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HYDROCARBON SYSTEMS OF THE SOUTH CASPIAN BASIN

BAKU – 2003

This is published upon decision of Academic Board
of Institute of Geology of Azerbaijan Academy of Sciences

Editor: **I.S.Guliyev**

I.S.Guliyev, P.Z.Mamedov, A.A.Feyzullayev, D.A.Huseynov, F.A.Kadirov, E.H.-M.Aliyeva, M.F.Tagiyev. Hydrocarbon systems of the South Caspian basin. Baku, “Nafta-Press”, 2003, p. 206.

The South Caspian Basin is among the oldest oil and gas bearing provinces in the world, which in as far back as early 20th century was the worldwide lead in petroleum industry. In the last years interest in this region was rekindled in connection with the discovery of large offshore oil and gas fields and attraction of foreign investments in their development. Considering this, in the paper different aspects of petroleum geology of the South Caspian - Kura Basin, tectonic structure, stratigraphy, reservoir quality, source rocks, oil and gas geochemistry, mud volcanism are dealt with on the basis of a great body of factual material. Specific features of this oil and gas province are shown to be high sedimentation rates of the young Pliocene-Quaternary deposits, low thermal regime, overpressuring, mud volcanism etc.

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Nafta Press
Azerbaijan,370143
Baku,H.Javid Ave 29 A

INTRODUCTION

Occurrence of oil seeps in Azerbaijan, on the Absheron Peninsula, has given rise to the use of oil in this area since the 6th century AD. Until the beginning of the 19th century, oil was still exploited using hand dug shallow pits. In the first half of the 19th century, the production system became more organized with the introduction of a leasing system to exploit petroleum and the emergence of hand dug wells. The maximum depth of wells at this time was 20 m. The first well drilled in 1848 on the Bibiheybet anticline produced the first oil spouter. At the beginning of the 20th century, Russia was the world's largest oil producer with approximately 96% of the oil production coming from Baku. In the first half of the 20th century, exploration extended into the Kura Basin and the shallow waters of the Caspian Sea. Hundreds of wells have been drilled offshore in shallow waters using fixed platforms. In 1949 about 30 km east of the Absheron Peninsula the giant offshore oilfield Neft-Dashlary was discovered. In the 1960's, mobile exploration rigs were used to explore deeper waters of the Caspian Sea. In 1979 a semisubmersible began to work in the Caspian allowing exploration in water depths up to 200 m.

About 40 fields have been discovered as for today in the South Caspian Sea. In the the South Caspian - Kura Basin (SCKB), oil and gas accumulations are contained within stratigraphic interval from the Upper Cretaceous to Upper Pliocene. The majority of commercial oil reserves, however, are located in the Middle Pliocene (>70%), the rest in the Miocene-Paleogene (~15%) and the Upper Cretaceous (~10%). More than 300 structures (**Fig. 1**) have been identified in the basin, over 100 of those have oil and/or gas deposits, with in excess of 700 individual oil pools altogether. Multi-layer structure of the hydrocarbon deposits is among the most distinctive features of the area. In the Middle Pliocene as many as 40 separate productive horizons have been identified. The hydrocarbon accumulations occur from near-surface down to 6172m depth, although the greater part of those being currently developed are within depth limits of 500 to 2000 m.

To date the number of oil and gas fields in Azerbaijan reaches 79; 55 onshore and 24 offshore fields. Onshore fields are at a late stage of development. At the same time the potential resources of the Azerbaijan sector of the Caspian Sea are immerse. Besides 24 fields indicated above, a considerable number of prospective structures have been discovered applying geophysical methods. Thus, future exploration is looking to the deeper waters of the central south Caspian Sea. Other future potential lies in deeper reservoirs, using enhanced recovery techniques to exploit current fields, looking for non-structural traps and exploiting gas hydrate accumulations.

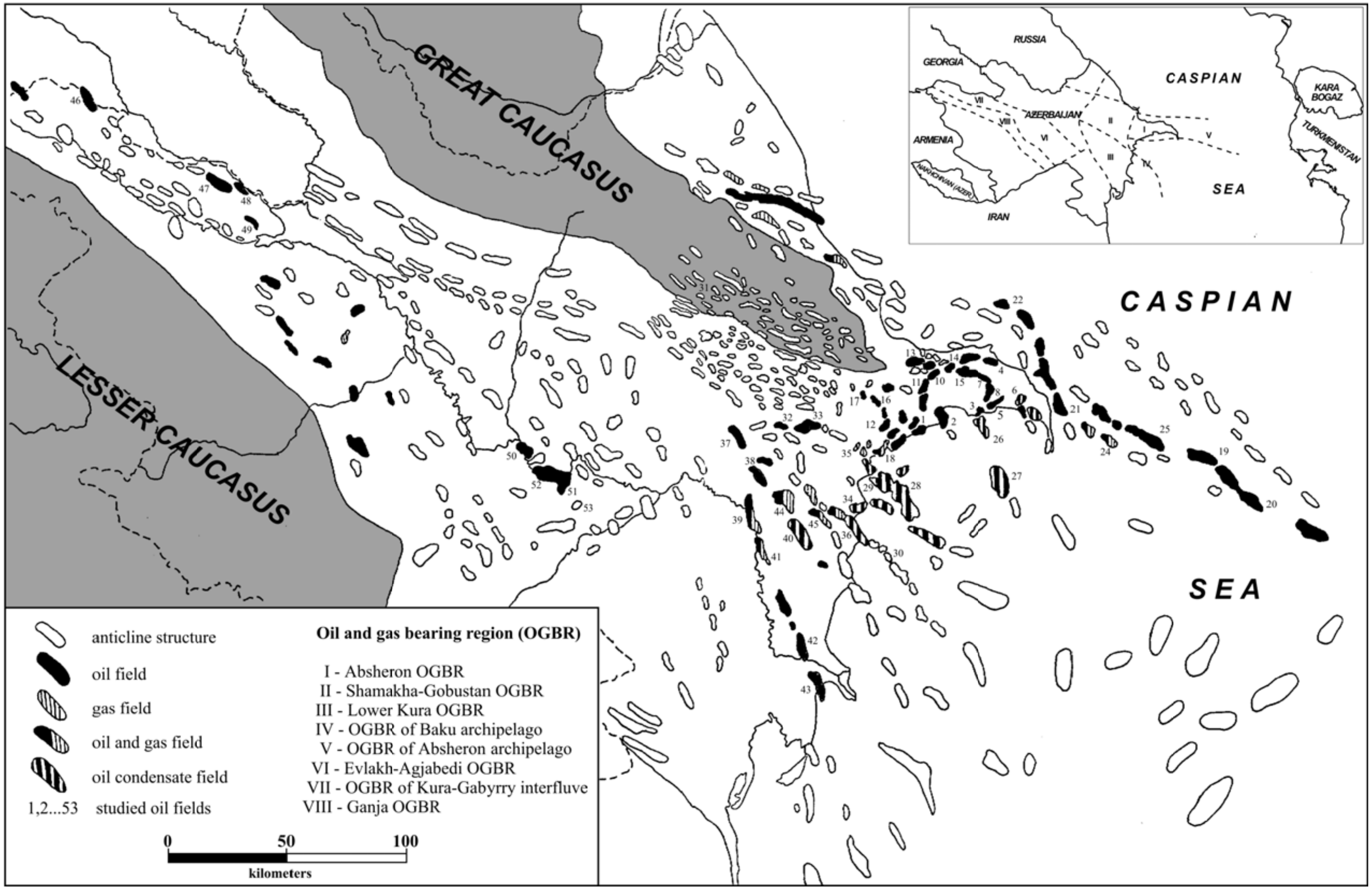


Fig. 1. Location map of oil and gas bearing regions, oil and gas fields and prospective structures: (I-V) - Oil and gas bearing regions: I - Absheron; II - Shamakhy-Gobustan; III- Lower Kura; IV - Baku Archipelago; V - Middle Kura.

I. REGIONAL GEOLOGY AND STRATIGRAPHY

Regional geology. The South Caspian - Kura Basin (SCKB) consists of the South Caspian Basin encompassing the territory of the south part of the Caspian Sea, and the Kura Basin covering intermontane onshore area of Azerbaijan and southeastern Georgia. On the north the SCKB is bounded by mountains of the Greater Caucasus, Kubadag and Greater Balkhan. The Absheron-Pri-Balkhan sill is regarded as a structural element to bound the basin in the Caspian Sea. On the south the SCKB adjoins the Lesser Caucasus and Elburz Mountains. On the west the area borders the Dzirul Massif, and on the east is restricted by the Lesser Balkhan-Kopetdag Mountains.

The SCKB consists of the following oil and gas bearing regions (OGBR): Absheron, Baku Archipelago, the Middle and Lower Kura (see previous **Fig.1**). The last two are parts of the intermontane Kura Basin located in Azerbaijan. On the north the Lower Kura OGBR is contiguous with the Shamakhy-Gobustan OGBR which represents a superimposed trough located at the south slope of the Great Caucasus. Therefore, this region may be considered as a north-east part of the Kura Basin.

Below brief geologic description of different oil and gas bearing regions within the SCKB is given (Bagir-zadeh et al., 1987; Geology of the USSR, 1972; Khain and Shardanov, 1952; Mamedov, 1973; Putkaradze, 1958; Shikhalibeyli, 1980).

The Absheron OGBR includes the Absheron Peninsula and the adjacent Absheron Archipelago. The Absheron Peninsula is traditionally regarded as the south-eastern plunge of the Greater Caucasus Megaanticlinorium. The structural elements with varied fold orientation have been affected by diapiric rises and mud volcanism.

The Baku Archipelago OGBR is located to the east of the Lower Kura OGBR and covers a structural zone within the South Caspian western shelf to a bathymetric contour of 200 m. A series of local uplifts have been recorded by seismic survey in the Pliocene-Quaternary structural stage; **Fig. 1.1** displays a seismic section stretching across the Baku Archipelago. The region is characterized by active tectonism, mud volcano eruptions, and numerous longitudinal and transverse faults. Folds have brachyanticlinal, asymmetrical form with steep limb angles (35-55^{o}).

The Middle Kura OGBR. In the Middle Kura Depression gentle folds of the Cretaceous and Paleogene molassal sediments have a NW-SE trending formed during the Alpine orogeny. Vertical movements in this period resulted in 1000 to 3000 m of uplift in the region. Unfolded sediments of the Pliocene have a monoclinal attitude. The northeastern flank of the Middle Kura Depression has been overthrusted by the older deposits of the Greater Caucasus south slope. Structures are stretched in parallel to the Greater Caucasus Mountains. On the southwest the depression is contiguous to the Lesser Caucasus. Here a row of structures goes parallel to the Lesser Caucasus Mountains.

The Lower Kura OGBR is bordered on the west-southwest by the Talysh-Vandam gravity maximum and on the north and northeast by the Lengebiz-Alyat uplift zone. On the east-southeast, it submerges into the South Caspian Basin where the coastline is considered as a borderline. Thickness of the sedimentary fill within the area reaches about 20 km, of which around 6 km is Pliocene-Quaternary in age. All of the folds in the Lower Kura OGBR are asymmetrical and cut by numerous faults to which large mud volcanoes and oil and gas seeps are confined. The thick Productive Series (PS) of Middle Pliocene crops out on the crest of the most elevated folds.

