kura type formed in the intermontane depression bordered by the Greater and Lesser Caucasus (the Lower Kura lowland and adjacent eastern part of the Baku Archipelago). Their section is mostly composed of detrital material. In the central part of the depression, sandy – silty – clayey sediments are widespread. The northern periphery of the depression (Lengebiz zone) is composed of rudaceous rocks alternating with fine-grained clastic varieties, with oil and gas accumulations in some structures. The total thickness of these sediments is 3,500 – 4,000 m and more. The sediments formed mainly from material brought by the Paleo-Kura, Paleo-Araks, Paleo-Pirsagat and other paleo-rivers. The low quartz content indicates an insignificant proportion of quartz-containing rocks in the source provenance; the high content of feldspars, pyroxenes, and hornblende implies a wide distribution of igneous rocks in the provenance area.

Sediments of the Kobystan type are spread over the southeastern zone of the Kobystan area in the Dzheirankechmez depression and the Alyaty Ridge zone. These sediments are represented by a thick sandy – silty – clayey sequence with rudaceous rocks distributed in marginal areas of the depression. Locally, the thickness of these sediments amounts to 2,500 – 2,800 m. A remarkable lithological peculiarity of sediments of the Kobystan type is their irregular alternation of sandy – silty – clayey varieties and higher clay content, compared with the Apsheron-type Productive sequence, and the poor lithological differentiation throughout the section.

Sediments of the Near-Caspian type. The northeastern slope of the Greater Caucasus is marked by development of the Productive sequence referred to as the 'Near-Caspian type'. It is represented by silty – sandy rocks with interbeds of conglomerates. The northeastern slope of the Greater Caucasus served as the main provenance for these sediments, providing detrital material for the large-pebbled and small-pebbled as well as the clayey – sandy sediments of this sequence. Accumulation of conglomerates occurred in the coastal zone of the basin, which approached the spurs of the Greater Caucasus extending northward up to the present-day Samur

River valley. The relative increase in quartz content and appearance of distene and staurolite in rocks distributed in northern part of the Caspian – Kuba area indicate the influence of a northern provenance during their accumulation. The shallow-water sedimentation settings of these sediments are inferred from poor sorting of sandy – silty material. The thick conglomeratic sequence developed in the western part of the region formed as a result of material delivered by mountain rivers. In the lower courses, these rivers deposited clayey – sandy sediments. Terrigenous material in this region was mainly transported by the Paleo-Samur river. In addition, the basin received material brought by several mountain rivers that formed fans in the basin.

Sediments of the South Caspian type accumulated in the foredeep located in the southernmost part of the Caspian depression adjacent to the Talesh and Alborz fold zones. These mountain systems were subjected to intense erosion, providing terrigenous material for the southern part of this basin.

Red-colored sequence. In the Turkmen hydrocarbon-bearing region, the Turkmen type of sediments represented by terrigenous red beds are widespread. Sediments of this type occur in the Near-Caspian plain of West Turkmenistan, where they fill an aerially large depression. They are present in almost all the structures of this region and contain large oil and gas accumulations. Their section is represented by alternating conglomerates, sands, silts, and clays, some 2,500 – 2,800 m thick.

Near the Kubadag and Greater Balkhan mountain system where the shoreline of the past basin is reconstructed, sediments of the Turkmen type are represented by conglomerates with pebbles and boulders of igneous rocks and coarse-grained sandstones. Sediments of the inner part of the basin become finer-grained.

Large volumes of detrital material were delivered by large and numerous rapid mountain rivers. Sediments of the Productive sequence accumulated in an isolated basin with an extremely unstable water level. These changes in level were comparable in amplitude with secular and millennial global sea-level fluctuations. The hydrological regime of the Caspian Sea, as an isolated basin, was controlled by varying-frequency climatic fluctuations, which influenced sediment successions of different orders (Kroonenberg *et al*., 2000). In addition to long-term sea-level changes, the basin was characterized by high-frequency cyclic oscillations. The latter played a decisive role in formation of sedimentary sequences and structure of the main hydrocarbon reservoirs. The study of exposed lower horizons revealed two distinct types of small-scale sedimentation cycles: units with the upward increasing and units with upward-decreasing grain-size of sediments. Their formation was controlled by high-frequency sea-level changes and climate-regulated sedimentary material influx, which influenced the internal sedimentary structure of individual stratigraphic units.

Distribution of organic matter and hydrocarbon-generation potential of Mesozoic sequences. Distribution of concentrations and types of organic matter and assessment of oil- and gas-generation potential of sedimentary rocks were studied using mainly pyrolysis data on drill cores, on rocks sampled from exposures, and on mud volcano breccia (Korchagina *et al.,* 1988). The results of this analysis are given below (Fig. 25).

The Jurassic complex. The Aalenian to Callovian sections that were examined are composed of clays, fine-grained sandstones, siliceous sediments and argillites. The upper Bathonian and lower Callovian portion of the section includes rocks with high-quality organic matter. Paleogeographic reconstructions show that the basin was closed at that time and increased salinity changed sedimentation environments. The Pr/Ph value is 0.39 – 1.41. Organic matter is of the mixed type and consists of amorphous algae, wood and plant remains, corresponding to types II and III. The organic carbon content averages 0.76%, varying from 0.05 to 3.42%. The oil-generating potential of the Jurassic rocks is relatively low (the hydrogen index HI averages 87).

The Cretaceous complex. The rock samples examined from the Hauterivian, Albian, Cenomanian, and Maastrichtian stages show a relatively low C_{org} content in the Cretaceous complex (from 0.05 to 1.84 %, averaging 0.22%). The low HI value (83) implies a gas-generation potential for these rocks.

The Paleocene complex. The rocks of this complex are characterized by the lowest C_{org} contents among the various Mesozoic – Cenozoic formations. The organic carbon concentration varies from 0.01 – 0.08%, averaging 0.03%.

The Eocene complex is characterized by low content and quality of organic matter. The organic matter is represented by inertinite and wood remains. The average content of organic matter is 0.46% and the hydrogen index does not exceed 29.

The Oligocene – lower Miocene complex (Maikop Group). Sediments of the Maikop Group are characterized by high C_{org} contents amounting to15.1% and averaging 1.86%. The hydrogen index ranges from 11 to 612, averaging 146. The quality and content of organic matter increase in an easterly direction toward the Caspian Sea, and correspondingly increases the hydrocarbon prospectively of the offshore part of the basin.

The middle Miocene complex (*Chokrakian)* is characterized by C_{org} contents varying from 0.09 to 2.44% and by a hydrogen index of 72 – 541, which indicates a sufficiently high quality of organic matter and points to the generation of both liquid and gas hydrocarbons by these rocks.

The Diatom Formation is considered to be one of main oil- and gas-generating complexes in the South Caspian depression. In its northern part, the formation is characterized

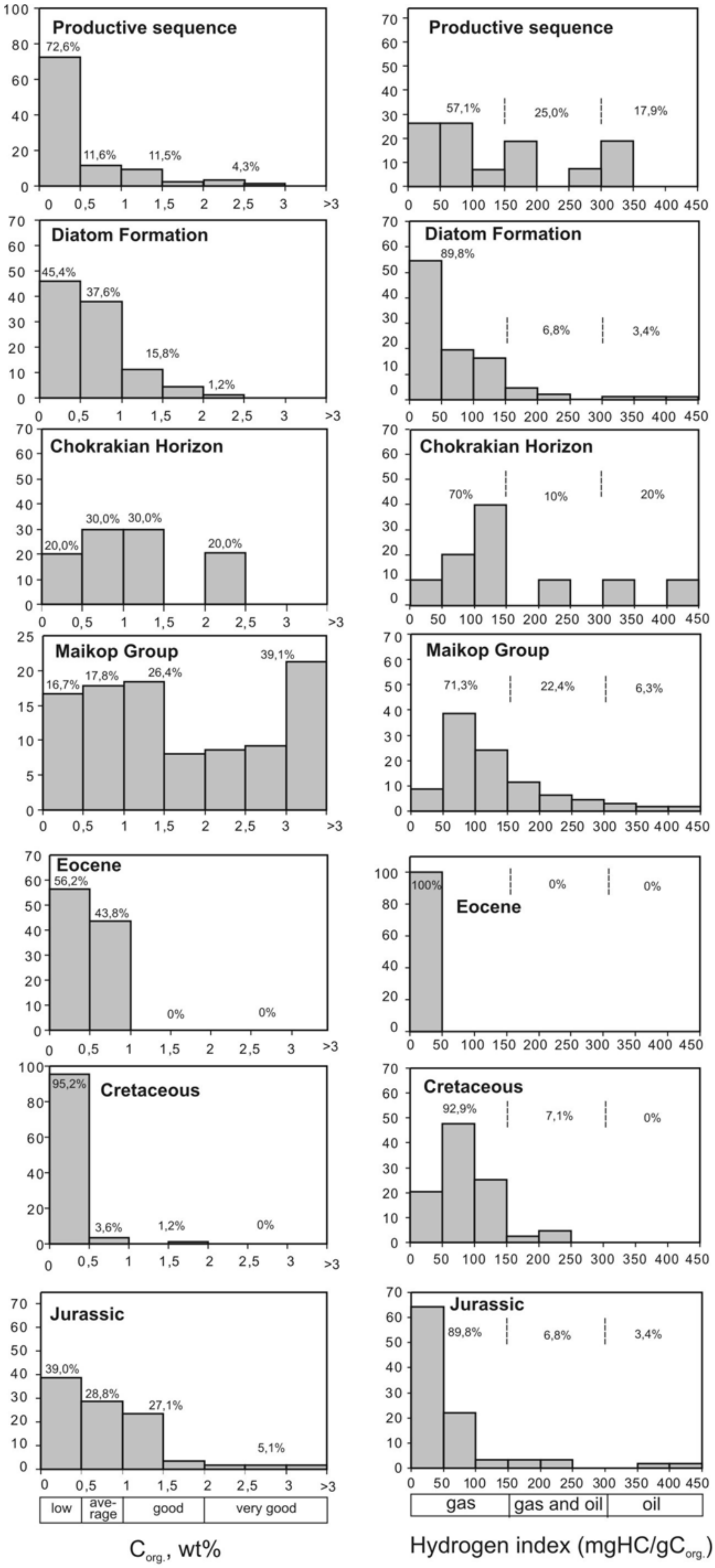


Fig. 25. Histograms of organic matter content and HI values for different stratigraphic units. Vertical axis designates occurrence rate, %. Categories of organic matter quality according to classification by Peters *et al*. (1977)

by an average C_{org} content of 0.63% and a hydrogen index ranging from 12 to 427 (average 105). The content and quality of organic matter in the Diatom Formation increases downwards in the section and along the regional dip. This is evident from the composition of rocks in mud volcano breccia of the Shemakha – Kobystan zone and drill cores from the Baku Archipelago. Kerogen in these rocks corresponds mostly to type II. Their high C_{org} content (0.09 – 7.8, average 1.03%) and HI (107 – 708, average 308) indicate the high oil- and gas-generation potential of the Diatom Formation in the subsided part of the South Caspian depression.

The Pliocene complex. The lower Pliocene sequence, formed in deltaic and coastal marine sedimentation settings, is characterized by the low quality of organic matter (II and III types) represented by redeposited remains of arboreal vegetation with an insignificant admixture of amorphous and algal components. The C_{org} contents vary from 0.02 to 2.71% averaging 0.47 and its hydrogen index ranges from 15 to 334 (average 147).

Hydrocarbon geochemistry. Oil from deposits of the South Caspian depression is referred to as naphthene-methane and methane-naphthene types. Its density ranges from 0.850 – 0.910 g/cm^3, although there are also very light (0.8 g/cm^3) and very heavy (>1.0 g/cm^3) varieties. The sulphur content does not exceed 0.1%. Gas condensate (density 0.729 – 0.81 g/cm^3) occurs in most oil deposits. Oil is biodegraded and oxidized, which is evident from the absence of n-alkanes. All oil varieties are characterized by high concentrations of normal alkanes n-C_{15}, n-C_{17}, and n-C_{19} with low n-C_{27}, n-C_{29}, and n-C_{31} values and by low pristhane-phithane ratios.

The $\delta^{13}C$ values in different oil types vary from -28.0 to -24.34‰ for the total carbon and from -29.1 to -24.9‰ for carbon of the alkane fraction. The distribution pattern of this parameter for the total carbon is polymodal, according to which oil varieties are grouped in two classes: isotopically light (-28.0 to -27.0‰) and isotopically heavy (-26.5 to -24.0‰). Most oil varieties are referred to the last class. A remarkable aspect of these oils is a distinct regular change in the isotopic ratio values throughout the stratigraphic section. The lightest oil varieties (on average -28.0‰) are characteristic of the Late Cretaceous reservoirs whereas heavier varieties occur in the Eocene, Maikopian, and Chokrakian reservoirs (-27.86, -27.64, and -27.5‰, respectively). The isotope ratio becomes sharply heavier in reservoirs of the Diatom Formation and Pliocene complex (-26.13, and -25.75‰, respectively).

The carbon isotope composition in methane from oil – gas deposits and mud volcanoes varies from -35.0 to -54.0‰ and from -35.0 to -60.0‰, respectively. Carbon isotope ratios vary from -35.0 to -45.0‰ in more than 70% of methane samples taken from mud volcanoes and from -40.0 to -50.0‰ in more than 50% methane samples from gas accumulations. On average, the carbon isotope composition in methane from mud volcanoes is 5% heavier than in gas accumulations. Gases from some mud volcanoes (e.g., Durovdag, Kainardzha, and others) and accumulations contain methane with anomalously light carbon (from -50.0 to -60.0‰).