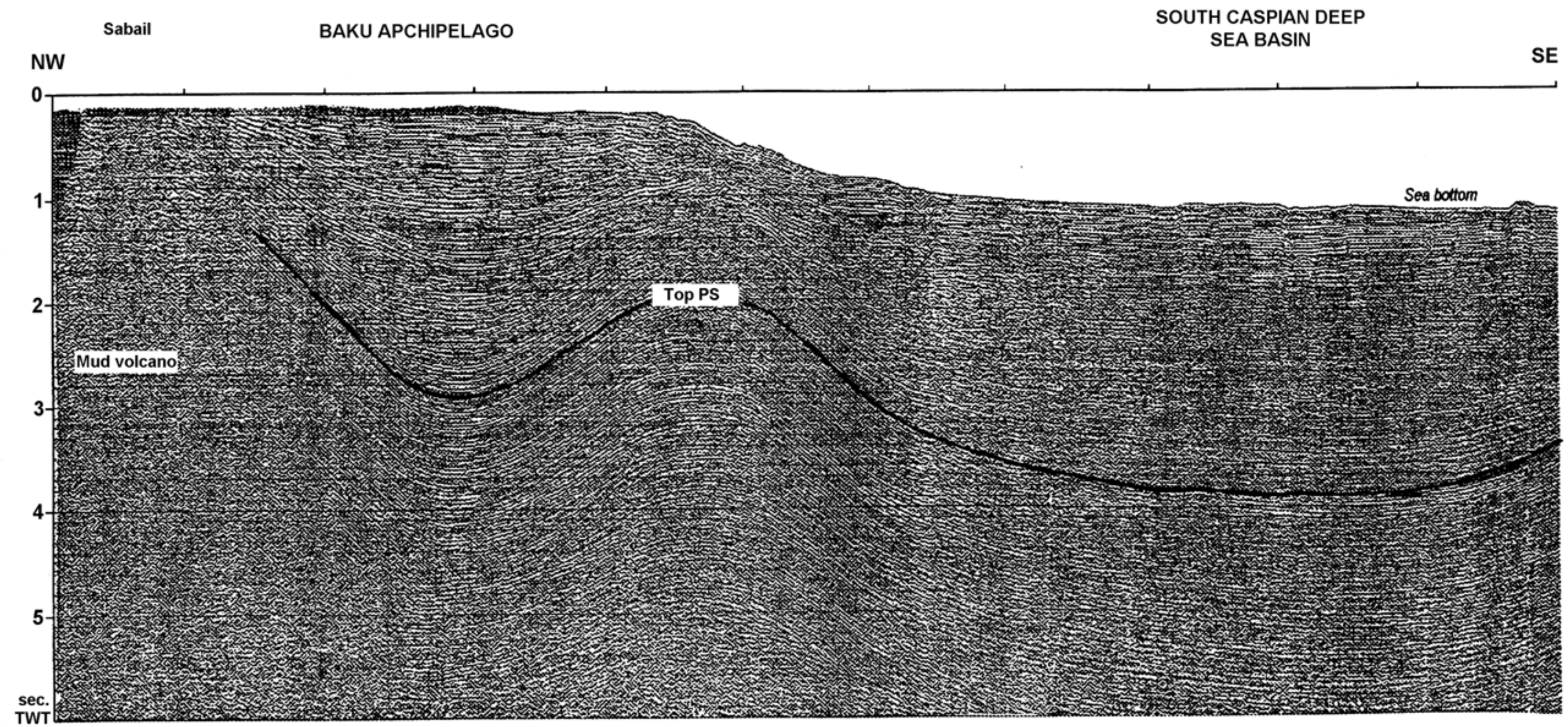


Fig. 1.1. Seismic cross-section across the deeply subsided part of the South Caspian Basin.

The Shamakhy-Gobustan OGBR is located at the southwest slope of the Greater Caucasus. Within the region the sedimentary complex, the upper section of which comprises thick Paleogene-Miocene deposits, has a southeastern dip. On geophysical data the thickness of the sedimentary cover is 15-20 km. Outcrops of the Cretaceous and Tertiary strata and oil and gas seepages are spread throughout the area extensively dislocated and folded since Oligocene. Structures are complicated with syn-sedimentary folds, thrusts, mud volcanoes and diapirs.

Stratigraphy. A complex of sedimentary, metamorphic and magmatic formations of broad stratigraphic range, from the Precambrian to Recent is involved in the geologic structure of Azerbaijan (Geology of the USSR, 1972; Ali-zadeh et al., 1997). Pre-Jurassic deposits are spread on the south of the Lesser Caucasus and are not of interest from the viewpoint of petroleum content. A generalized stratigraphic column of the SCKB is given in **Fig. 1.2**.

SYSTEM / SERIES			STAGE	SUBSTAGE		TYPE OF HC
CENOZOIC	QUARTERN.					
			ABSHERON			● ○
	TERTIARY	PLIOCENE	AGJAGIL			● ○
			PRODUCTIVE SERIES	Upper	SURAKHANY	● ○
					SABUNCHI	
					BALAKHANY	
					FASILE (BREAK) SUITE	
				Lower	SUPRA-KIRMAKI SHALE	
					SUPRA-KIRMAKI SANDSTONE	
					KIRMAKI	
					INFRA-KIRMAKI	
					GALA	
			PONTIAN			
		UPPER MIOCENE	DIATOM SUITE		MEOTIAN	●
					SARMATIAN	
		MIDDLE MIOCENE			KONK	
					KARAGAN	
			SPIRIALIS BEDS		CHOKRAK	●
					TARKHAN	
		LOWER MIOCENE	MAIKOP		UPPER	● ○
		OLIGOCENE			LOWER	
		EOCENE	KOUN		UPPER	● ○
					MIDDLE	
					LOWER	
		PALAEOCENE	SUMGAIT			

SYSTEM / SERIES			STAGE	SUB-STAGE	TYPE OF HC
MESOZOIC	CRETACEOUS	UPPER	DANIAN		● ○
			MAASTRICH.		
			CAMPANIAN		
			SANTONIAN		
			CONIACIAN		
			TURONIAN		
			CENOMANIAN		
		LOWER	ALBIAN		
			APTIAN		
			BARREMIAN		
			HAUTERIVIAN		
			VALANGINIAN		
			BERRIASIAN		
	JURASSIC	UPPER	TITHONIAN		
			KIMMERIDG.		
			OXFORDIAN		
		MIDDLE	CALLOVIAN		
			BATHONIAN		
			BAJOCIAN		
			AALENIAN		

Fig. 1.2. Summary stratigraphic column of the South Caspian-Kura Basin.

The Mesozoic deposits in the SCKB lie at great depths and are exposed within the Great and Lesser Caucasus Mountains.

The Jurassic. The accessible for study section of the Lower and Middle Jurassic in the Azerbaijan part of the Great Caucasus extends in the form of a wide zone from the north-western boundaries of the country through the Caspian sea-coast, and then submerges under the thick cover of the Cretaceous and Tertiary sediments (**Fig. 1.3**). The Middle Jurassic is represented by dark, organic rich shales and sandstones. The Upper Jurassic is up to 3000 m thick and consists of flysch deposits overlain by Tithonian limestones.

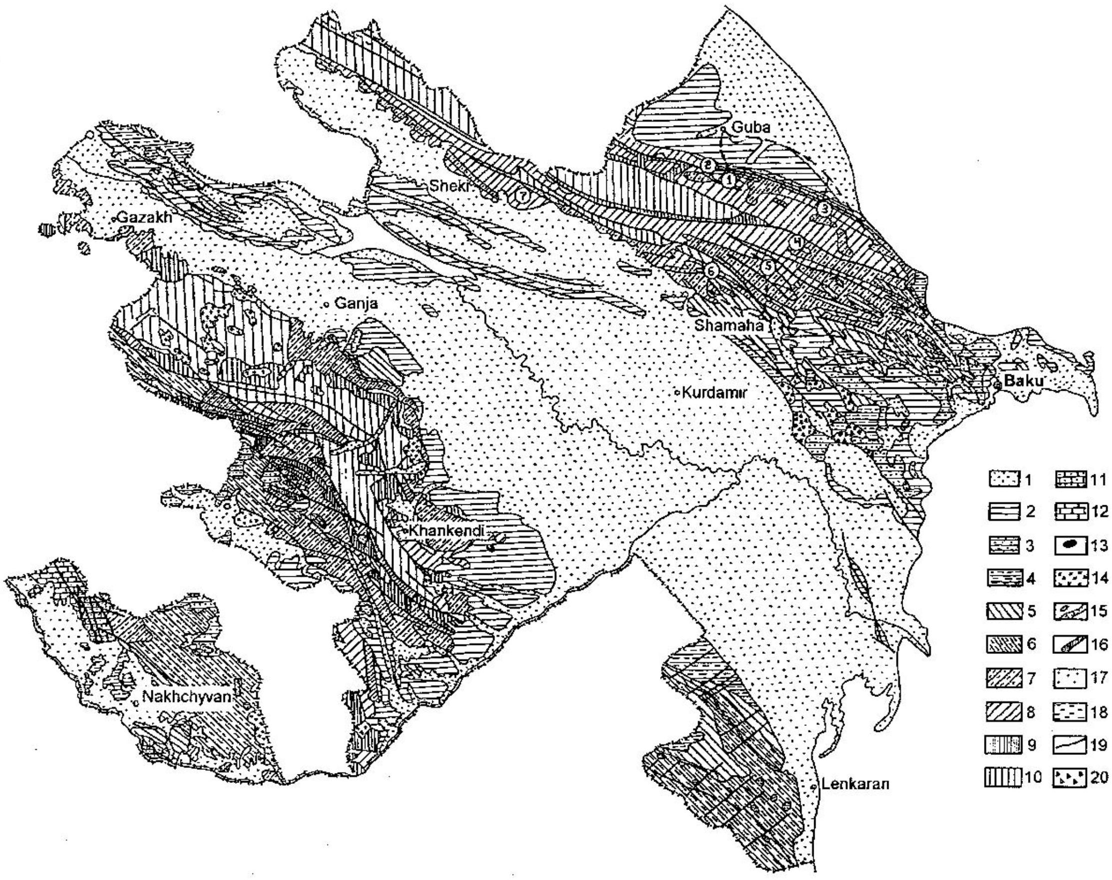


Fig. 1.3. Schematic geological map of Azerbaijan.

1 - Quaternary; 2 - Upper Pliocene-Lower Quaternary; 3 - Upper Miocene-Middle Pliocene; 4 - Middle and Upper Miocene; 5 - Oligocene-Lower Miocene; 6 - Upper Cretaceous-Upper Eocene; 7 - Uppere Cretaceous; 8 - Lower Cretaceous; 9 - Upper Jurassic; 10 - Lower and Middle Jurassic; 11 - Triassic; 12 - Upper and Middle Paleozoic; 13 - Cambrian-Pre-Cambrian; 14 - Cenozoic acid intrusive formation; 15 - Cenozoic basic and alkiline intrusive formation; 16 - Upper Cretaceous ultrabasic; 17 - Mesozoic acid intrusive formation; 18 - Mesozoic basic intrusive formation; 19 - Overthrusts, reversed faults and faults; 20 - breccia of mud volcanoes.

The Cretaceous deposits have wide spread in Azerbaijan. They participate in the structure of nearly all tectonic zones of the Lesser and Greater Caucasus, jutting out in troughs and wings of anticlinoria. The upper stages of the Cretaceous have been penetrated by boreholes in the Middle Kura OGBR. The Lower Cretaceous section begins with a thick carbonate flysch sequence of Valanginian age which is overlain by calcareous shales of Hauterivian-Albian age. Thickness of the Lower Cretaceous ranges up to 2500 m. The Upper Cretaceous represents a sequence of flysch deposits with thickness to 2000 m.

The cenozoic. The Tertiary and Quaternary sediments penetrated by petroleum exploratory wells have been studied in greater detail compared to those of Mesozoic.

Thickness of the Cenozoic varies over a wide range and shows the tendency for an increase towards the center of the South Caspian Basin. From Paleogene to Miocene time a deep sea completely covered all of the basin territory.

The Paleocene Sumgait Suite consists of 100-300 m of reddish and greenish brown shales with thin interbedded sandstones.

The Eocene Koun Suite is represented by alternating calcareous shales, sandstones and black shales with remains of foraminifera, ostracodes and fishes. Thickness of the Eocene deposits within the Shamakhy-Gobustan region amounts to 1400-1500 m with a marked southeasterly increase. According to drilling evidence on the Absheron Peninsula thickness of the Eocene exceeds 1600 m.

The Oligocene-Lower Miocene Maikop Series is composed of dark-grey and chocolate-colored laminated claystones with abundant fish imprints and residues of fossilized tree stems. On the whole, uniform clayey content of rocks with very rare sandy interlayers is characteristic of Maikop strata. Unlike the older strata nearly all the rocks contain more pyrite than iron oxides suggesting reducing conditions throughout the Maikop period. Thickness is quite variable ranging from less than 500 to 2000 m.

The Middle Miocene is subdivided into the Tarkhan, Chokrak, Karagan and Konk units, and dominantly composed of shales and marls. The Tarkhan-Chokrak beds contain about 100 m of black shales with interbedded dolomites and in places sandstones (on the Absheron Peninsula). Thickness of the Chokrak beds increases southwards, attaining 500 m in the South Gobustan where some sandstone bodies occur within the strata.

The Middle-Upper Miocene Diatom Suite containing Karagan, Konk, Sarmat and Meotian stratigraphic units rests on Chokrak unit. In the Diatom section gray and greenish gray clays are dominant lithology, containing interlayers of yellowish brown fragmentary siltstones, carbonate and sandy rocks of 15 cm to 1 m in thickness. Fish imprints, scale residues and diatomites are common in this formation. Maximum thickness reaches 1500 m.

The Upper Miocene Pontian deposits rest on older formations unconformably and is represented throughout the area by shales with intercalations of marls. Thickness varies within 110-200 m in the Absheron and 300-500 m in Gobustan regions.

The Lower Pliocene is termed Productive Series (PS) owing to occurrence of major oil producing horizons within these deposits. The PS is the thickest unit in the sedimentary section of the Lower Kura Depression and the South Caspian Basin; in the central most buried part of the latter it has thickness as great as around 7000 m. The PS consists of alternating sandstones, siltstones and shales deposited in a deltaic or lacustrine environment. The individual sandstone layers may be as thick as about 100 m, however, they thin towards the flanks and wedge out in marginal areas of the basin. Across the area to 40 productive sandstone horizons were identified and sequentially numbered. The PS is subdivided into upper and lower parts. The lower part includes the following suites: Gala (KaS), Sub-Kirmaki (PK), Kirmaki (KS), Supra-Kirmaki Sandy (NKP) and Supra-Kirmaki Shaly (NKG). The upper PS includes the Fasile (Break), Balakhany, Sabunchu and Surakhany Suites.

The Upper Pliocene Agjagil Suites and **Absheron-Quaternary** sediments are represented by alternation of sand, sandstone and claystone beds totaling 2500 m in thickness. The Absheron formation contains claystones, siltstones and sandstones. Agjagil deposits are largely composed of clays with rare sandstone interlayers and fulfil the role of a regional-scale seal for oil and gas accumulations in the PS.

II. GEOTECTONIC EVOLUTION AND DEEP STRUCTURE OF THE SOUTH-CASPIAN MEGADEPRESSION

The South Caspian Megadepression (SCMD), including Kura, South Caspian itself and West Turkmenian depressions, by its tectonic position, peculiarities of evolution, diversity of morphostructural elements and sedimentation bodies, oil-gas content of sedimentary complexes takes the first place among sedimentary basins developed within Mediterranean-Himalayan mobile belt (MHMB). Stretching in the sublatitudinal direction SCMD on the north is limited by anticlinoriums of the Greater Caucasus and Greater Balkhan, on the west - Dzirul massive, on the east - spurs of Kopetdag, on the south-northern slopes of the Lesser Caucasus, Talysh and Alborz. SCMD is characterized by a large thickness of sedimentary cover - 25-30 km in comparison with 12-17 km in other deep-water basins of mobile belts. This basin is related to rare basins of rapid subsidence and avalange sedimentation. Reduction of areas of shelf accumulation and decrease of total dimensions of basin in Cenozoic is typical to SCMD. The most reduction one can observe in Neogene-Pleistocene. The reason of such reduction is its location within tectonic belt of compaction, undergone an external reduction of the earth crust in Cenozoic.

Tectonic zonation of region traditionally was made on the base of static approach i.e. recent tectonic position of structures and the largest morphoelements and geological structure of sedimentary basins (SB). As the newest paleoreconstruction, show, many of them in the past were in other place formed in other geodynamic conditions and within quite another type of basin. Most SB of region are presented on the plan in the postorogenic position and their structure strongly differs from the previous one.

In the light of newest highly informative geophysical data and petrologic research as well as super-deep drilling based on old materials and other indirect methods evident shortages and inexactitude were revealed. These ideas wrongly interpret evolution of South Caspian Depression its Kura and Western-Turkmenian centroclins and bordering their mountain constructions because of not taking into account horizontal movements and rifting as well as compacting tectonic movements in the formation of fold structures in region. When interpreting the nature of large structures and morphologic elements data on recent analogues of geosynclinals - active margins of continents with their island arc, back-arc, intra-arc troughs (seas), deepwater trench etc were ignored. Recognition of ophiolite covers of the Lesser Caucasus as remnants of oceanic lithosphere, establishment of island arc genesis of thick volcanites, basalt-andesit-rhyolite series in Kura depression and Talysh, determination of grabenshaped structures of extension and passive elements on the edge of Scythian-Turan plates seismic sections as well as consideration of new data of other geophysical methods led to the transformation of existing ideas about tectonic processes of main geostructures of region formation.

The main significance during deciphering of geodynamic processes of the recent structure of South-Caspian basin formation is emphasized on use of mobilistic conception of tectonics of lithosphere plates. Based on data of structural, paleogeographic, paleofacial, paleomagnetic, petrologic and geophysical studies and study of ophiolites geology in region this conception postulate the existence in the geological past on the place of Caucasian-Caspian segment of Mediterranean-Himalayan mobile belt typical for active continental margin of structures and geological bodies namely Lesser Caucasian branch of the Mesotethys ocean (relicts of the crust are ophiolites), volcanogenic island arc of back-arc Greater Caucasian sea and passive elements on the edge of Eurasian continental margin. Formation of these structures occurred in the oceanic space where Afro-Arabian and Eurasian platform interacted with microcontinental fragments located between them (Anatolian, Iranian, Trans-Caucasian, Maker, etc.).

Opening of marginal Greater Caucasian sea and formation of Lesser-Caucasian volcanic island arc (IA) are associated with subduction of oceanic crust of Mesotethys (Middle Jurassic - Early Cretaceous) with its complete absorption in the Caucasian segment. Drift of Afro - Arabian platform northward led to closure of the Lesser Caucasian branch of Mesotethys. Process of closure started in Senonian and finished in the end of Cretaceous. According to some researchers period of convergence of Afro-Arabian platform with Eurasia falls to Paleocene-Eocene. At the end of Eocene all the crust of Mesotethys ocean was completely absorbed and then there occurred a collision of Anatolian and Iranian microcontinents with located northward Trans-Caucasian microcontinent. As a result of it there were formed structures of compaction of the Lesser Caucasus. Re-compaction of the closed together indicated microconinents (Iranian and Anatolian) to Eurasia led in its turn to horizontal compaction of the Greater Caucasian sedimentation basin. Herewith Trans-Caucasian microcontinent played the role of buffer was compacted to Scythian plate and formed structures of compaction within the Greater Caucasus and Iranian microcontinent under influence of Arabian plates created a base forming thereby a collision process within Kopetdag. Thus, at the beginning of Oligocene in the studied region there was developed a basin of the Eastern ParaTethys isolated from the World Ocean with oceanic crust and stagnant conditions in which in Oligocene early Miocene accumulated black non-carbonate and poor-carbonate clayey sediments of Maycop suite.

Thus, the Greater and Lesser Caucasus and Kopetdag were formed as a result of compaction of sedimentation basins within collision of microcontinental blocks with each other and Eurasia. Together with a growth of mountain constructions within territories bordering megadepression within the South Caspian, Kura and Western-Turkmenian depressions in Neogene (especially in the Miocene) there occurred a warping and deepening of sedimentation basins. Unlike periphery areas of marine basins which were undergone strong tectonic deformations and folding, the closed South-Caspian Depression was relatively poor deformed. Nevertheless its rough basement was split into separate blocks and sedimentary series was rumpled into folds.

Such are the ideas dealing with evolution of the South-Caspian segment from the plate-tectonic point of view. Some aspects are hypothetical and do not share by other researchers. That's why mobilistic interpretation of the recent tectonics of region formation is needed in proving by authentic and objective actual data of highly-informative geophysical methods as well as new data of deep drilling in region.

2.1.1. Peculiarities of the Earth's crust structure of the South Caspian Megadepression

The basic problem of geology of region is the determination of genesis, age and structure of consolidated crust and basal series of sedimentary cover in the South Caspian Megadepression in its deep-seated part of the South Caspian depression.

Solution of this problem obtains a specific significance due to widely-used oil-gas prospecting works of so-called "basin analysis" providing the studying of SB as an integrated system and new practice of genesis mechanism of HC and formation of their deposits in the earth crust. Basin "worldoutlook" is emphasized upon the most favorable zones in lithosphere where occur "warming up" of organics and quick "preparation" of HC. According to data of many researchers (Gavrilov, 1998; A. Perradon, 1980; Kucheruk, 1984; Klechev, 1986 et. al.) such zones are concentrated in the geodynamically strained and strongly heated up areas of collision and divergence of plates (subduction, obduction, rifting). That' why determination of boundaries of lithosphere plates study of peculiarities of structure and type of consolidated crust, establishment of favorable for HC formation and accumulation obtains a basic significance. These studies are necessary not only for estimation of prospective of oil-gas content of different age sedimentary complexes but for creation of new prospecting of criteria of HC deposits and development of scientifically-substantiated strategy of prospecting works in terms of oil and gas in the studied basin.

For the last 3-5 years the existing ideas about consolidated crust - crystalline basement of megadepression were formed on the base of data of deep seismic sounding (DSS) and correlation method of refracted waves (CMRW) processed by technique and methodic capabilities of seismometry at the end of 50s – beginning of 60s of XX century as well as basing on indirect data of gravimetry and magnetometry within the water area and data of drilling on the shelf and adjacent onshore territories as well.

All 11 sea profiles of DSS were processed in the Pre-Apsheron water area and only two of them (profiles №№ 1 and 9) had cut the middle part of the South Caspian. Very poor and ambiguous information about the consolidated crust of the South Caspian was obtained on these profiles.

At the early stages of DSS data interpretations when changes of seismic velocities were associated with changes of matter composition of rock one could trace the common boundary of basement the separate sporadically tracing velocity boundaries were not-extent (about 50-70 km), and windows between them had the most extent (150-200 km). Highly symbolically they could be related to the one and the same border – so-called Conrad' discontinuity. Obviously these short boundaries reflected the heterogeneous structure and tectonic stratification of the earth crust rather than its regional petrographic strata. Nevertheless some researchers within the consolidated crust determined two geophysical layer: granite with V_{rp}-6.0-6.4 km/s and basalt with V_{rp}=6.5-7.8 km/s. Investigation of these layers correlation between each other and with relief of Moho were the basic content of geological interpretation of DSS - CMRW data within region (**Fig. 2.1.1**)

By the absence of reliable seismic information in the vast areas between profiles of data of gravitational fields recalculation into the upper space as well as calculations of local anomalies and their gradients were the only sources of information about the deep structure of depression. In the observed field of gravity, depression was expressed by regional minimum of the highest order on the background of which South Caspian maximum was contoured. Some researchers determined another one quite doubtful maximum in the region of Baku archipelago and wasn't proved by data of regional seismometry and gravimetric observations of last years. Presence of the South-Caspian gravitational maximum some researchers associated with projection of block of crystalline basement, the other one with a rise of crust of oceanic type within mantle mega-arc, the third -with introduction of large mass of erupted rocks of Mesozoic.

All available geology-geophysical information considering data of offshore deep drilling, seismologic, geochemical, thermobaric studies was generalized and repeatedly reinterpreted with application of methodic elaborations and up-to-date computing and processing techniques. As a result of it 3 or 4 bedded models of the environment, summary maps - schemes on the surface of basement and Moho, maps of thickness of granite and basalt layers, maps of deep faults etc were compiled by different researchers. These options of total constructions differing in details gave quite schematic total ideas about morphology of Moho surface and crystalline basement. On the whole South Caspian depression with its centroclins - Kura and Western Turkmenian depressions by the surface of consolidated crust represents the largest megadepression of near-latiudianl orientation, filled by sedimentary series of a large thickness.