The carbon isotope composition in ethane and propane from mud volcanoes ranges from -23.3 to -29.6‰ and from -25.8 to -25.9‰, respectively.

Downward, the carbon isotope composition in methane becomes heavier, which is consistent with experimental data on the dependence of this parameter on the degree of catagenetic transformation of organic matter (Guliev and Feizullaev, 1996; Guliyev *et al.,* 1997, 2001a, 2001b). Similar trends are also characteristic of stratigraphic successions: the older the stratigraphic unit the heavier the carbon isotope composition. For instance, the value of this parameter ranges from -43.8 to -49.3‰ in methane of the Productive formation (Lower Kura depression), from -41.1 to -41.4‰ in the Maikop Group, and from -34.3 to -38.6‰ in the Caspian – Kuba region.

Reservoirs and seals. Compared with other structures, the South Caspian depression is better studied by information from wells to deeper levels, down to 6.7 km. Many developed fields are connected with mud volcanoes rooted at depths of 8 to 14 km. Rock fragments delivered to the present-day surface represent valuable material for the study of different-age reservoirs occurring at depths of 7 km and deeper.

The reservoir parameters are studied using core material from deep boreholes (Bredehoeft *et al*., 1988; Buryakovskii et al., 1991; and others), supplemented by analytical data on Upper Cretaceous and Paleogene-Miocene rocks from breccia of mud volcanoes located in the southeastern part of the Kobystan area, Lower Kura depression, and Baku Archipelago.

The study of over 2,500 samples from land and offshore sections shows that the porosity and permeability of rocks regularly decreases down section (Fig. 26).

A noticeable decrease in porosity and permeability of sandstones and other rocks is observed at a depth of 4 km, below which these parameters remain relatively stable down to a depth of 6 km (approximate depths of samples from the deep-sea part of the basin). Within the upper 4 km of the section, the porosity and permeability of most sandstone rocks are about 26% and 800 mD, respectively. In the interval of 4 to 6 km the average porosity remains at the level of about 15 – 20% and the permeability decreases to 250 mD. The porosity of argillites (sometimes with a significant admixture of sand) shows high variations at all depths (usually from 0 to 24%) and low permeabilities (averaging 0.5 mD and lower)

Rocks delivered with mud volcano breccia from depths exceeding 10 km are characterized by porosities of about 19% and permeabilities around 70 mD (average values). Argillites from depths of approximately 6 km show porosities up to 29% and permeabilities ranging from 8 mD to (less commonly) 90 mD.

The initial porosity and permeability values for sandstones at shallow depths can be as high as 26% and 160 mD, respectively. In most samples (87%), permeability is below 80 mD. Nevertheless, over 20% of samples from the depth interval of 1 to 2 km show permeability exceeding 650 mD, values probably indicative of development of relatively pure, unconsolidated sands.

The data on porosity and permeability properties of siltstones demonstrate high porosity values for fine-grained fractions: 68% of samples in several upper kilometers of the section are characterized by porosity values of approximately 15 – 28%. The permeability values are also high, exceeding 50 mD for 50% of samples.

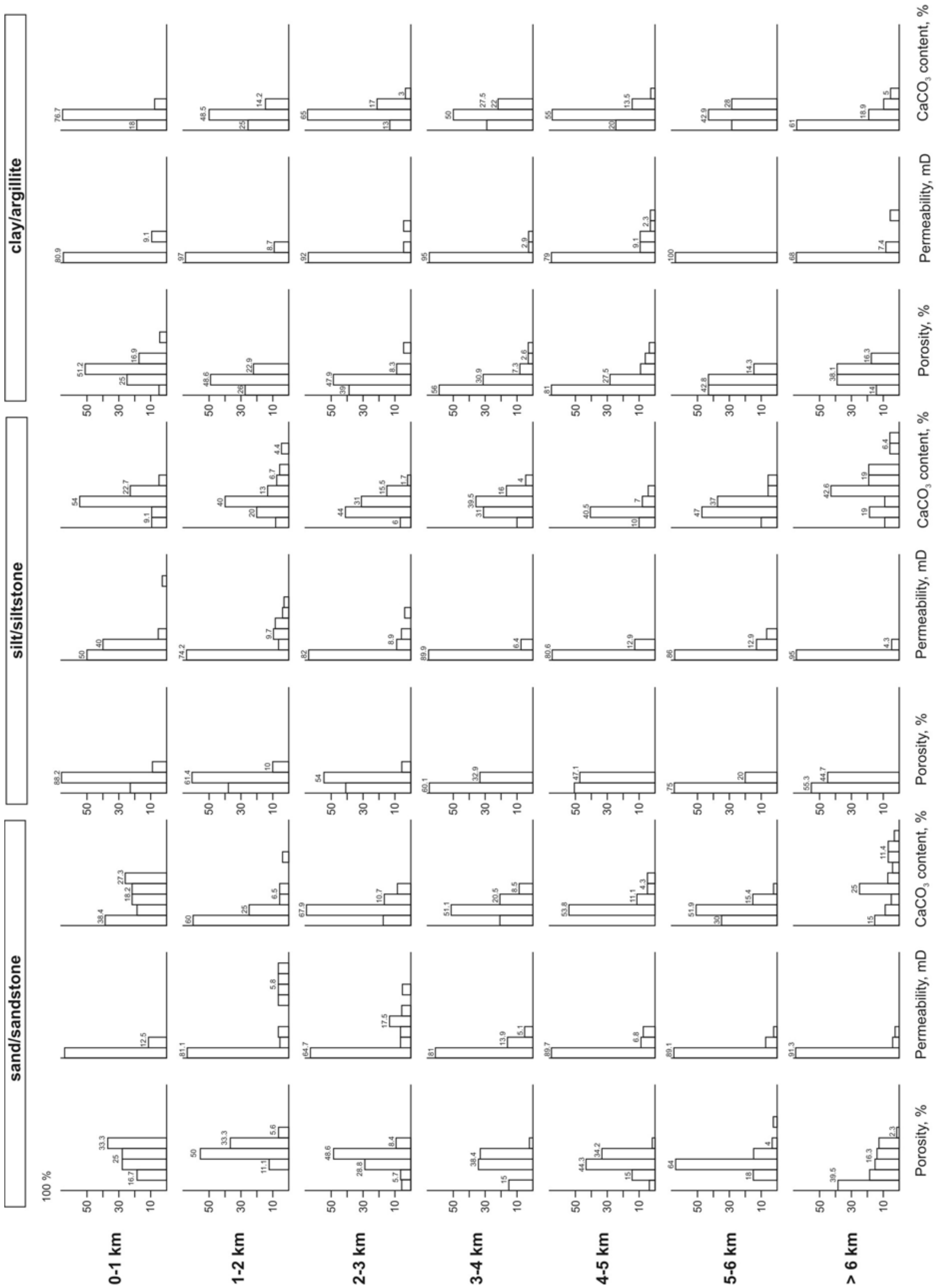


Fig. 26. Relationship between porosity, permeability and $CaCO_3$ content on the depth of occurrence of reservoirs (the Neogene complex of the South Caspian depression, over 2,500 samples. Columns (Top) 1-3: Sandstone; Columns 4-6: Alevrolite; Columns 7-9: Argillite. Columns (Bottom): Columns1, 4, 7 – Porosity, %; Columns 2, 5, 8 – Permeability, mD; Columns 3, 6, 9 – Concentration of $CaCO_3$, %.

The main seals of commercial hydrocarbon accumulations in the South Caspian depression are composed of hydromicaceous and montmorillonite clays. The clay sediments on the western slope of the depression are characterized by the relatively high content of smectite (up to 60%), decreasing downward in the section. The content of illite, kaolinite, and chlorites are up to 45, 10, and 5%, respectively. The composition of clays from the eastern slope of the South Caspian depression is characterized by prevalent illite (50 – 60%) with subordinate montmorillonite (2 – 17%), kaolinite (10 – 25%), chlorite (5 – 10%), and mixed-layered minerals (5 – 10%) represented by illite–chlorite, montmorillonite–chlorite, and vermiculite–montmorillonite.

Differences in composition of clay minerals from sedimentary sections in the western and eastern slopes of the depression resulted from their different origin and, partly, post-sedimentation alterations.

Thermobaric formation conditions. The total number of temperature measurements exceeds 6,000 with the deepest of them carried out at depths of 6 km. The thermal field of the South Caspian depression is characterized by substantial variations (Aliyev and Aliyev, 2000). This can be explained either by transfer of heat through fluids migrating along a regional system of faults bordering large blocks with differently subsided basement, or by redistribution of matter within the sedimentary cover, or by temperature anomalies associated with the distribution of oil and gas accumulations.

The western slope of the South Caspian depression is characterized by low heat flow values ranging from 20 to 90 mWm^{-2}. Some thermal anomalies are probably related to oil reservoirs. Distribution of heat flow values in the South Caspian depression is probably controlled by sedimentary cover and by the geological development of the region. The thermal regime of the region was most likely determined by the convective component of the heat flow that depended on vertical migration of slightly mineralized waters from sediments underlying the Productive formation. Mud volcanism is another factor responsible for formation of local thermal anomalies. The approximately latitudinal thermal anomaly with values of 90 mWm^{-2} and higher can be related to the influence of mud volcanoes.

The low heat flow is a characteristic feature of the entire western part of Azerbaijan, the inner part of the South Caspian depression where they decrease toward the area of maximum subsidence, and of the coastal zone of the Middle Caspian Basin where they increase eastward. Intermediate heat flow values are recorded in the deep-sea part of the South Caspian Basin, in the Lower Kura depression, Apsheron Peninsula, and adjacent archipelago. High heat flow values are associated with large oil and gas accumulations and intense mud volcanism.

Many areas show distinct correlation between heat flow intensity and depth of the crystalline basement (or thickness of sedimentary cover). Elevated heat flow values are observed in areas where the crystalline basement occurs at shallow depths (thin sedimentary cover) and vice versa. This can be explained by radiogenic heating in underlying rocks and heat transfer through the sedimentary sequence.

The previous comments imply that distribution of the heat flow throughout the South Caspian depression is determined by the following factors: (1) depth of occurrence of the crystalline basement (thickness of sedimentary cover) in regions where convective heat transfer is the prevalent mechanism; (2) convective heat and mass transfer in areas of development of significant oil and gas deposits; (3) neotectonic movements and mud volcanism; and (4) faults that provide a good conductor of heat from deeper levels.

Initial formation pressures in reservoirs obtained by pressure-gauge measurements in wells and pore pressures in clays made it possible to define zones of anomalous reservoir pressures (ARP) in the section of the northwestern slope of the South Caspian depression (Fig. 27). The respective average gradient values of initial formation pressures in reservoirs and pore pressures in clays within the examined depth interval are as follows (mPa/m): 0.0107 and 0.126 for the Apsheron Archipelago; 0.0117 and 0.0145 for the offshore South Apsheron area; 0.0126 and 0.0181 for the Baku Archipelago and Lower Kura depression. The highest difference (1.5 times higher) between initial formation pressures in reservoirs and pore pressures in clays is observed in the Baku Archipelago with its greater thickness of clay sequences. The ARP increases with increase in the relative content of clay rocks both throughout the section and through individual beds in reservoirs. The highest ARP values are typical of clayey sequences of the Baku Archipelago, which retain an extremely high porosity and structure of the pore spaces.

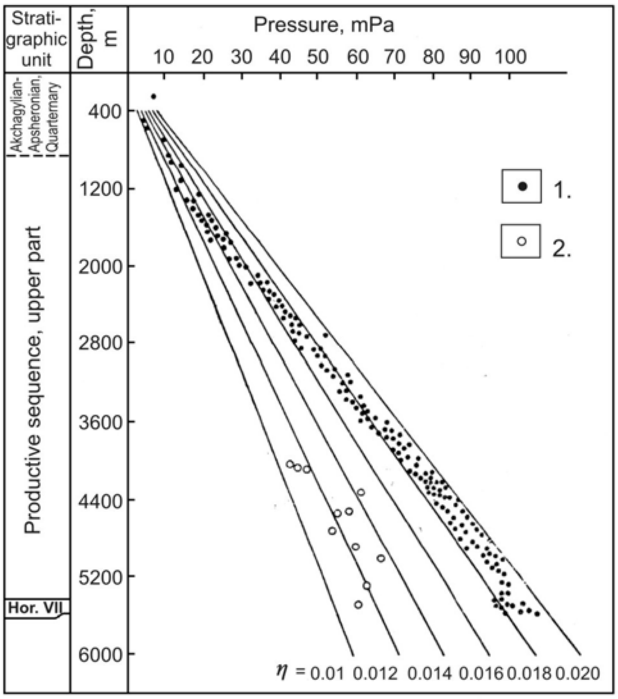


Fig. 27. Relationship between pore pressures in clays (1) and initial formation pressures in sand reservoirs (2) on the depth of occurrence of these formations (oil fields of the Baku Archipelago). X-Axis – Pressure, Mega-Pascal; Y-Axis – Depth, m; Left Column - Stratigraphy (Top-Bottom: Apsheron Akchagalsk Quaternary; Upper Part of Productive Sequence; Horizon VII).

The development history and present-day position of the South Caspian depression determined the formation of a unique oil- and gas-bearing basin that is characterized by widespread distribution of hydrocarbon-source potential organic matter. Convective processes and phase transitions occur throughout the entire basin and result in physical instability of its sedimentary rocks and fluids and, as a consequence, in intense dynamic processes. Such basins can be classed as 'non-equilibrium'.