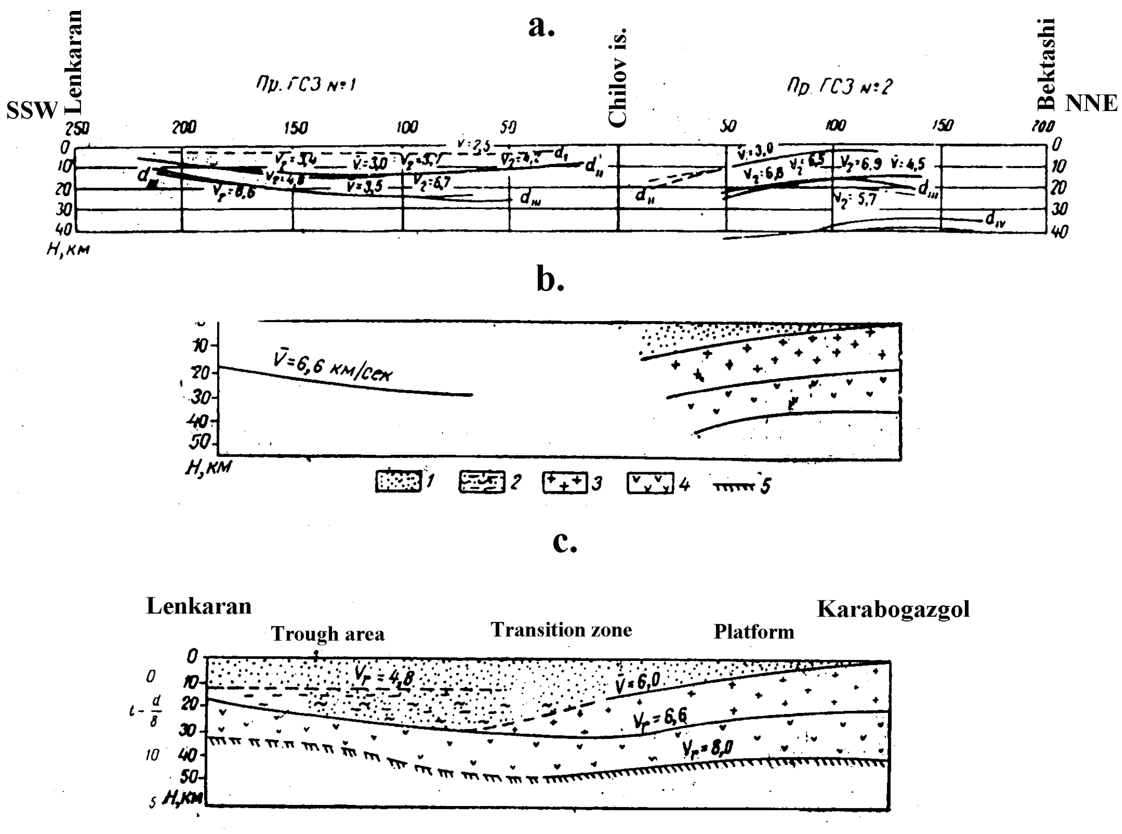


Fig. 2.1.1. The Earth crust section according to DSS data on profile 1-2 (Lenkoran-Karabogazgol) (a, b), its first geological interpretation (c) (R.M.Gajiyev, 1965)

Large trough with a depth 45-50 km was determined on maps by the foot of the earth crust in the Near-Apsheron part of the South Caspian.

According to data of Acsenovich, 1962 and I.A. Rezanov /1974/ area of granite layer absence covers rather significant area covering Apsheron Pri-Balkhan zone, Pri-Apsheron trough, Low-Kura depression and partially Pri-Lenkoran trough. L.I.Lebedev etc (1987) it is supposed, that within deepwater PreAlbors trough there is absent granite layer and here sedimentary rock lay upon basalt ones. According to V.A.Kornev (1961), V.I.Kulikov (1964), E.E.Milanovsky (1967) in the South Caspian granite layer is completely absent.

Presence of basalt window in the central part of the South Caspian is associated according to hypothesis about "basification" of the Earth crust with a treatment and metamorphization of crust till the partial disappearance of its granite bed thanks to introduction of mantle material. However according to modern petrologists the idea that continental crust can turn into oceanic is not acceptable from thermodynamic point of view, though the reverse process is quite obvious (UYEDA 1971).

Moreover, to our opinion the hypothesis itself about the subsided "intermediate massif" contradicts as according to Archimedes law land massive to contain the floatability should have a thick continental crust under it. It means, hat if hypothetic "intermediate massif" subsided at a large depth (20-25 km) and became the basement of deepwater depression so massive buried under loose sedimentary formations should create a huge negative gravitational anomaly. However there is no such anomaly nether under the South Caspian nor in any other place of region.

Serious divergences in opinions of researchers are marked in terms of age assessment of crystaline basement of megadepression. Most of them (G.A. Akhmedov, 1964, E.Shikhalibeili, 1984; Bagirzade, Kerimov, Salayev, 1987) age of SCD's basement are estimated as Hercynian in some its areas - even Baikalian.

E.Sh. Shikhalibeili on one of its recent work age of consolidated crust surface estimated as Mesozoic and marked that Paleozoic deposits in the South Caspian are obviously absent or presented by small-thick section. Reasons and grounds for so contradiction ideas in terms of history of development and structure of the crust of the South Caspian one shouldn't search only on concrete assessments of parameters of the crust according to DSS, SMRW and gravimetry data or in ambiguous interpretation of geophysical data. To our opinion they must be found in distortion of geophysical information aimed to mistaken and preconceived idea about the depression above the "intermediate massif" formed by Pre-Alpine (ancient) consolidation.

2.1.2. Model of consolidated crust structure according to a new data of geophysical investigations

Wide use of geodynamic conception in the evolution of lithosphere and obtaining of new "basin" worldoutlook in terms of interpretation of mechanisms formations of oil-gas-bearing sedimentary basins required the revision of an old model of the SCMD crust and formation of principally new ideas in terms of its structure and evolution.

Due to the above mentioned facts in 80s-90s of the XX century there appeared a necessity to review the old materials of DSS and CMRW, and their reinterpretation applying new machine methods as well as development of some seismic profiles in the South Caspian by method of common depth point (CDP) with large recorded to (12-20 sec.) dip moveout processing. As a result of reinterpretation of DSS-CMRW old materials in 80s N.I.Pavlenkova and M.M. Radjabov (1988) came to the conclusion, that their geological interpretation was earlier based upon simplified and unreal model of crust. Such model was presented as a small number of homogenous thick layers separated by boundaries of the first type, velocity of which increase stepwise from layer to layer. Features of waves interoperation of refracted-head type resulted in falling from the section or series with relatively decreased velocities or series velocity of which increased gradually (gradient series). One-dimensional velocity model for South Caspian and two-dimensional velocity models (sections) for sea profiles were complied by M.M. Radjabov. On the new model of profiles DSS-1-2 surface of basement in Pri-Lenkoran water area is subsided at depths 3-7 km it is smoothly subsided in the direction of deepwater depression to 28-30 km and again rises to 20-22 km on the edge of epihercian platform -3-5 km (**Fig 2.1.2**).

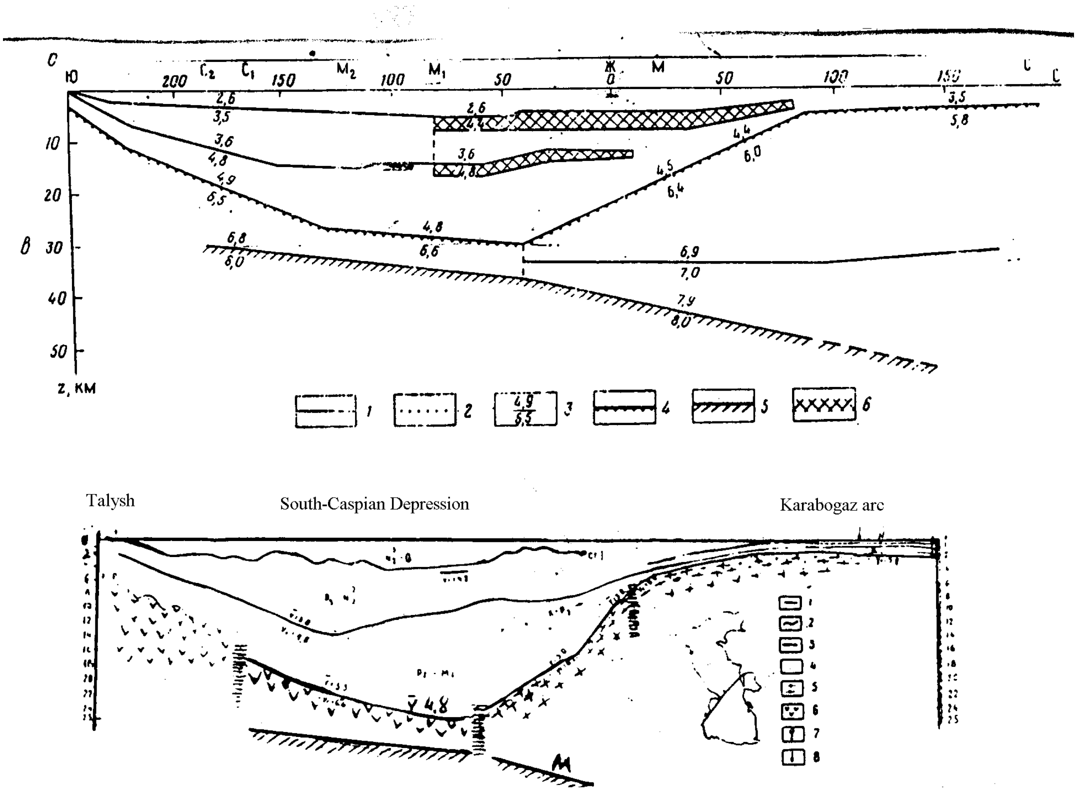


Fig. 2.1.2 The Earth crust model according to results of re-interpretation of profile data of DSS 1-2 (a) (M.M. Rajabov et al., 1988) and geologic-geophysical section on the same profile (b) (A.N. Gajiyev et al., 1986)

Moho discontinuity distinguished on the section, which under the depression forms mega-arc at depths 30-34 km and toward platform it decrease at depths (50-70 km). Consolidated crust under depression is characterized by typical for oceanic crust parameters: thickness 6-8 km and values of velocities of longitudinal waves V=6,5-6,8 km/s.

According to new two-dimensional model of profile DSS-9 thickness of consolidated crust increases to 8-9 km (in Pri-Balkhan region) to 14 km toward South Caspian projection of basement at the expense both rise of the surface "φ" and subsidence of the surface "M". On the south-western end profiles in the upper part of consolidated crust are characterized by velocity V=6.0 km/s that testifies to supposition about the presence of rock of exialitic composition which overlap basalt layer. Herewith within consolidated crust no boundary is distinguished.

Prospective of reliable models creation of the Earth's crust structure are associated with modification of seismometry with near-vertical falling and return of waves. Highly-informative materials of CDP method with a large dip moveout processing (more recorded to 10-20 s) give a direct and objective information about the structure and depth of consolidated crust.

On the seismic sections of CDP method of regional profiles one can find a reflection of large geostructures and morphoelements. These sections provide sufficient space for determination of tectonics and geodynamic development of SCMD on the base of mobilistic conception of lithosphere plates.

On the seismic sections of profiles worked in the South Caspian with a large dip moveout processing (16-20 sec.) section is found at depth 36-40 km (**Fig. 2.1.3**).

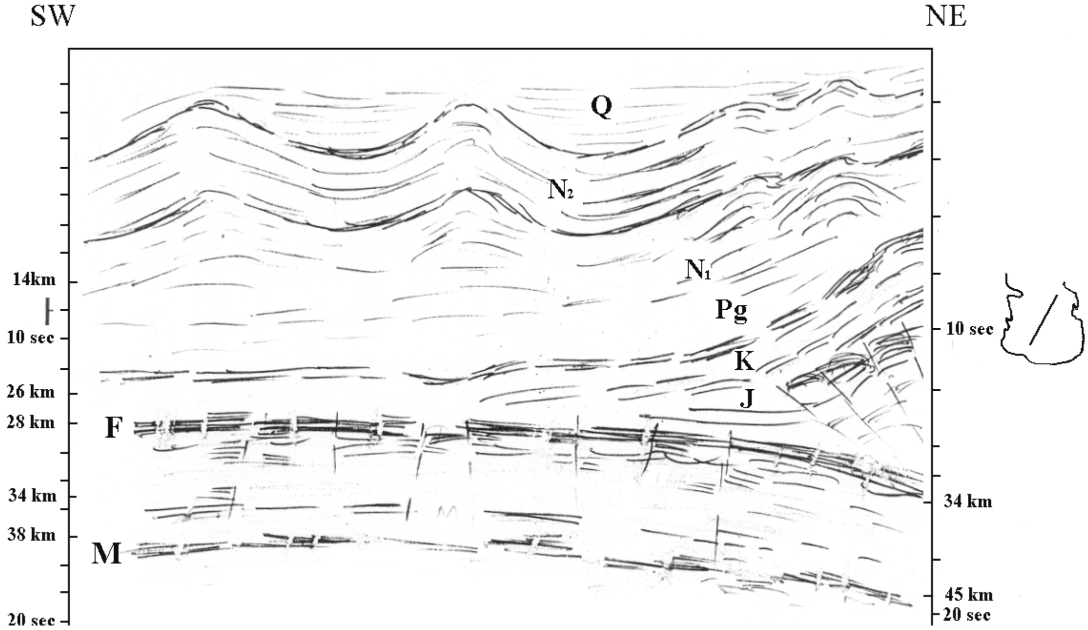


Fig. 2.1.3 Sketch of the seismic section of deep profile by method of CDP through the South Caspian

At 12-15 sec high-amplitude section of subparallel reflections interpreting as a boundary sedimentary cover-basement (J.Knapp, C.Diagonescu, J.Conor and et. 2000) is distinguished. Lower at 16-18 sec a transparent medium corresponding to consolidated crust under depression is distinguished. narrow strip of low-frequent subparallel reflections accumulation obviously reflects the small stratification of lowers of consolidated crust. This strip was named as "zone of reflectivity" (N.I. Pavlenkova, 1996) and its low edge correspond to Moho surface. At sections of CDP method the thickness of consolidated crust in the Pri-Apsheron are (by corresponding errors in calculations and extrapolations of velocities at great depths) is 7-8 km.

On the seismic sections of the profiles of the SW-NE orientation in the northern part of the South Caspian and especially in the complicated zone of conjunction of Apsheron-Pribalkhan folding belt and Turan plate, one can observe the subsidence of "F" surface proving the hypothesis about underthrust of hard oceanic crust of the South Caspian under continental crust Turan plate.

The basic information obtained from seismic sections of CDP method is the direct and visual reflection of roof of consolidated crust as a surface of acoustic basement. Foot of the crust - Moho discontinuity is less firmly distinguished on the seismic sections. Within the consolidated crust one can observe poor in situ subparallel and sloping reflections separated by intervals that obviously reflects the complicated blocked - lens structure of magma-metamorphic substrata. In the light if ideas about mechanism of formation and spreading of crust in the back-arc troughs - marginal seas forming the complicated conglomerate of covers, sills, dikes. Such a seismic picture (considering capacity of CDP method at a great depths) can regarded as some approach of reflection of complicated internal structure of magmametamorphic substrata.

Another one basic result of seismometry CDP is the establishment of the absence of some regional boundary inside of the consolidated crust. Generalization of data of method of CDP and continuous seismic profiling (CSP) in many regions of the World showed, that there is no such a boundary in the crust (Kunin, 1989). Hence, traditional determination of two geophysical layers (granite and basalt) in the consolidated crust losing its sense.

Direct seismic information about consolidated crust under the sedimentary cover of the South Caspian Depression unfortunately one can observe only on several profile sections. Nevertheless it clarifies some conceptually basic peculiarities of the Earth's crust structure in the South Caspian depression. Firstly, seismic sections show, that two-bedded granite-basalt model of consolidated crust is far from reality; in the basement of depression one can find a thinned crust of oceanic type. Thus, hypothesis about development of the South Caspian Depression under the old "intermediate massif" of continental origin was refused. Secondly, the revealed by seismic sections the subsidence of oceanic crust in the northern direction as well as displacement of blocks of continental crust in the marginal part of Scythian-Turan platform toward depression are documented evidences of riftogenic genesis of the basin.

The basic structures proving the bathypelagic sedimentary basin in the considered region are the ancient (Mesozoic) continental slopes. Sharp and high slopes typical for marginal-sea and oceanic depressions (**Fig. 2.1.4**) are clearly observed on the seismic sections. Leaning of basal layers of sedimentary cover to slopes both from the platform side, and from the Trans-Caucasian microcontinent side, as well as specific sedimentation bodies testify the existence of starved deepwater depression in the early-alpine stage.

2.1.3. Absheron-Pribalkhanian mesozoic trough-relict of marginal Great Caucasian sea

Detailed and regional geophysical research of the tectonic structure of the South Caspian depression (SCD) show, that it has a much in common both in structure of the crust and its geology-geophysical parameters with marginal-marine basins of the world ocean. Due to it let's consider the known basic peculiarities and development of such basins as they can serve a comparative material for determination of regularities of development and tectonic processes in the relict basin of the South Caspian.

Emergence and development of marginal seas according to studies of Karig /1974/, Boillot /1983/, Uyeda /1971/, N.A. Bogdanov /1988/, etc, occurred step by step due to disconsolidation, destruction, extension and subsidence of the ancient crust on the edge of continents and in the marginal parts of oceans. Within areas of mantle uplifts there occurred a subsidence of faults in the crust and lithosphere on the whole along of which there ejected basalt melts. Oceanic crust in the marginal seas are originated in zones of a so-called diffusive spreading; rift embryo with triple dissection, two of the branches of which gradually form a main trough. Extension along the troughs is compensated by formation of accrecional prisms and zones of tectonic compaction of crust.

According to data /Khain, 1996; Bogdanov, 1988 et al/ of works processes of spreading on the marginal-marine relict depressions of Tethys direction (depression of Mexican Gulf, Ionic and Levan Sea, South Caspian) occurred in the mid-late Jurassic and Cretaceous periods (I phase) as well as in the early Cenozoic (II phase) they are considered to be relict back-arc structures which retained even after the Mesotethys ocean was closed.

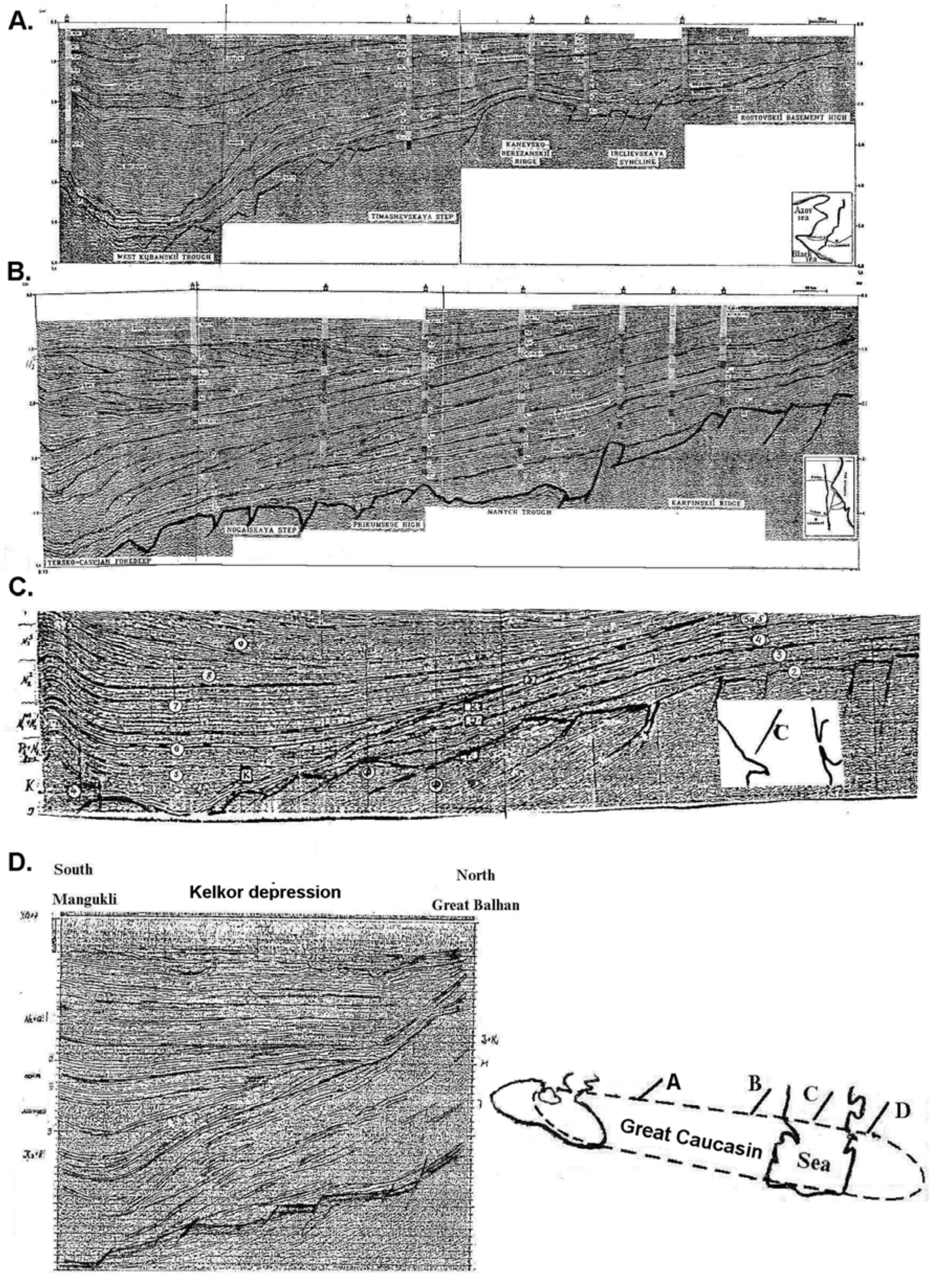


Fig. 2.1.4 Old continental slopes on the north margin of the Great Caucasian sea (A and B - Atlas …, 1990; C - P.Z. Mamedov and D.Kh. Babayev, 1995; D – P.Z.Mamedov, 1992)

Marginal-marine deepwater depressions in the Pacific and other oceans started to form in late Cretaceous. The seconds phase of extension and opening of new troughs (graben-troughs) there occurred in Oligocene and Miocene (Boillot, 1983, Bogdanov, 1988). Late (Cenozoic) extensions were stipulated by geodynamic processes, which led to collapse of volcanic arcs and formation of a new trough in the intra-arc basin. Almost in all marginal seas there are two different-age graben-trough with oceanic crust (except Philippine Sea where they are three). Moreover, there can be observed a rejuvenation of these structures towards the ocean. As a rule, the troughs are divided by submarine uplifts and plateaus (or died out arcs) of microcontinent origin.

Sometimes between the latter there occurs a tectonic huddling in the contact zones of "the old" and "the young" oceanic crust in the adjacent troughs. For us the marginal seas were tectonotypes for the construction of model of the formation and evolution of the SCB at the early Alpine stage.

A number of reconstructions of the Caucasian-Caspian region were made, among them for the Middle Jurassic-Eocene one can identify the Greater Caucasus marginal sea in the rear of the Lesser Caucasian island arc. They were made on the base of data of paleomagnetic, petrologic, paleotectonic and paleogeographic studies. In the most of them the rift trough is an embryo of future marginal in the early-middle Jurassic. It is located 150-200 m south of the Eurasia margin. According to S.I. Dotduev's (1986) reconstructions the rift trough discovered in the Lias-Aalenian stretched from the north-west south-eastwards and covered north-east of the Black Sea, the Rhion valley, sublatitudinal part of Kura river, Jeirankechmez and Pri-Apsheron Pliocene-Quaternary depressions and then stretched eastwards into the SCB. In the north and in the south flanks of the depression this research worker identifies slope, shelf and littoral-offshore facial zones. The rift depression in Lias-Aalenian was 50-60 km wide in the South Caspian and in the Trans-Caucasus it was about 100-140 km.

Width of the whole sedimentary basin (shelf and slope inclusive) was not more than 400-450 km (**Fig. 2.1.5**).

This basin existed in the Jurassic and in the Cretaceous. In the Senonian due to the collision of the north-west flank of the Trans-Caucasus microcontinent with Eurasia the basin became closed near the Crimea and the west Caucasus whereas its eastern part (East Caucasus, Kopetdag) remained not closed. During the further evolution of the region and complex tectonic processes determined by the movement of plates the sedimentation basin gradually decreased.

It is very important to determine existence of graben-troughs of different ages in the base of the SCB and the location of the primary trough. The character of the anomalous magnetic field is not similar and mosaic and it is one of the main diagnostic features of zones of the diffusion spreading in the marginal seas. The regional magnetic field is influenced by the layer which includes the basalt crust and the upper mantle above "Curie point". Below this point the environment is not magnetic. Exactly this layer consisting of a series of basalt magmatites in the form of sills and parallel dykes creates a positive geomagnetic background.

We made a conclusion that the magnetic field of the South Caspian is rather differentiated. In the north of the South Caspian there exist mainly negative anomalies of intensity up -200 Gamm. South of the Apsheron-Pribalkhan folded zone (APFZ) isolines of the magnetic field are characterized by a dissected configuration and positive anomalies of intensity up to +800 Gamm (Dzabayev, 1970).