The formation of hydrocarbon systems in non-equilibrium and so-called 'traditional basins' is substantially different. In non-equilibrium basins, of great importance for hydrocarbon generation, migration and accumulation are different types of convection (thermal, chemical, sedimentological), diapirism of enormous low-density clay bodies, deformation of the sedimentary cover, formation of sub-vertical faults and fracture zones, rapid transfer of matter during mud volcano eruptions, and other processes, in addition to hydrocarbon migration along faults and fissures and their subsequent accumulation in traps.

The formation of hydrocarbon systems in this "non-equilibrium" situation should be considered as a constituent of an intricate mass-exchange phase transition process in the sedimentary cover that has resulted in the development of local hydrocarbon sources, specific mechanisms, and migration paths, as well as particular structural elements. This complexity in the formation of hydrocarbon accumulations determines their diversity in the environment.

Types of hydrocarbon accumulations. The largest accumulations so far discovered are localized in the Azerbaijan segment of the Caspian Sea depression: the Neftyanye Kamni, Gyuneshli, Azeri, Chyrag, Sangachaly – Duvannyi – Khara-Zyrya, Bulla-more, and Bakhar fields.

In the late 1980s, exploration efforts culminated in the discovery of the Kyapyaz, Zapadnyi Apsheron, Gyuneshli (one commercial oil pool in the Nadkirmakinskaya Formation), and Chyrag (one commercial oil pool in the Balakhany Formation) accumulations. Commercial gas condensate discoveries were recorded in the Nadkirmakinskaya Formation and commercial oil was produced from the Hiatus Formation in the northeastern slope of the depression. The last few decades are marked by discovery of the following deposits:

- The Alyaty offshore accumulation, an oil pool within Bed VIII of the Productive sequence in the arch and northeastern fault-related blocks;
- The Bulla Island accumulation, a gas pool within Bed VII of the Productive sequence in the south-southeastern fault-related blocks;
- The 8 Marta accumulation, a gas condensate pool within Bed VII of the Productive sequence;

- The Bakhar accumulation, a gas condensate pool within the Sabunchi Formation;
- The Azeri accumulation (1987), an oil pool within the Hiatus Formation and Bed X of the Balakhany Formation and a gas condensate pool within the Nadkirmakinskaya Formation;
- The gas accumulation in the Azeri shelf discovered by exploration well Nakhichevan-1 in 1993. Gas and condensate are presumably obtained from the Productive sequence. According to preliminary estimates, gas reserves in this accumulation are 25 billion m^3 (860 BCF). This is the first offshore field found on the Azeri shelf in the last five years. It is along the strike of the anticlinal zone that extends northward parallel to the large hydrocarbon fields of the Apsheron Peninsula. The water depth in this area is approximately 100 m. The field's development should be started in three years time.

Of a great importance is the fact that commercial oil production from the Hiatus Formation in the northeastern slope of the Chyrag deposit indicates its possible connection with the oil accumulation within the same formation in the neighboring Azeri deposit. The first oil production at rates exceeding 1,000 tonnes/day was obtained from well Chyrag-1 on November 12, 1997.

The main characteristic feature of oil deposits discovered in the Productive sequence of Azerbaijan is their multi-layer structure (up to 40 oil- and gas-bearing reservoirs) and occurrence of various hydrocarbon accumulations not only within a single deposit, but within a single bed as well (Baba-Zadeh, 1964).

Particularly widespread are oil and gas accumulations in traps that resulted from deformation of beds into anticlinal (brachyanticlinal) folds with an insignificant influence of lithological and other factors. Typical anticline-related accumulations are those that occur within the Productive sequence of the Surakhany, Kala, Bibi-Eibat, and Balakhany –Sabunchi – Ramany fields.

The second largest group of hydrocarbon accumulations is represented by trapped accumulations that formed along tectonic fractures (normal faults and up-thrown traps) complicating anticlinal folds. Most hydrocarbon accumulations within the Productive sequence of the Apsheron Peninsula (Karachukhur, Buzovna – Mashtagi, and Lokbatan accumulations), Baku Archipelago (Bulla-more and Khara-Zyrya accumulations), Apsheron Archipelago (Darwin Bank and Chilov Island accumulations), Lower Kura depression (Kalmas and Mishovdag accumulations), and also the Umbaki accumulation within the Maikop Formation in Kobystan are of this type. Hydrocarbon accumulations of Azerbaijan deposits that occur in fault blocks are characterized by a significant height (300 – 400 m), length (up to 6,000 m), and width (up to 4,000 m). Unlike accumulations in the anticlinal zones, they have no gas caps.

Stratigraphically trapped oil accumulations connected with beds pinching out up-dip were first defined in Azerbaijan in 1938 – 1939 in the western part of the Apsheron Peninsula (Chakhnaglyar, Binagady, Sulutepe discoveries). Connection of the Productive sequence with underlying formations is an important factor in the formation of accumulations of this type.

During the initial formation stage, the basin that accumulated the Productive sequence was relatively small. Its gradual increase in size resulted in maximum lateral distribution of the upper horizons of the Productive sequence. This extending growth of the basin led to separate horizons and formations of the Apsheron Peninsula and Kobystan area successively pinching out, from lower to upper, from the southeast to the northwest, against the regional dip direction. These regional pinch-outs can form stratigraphic traps for hydrocarbons (e.g. Palchyg Pilpilyasy, Kekhne Kala accumulations).

Lithologically trapped oil accumulations are widespread in the Apsheron area (Kushkhana – Karadag, Govsany) and Lower Kura depression (Neftechala). Most favorable for the development of non-anticlinal traps are the shelf and continental slope, tectonic scarps and terraces, zones of pinch-out beds, erosion channels, deltaic and fluvial successions, coastal bars and marginal reefs.

Many stratigraphic traps were predicted and discovered in the northwestern part of the Apsheron Archipelago. These are located in Lower Cretaceous reef structures and in turbidities occurring on the slopes of Paleogene troughs and also in pinch-out zones of the Kalinskaya and Podkirmakinskaya formations of the Productive sequence, Pliocene paleo-delta and clinoform bodies of the Turkmen shelf.

The structurally and stratigraphically trapped oil accumulations often include so-called "suspended pools". These are irregular bodies (reservoirs) with their water/oil contact located within the limb of the structure. Pools of such type are widespread in the Apsheron Peninsula (Surakhany, Bibi-Eibat, Balakhany – Sabunchi – Ramany, and Karachukhur accumulations).

Wide distribution of mud volcanism and clay diapirism in the South Caspian depression enables the formation of (rare?) oil accumulations trapped up dip at the contact of the reservoir with the surface of these diapiric bodies (e.g. oil accumulations within the Kirmakinskaya Formation of the Productive sequence in the eastern part of the Buzovna accumulations).

Oil exploration prospects and hydrocarbon reserves. The Shakhdeniz, Karabakh, Dan Ulduzu, Ashrafi, Lenkoran–Talesh-more, Oguz, Apsheron, Nakhichyvan, Inam and other structures were explored recently. According to calculations, these promising structures should contain approximately 1.6 billion tonnes of extractable oil reserves and 1,000 billion cubic meters of natural gas. This could increase oil and gas production by up to 50 – 60 million tonnes/year and 14 – 15 billion cubic meters/year, respectively.

The main potential hydrocarbon reserves are localized in the deep-sea part of the Caspian Sea. So far, 145 prospective structures, 400 of them at water depths shallower than 60 m, 33 structures at water depths of 60 – 200 m, and 72 structures at water depths exceeding 200 m are established in this region (Aliev, 1998).

The deep-sea part of the basin is one of the least studied areas. Hydrocarbon reserve potential has not been estimated for this zone. In this zone, productive horizons occur at depths exceeding 5,500 – 6,000 m under complex temperature-pressure conditions.

Specialists from different countries have calculated the potential hydrocarbon reserves in the Azerbaijan segment. Their estimates range from 4 to 8 billion tons of oil-equivalent (30 to 60 billion barrels of oil-equivalent). The highest estimates of oil reserves (up to 200 billon of barrels. i.e., ~30 billion tonnes) were proposed by the Energy Department of the United States. The calculations performed by the *GEON Center* (Russia) together with the *Institute of Geology, National Academy of Sciences of Azerbaijan* (Levin *et al.,* 2000a, 2000b) show that most of the potential hydrocarbon reserves in the South Caspian Sea are likely to be found in the Miocene-Pliocene formations. The highest density of hydrocarbon reserves is a feature of the Apsheron – Balkhan sill area (the so-called Caspian “golden belt”) with the most discovered reserves and with a significant area containing large, highly promising structures located offshore, south of the Apsheron Peninsula. The total hydrocarbon reserve potential of this zone is estimated to be approximately 20 billion tonnes of oil-equivalent

18. SEISMICITY OF THE CASPIAN REGION

The Caspian region is characterized by spatially variable seismicity. It increases in two directions: from north to south and from northeast to southwest. The boundary between the aseismic and highly seismic areas crosses the Caspian Sea from Makhachkala to the southern fringes of the Kara-Bogaz-Gol Gulf (Fig. 28). The earthquake intensity varies within wide limits of magnitude ($3 \leq M \geq 7.5$ on the Richter Scale). The periodicity of destructive earthquakes during the instrumental measurement period of the 20th century was 4 – 5 years and decreased with time. The period of 1998 – 2000 was marked by five destructive earthquakes: in Dagestan of the Ciscaucasia region (two) and in the offshore part northwest of Baku, near the town of Balkhanbad (former Nebit-Dag), and near the town of Astara in the territory of Iran (one earthquake in each area). Epicenters of earthquakes with magnitude of >5 are either confined to fault-bounded blocks or occur along faults. Both vertical and lateral distribution of seismic activity is irregular. Distances between earthquake epicenters vary from 50 to 125 km and they substantially decrease between foci of hypocenters. In the opinion of N.V. Kondorskaya (personal communication), foci are 5 – 8 km across under a magnitude of 5.5, and 40 – 65 km across between magnitudes of 5.5 and 7.0.

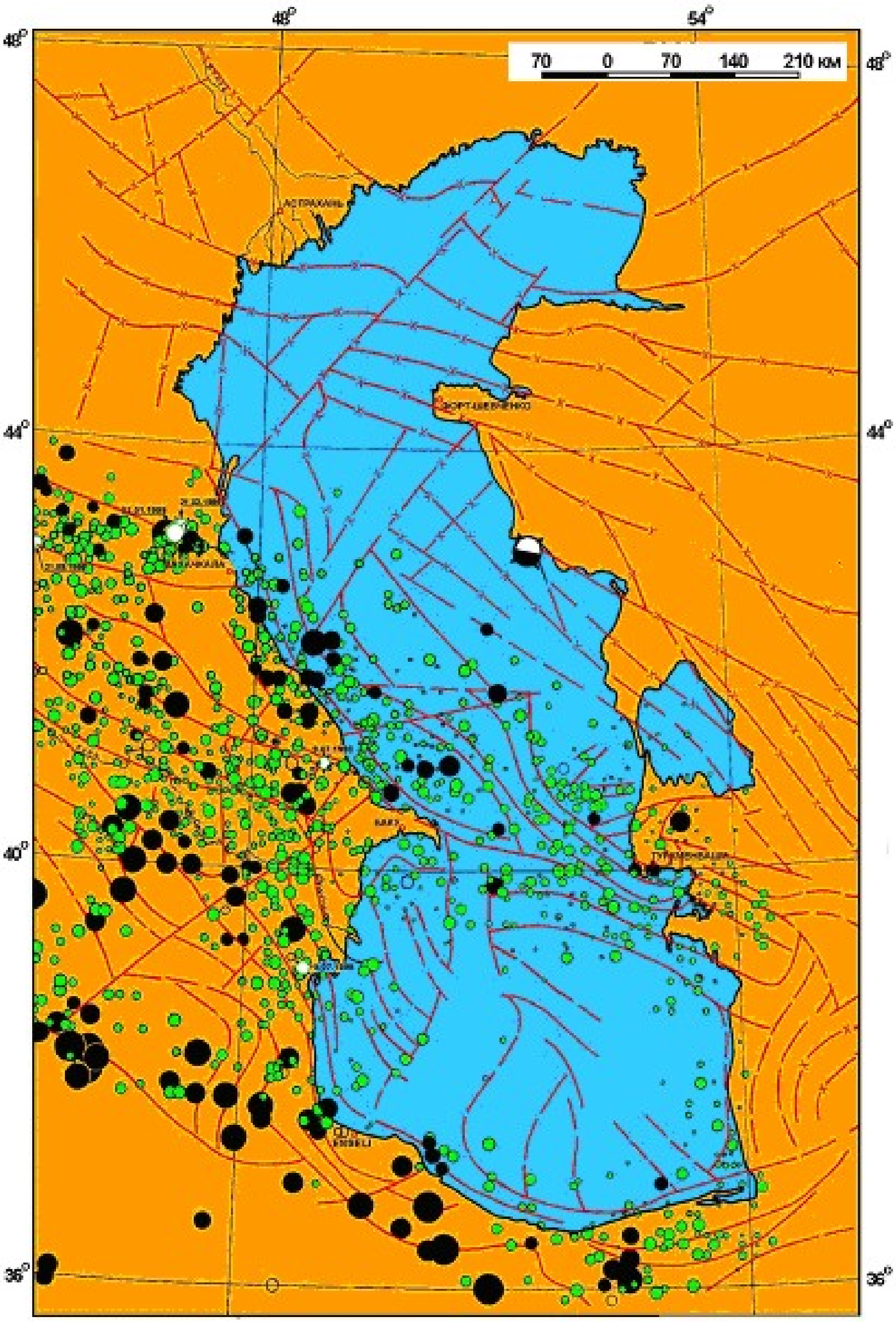


Fig. 28. Distribution of faults and earthquakes in the Caspian region. Compilation by L.E. Levin and N.V. Kondorskaya (with additional data from Panakhi, 1988; Kondorskaya and Ulomov, 1993; Special catalog of earthquakes GSHP; Caucasus test area). Legend: Black circles –Magnitude of Earthquakes; 'Sunbursts' – Catastrophic earthquakes during 1998 – 1999; 'Half-black circle' – Earthquake in 1273 with magnitude M=7.2; Solid lines – Active faults; Dashed lines – Probably active faults; Lines with x – Non-active faults.