One positive isometric anomaly is located east of structure Seyar (former bank Makarov). As to A.A. Dzabayev (1970) the source of this anomaly is a massif of the Mesozoic magmatic rocks of a basic and ultrabasic composition located at depth 17-18 km. A chain of positive residual anomalies (according to Metaxa et al., 1979) is located in the zone which is a continuation into the sea of rift valley mapped by I.S. Dotduyev (1986) (**Fig. 2.1.5**).

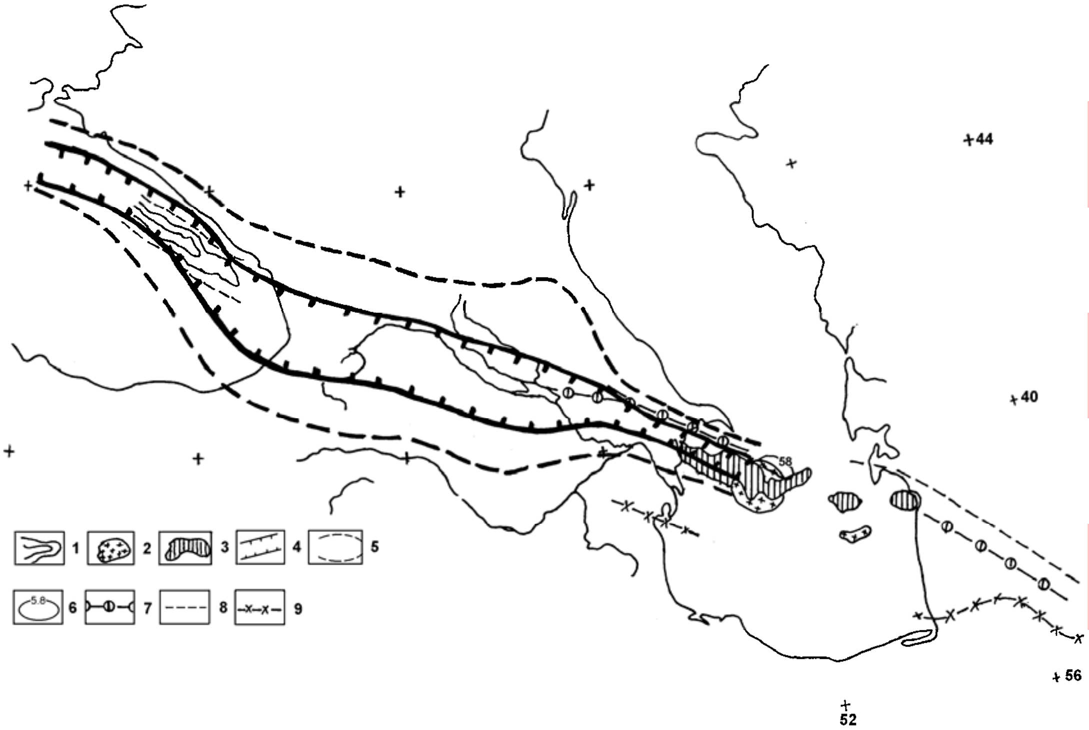


Fig. 2.1.5 Location of riftogenic trough in the Middle Jurassic and axes of the maximal subsidence in different time (according to P.Z. Mamedov) ; 1 - positive values of transformation (for Black Sea by Schreider et al., 1997); 2 - relative maximums of the magnetic field (by Dzabayev, 1969); 3 - outlines of the positive remained magnetic anomalies according to field's re-calculation 5-25 km up (by Andreyev et al, 1979); 4 and 5 - borders of the Middle Jurassic rift trough and shelf; 6 - area of the mantle high velocity matter (by Yakobson, 1990); 7-9 - axes of maximal submersion at different times (by "USSR Geology" book): 7 - J3, 8 - K2, 9 - Oligocene.

The positive magnetic anomaly (about +300-500 Gamm) stretching NW-SE is identified within the East-Black Sea depression as well. According to the results of the magnetic field transformation into the lower semi-segment Shreider et al. made a conclusion that this anomaly shows a magnetic nonuniformity of "the basalt" layer. The authors considered the relation of the anomaly with magmatites intruded into the rift structure in marginal sea.

Locations of a lens of a high-speed substance of the mantle coincide with the supposed area of the spread of the rift structure in the South Caspian. The lens was determined according to data of radioscopy by Rayleigh wave (Yakobson, 1990). Here had been determined a presence on great depth the horizon with high electric-conductivity identified with asthenosphere (G.Ye.Gugunava, 1985), centre of magma-generation at depth 50-60 km (A.Avagimov, 1975; T.Ashirov, 1976) and independent zone of increased heat flows (R.I.Kutas et al., 1975).

A nice convergence of a number of different data allows to make a conclusion that is the studied area of the South Caspian in the crystal base of the depression there occur traces of the main trough which marked the beginning of the Greater Caucasian Sea.

General compression of the sedimentation basin in the Cretaceous period under the pressure of the Afro-Arabian plate was accompanied by the underthrust of the crystal crust of the depression under the Eurasian margins. At the end of the Mesozoic and in the Paleocene a narrow trough superimposed on the north slope of the Trans-Caucasian microcontinent was preserved in the Caucasian segment. In the Caspian segment this trough transformed into a subduction trench one with a steep north flank. In these geologic periods in the axial part of the trough its bottom occurred at depth 3-4 km and was overlapped by a thin sedimentary cover (about 0.05-1 km). It was in a state of isostatic balance due to the disconsolidation of the upper mantle.

Within the Alpine cycle (180 m.y.) the crystal base - the bottom of the old trough in the Apsheron-Pribalkhan zone subsided as deep as 27-30 km and for the last 5-7 m.y. - 10-12 km. This promoted formation of a unique depression with the abnormal structure of the earth crust.

The accumulation in the SCB and in the Apsheron-Pribalkhan zone of a 27-30 km sedimentary cover which is nearly as thick as the continental crust in the adjacent epihercyan platform within a geologically short time demonstrates that is basic series acquired physical properties of the consolidated crust. These peculiarities of the SCB structure explain the existence above the crust of spots with "granite" velocities.

The downwarping of the trough bottom and its subsidence northwards resulted in the disturbance of the isostatic balance. Defect of the mass associated with the conformable bend and with the subsidence of the crust surfaces ("F") and of the mantle ("M") determine large linear negative anomaly in Bouguer gravity (130 ÷ 140 m Gal) at sea level. Such anomalies are typical for trench formed in subduction zones of the oceanic lithosphere under the continental one.

Processes of subduction of the Mesotethys lithosphere and general regional compression of the Great Caucasus Sea were accompanied by the splitting of the IA, extension and opening to the south of it of new rift troughs which transformed into a vast graben-trough. According to M.I. Rustamov et al (1999) such openings took place at several episodes of the back-arc volcanism, namely in the Neocomian, Aptian-Senomanian and Senonian.

According to L.P.Zonenshine /1990/ and Shreider et al /1997/ the most considerable opening took place in the Paleocene-Eocene (**Fig. 2.1.6 and Fig. 2.1. 7**).

The opening occurred from the west eastwards from Adjar-Trialetiya to the Lesser Caucasus and Talysh and then through the South Caspian in Aladag-Benalud. It was accompanied by the formation of a new and younger oceanic crust in a line 200-250 km wide. Recent seismotomographic studies (Yakobson, 1997, 2000) determined outcrops of a substance with mantle and basalt velocities in the base of the sedimentary cover in a wide line from the south coasts of Azerbaijan (south of the Kyzylagach bay) till the north slopes of volcano Demavend and in the south-east corner of the SCB. Existence in the south part of the SCB of a deep graben-trough along the base was proved by radioscopy by Rayleigh wave (RW). The graben-trough becomes narrower towards Alborz where its depth grows from 2 till 9 km. Configuration of the trough is shown in isopachs of sedimentary covers (**Fig. 2.1.8**) and in configuration of the south continental slope of the Caspian Sea.

The formation in the south Caspian of the rift trough M.G. Grachevski /1989/ associates with isostatic pinching of the astonospheric plastic matter out of the continental crust of the Iranian plate northwards under the influence of thick carbonaceous series with barrier-reef ledges of the Paleozoic and Mesozoic age.

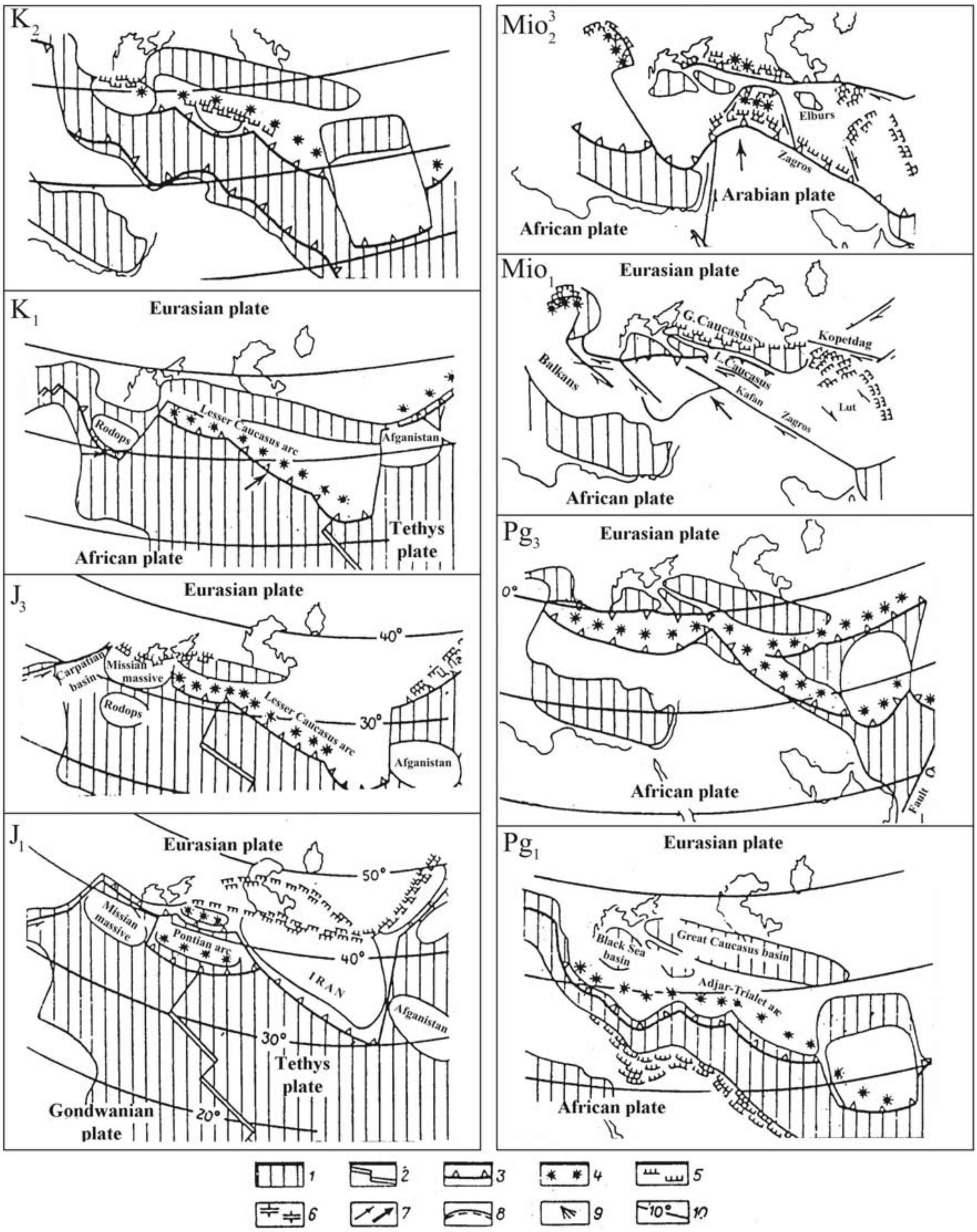


Fig. 2.1.6. Paleotectonic re-constructions of the Tethys mobile zone (L.L.Zonenshine et al., 1990). 1 – Oceanic crust; 2 – Spreading center; 3 – Subduction (convergent) zone; 4 – Volcanic arc; 5 – Folding and seal formation; Continental rifts; 7 – Direction of plate and micro-plate movement; 8 – Continental and micro-continental boundaries; 9 – Subsea evacuation cone; 10 – Paleolatitude