Against a background of regional seismicity with magnitudes of $3 \leq M \leq 5.5$, more intense seismicity is confined to three belts: the Alborz – Resht – Lesser Caucasus belt with $M \geq 7.5 - 8.0$; the Greater Caucasus – Kopetdag belt with $M \geq 7.0$, and the Terek – Caspian trough – Greater Balkhan belt with $M \geq 6.0 - 6.5$. The second and third belts of more intense seismicity include a significant part of the South and Middle Caspian shelf. For instance, according to the data by B.M. Panakhi (Panakhi and Kasparov, 1988), epicenters of earthquakes of 1931 – 1982 in the South Caspian region were located mainly in the shelf or continental slope areas (approximately between isobaths of 100 and 500 m).

Sedimentary sequences in this area are crossed by abundant seismogenic fractures. This indicates that the seismicity in the land fringing the South Caspian is most likely related to continuing subsidence of the latter (Yakobson, 2000). Although the northern part of the Scythian and Turan plates, central part of the South Caspian Basin and South Azerbaijan volcanic massif were seismically inactive or almost inactive during the 20th century, there are historical data on the earthquake that occurred south of the Shevchenko Fort in 1273 that was characterized by an extremely high magnitude (M=7.2) (Polyakova and Medvedeva, 1997).

The statistical analysis of seismicity using recorded data since instrumental measurements have been taken (Kondorskaya and Ulomov, 1993; Kondorskaya et al., 1994) reveals irregular vertical distribution of hypoceneters and of released energy. The lithosphere is characterized by substantial layering and consists of nine layers that differ in number of hypocenters and released seismic energy (Levin *et al.,* 2001). Up to 80% of hypocenters and released seismic energy are confined to the elastic-brittle lithospheric layer at a depth of approximately 50 km. There are also separate intervals with higher and lower values of the released seismic energy. The maximum number of seismic events corresponds to depth intervals of 0 – 10 km and 11 – 20 km. These intervals are characterized by the inverse relationship between the number of earthquakes and energy of seismic waves. The interval of 0 – 10 km is marked by the maximum number of events (1,968) and a released energy value of 5.41×10^{20} ergs, whereas in the interval of 11 – 20 km these parameters are 916 and 66.00×10^{20} ergs, respectively. At depths exceeding 50 km, i.e., in the elastic-brittle layer of the lithosphere, the number of events and released energy substantially decrease. In the interval of 90 – 100 km the energy values increase again by two to three orders of magnitude whereas the number of events is low. This is explained by the large magnitudes of earthquakes caused by destruction of the elastic-brittle lithospheric layer in subduction zones. The occurrence of relatively deep-focus earthquakes along collision boundaries of the Alpine belt provided grounds for defining a new subduction type, the so-called *S-subduction* (Khain and Lobkovskii, 1994). It reflects intrusion of the cooled mantle part of the continental lithosphere into a relatively hot plastic-viscous mantle layer and, sometimes, immediately into the athenosphere. Destruction of cooled slabs of the supra-athenosphere mantle causes earthquakes of high magnitudes. This is confirmed by physical parameters of earthquake centers (Tuliani, 1983, 1999). The seismicity related to the S-subduction appears to be most intense when the plane of the subducted slab is crossed by regional lineaments as, for instance, in the Caucasus (Racha – Dzhava, Groznyi, and other earthquakes).

Five types of seismoactive zones are defined for shallow-focus earthquakes (Levin *et al.*, 2000):

- Along collision-type boundaries of plates;
- Along the boundary between the East Black Sea and South Caspian microplates associated with their horizontal displacement;
- Intra-plate seismicity along the periphery of athenospheric lenses with a sharp gradient of the lithosphere thickness;
- Seismoactive zones located immediately above athenospheric lenses;
- Intra-plate seismicity related to tectonic ruptures in the southern part of the Eurasian plate.

Some local peculiarities in seismicity are determined by the following points: (1) seismic intensity increases with time northward in the line of subduction and convective flow of the melted asthenosphere; (2) some earthquakes with magnitudes of ≥7.1 are localized above asthenospheric lenses, which indicates continuing process of athenospheric upwelling; and (3) areas of mud volcanism development are characterized by low seismicity.

Several strong earthquakes confirm the high seismicity of the collision boundary between the South Caspian microplate and Eurasian plate: e.g. Nebit-Dag (1978, 2000), Kum-Dag (1983), Burun (1984), and Baku (2000) earthquakes. These earthquakes and the analysis of seismicity for the central part of the Alpine belt provide grounds for defining the autonomous Apsheron – Cheleken – Kum Dag seismoactive zone along the collision boundary (Levin and Kondorskaya, 1997; Levin *et al.,* 2000). Such elevated seismicity is also characteristic of the zone of the Transcaucasian transcurrent uplift where its seismic activity also migrates northward (Rogozhin *et al.,* 1998). This is evident from the spatial distribution of several strong earthquakes (Paravan in Turkey, Spitak in Armenia, Racha – Dzhava in Georgia).

The seismicity of areas with mud volcanism development has been analyzed in special studies (Panakhi, 1988; Panakhi and Rakhmanov, 2000). Such seismicity is determined by the following parameters: (1) earthquake hypocenters occurring at depths of 10 – 20 km in sedimentary cover and 40 – 50 km in the earth crust and upper mantle; (2) low magnitudes of most earthquakes (M = 4.0 – 5.9 and occasionally up to 6.4); (3) absence of any specific relationship with mud volcano activity; eruptions are observed both prior to and after earthquakes.

Earthquakes with magnitudes of 5.0 to 5.8 and magnitudes exceeding 5.8 show some differences in their geodynamic settings: (1) destructive earthquakes with magnitudes ≥5.8 occurring at depths up to 40 km are confined either to peripheral areas of athenospheric upwelling zones or to plate boundaries with horizontal displacement; (2) similar earthquakes with hypocenter depths of 50 to 110 km result from destruction of cooled slabs of supra-athenosphere mantle in subduction zones. Earthquakes with magnitudes of 3.5 to 5.8 occur mainly along collision plate boundaries with sharp gradients in lithosphere thickness and immediately above athenospheric lenses. The areas with mud volcanism development are characterized by lowered or moderate seismic activity.

The most violent seismic zones in the Caspian region are the Apsheron – Cheleken – Kumdag zone and the Middle Caspian depression, where earthquakes occur in the subducting plate. Of similar violence are earthquakes occurring in the zone of the Transcaucasian transcurrent uplift, located west of the previously mentioned region.

CONCLUSIONS

In conclusion, it is useful to summarize comparative characteristics of the three basins constituting the Caspian hydrocarbon-bearing megabasin (Table 2).

Table 2.
Comparative characteristics of hydrocarbon-bearing basins of the Caspian region

Geological – geophysical parameters	**North Caspian**	**Middle Caspian**	**South Caspian**
Basement age Age of sedimentary fill	Precambrian Later Riphean or Devonian – Quaternary	Paleozoic Permian - Triassic	Paleozoic - Triassic Jurassic - Quaternary
Thickness of sediments, km	22 – 24	12 –14	22 – 25
Thickness of underlying crust	40	40	40
Thickness of lithosphere, km	200	150	70
Heat flow	Low	Moderate or elevated	Low or moderate
Stratigraphic interval with hydrocarbons	Devonian - Paleogene	Triassic - Miocene	Cretaceous - Eopleistocene
Age of main oil-generating formations	Devonian – Lower Permian	Jurassic, Aptian – Albian; Oligocene - Miocene	Oligocene - Miocene
Structural peculiarities	Salt diapirism	Platform-type folding; elements of disruption and diapirism in the south	Clay diapirism and mud volcanism

The information in the table demonstrates that these basins are more different than they are similar. In fact, the only similar features are those that are characteristic of all or most known hydrocarbon-bearing basins, i.e. a large thickness of sedimentary cover and rifting of the continental crust. All three basins belong to the single global-scale Barents – Caspian belt of oil- and gas-bearing basins, but they developed autonomously for a long time and were united only at the terminal stage of their individual evolution. They are also connected by inter-basin uplifts:

Karpinsky – Buzachi between the North Caspian and Middle Caspian basins and Apsheron – Balkhan between Middle and South Caspian basins. These uplifts received hydrocarbons generated in their adjacent basins and, as a consequence, contain large hydrocarbon accumulations, particularly the Apsheron sill.

The differences between these basins mostly concern the basement and riftogenesis age, destruction degree, stratigraphic range of sedimentary cover, interval of hydrocarbon-bearing sequence, age of hydrocarbon-generating formations, internal structure and parameters such as the lithosphere thickness, heat flow values and seismicity. Of importance is the difference in the destruction degree of the continental crust. It is minimal in the Middle Caspian basin and maximum in the South Caspian depression. This determines, to some extent, the thickness of sedimentary fill and hydrocarbon reserve potential, whereas the destruction degree itself is controlled by the activity of endogenic processes, subduction influence and mantle diapirism (athenospheric upwelling) at the riftogenic stage of basin development.

REFERENCES

Abasov, M.T., Abbasov, Z.Ya., Aliyarov, R.Yu., Dzhalalov, G.I., Kondrushkin, G.I., Mustafaev, R.T., Sarafanova, V.L., and Feizullayev, Kh.A., 2001. Development of the offshore deep-burried gas liquids, Azerbaijan. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 91–96 (in Russian).

Abdulin, A.A., Pilifosov, V.M., and Votsalevsky, E.S., 1995. New concepts of the mechanisms of the salt dome formation, North Caspian Basin. Geologiya Kazakhstana (Kazakhstan Geology), no. 5–6, pp. 23–32 (in Russian).

Abrams, M.A., and Narimanov, A.A., 1997. Geochemical evaluation of hydrocarbons and their potential sources in the western South Caspian depression, Republic of Azerbaijan. Marin. & Petrol. Geol., v. 14, pp. 451–468.

Adamia Sh.A., 1975. Plate tectonics and the evolution of the Alpine system: Discussion. Geol. Soc. Amer. Bul. v. 86, pp. 719–720.

Adamia, Sh.A., Gamkrelidze, I.P., and Zakariadze, G.S., 1977. Evolution of an active continental margin as exemplified by the Alpine history of Caucasus // Tectonophysics, v.40, no. 3/4, pp. 183–199.

Agabekov, M.G., Kerimov, K.M., Moshashvili, A.B., and Khain, V.Ye., 1976. New data on the structure of the central part of the Kura Basin. Geotektonika (Geotectonics), no. 5, pp. 76–82 (in Russian).

Akhmedbeyili, F.S., Budagov, B.A., Mamedov, A.V., et al., 1991. Neotectonic map of Azerbaijan. Scale 1:500 000. Baku Cartographic Enterprise. Baku (in Russian).

Akhmedbeyili, F.S., Korobanov, V.V., and Shirinov, A.N., 1999. Some peculiarities of geodynamic neotectonic processes in the hydrocarbon-bearing areas of Azerbaijan. In: “Neotectonics and its impact on forming and distribution of oil and gas pools”. Proceeding of International Meeting. Nafta-Press, Baku, pp. 21–25 (in Russian).

Akhmet’yev, M.A. and Zaporozhets, N.I., 1996. Dinocysts changes in the Paleogene and Lower Miocene successions of the Russian Platform, Crimea-Caucasus Region and Turan Plate as response to ecosystem reorganizations. In: The Problem of Micropaleontology. GEOS, Moscow, pp. 55–69 (in Russian).

Alavi, M., 1996. Tectonostratigraphic synthesis and structural style of the Alborz mountain system in northern Iran. J. Geodynam, v. 21, no. 1, pp. 1–33.

Aliev, N.A., 1998. Hydrocarbon potential of the South Caspian. Azerb. neft. khoz-vo (Azerbaijan petroleum industry), no. 7, pp. 2–7 (in Russian).

Alikhanov, E.N., 1964. Petroleum fields of the Caspian Sea. Azerbaijan State Publishing House, Baku, 370 p. (in Russian).

Alikhanov, E.N., 1977. Hydrocarbon-bearing potential of the Caspian Sea. Nedra, Moscow, 270 p. (in Russian).

Alikhanov, E.N., 1978. Geology of the Caspian Sea. Elm, Baku, 280 p. (in Russian).

Ali-Zadeh, A.A., Ashirmamedov, M., Khadzhinurov, N., Akmamedov, A., Amaniyazov, K., Solodkov, V., Uzakov, O., Geldyev, E., and Mamiesenov, N., 1985. Geology of the petroleum fields of south-western Turkmenistan. Ylym, Ashkhabad, 356 p. (in Russian).

Ali-Zadeh, Ak.A., 2000. Stratigraphy of the Mesozoic and Cenozoic deposits. In: I. Lerche, Ak.A. Ali-Zadeh (eds.) South Caspian Basin: stratigraphy, geochemistry, and risk analysis. Baku: Nafta-Press, pp. 6–93.

Aliyev, S.A., and Aliyev, A.S., 2000. Heat flow in depression of Azerbaijan. In: L. Gupra Mohan, M. Yamano (eds.) Terrestrial heat flow and geothermal energy of Asia. Oxford & IBH Publishing Co. PVT. Ltd. New Delhi.

Allen, M., Jackson, J., Hovius, N., Ghassemi, M., and Izmail-Zadeh, A., 2001. Neotectonics of the South Caspian Region: Incipient Subduction of a Trapped Ocean Basin. EUG XI Abstracts, Oxford University Press, pp. 399.