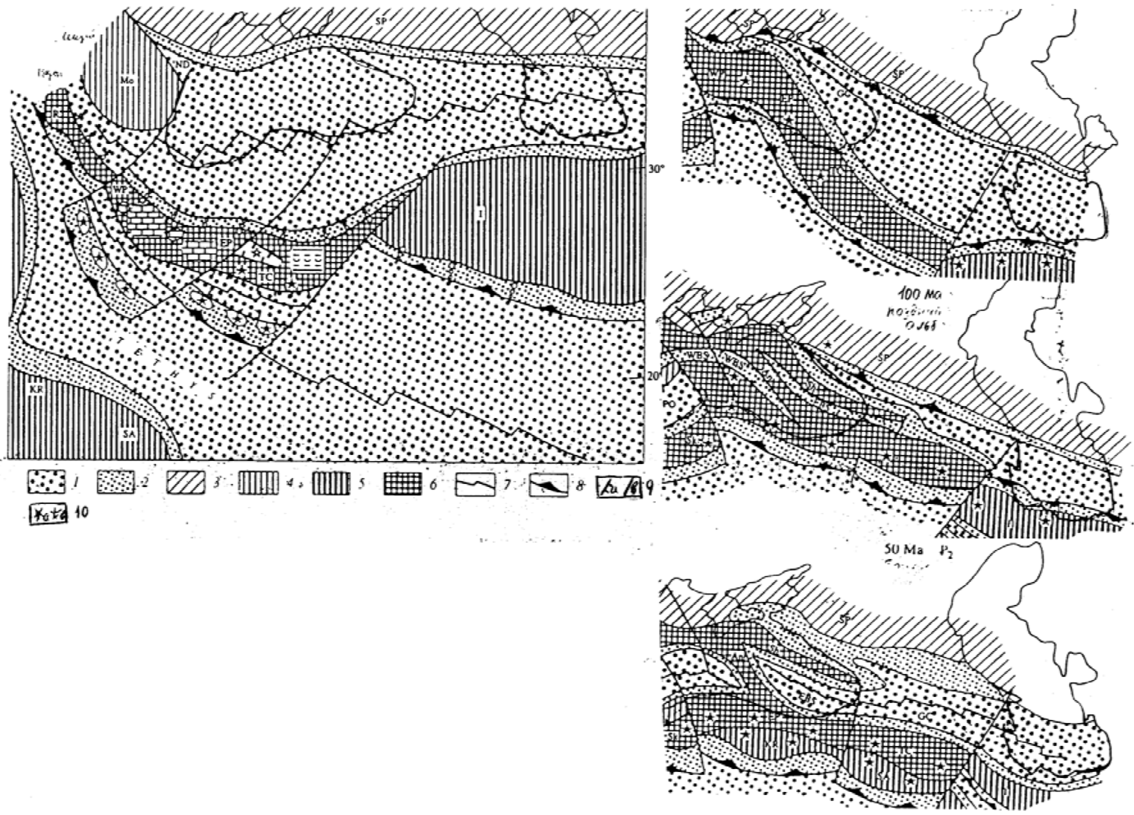


Fig. 2.1.7. Paleotectonic schemes for the Middle Jurassic end (a), Early Cretaceous (Barremian-Aptian) (b), Albian (c) and the Middle Eocene (d) (A.A. Shreider et al., 1997)

In the gravitation field the graben-trough is characterized by rather weak negative anomalies (- 5 ÷ 15 mGal). Within the graben the crystal base is covered by thick (22-30 km) sedimentary cover. Theoretically at the level of the sea a very large negative field - not less than 120 ÷ 150 mGal must be fixed. Geophysicists-gravimetrists associate the reason of compensation of a large gravitation field like that with the existence under the base of the depression of a great amount of consolidated masses. Existence in the base of the south part of the SCB of three zones with mantle velocities was determined by RW (Yakobson, 1997). Two of them are located within the south trough (**Fig. 2.1.8**). In the plan contours of those zones completely coincide with the area in the South Caspian which is characterized by a rather weak negative gravitation field. Hence, the main reasons of the compensation of a large negative negative anomaly at the level of the sea are the intruded into the crust mantle uplifts which are characterized by increased values of velocities and excess density.

Rift structures in the north Iran and in the south par of the sea are very well illustrated by in the geologic-geophysical sections (**Fig. 2.1.9**).

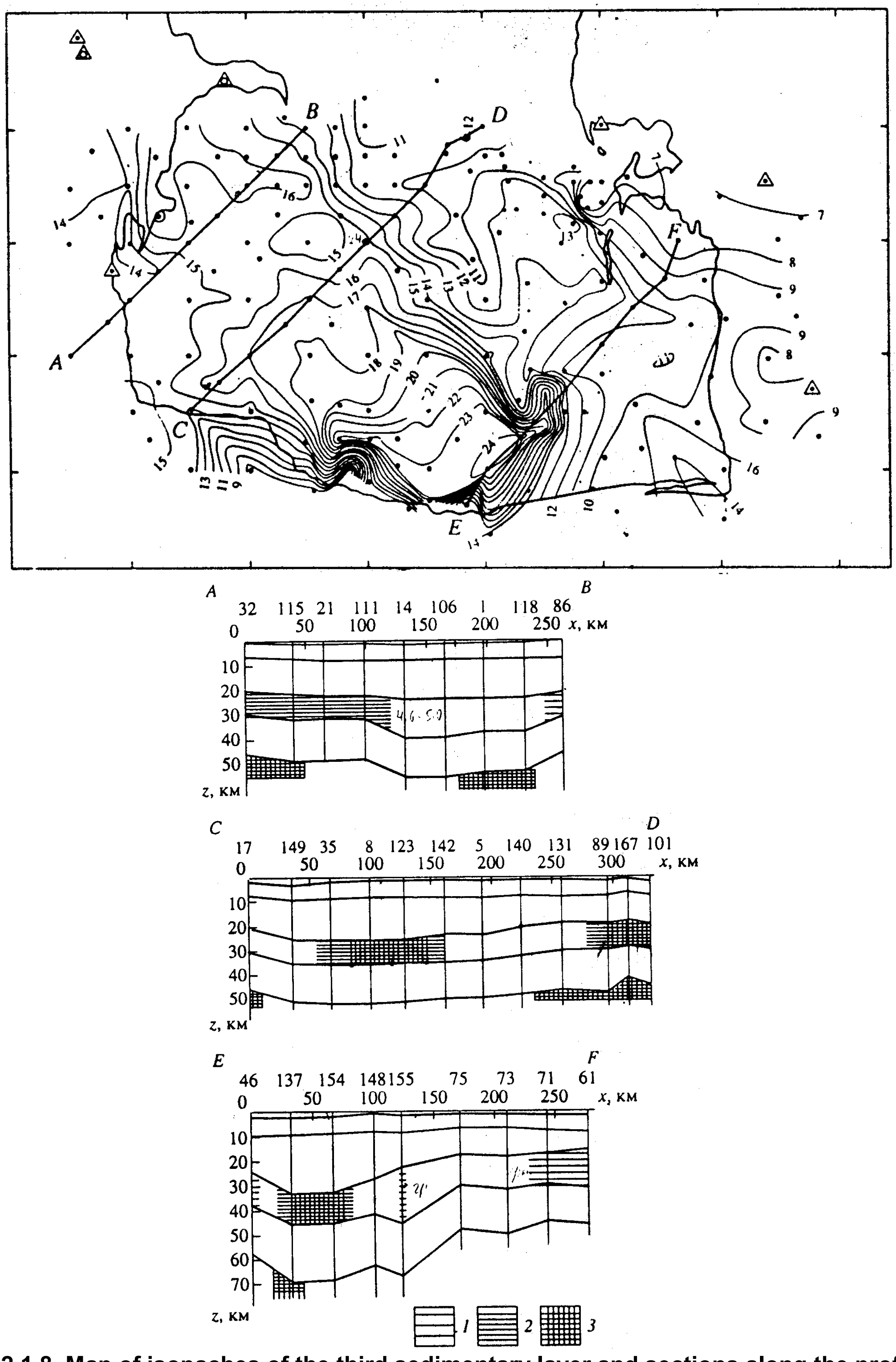


Fig. 2.1.8. Map of isopaches of the third sedimentary layer and sections along the profiles (A.N. Yakobson, 1997).
Velocities of cross waves: 1-vs≤3.8 km/s; 2-vs>4.6<5.0 km/s; 3-vs>5.0 km/s.

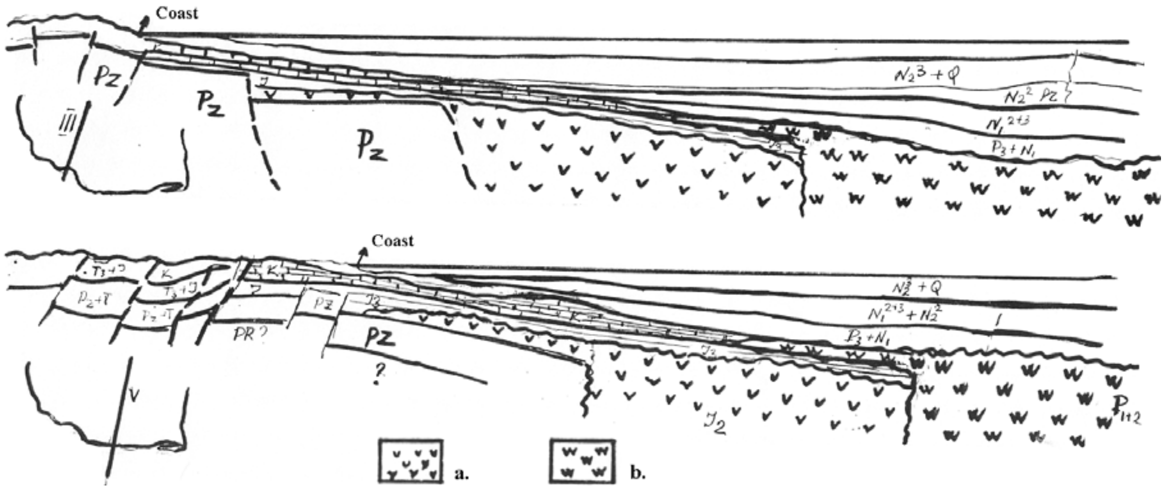


Fig. 2.1.9 Geologic-geophysical sections of the North Iran and the Caspian south part. (a) - Mezosoic basalts; (b) – Paleocene-Eocene basalts. (by P.Z. Mamedov, 1997)

Dislocation and sedimentation of blocks of the Pre-Alpine crystal base in the North Iran towards the SCB along the faults touching the Mesozoic complexes of rocks as well as typical features of their unconformable overlapping by the Cenozoic series prove the fact of later extension processes with the formation of the graben-trough. Younger age of the South downwarping is proved by age of the volcanic rocks in Talysh and in the North Alborz and by increased values of the heat flow as well.

Location of the rift trough with the oceanic crust in the South Caspian resulted in the formation of a sublatitudinal zone of contact of its young plastic crust with a stable and hard Jurassic-Cretaceous crust of the north trough. Due to the huddling of basalt masses of different ages the crust has a complex relief. The isolated positive anomalies in the Mil-Okarem zone in the South Caspian mark the contact zone of "the old" and "the young" basalt crust.

Thus in the Greater Caucasian Sea there occurred the same tectonic processes as in the recent marginal seas. They completely correspond with the Karig's classical model of the stage-by-stage opening and development of deep-water depressions of different ages in the back-arc (marginal) seas.

According to Shreider's et. al (1997) re-constructions the Eocene opening involved the East-Black Sea depression, the Lesser Caucasus and the South Caspian. Distinct polarity from the south of a 5 km series of the Eocene volcanites in Talysh and basalts of the same age in Benalude makes it possible to suppose that the basalt crust in the base of the Pre-Alborz trough of the Caspian Sea is of the same age. However, in the marginal seas the new cycle of the formation of a young back-arc trough starts when the extension stops in a mature trough. For this reason the south trough is the end of the late Cretaceous or Paleocene because according to data of the paper /Dotduyev, 1986; Zonenshine, 1987/ the widening of the Greater Caucasian Sea stopped in the Senonian and there occurred a split of the volcanic arc. For this reason the most probable time of the formation of the south rift trough - is the end of the late Cretaceous and the beginning of the Paleogene. In any case it must be older than the Talysh inter-arc rift located south-west of it. It should be taken into account that the South Caspian uplift of the base is a fragment cut of the Iranian microcontinent and it stopped to supply clastic material to the trough located south of it in the Paleocene-Eocene.