Allen, M.B., Jones, S., Ismail-Zadeh, A., Simmons, M., and Anderson, L., 2002. Onset of subduction as the cause of rapid Pliocene-Quarternary subsidence in the South Caspian basin. Geology, v. 30, no. 9. pp. 775–778.

Ammosov, I.I., and Sharkova, L.S., 1971. Catagenesis and hydrocarbon-bearing potential of the Jurassic formations, Southern Mangyshlak. In: The Problems of diagnostics of conditions and oil generation zones. IGIRGI, Moscow, pp. 31–57 (in Russian).

Ammosov, I.I. and Sharkova, L.S., 1973. Paleogeothermal fields and hydrocarbon-bearing potential of the Jurassic formations, West Central Asia and Kazakhstan. In: Geology and hydrocarbon-bearing potential of West Kazakhstan and Central Asia. Nauka, Moscow, pp. 90–96 (in Russian).

Aplonov, S.V., 1995. New data on geodynamics of the North Caspian Basin. Ros. Geofiz. zhurn. (Russian Geophysical Journal), no. 5–6, pp. 35–42 (in Russian).

Artyushkov, E.V., 1993. Physical tectonics. Nauka, Moscow, 456 p. (in Russian).

Artyushkov, E.V., Mörner, N.-A., and Tarling, D.H., 2000. The cause of loss of lithospheric rigidity in areas far from plate tectonic activity. Geophys. J. Int., v. 143, pp. 752–776.

Atlas of hydrocarbon-bearing and prospect areas of Azerbaijan., 1987. VSEGEI, Leningrad, (in Russian).

Axen, G.J., Lam, P.S., Grove, M., Stocklin, D.F., and Hassanzadeh, J., 2001. Exhumation of the west-central Alborz Mountains, Iran, Caspian subsidence, and collision-related tectonics. Geology, v. 29, no. 6. pp. 559–562.

Azizbekov, Sh.A., Bagirov, A.E., Veliev, M.M., Ismail-Zadeh, A.D., Nizheradze M.Sh., Yemel'anova, Ye.N., and Mamedov, M.N., 1979. Geology and volcanism of the Talesh. Elm, Baku, 246 p. (in Russian).

Baba-Zadeh, B.G., 1964. The classification of the hydrocarbon pools and fields of Azerbaijan and rational exploration strategy. Nedra, Moscow (in Russian).

Bagir-Zadeh, F.M., Narimanov, A.A., and Babaev F.R., 1988. Geological and geochemical peculiarities of the Caspian Sea fields. Nedra, Moscow, 207 p. (in Russian).

Bagir-Zadeh, F.M., et al., 1978. Subsurface structure and hydrocarbon-bearing potential of the South Caspian megabsin. Azerneshrb, Baku (in Russian).

Bailey, N.J.L., Guliyev, I.S., and Feyzullayev, A.A., 1996. Source rocks in the South Caspian. AAPG/ASPG Research Symposium "Oil and gas petroleum systems in rapidly-subsiding basins". Baku.

Barde, J.-P., Gralla, P., Harwijanto, J., and Marsky, J., 2002. Exploration at the eastern edge of the Precaspian basin: Impact of data integration on Upper Permian and Triassic prospectivity. Amer. Assoc. Petrol. Geol. Bull., v. 86, no. 3, pp. 399–415.

Berberian, M., 1983. The southern Caspian: A compressional depression floored by a trapped, modified ocean crust. Can. J. Earth Sci., v. 20, pp. 163–183.

Bredehoeft, J.D., Djevanshir, R.D., and Belitz, K.R., 1988. Lateral fluid flow in a compacting sand-shale sequence: South Caspian Basin. AAPG Bull., v. 72, pp. 416–424.

Brunet, M.-F., Volozh, Yu.A., Antipov, M.P., and Lobkovsky, L.I., 1999. The geodynamic evolution of the Precaspian Basin (Kazakhstan) along a north–south section. Tectonophysics, v. 313, pp. 85–106.

Buryakovsky, L.A., Dzhafarov, I.S., and Kerimov, V.Yu., 1991. Prospecting and Exploration of the offshore petroleum fields. Nedra, Moscow, 232 p. (in Russian).

Chadovich, T.Z., and Polovnikova, I.A., 1989. Geothermal conditions of the Mesozoic–Cenozoic sequences of western Kazakhstan. Sovetskaya Geologiya (Soviet Geology), no. 2, pp. 70–74 (in Russian).

Crawford, A.R., 1977. A summary of isotopic age data for Iran, Pakistan, and India. Liv. Mem. Albert F. de Lapparent. Mem. Hors-Serie No. 8 Soc. Geol. France, v. 8, pp. 251–260.

Dadashev, F.G., 2001. On prospects of the petroleum production in the South Caspian Basin during XXIst Century. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 173–176 (in Russian).

Devlin, W. J., Gogswel, J. M., Gaskins, G. M., Isaksen, G. H., Pitcher, D.M., Puls, D.P., Stanley, K.O., and Wall, G.R.T., 1999. South Caspian basin: young, cool and full of promise. GSA Today, v. 9, no. 7, pp. 1–9.

Dewey, W.J., Pitman, W.C., Ryan, W.B.F., and Bonnin, J., 1973. Plate tectonics and the evolution of the Alpine system. Geol. Soc. Amer. Bul., v. 84, pp. 3137–3180.

Dimakov, A.N., and Tamarov, A.I., 1973. Subsurface structure of the Mangyshlak. Proceedings of the All-Union Oil Research Geological Prospecting Institute, Issue 322, Nedra, Leningrad, 75 p. (in

Russian).
Fedorov, D.L., Konovalov, Yu.F., Levin, L/T., and Solodilov, L.N., 2000. Hydrocarbon-bearing potential and geodynamics of the Caspian-Caucasus Region. Nedra Povolzh'ya i Prikaspiya (Interior of the Volga and Caspian regions). NVNIIGG Proceedings, issue 23, Saratov, pp. 12–15 (in Russian).
Fomenko, K.E., 1972. The structure of the crystalline basement of the North Caspian basin on geophysical evidence. Geol. nefti i gaza (Petroleum Geology), no. 10, pp. 39–46 (in Russian).
Gadzhiev, A.N., 1985. Subsurface structure: seismostratigraphic peculiarities of the Mesozoic–Cenozoic sequences and the evaluation of the hydrocarbon-bearing potential of the South Caspian megabasin. Review: Geology and exploration of offshore petroleum fields. Issue 4, VNIIEGAZPROM, Moscow, pp. 1–41 (in Russian).
Gadzhiev, A.N., 1985. Tectonics and hydrocarbon-bearing potential of the Turkmen Shelf of the Caspian Sea based on geologic-geophysical evidence. Review: Geology and exploration of offshore petroleum fields. Issue 4, VNIIEGAZPROM, Moscow, pp. 1–36 (in Russian).
Gadzhiev, A.N. and Popkov, V.I., 1988. The structure of the sedimentary cover of the Middle Caspian. Geotektonika (Geotectonics), no. 6, pp 101–112 (in Russian).
Garetsky, R.G., Golov, A.A., Zhuravlev, V.S., Nevolina, N.V., Samodurov, V.I., Fomenko, K.E., Evektov, Ya. S., and Yanshin, A.L., 1972. North Caspian: the deepest depression of Precambrian cratons. XXIVth Session of the IGC. Reports of Soviet geologists, problem no. 3. Nauka, Moscow, pp. 102–112 (in Russian).
Gasanov, T.A., 1996. Geodynamics of the ophiolites in the structure of the Lesser Caucasus and Iran. Elm, Baku, 456 p. (in Russian).
Gasanov, T.A. and Alyeva S.G., 2001. The stratigraphy of Akchagylian and Apsheronian sequences in the piedmont of the south-western Lesser Caucasus. Otechestvennaya Geologiya (Domestic Geology), no. 2, pp. 29–34 (in Russian).
General Bathymetric Chart of the Oceans (GEBCO), 5th Edition (1975–1984). Published by the Canadian Hydrographic Service, Ottawa, Canada, under the authority of the IHO and the IOC (UNESCO). Scale 1:10000000, 19 sheets.
Geodekyan, A.A., Trotsyuk, V.Ya., Berlin, Yu.V., and Pilyak V.L., 1980. Genetic regularities in the hydrocarbon-bearing potential of the offshore areas. Nedra, Moscow, 268 p. (in Russian).
Geology and hydrocarbon-bearing potential of the Ciscaucasian Region, 2001. GEOS, Moscow, 299 p. (in Russian).
Grechishnikov, N.P., 1984. Paleogeothermal parameters of sediments in the platform part of the East Ciscaucasian Region and distribution of hydrocarbon pools. Sovetskaya Geologiya (Soviet Geology), no. 5, pp. 18–30 (in Russian).
Guliev, I.S. and Ivanov, V.V., 2001. A new paradigm for prospecting of hydrocarbons in the South Caspian basin. In: New ideas in the petroleum geology and geochemistry. Materials of a 5th Int. conf. Part I. Moscow State University, Moscow, pp. 113–115 (in Russian).
Guliev, I.S., Kadirov, F.A., Reilinger, R. E., Gasanov, R.I., and Mamedov, A.R., 2002. Active tectonics in Azerbaijan based on geodetic, gravimetric, and seismic data. Doklady Earth Sciences, v. 383, no. 2, pp. 174–177.
Guliev, I.S., Feysullaev, A.A., and Guseinov, D.A., 2001. Carbon Isotopic Composition of the Hydrocarbon Fluids of the South Caspian Megadepression. Geochemistry International, no. 3 pp. 237–243.
Guliev, I.S., Frantsu, I., Muller, R., Feysullaev, A.A., and Mamedova, S.A., 1991. Geological-geochemical peculiarities of the petroleum generation in the alpine intermontane troughs. Geokhimiya (Geochemistry), no. 1 pp. 148–156 (in Russian).
Guliyev, I.S., and Feizullayev, A.A., 1996. Geochemistry of hydrocarbon seepages in Azerbaijan. In: Hydrocarbon migration and its near-surface expression: AAPG Memoir, v. 66, pp. 63–70.
Guliyev, I.S., Feisullayev, A.A., and Tagiyev, M.F., 1997. Isotopic-geochemical characteristics of hydrocarbons in the South Caspian Basin. Energ. Explor. & Exploit., v. 15, no. 4/5, pp. 311–368.
Guliyev, I.S., Feyzullayev, A.A., and Huseynov, D.A., 2001. Isotope geochemistry of oils from fields and mud volcanoes in the South Caspian Basin, Azerbaijan. Petrol. Geosci., v. 7, pp. 201–209.
Huseynov, D.A., 2000. Origin of oils in the western part of the Kura – South Caspian oil-gas bearing basin. Extended Abstracts Book. 62th EAGE Conference and Technical Exhibition. Glasgow.
Inan, S., Yalcin, N., Guliev, I., Kuliev, K., and Feisullaev, A., 1997. Deep petroleum occurrences in the Lower Kura Depression, South Caspian Basin, Azerbaijan: an organic geochemical and basin modelling study. Marin. Petrol. Geol., v.14, no. 7/8, pp. 731–762.
Investigation on oil and gas genesis in the Bulgarian segment of the Black Sea, 1984. Bulg. Ac. of Sci., Sofia, 290 p. (in Russian).
Ismagilov, D.F., Kozlov, V.N., Martirosyan, V.N., and Terekhov, A.A., 2003. The Sediments of the Middle Caspian Region: Structure and Sedimentation History Based on Seismic Data. Geotectonics, v. 37, no. 4, pp. 304–315.
Ismagilov, D.F., Kozlov, V.N., Khortov. A.V., and Khortova G.V., 1999. On the prospects of the hydrocarbon-bearing potential in the North-West Caspian and in the Volga River delta based on results of seismic surveying under super-shallow

conditions. Geol., Geofiz. i razrab. neft. mestorozh. (Geology, Geophysics and Petroleum Fields Exploration), no. 3, pp. 19–22 (in Russian).

Ismail-Zadeh, A.D., 1999. Graben-riftogenic patterns of the Kura-South-Caspian Basin and regularities in distribution of fields. In: “Neotectonics and its impact on forming and distribution of oil and gas pools”. Proceeding of International Meeting. Nafta-Press, Baku, pp. 60–67 (in Russian).

Jackson, J., Priestley, K., Allen, M., and Berberian, M., 2002. Active tectonics of the South Caspian Basin. Geophys. J. Int., v. 148, pp. 214–245.

Kas’yanova N.A., 1998. A new data on the structure and hydrocarbon-bearing potential of the North-West Capian offshore. Geologiya nefti i gaza (Petroleum Geology), no. 4. pp. 10–16 (in Russian).

Katz, B., Richards, D., Long, D., and Lawrence, W., 2000. A new look at the components of the petroleum system of the South Caspian Basin. J. Petrol. Sci. Engin., v. 28, pp. 161–182.

Kengerli, T.N., 1996. Alpine geodynamics of the Earth crust of Azerbaijan. In: Proceedings of 5th Int. Congress of Intern. Ecoenergy Academy. Elm, Baku, pp. 199–205 (in Russian).

Kerimov, K.B., Gadzhiev, F.M., and Gasanov, I.S., 1999. Hydrocarbon resources of the Kura-South-Caspian megabasin. Azerb. neft. khoz-vo (Azerbaijan petroleum industry), no. 7, pp. 1–11 (in Russian).

Khain, V.E., 2000. The Barents-Caspian hydrocarbon-bearing belt as one of the world largest provinces. In: A.N. Dmitrievsky (ed.) Fundamental basis for the technological innovation in petroleum industry, Nauka, Moscow, pp. 17–22 (in Russian).

Khain, V.E., Lobkovsky L.I., 1994. Development scenarios of the residual mantle seismicity in the Alpine belt of Eurasia. Geotektonika (Geotectonics), no. 3, pp. 12–20, (in Russian).

Khalilov, E.N., 2003. New Data on the Existence of the Benioff Zone in the Caucasian–Caspian Region. Doklady Earth Sciences, v. 388, no. 1, pp. 138–140.

Kholodov, V.N., 2002. Mud Volcanoes, Their Distribution Regularities and Genesis: Communication 1. Mud Volcanic Provinces and Morphology of Mud Volcanoes. Lithology and Mineral Resources, v. 37, no. 3, pp. 197–209.

Kholodov, V.N., 2002. Mud Volcanoes: Distribution Regularities and Genesis (Communication 2. Geological–Geochemical Peculiarities and Formation Model). Lithology and Mineral Resources, v. 37, no. 7, pp. 293–309.

Khortov, A.V., and Shlezinger, A. Ye., 1999. The North Apsheron sedimentary basin and prospects of its hydrocarbon-bearing potential. Geol., geofiz. i razrabotka neft. mestorozhd. (Geology, Geophysics and Petroleum Fields Exploration), no. 8, pp. 12–14 (in Russian).

Kiryukhin, L.G., Volchegursky, L.F., and Kapustin, I.N., 1981. Tectonic map of the North Caspian basin. The subsalt series. Scale 1:1 000 000. Explanatory notes. VNIGRI, Leningrad (in Russian).

Kisin, I.G., 1967. Geothermal conditions and heat flow magnitude in the Central and Eastern Ciscaucasian Region. In: Regional geothermal flux and distribution of thermal waters in the USSR. Nauka, Moscow, pp. 108–114 (in Russian).

Kondorskaya, N.V., and Ulomov, V.I., 1993. The specialized earthquake catalogue of North Eurasia since antiquity to 1990. Earth science database of the RFBR Scientific Centre. http://www.scgis.ru/system of data bases (in Russian).

Kondorskaya, N.V., and Shebalin, N.V., Tatevossian R.E., 1994. Special catalogue of Earthquakes for the GSHAP. Test Area “Caucasus” from 2000 b. c. through 1993. http://www.scgis.ru/system of data bases.

Konishchev, V.S., 1984. The comparative tectonics of the halokinesis in the cratonic areas. Nauka i tekhnika (Science and engineering), no. 5, Minsk, 190 p. (in Russian).

Kopp, M.L., and Shcherba I.G., 1985. Late Alpine development of the East Caucasus. Geotektonika (Geotectonics), no. 6, pp. 94–108, (in Russian).

Kornev, V.V., Lutsuk, E.M., and Sungurnov, A.M. 1962. Basic characteristics of the Caspian Sea domain inferred from marine geophysics. Sovetskaya Geologiya (Soviet Geology), no. 12, pp. 80–90 (in Russian).

Korchagina, Yu.I., Guliev, I.S., and Zeinalova, K.S., 1988. Oil and gas source potential of the deep burried Mesozoic-Cenozoic sequences in the South Caspian Depression. In: The problem of the hydrocarbon-bearing potential of the Caucasus. Nauka, Moscow, pp. 34–40 (in Russian).

Kraichik, M.S., 1983. Geothermal criteria of the hydrocarbon-bearing potential in the western Turan Plate. (Geologiya nefti i gaza) Petroleum Geology, no. 7, pp. 44–48 (in Russian).

Krasnopevtseva, G.V., 1984. The deep structure of the Caucasus seismic region. Nauka, Moscow, 108 p. (in Russian).

Kroonenberg, S.B., Badyukova, E.N., Storms, J.E.A., Ignatov, E.I., and Kasimov, N.S., 2000. A full sea-level cycle in 65 years: barrier dynamics along Caspian shores. Sediment. Geol., v. 134, no. 3/4, pp. 257–274.

Krylov, N.A., 1971. General peculiarities of tectonics and hydrocarbon-bearing potential of young platforms. Nauka, Moscow, 156 p., (in Russian).

Kunin, N. Ya., 1977. Geologic patterns and oil-bearing potential of the North Caspian basin: the crustal structure. In: Geologic structure and hydrocarbon-bearing potential of the continental salt-dome areas based on geophysical evidence. Nedra, Moscow, pp. 90–95, (in Russian).

Kunin, N. Ya., and Korobkin, L.M., 1971. Regional geophysical investigations of the South Mangyshlak deep structure. In: Review: The regional prospecting and well logging. VIEMS, Moscow, pp. 3–20, (in Russian).

Kutas, R.I., Lyubimova, E.A., and Smirnov, Ya.B., 1975. Geological-geophysical analysis and the heat flow map of the European part of the USSR. In: Investigations of the thermal and electromagnetic fields of the USSR. Moscow, pp. 20–27 (in Russian).

Lebedev, L.I., Aleksina, I.A., Kulakova, L.S., Bars, E.A., Gorchilin, V.A., Edigaryan, Z.P., Narimanov, A.A., Nikishin, A.V., Pashaly, N,V., Skul'skaya, Z.M., Turovsky, D.S., Kholodov, V.N., and Yusufzadeh, Kh.B., 1987. The Caspian Sea. Geology and hydrocarbon-bearing potential. Nauka, Moscow, 295 p. (in Russian).

Lebedev, L.I., 2002. Prospects of the hydrocarbon-bearing potential of the Caspian Sea. In: M.N. Alekseev (ed.) Geology and mineral resources of the Russian shelves. GEOS, Moscow, pp. 141–165 (in Russian).

Lebedev, L.I., 2001. Prospecting of oil and gas pools in the South Caspian basin. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 74–77 (in Russian).

Letavin, A.I., 1978. The taphrogenic complex of the southern USSR young platform (tectonics, rock associations, and hydrocarbon-bearing potential). Nauka, Moscow, 148 p. (in Russian).

Letavin, A.I., Romanov, Yu.A., Savel'eva, L.M., and Shumova, T.F., 1975. Tectonics of the East Ciscaucasian Region. Nauka, Moscow, 80 p. (in Russian).

Levin, L.E., Solodilov, L.N., and Kondorskaya, N.V., 2000. The central part of the Alpine belt of Eurasia: geodynamics, thermal regime, seismicity. Vulkanologiya i seismologiya (Volcanology and seismology), No. 2, pp. 44–53 (in Russian).

Levin, L.E., and Fedorov, D.L., 2001. Middle Caspian and South Caspian basins: geological-geophysical characteristics of the hydrocarbon-bearing systems and distribution of the hydrocarbon resources. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 278–286 (in Russian).

Levin, L.E., Fedorov, D.L., and Guliyev, I.S., 2000a. Caspian region: Map of distribution of total potential resources of Paleozoic-Quaternary deposits. Center GEON and GIA. Moscow–Baku.

Levin, L.E., Fedorov, D.L., Aliyev, G.-M.A., and Guliyev, I.S. 2000b. Potential hydrocarbon resources of the South and Middle Caspian basins. In: Abstract-book of the Azerbaijan International geophysical conference. Baku., p. 119.

Levin, L.E., and Kondorskaya, N.V. 1997. Heat flow, plate tectonics and seismicity in the central part of the Mediterranean belt. In: Abstr. JASPEI. "The 29th Ass. of the Earth's Interior". The Saloniki, Greece, p. 92.

Lyubimova, E.A., Polyak, B.G., Smirnov, Ya.B., Kutas, R.I., Firsov, V.V., Sergeenko, S.I., and Lyusova, L.N., 1973. A review of heat flow data of the USSR. In: Heat flow from the Earth crust and upper mantle. Moscow, pp. 159–194 (in Russian).

Lyubimova, E.A., Nikitina, V.N., and Tomara, G.A., 1976. Thermal fields of the inner and marginal seas of the USSR, Nauka, Moscow, 84 p. (in Russian).

Mamedov, A.V., 1996. The geologic structure of the Middle Kura depression. Elm, Baku, 191 p. (in Russian).

Mavrichev, V.G., Kozeev, S.I., Vinogradov, P.A., Delia, C.V., Shtun', S.Yu., 2001. The multi-level basement of the North Caspian shelf and its manifestation in the structure of sedimentary cover inferred from the results of the large-scale aeromagnetic survey. Otechestvennaya geoloiya, No. 6 pp. 3–12 (in Russian).

Mirzoev, D.A., and Sharafudinov, F.G., 1986. Geology of oil and gas fields of Daghestan. Daghestan Publishing House, Makhachkala, 312 p. (in Russian).

Mirzoev, D.A., and Pirbudagov, V.M., 2001. Tectonics and hydrocarbon-bearing potential of the Daghestanian segment of the Terek-Caspian trough. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 265–270 (in Russian).

Novikov, V.P., 1975. The geothermal regime of sedimentary basins in different structural zones. In: The problems of geology and hydrocarbon-bearing potential in the eastern USSR, Moscow, pp. 19–27 (in Russian).

O`Conner, R.B. Jr., Castle, R.A., Nelson, D.R. 1993. Future oil and gas potential in Southern Caspian basin. Oil and Gas J. v. 3, pp. 117–126.

Ognev, A.O., and Zhylkaidarova, A.M., 1986. Physical properties of sedimentary rocks in the Western Turan plate. Geologita nefti i gaza (Petroleum Geology), no. 7, pp. 43–49 (in Russian).

Oil and gas fields of the USSR, 1987. Nedra, Moscow, v. 1, 301 p., v. 2, 357 p. (in Russian).

Okun'kova, F.E., 1971. Mineralogical-petrographical criteria for hydrocarbon-bearing of rocks: a case of the East Ciscaucasian region. VNIGNI Proceedings, issue 98, pp. 59–85 (in Russian).

Panakhi B.M., 1988. Seismicity of the mud volcanism areas. Doctorate dissertation (physics and mathematics), OIPZ RAS, Moscow.

Panakhi B.M., and Kasparov, V.A., 1988. The problems of the Caspian Sea seismic regime. Izv. AN AzSSR, Earth Sciences Series, no. 1, pp. 91–98 (in Russian).

Panakhi B.M., and Rakhmanov, R.R., 2000. Seismicity of mud volcanism areas. In:

Prediction and control of geodynamic and environmental conditions in the Caspian Sea Region in connection with development of the oil and gas industry. Scientific World, Moscow, p. 11–112 (in Russian).

Peters, K.E., Ishiwatari, R., and Kaplan, I.R., 1977. Color of kerogen as index of organic maturity. Amer. Assoc. Petrol. Geol. Bull., v. 61, no. 4, pp. 504–510.

Pilifosov, V.M., 1986. Seismostratigraphic models of the subsalt sequences of the North Caspian basin. Nauka, Alma-Ata, 189 p. (in Russian).

Pilifosov, V.M., Votsalevsky, E.S., Azerbaev, N.A., and Pronin, A.P., 1997. The problem of Paleozoic volcanism of the southern North Caspian basin. Geology of Kazakhstan, no. 1, pp. 4–10 (in Russian).

Pilifosov, V.M., Votsalevsky, E.S., and Vasil'ev, B.A., 1996. Tectonics of the North Caspian–North Ustyurt junction area. Geologiya Kazakhstana (Geology of Kazakhstan), no. 1, pp. 66–79 (in Russian).

Polyakova, T.P., and Medvedeva, N.S., 1997. A nontraditional approach to seismic hazard estimation. Doklady Earth Sciences, v. 356, no. 7, pp. 1118–1122.

Popkov, V.I., 1992. Tectonics of the western Turan Plate. IGiRGI, Moscow, 148 p. (in Russian).

Popkov, V.I., Voskoboy, V.A., and Nurmanov, A.M., 1993. Subsurface structure of the North Ustyurt inferred from the common midpoint shooting. IGiRGI, Moscow, 93 p. (in Russian).

Priestley, K., Baker, C., and Jackson, J. 1994. Implication of earthquake focal mechanism data for the active tectonics of the south Caspian Basin and surrounding regions. Geophys. J. Int., v. 118, pp. 111–141.

Rezanov, I.A., and Chamo, S.S. 1969. Reasons for absence of a granitic layer in basins of the south Caspian and Black sea type. Can. J. Earth Sc., v. 6, pp. 671–678.

Rodionova, K.F., Burshtar, M.S., Mileshina, A.G., and Okun'kova, F.E., 1972. Geochemical peculiarities of Jurassic and Lower Cretaceous rocks and oils in the East Ciscaucasian region. VNIGNI Proceedings, issue 120, pp. 68–75 (in Russian).

Rogozhin, E.A., Nechaev, Yu. V., Solodilov, L.N., and Ismail-Zadeh, T.A., 1998. Seismicity trends in the Caucasus and seismogenic zones of the Stavropol region. Razvedka i okhrana nedr (Prospecting and resources conservation), no. 2, pp. 23–28 (in Russian).

Saint-Germes, M.L., Bazhenova, O.K., Baudin, F., Zaporozhets, N.I., and Fadeeva, N.P., 2000. Organic Matter in Oligocene Maikop Sequence of the North Caucasus. Lithology and Mineral Resources, v. 35, no. 1, pp. 47–62.

Sergienko, S.I., 1971. Geothermal regime of the East Ciscaucasian region. Nauka, Moscow, 96 p. (in Russian).

Shahpasand-Zadeh, M., 1991. Structural analysis and sedimentary environment of Gorgan metamorphic complex (Gorgan schist). M.Sc. Thesis. Tehran: Univ. of Tarbiat Moallem. 297 p.

Shikalibeili, E. Sh., and Grigoriants, B.V. 1980. Principal features of the crustal structure of the south-Caspian basin and the conditions of its formations. Tectonophysics, v. 69, pp. 113–121.

Shikhalibeili, E. Sh., 1996. Some problems of the geological structure and tectonics of Azerbaijan. Elm, Baku, 215 p. (in Russian).

Silant'ev, Yu.B., 1997. Thermodynamic models of the North and Middle Caspian as a basis for prospecting hydrocarbon-bearing potential. Geol., geofiz. i razrabotka neft. mestorozhd. (Geology, Geophysics and Petroleum Fields Exploration), no. 8, pp. 5–8 (in Russian).

Sobornov, K.O., 1996. Structural Segments of the East Caucasus Thrust Belt. Geotectonics, v. 30, no. 5, pp. 410–421.

Stocklin, J., 1974. Northern Iran: Alborz Mountains. Geol. Soc. London Special Pub., no. 4, pp. 213–234.

Tagiev, M.F., Nadirov, R.S., Bagirov, E.B., and Lerche, I. 1997. Geohistory, thermal history and hydrocarbon generation history of the north-west South Caspian basin. Marin. Petrol. Geol. v. 14, no. 4, pp. 363–382.

Trotsyuk, V.Ya. 1982. Prospects of hydrocarbon-bearing potential in the offshore areas. Nedra, Moscow, 200 p. (in Russian).

Trotsyuk, V.Ya., and Marina, M.M., 1988. Organic carbon in the World Ocean sediments. Nauka, Moscow, 174 p. (in Russian).

Trukhachev, N.S., 1976. Geologic peculiarities in distribution of the oil and gas pools within the sedimentary cover of the Kalmykia–Astrakhan' North Caspian. VNIIOENG, Moscow, 77 p. (in Russian).

Tsimmer, V.A., 1977. On the nature of the subsurface interfaces in the North Caspian basin. In: Crustal and upper mantle structure inferred from the seismic profiling records. Naukova Dumka, Kiev, pp. 302–306 (in Russian).

Tuliani, L.I., 1983. Relationship between the earthquake magnitude and thermodynamic characteristics of the seismofocal zone. Doklady AN SSSR, vol. 270, no. 1, pp. 74–77 (in Russian).

Tuliani, L.I., 1999. Seismicity and seismic risk based on thermodynamic and rheologic characteristics of the tectonosphere. Nauchnyi Mir, Moscow, 210 p. (in Russian).

Vincent, S.J., Allen, M.B., Inger, S., Simmons, M.D., Hinds, D., Voronova, L., Ismail-Zadeh, A., Hovius, N., Barabadze, T., Ghassemi, M., Flecker, R., Jackson, J., and Aliyeva, E. 2001 Arabian-Eurasia Collision and the Development of Alborz-Talysh-Caucasus Ranges; Petroleum System Implications for the South Caspian and Eastern Black Sea Basins. AAPG Bulletin. v. 85, no. 13 (Supplement). AAPG Annual Meeting, Denver, Colorado, June 3-6.

Volozh, Yu.A., Antipov, M.P., Leonov, Yu.G., Morozov, A.F., and Yurov, Yu.A., 1999. Structure of the Karpinsky Range. Geotectonics, v. 33, no. 1, pp. 24–38 (in Russian).

Volozh, Yu.A., 1991. Sedimentary basins of the Western Kazakhstan on the basis of seismic stratigraphy. Doctorate dissertation (Geology and Mineralogy), GIN Ac. Sci. USSR, 49 p. (in Russian).

Volozh, Yu.A., Votsalevsky, E.S., Pilifosov, and V.M., 1989. The problem of the hydrocarbon-bearing potential of suprasalt sequences, North Caspian Basin. Izv. of Kazakhstan SSR Ac. Sci., Geol. Ser., no. 4, pp. 3–15 (in Russian).

Volozh, Yu.A., Lipatova, V.V., et al., 1981. The Triassic of southern Mangyshlak. VNIGNI Proceedings, issue 224, 210 p. (in Russian).

Volozh, Yu.A., Sapozhnikov R.B., and Tsimmer, V.A., 1975. The crustal structure of the North Caspian Depression. Sov. Geol. (Soviet Geology), no. 11, pp. 93–101, (in Russian).

Volchegursky, L.F., Vladimirova, T.V., Kapustin, I.N., and Natapov, L.M., 1995. The evolution of the North Caspian Depression during the Middle–Late Paleozoic. Otechestvennaya Geologiya (Domestic geology), no. 2, pp. 44–49 (in Russian).

Voronin, N.I., 2001. Tectonic history and hydrocarbon-bearing potential of the Astrakhan Arch. In: Ye.B. Grunis, N.A. Krylov (eds.), Actual problems of the petroleum geology. Nauchnyi Mir, Moscow, pp. 229–224 (in Russian).

World Atlas, 1999. 3rd Edition. Russian Federal Survey of Geodesy and Cartography, Roskartografia, 563 p. (in Russian).

Yakobson, A.N., 2000. Lithosphere of the South Caspian. Otechestvennaya Geologiya, no. 2, pp. 57–64 (in Russian).

Yassini, I., 1981. Paratethys Neogene deposits from the Southern Caspian Sea, North Iran. Bul. Ir. Petrol. Inst., no. 83, pp. 1–23.

Zamarenov, A.K., Shebaldina, M.G., Fedorov, D.L., Yugay, T.A., and Yatskevich, S.V., 1986. The subsalt hydrocarbon-bearing formations of the North Caspian basin: sedimentary models. Nedra, Moscow, 137 p. (in Russian).

Zhuravlev, V.S., 1972. Comparative tectonics of the exogonal depressions of the East Europe Platform, Pechora, North Caspian and North Sea basins. Nauka, Moscow, 397 p. (in Russian).

Zolotov, A.N., Solov’ev, B.A., Obryadchikov, O.S., Fedorov, D.L., Kononov, Yu.S., and Utegaliev, S.U., 1989. Discovery and prospecting of the unique fluidal system fields in the subsalt complex of the North Caspian Basin. In: G.A. Gabrielyanz (ed.), Oil and gas prospecting. Reports of Soviet geologists, XXVIIIth Session of the IGC, VNIGNI, Moscow, pp. 48–56 (in Russian).

Zonenshain, L.P., and Le Pichon, X., 1986. Deep basins of the Black Sea and Caspian Sea as remnants of Mesozoic back-arc basins. Tectonophysics, v. 123, pp. 181–211.

Zonenshain, L.P., Kuzmin, M.I., and Natapov, L.M., 1990. Geology of the USSR: a plate tectonics synthesis. In: B.M.Page (Ed.), Geophysics Geodynamics Series, vol. 21. American Geophysical Union, Washington, DC. 242 pp.

List of hydrocarbon accumulations in the Caspian region

(see Fig. 18)

A. North Caspian depression

1. Astrakhan’ (C_2b)
2. Raznochinkovskoe (N_2)
3. Kirikilinskoe (N_2)
4. Talovskoe (J_3)
5. Karakul’skoe
6. Beshkul’skoe (J_2a)
7. Oktyabr’skoe (J_2cl)
8. Zaburunskoe (K_1nc-a)
9. Gran (J_2, K_1al)
10. Zhanatalap (J_2b-bt; K_1br-a)
11. Martyshi (J_2bt; K_1br-a)
12. Vostochnye Martyshi (K_1br-a)
13. Chalik (K_1)
14. Kamyshitovoe (K_1br-al)
15. Yuzhno-Kamyshitovoe (J_2; K_1al)
16. Baichunas (J_2; K_1br-a; K_2km)
17.Tentyaksor (K_1ht, a)
18. Korsak (K_1a-al; K_2t-km)
19. Airankul (K_1nc-a)
20. Kyzylkala (J_2; K_1a)
21. Koschagyl (T_3; J_2; K_1)
22. Kulsara (T_3; J_2b-cl; K_1a-al)
23.Tyulyus (J_2b,cl)
24. Zapadnyi Terenuzyuk (K_1al; K_2km)
25. Terenuzyuk (K_1vl,a-al; K_2st-t-km)
26. Pustynnoe (K_1; K_2cm)
27. Karaton (J_2; K_1br, a1; K_2km; Pg_2)
28. Pribrezhnoe (K_1al; K_2km)
29. Tazhigali (J_2; K_1br, a1; K_2cm)
30. Koshkimbet (K_1–K_2)
31. Karaarna (K_1a-al; K_2cm)
32. Vostochnyi Karasor (K_2)
33. Korolevskoe (C_2b; K_2cm)
34. Tengiz (C_2b)
35. Morskoe (K_1a-al)
36. Zapadnaya Prorva (T_3; J_2bt; J_3)
37. Tsentral’naya Prorva (T_3; J_2bt; J_3)
38. Aktyube (J_2bt-cl)
39. Lebyazh’e (J)
40. Kashagan (C_1oks-sr, C_2b)
41. Kalamkas (J_2; K_1ht-a)
42. Karazhanbas (J_2bt; K_1ht-br)
43. Bol’shesorskoe (J; K)
44. Severo-Buzacinskoee (J_2bt; K_1br-a)
45. Zhalgyztyube (K_1br)
46. Severo-Karynskoe

B. Middle Caspian basin

47. Tsubukskoe (K_1al)
48. Tengutinskoe (J_2; K_1)
49. Oleinikovskoe (K_1)
50. Mezhevoe (K_1)
51. Promyslovskoe (K_1; K_2)
52. Dvoinoe (K_1a)
53. Nadezhdinskoe (K_1a)
54. Krasnokamyshanskoe (K_1a)
55. Severo-Kamyshanskoe (K_1a)
56. Ekaterininskoe (K_1a)
57. Komsomol’skoe (J_2; K_1)
58. Svetloyarskoe (J_2; K_1)
59. Nadyn-Khudukskoe (K_1a)
60. Vostochno-Kamyshanskoe (K_1a)
61. Chernozemel’skoe (K_1a)
62. Ermolinskoe (K_1a)
63. Ulankhol’skoe (K_1nc-a)
64. Kaspiiskoe (J_2; K_1)
65. Yuzhno-Buinakskoe (T_2)
66. Stepnoe (J_2; J_3; K_1nc)
67. Iminskoe
68. Sukhokumskoe (J_2; J_3; K_1nc-a)
69. Vostochno-Sukhokumskoe (T; J; K)
70. Dakhadaevskoe (J; K)
71. Ravninnoe (T; J)
72. Solonchakovskoe (T; J; K)
73. Yubileinoe (T_1; J_3; K_1nc)
74. Yuzhno-Talovskoe (T)

74a. Khvalynskoe (J, K)

75. Kumukhskoe (T_1)
76. Gudermesskoe (K_2; N_1)
77. Benoi (K_2; Pg_1; Pg_3)
78. Shamkhal-Bulakskoe (K_1; K_2; Pg_1)
79. Ternair (N_1)
80. Makhachkalinskoe (K_2km; N_1)
81.Tarki (K_2)
82. Dmitrovskoe (K_2)

83. Achi-Su (K_2; N_1)
84. Izberbash (N_1)
85. Inchkhe-more (N_1)
86. Gasha (K_2km)
87. Selli (K_2km)
88. Kayakent (N_1)
89. Berikei (K_1; Pg_3)
90. Duzlak (K_1; Pg_3)
91. Dagestanskie Ogni (K_1; Pg_3)
92. Khoshmenzil (N_1)
93. Tyubedzhikskoe (K_1nc-al)
94. Zhangurshi (K_1nc-al)
95. Skalistoe (K_1a)
96. Zholaksan (K_1a)
97. Dunga (J_1cl; K_1a)
98. Espelisai (J_2cl)
99. Karimanskoe (J)
100. Karsyaz-Tospasskoe
101. Tarlinskoe (J_2)
102. Assar (J_1; J_2a-cl)
103. Burmasha (J_2b)
104. Zhetybai (J_2a-cl)
105. Vostochnyi Zhetybai (J_2aal-b)
106. Karamandybas (J_1; J_2a-cl)
107. Uzen (J_2a-cl; K_1nc, al; K_2cm)
108. Tenge (J_2a-cl)
109. Shalabaiskoe (J_2)
110. Kurganbai (J)
111. Kaundy (J)
112. Oimasha (T_2)
113. Rakushechnoe (T_1; J_2b)
114. Severo-Rakushechnoe (T_1; J_2b)
115. Tamdi (K_1nc)

C. South Caspian basin

116. Zagli-Zeiva (K_1al)
117. Siazanskoe (K_1; Pg_3-N_1^1)
118. Sovetobad (K_1al)
119. Zapadno-Apsheronskoe (N_2^2)
120. Banka Apsheronskaya (N_2^2)
121. Banka Darvina (N_2^2)
122. Artem (N_2^2)
123. Gyurgany-more(N_2^2)
124. Ostrov Zhiloi (N_2^2)
125. Yuzhnoe - 1 ((N_2^2)
125a.Yuzhnoe -2 (N_2^2)
126. Aslanovo (N_2^2)
127. Gryazevaya Sopka (N_2^2)
128. Neftyanye kamni -1 (N_2^2)
128a. Neftyanye kamni - 2 (N_2^2)
129. Gyuneshli (N_2^2)
130. Chirag (N_2^2)
131. Azeri (N_2^2)
132. Promezhutochnoe (N_2^2)
133. Livanovo-Tsentr (N_2^2)
133a. Livanovo-vostochnoe (N_2^2)
134. Barinova (N_2^2)
135. Gubkina (N_2^2)
136. Aga-Neimatulla (N_2^2)
137. Lam (N_2^2)
138. Zhdanovo (N_2^{2+3})
139. Pricheleken-kupol (N_2^2)
140. Cheleken-susha (N_2^{2+3})
141. Cheleken-vostochnyi (N_2^{2+3})
142. Koturtepinskoe (N_2^2)
143. Barsagel'messkoe (N_2^2)
144. Burunskoe (N_2^2)
145. Nebit-Dag (N_2^2)
146. Kara-Tepe (N_2^2)
147. Balakhany-Romany (N_2^2)
148. Surakhany (N_2^2)
149. Buzovny-Mashtagi (N_2^2)
150. Kala (N_2^2)
151. Gousany (N_2^2)
152. Zyrya (N_2^2)
153. Binagady (N_1; N_2^2)
154. Sulutepe- Atashkya (N_1; N_2^2)
155. Bibi-Eibat (N_2^2)
156. Sarycha-Gyulbakht (N_2^2)
157. Lokbatan (N_2^2)
158. Shongar (N_2^2)
159.Puta-Kergez (N_2^2)
160. Karadag (N_1; N_2^2)
161. Karadag-more (N_2^2)
162. Umbaki (N_2^2)
163. Miadzhik (N_1; Pg_3)
164. Kyanizadag (Duvannyi) (N_2^2)

165. Samgachaly-more (N_2^2)
166. Duvannyi-more (N_1; N_2^2)
167. Ostrov Bulla (N_2^2)
168. 8 Marta (N_2^2)
169. Bulla-more (N_2^2)
170. Peschanyi-more (N_2^2)
171. Bakhar (N_2^2)
172. Dashgil-Delyaniz (N_2^2)
173. Alyaty-more (N_2^2)
174. Kalamadyn (N_2^2)
175. Pirsagat (N_2^2)
176. Garasu (N_2^2)
177. Mishovdag (N_2^2)
178. Kalmas (N_2^{2+3})
179. Khudyrly (N_2^{2+3})
180. Azgybir (N_2^2)
181. Kyursangya (N_2^{2+3})
182. Kyurovdag (N_2^{2+3})
183. Karabagly (N_2^{2+3})
184. Babazanan (N_2^2)
185. Khilly (N_2^2)
186. Neftechala (N_2^{2+3})
187. Kum-Dag (N_2^{2+3})
188. Kyzyl-Kum (N_2^{2+3})
189. Kuidzhik (N_2^2)
190. Erdekli (N_2^2)
191. Gograndag (N_2^2)
192. Ekiz-Ak (N_2^2)
193. Karadashlinskoe (N_2^2)
194. Kamyshladzha (N_2^2)
195. Okaremskoe (N_2^2)
196. Bugdaily (N_2^2)
197. Shakhman (N_2^2)
198. Akmani (N_2^2)
199. Chukuri (N_2^2)
200. Khangul (N_2^2)
201. Keimir (N_2^2)
202. Akpatlaukh (N_2^2)
203. Adamkutu (N_2^2)
204. Chainok (N_2^2)
205. Chikishlyar (N_2^2)
206. Kavyl (N_2^2)
207. Gasankuli (N_2^2)
208. Adzhiyat (N_2^2)
209. Kukurchan (N_2^2)
210. Chalayuk (N_2^2)
211. Zardob (N_2^2)
212. Muradkhanly (K_2; Pg_1;N_1)
213. Kazanbulag (Pg_2; Pg_3)
214. Adzhidere (Pg_3)
215. Naftalan (Pg_3)
216. Mirbashir (Pg_3)

Appendix 2

Pyrolytic characteristics of organic matter, western fringing of the Middle Caspian Basin

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	C_{opr}, wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
1	2	3	4	5	6	7	8	9
1	Oleinikovskaya, 4	1232,0	K_1apt-alb	0,47	2,05	2,5	79	478
		1244,0	K_1apt-alb	0,09	1,44	0,82	175	481
2	Dzhanaiskaya, 2	1742,0	K_1apt-alb	0,13	0,92	0,81	113	445
		1905,0	K_1apt-alb	0,03	0,7	0,25	68	437
		1926,0	K_1apt-alb	0,14	0,22	0,28	78	444
3	Krasnokamyshanskaya, 3	1906,0	K_1apt-alb	0,18	1,63	1,25	130	437
		2149,0	K_1apt-alb	0,14	0,62	0,53	116	433
		2194,0	K_1apt-alb	0,35	2,12	1,56	135	436
		2197,0	K_1apt-alb	0,8	0,35	0,28	125	482
4	Kaspiiskaya, 4	1572,0	K_1apt-alb	0,28	1,04	0,87	119	467
		1578,0	K_1apt-alb	0,15	0,65	0,39	116	470
		1582,0	K_1apt-alb	0,15	0,93	0,72	129	432
5	Solnechnaya, 6	3129,0	K_1apt-alb	0,13	0,91	0,74	122	445
		3498,0	J_2bj-bt	0,13	0,77	0,40	192	459
		3514,0	J_2bj-bt	1,09	2,79	0,95	293	445
		3521,0	J_2bj-bt	5,50	8,37	2,72	307	458
		3592,0	J_2bj-bt	0,72	14,39	5,32	270	451
		3725,0	J_2bj-bt	0,07	1,00	0,83	120	463
		3776,0	J_2bj-bt	0,37	8,02	5,17	155	461
6	Buinakskaya, 1	3485,0	J_2bj-bt	0,06	0,83	0,42	193	448
		3490,0	J_2bj-bt	0,09	1,27	0,60	211	443
		3513,0	J_2bj-bt	0,04	0,47	0,43	109	447

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	C_{opr}, wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
		3680,0	J_2bj-bt	0,06	0,54	0,43	125	451
		3741,0	J_2bj-bt	0,07	0,49	0,36	136	460
		3801,0	J_2bj-bt	0,08	0,75	0,48	156	448
		3941,0	J_2bj-bt	0,34	1,53	0,77	198	447
		3979,0	J_2bj-bt	0,08	0,94	0,72	130	457
7	Artezianskaya, 1	2624,0	K_1apt-alb	0,44	1,36	0,83	163	438
		2742,0	K_1apt-alb	0,24	1,04	0,77	135	440
		2751,0	K_1apt-alb	0,20	0,83	0,99	87	436
8	Zhuravsko-Severnaya, 1	1933	P	0,17	0,62	0,34	182	439
		3070,0	K_1apt-alb	0,14	0,35	0,29	120	458
		3090,0	K_1apt-alb	0,12	0,30	0,23	130	469
		3193,0	K_1apt-alb	0,22	0,54	0,54	100	472
		3334,0	K_1apt-alb	0,12	0,29	0,31	93	468
		3497,0	K_1apt-alb	0,01	0,28	0,28	100	532
9	Pasholkinskaya, 1	3133,0	K_1apt-alb	0,11	0,14	0,11	127	490
		3367,0	K_1apt-alb	0,30	0,56	1,24	145	486
		3377,0	K_1apt-alb	0,37	0,72	1,52	47	476
10	Dovsunskaya, 4	2999,0	K_1apt-alb	0,18	0,63	0,35	180	466
		3006,0	K_1apt-alb	0,21	0,78	0,63	123	464
		3012,0	K_1apt-alb	0,29	0,91	0,64	142	461
		3050,0	K_1apt-alb	0,02	0,18	0,14	128	468
11	Ullubievskaya, 1	3358,0	K_1apt-alb	0,10	0,58	0,91	63	444
		3384,0	K_1apt-alb	0,112	0,52	0,80	65	442
		3408,0	K_1apt-alb	0,14	0,24	0,33	72	440

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	C_{opr}, wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
12	Severo-Kochubeevskaya, 1	3415,0	K_1apt-alb	0,10	1,18	0,88	134	434
		3452,0	K_1apt-alb	0,14	0,21	0,32	65	438
		3900,0	K_1apt-alb	0,12	0,87	0,62	140	447
		3915,0	K_1apt-alb	0,15	1,0	0,65	153	451
		4189,0	K_1apt-alb	0,14	1,03	0,53	194	463
	Severo-Kochubeevskaya, 2	3686,0	J_2bj-bt	0,23	0,76	0,52	146	441
		3900,0	J_2bj-bt	0,23	1,79	0,95	188	460
		3918,0	J_2bj-bt	0,22	1,07	0,66	162	457
		3945,0	J_2bj-bt	0,11	1,05	0,51	205	454
		3952,0	J_2bj-bt	0,18	1,40	0,91	153	456
		4080,0	J_2bj-bt	0,22	1,02	0,47	217	464
13	Perekrestnaya, 12	3410,0	K_1apt-alb	0,07	0,65	0,45	144	442
		3416,0	K_1apt-alb	0,09	0,08	0,04	200	443
		3717,0	J_2bj-bt	0,14	1,22	0,49	248	464
		3794,0	J_2bj-bt	0,20	1,22	0,63	193	463
		3888,0	J_2bj-bt	0,12	0,86	0,42	204	470
		3925,0	J_2bj-bt	0,12	1,58	0,63	250	472
14	Maiskaya, 2	2595,0	P_3	2,21	44,83	5,57	804	435
		2600,0	P_3	1,68	37,85	4,80	788	437
15	Stal'skaya, 1	2751,0	P_3	2,25	27,95	4,2	665	431
		2756,0	P_3	1,75	20,32	3,12	651	431
16	Kapievskaya, 1	2750,0	P_3	0,24	1,87	0,65	287	434

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	C_{opr}, wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
17	Tarumovskaya, 1	4251,0	K_1apt-alb	4,15	7,41	1,99	372	444
		4269,0	K_1apt-alb	0,29	1,17	0,66	177	450
		4547,0	K_1apt-alb	0,07	0,35	0,74	47	460
		4554,0	K_1apt-alb	0,04	0,32	0,53	60	462
		4665,0	K_1apt-alb	0,03	0,30	0,43	69	479
		4673,0	K_1apt-alb	0,03	0,39	0,46	84	469
		4744,0	K_1apt-alb	0,02	0,14	0,15	93	464
18	Arkhangel'skaya, 1	3435,0	K_1apt-alb	0,38	0,38	0,48	79	385
		3708,0	K_1apt-alb	0,09	0,40	0,50	80	471
		3730,0	K_1apt-alb	0,02	0,09	0,09	100	488
19	Baksan, 14	749,2	J_2 bj-bt	0,07	0,46	0,28	164	448
		765,2	J_2 bj-bt	0,13	1,04	0,60	173	443
		784,2	J_2 bj-bt	0,11	0,44	0,21	209	449
		990,2	J_2 bj-bt	0,05	0,65	0,55	118	444
		1029,3	J_2 bj-bt	0,08	0,82	0,83	98	449
		1034,2	J_2 bj-bt	0,01	0,49	0,42	116	443
		1040,9	J_2 bj-bt	0,03	0,58	0,51	113	443
		1044,8	J_2 bj-bt	0,03	0,63	0,32	196	449
20	Argudan-Urukh, 35	837,4	P_3	0,25	2,68	1,118	148	411
		853,1	P_3	0,38	7,61	3,03	251	411
		858,4	P_3	0,23	3,55	2,20	161	411
		867,2	P_3	0,19	7,64	2,30	332	432
		898,4	P_3	0,14	2,78	1,92	144	416
		904,3	P_3	0,62	16,63	4,71	353	409

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	C_{opr}, wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
		928,4	P_3	0,22	3,82	1,92	198	420
		942,5	P_3	0,21	3,22	1,74	185	416
		950,9	P_3	0,20	2,95	1,33	221	431
		968,0	P_3	0,14	2,73	1,41	193	432
21	Zamankul, 72	3075,0	P_3	1,13	15,70	2,48	633	436
22	El'darovo, 59	3830,0	P_3	0,78	2,77	0,92	301	444
	El'darovo, 60	4281,0	P_3	0,28	1,05	0,32	328	445
		4339,0	P_3	1,39	4,04	1,61	250	446
23	Mineral'naya, 1	5088,0	K_1apt-alb	1,69	6,07	1,99	305	457
24	Khayan-Kort, 64	3928,0	K_1apt-alb	0,30	1,01	0,58	174	454
		4299,0	K_1apt-alb	0,06	0,29	0,33	87	464
25	Starogroznenskaya, 1006	4492,0	P_3	0,25	0,58	0,24	241	450
		4595,0	P_3	0,17	0,57	0,22	259	452
		4818,0	P_3	0,30	1,07	0,36	297	443
26	Elistanzhi, 39	1073,1	P_3	1,25	9,39	1,89	496	441
		1082,0	P_3	0,28	1,65	0,39	423	440
		1100,7	P_3	0,40	1,54	0,47	327	436
	Elistanzhi, 37	290,5	J_2 bj-bt	0,04	0,35	0,34	102	442
		293,7	J_2 bj-bt	0,05	0,37	0,32	115	443
		305,0	J_2 bj-bt	0,02	0,60	0,51	117	446
		327,0	J_2 bj-bt	0,05	1,02	0,54	188	447
		337,4	J_2 bj-bt	0,09	1,13	0,50	226	447
		362,1	J_2 bj-bt	0,07	1,15	0,72	159	444
		384,1	J_2 bj-bt	0,06	0,95	0,62	153	441

Ordered number	Area, borehole number.	Sampling depth, m	Age of sediments	S_1	S_2	$C_{opr,}$ wt %	HI kgHC/t C_{opr}	T_{max} ^0C
				kgHC/t of rocks				
		394,1	J_2 bj-bt	0,06	0,54	0,63	85	444
		516,0	J_2 bj-bt	0,05	0,50	0,50	100	443
		530,7	J_2 bj-bt	0,08	0,69	0,56	123	443
		551,4	J_2 bj-bt	0,02	0,51	0,58	87	447
27	Vostochnyi Kapchugai, 26	1307,0	P_3	1,41	4,12	1,57	262	454
		1309,4	P_3	2,28	6,13	2,29	267	451
		1312,4	P_3	1,11	3,97	1,65	240	450
		1318,3	P_3	2,35	6,17	2,93	210	456
		1321,3	P_3	2,85	5,19	1,82	285	450