Thickness of the volcanogenic cover and sedimentary series filling in the graben-trough, exact configuration and morpho-structure of its flanks can not be determined exactly due to the absence of the linking seismic profiles between the Iranian coast and depression of the South Caspian. Only in the Pri-Lenkoran-Astara coastal line there exist seismic information about the volcanogenic-sedimentary series subsiding towards the depression. The surface of the Eocene volcanites with a specific hummocky and roughly configuration of the reflecting elements is very well traced there. The character of seismic reflections from volcanites is completely similar to that of the volcanogenic cover in the Pre-Talysh trough and even in the Mugan monocline. In the seismic sections of the marine profiles of the north-east orientation the surface of the Eocene volcanites subsides steeply towards the deep-water trough and joins a deeper hummocky surface. The latter probably marks the top of the Mesozoic magmatites (basalts) which formed the crust of the oceanic type during the early (Middle Jurassic) episode of the Greater Caucasian marginal Sea opening.

2.1.4. Structure and nature of the South Caspian uplift of the basement

A special place in a complex and mosaic structure of the SCB is occupied by an uplifted along the crystal basement the South Caspian protrusion-massif (or Godin's uplift). For the first time is was determined according to gravimetric data. In the gravitation field the uplift corresponds with a large positive anomaly 20-25 mGal in the form of gradient on the background of a weak negative field (-10 ÷ 15 mGal) of the basin. To clarify its tectonic nature and structural character is one of very important problems of the Caspian geology. Some research workers think that it is morphologic element formed in the zone of bend and blowing of the oceanic crust in the subduction zone (R. Gajiev, 1965; E. Khalilov, 1983 et al.) and the others think that it is uplifted fragment of the structure of "intermediate massif" type of the pre-Cambrian or the Paleozoic consolidation where the whole SCB is located ostensibly (Godin, 1969; Shikhalibeili, 1984, Gasanov, 1966 et al.). However, the deep structure of the SCB is not studied very well enough and the geophysical information about it is not sufficient. No one of 11 profiles of the DSS does not completely cross the area of the gravitation anomaly location. Only profile DSS-9 reaches its north-west periphery and crosses only one positive isoline (+5 mGal) of the gravity field.

There exist no unique opinion among geophysicists about the petrographic composition and depth of the gravitating object in the earth crust of the basin. By the absolute values of the gravity the South Caspian gravitation maximum (SCGM) is nearly two times weaker the Sefidrud maximum (+ 40 ÷ 50 mGal) mapped in the south littoral zone of the Caspian Sea. According to drilling and geologic-geophysical data there is a high position (up to - 1 ÷ 2 km) of the paleozoic crystal basement. SCGM by the absolute values of gravity nearly 4-6 times give up to the Talysh-Karadonlu gravitation maximum (+ 65 ÷ + 120 mGal). Geophysicists-gravimetrists associated the nature of the latter with a high position of the crystal basement of the pre-Alpine consolidation (up to - 5 ÷ 6 km) south of the interflow of Kura and Araks rivers. However, petrographic studies of data of deep and ultradeep drilling demonstrated that the section from 2.7 to 8.3 km is composed of the magmatic (basalt-andesite-rhyolite) formations and there is absence of geophysical information about any anomaly-forming body under it. The reinterpretation data from the DSS-9 profile (Radjabov, 1987; Pavlenkova et al., 1988) it is absolutely demonstrate that in the north-east of the SCB thickness of the consolidated crust and the sedimentary cover is 11-13 and 20 km respective

Seismic monitoring by the CDP method determined inexactness in the assessment of the occurrence depth of Godin's uplift according to data of the DSS and gravimetry. Direct seismic information about the deep structure of the South Caspian along the sub-latitudinal regional profile "Byandovan-Okarem" allowed to clarify structural peculiarities and the occurrence depth of the base uplift in its north periphery (**Fig. 2.1.10**).

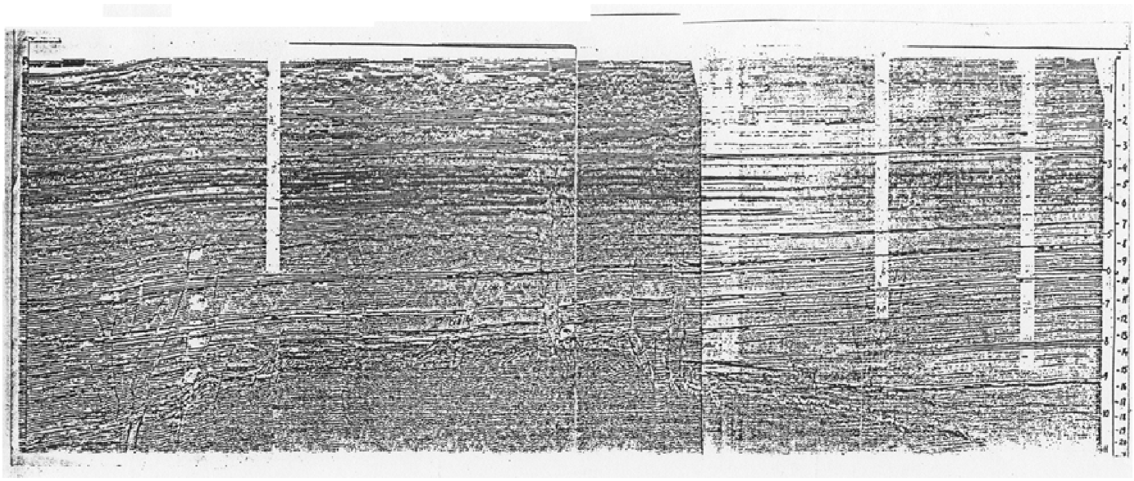


Fig. 2.1.10. Fragment of the seismic section of Byandovan-Okarem regional profile

The seismic section distinctly shows an uplift of the acoustic base of an arc-horst type at depth 13.5-15 km. It is nearly 5-7 km higher than the depth showed in the 2D model of the DSS-9 profile in the cross point with profile by CDP. In the model of profile CDP at depth 13-15 km one can identify a high velocity series confined to the upper Mesozoic by the paper authors (Guliyev et al, 1988).

The same inexactness in the estimation of the base depth according to data of the DSS and CDP was determined in the Black Sea and in many other deep-water depressions (Tugolesov et al., 1988).

In the velocity model of profile DSS-9 the upper consolidated crust is characterized by the values of longitudinal waves (P-waves) velocities (V=6.0 km/sec) which are typical not only for the sialic component, but for layer II of the oceanic crust. In the lower crust the velocities are increased – ("basalt") - 7.7-7.9 km/sec. There exist no boundary within the crust.

Several sea profiles CDP were processed (to 10 sec) in the east of the SCB. They provide direct information about the structure as deep as 17-18 km. On the seismic sections the surface of the empty arc and microblocks which in the form of terraces go down in the south-west direction are traced very well (**Fig. 2.1.11**).

This surface by peculiarities of the wave field is erosion surface. Sedimentary layers lean against its slopes. Conjugation of the uplift with the adjacent south trough occurs along the faults. This is typical for the flanks of the rift depressions. The substrate below the acoustic base surface possess all specific features (weak interrupted or stroky recording with chaotic located elements) typical for the consolidated crust. Mangino and Priestley

(2001) by method of RFA - Reseiver function Analys in the upper part of metamorphic basement identified a layer with velocities of the P-waves V_p=5.8 km/sec. According to these research workers the continental crust 15-20 km thick developed in the east of the SCB. By seismotomography (Yakobson, 1988; 1997) there were determined fields and spots with "the granite" velocities of S-waves V_s=3.8 km/sec which correspond with the granite residuals in the form of columns in a crystal socle. Thus, summarizing data of different and independent geophysical studies about thickness of the crust and velocities of seismic waves therein the consolidated crust in the South Caspian uplift is close to the subcontinental crust of "intermediate" type. The tectonic block differs from the basalt crust underlying most of the SCB. This uplift by the same indices differs from the buried blocks-massifs in the Trans-Caucasian microcontinent (TCMC). Blocks-massifs of TCMC are characterized by a mature continental crust 30-35 km thick. Godin's uplift is a horst-like structure with microblocks displaced along faults southwards. The fact of such displacement of microblocks and the existence of a deep graben-trough along the crystal base in the south proves its structural association with the north slope of the Iranian microcontinent (IMC). The similar "transition" type of the crust and close geophysical indices demonstrate that the Godin's protrusion is a fragment of IMC separated from the north slope as a result of riftogenesis. In the process of the widening of the rift crevise and development of listric faults the microcontinental block was the north shoulder of the graben-trough.

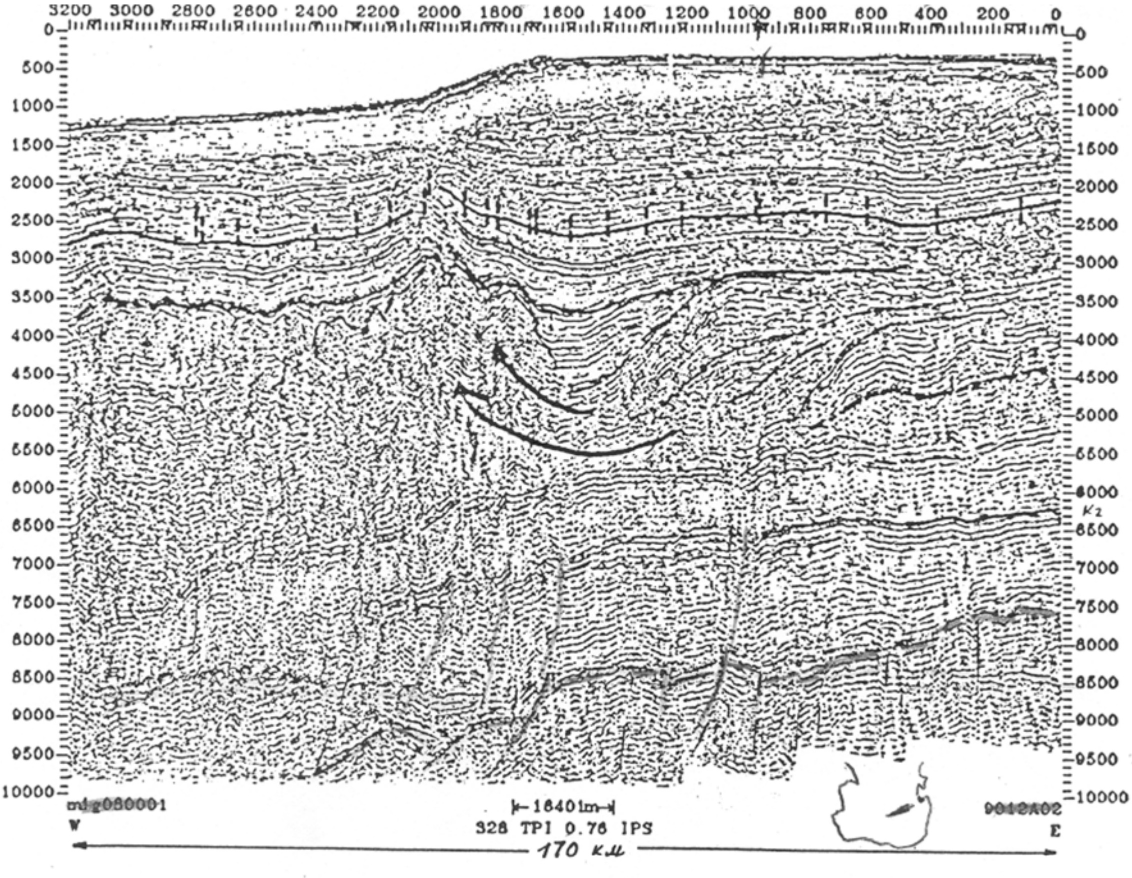


Fig. 2.1.11. Seismic time section of the South Caspian south part (materials of "Kaspmorneftegeofizrazvedka", papers of D. Babayev and P. Mamedov, 1995)

Hence, geological data about the Iranian coast and objective data of seismometry CDP and seismotomography allow to make a conclusion that Godin's protrusion being a substrate of the pre-Alpine consolidation separated from its north slope at the end of the Cretaceous or in the Paleocene and during intensive back-arc volcanism and extension in the Eocene it moved 150-200 km to the north-east. The identified semitransparent thin seismic sequence (SC-3) between the carbonaceous series (SC-4) and metamorphic basement of the uplift is probably the analogue of the upper Mesozoic volcanogenic series overlapping Paleozoic substrate near Cape Sefidrud and cities of Resht, Enzeli, Shakhsevar etc.

According to some research workers in a vast territory from the Black Sea till Afghanistan there were formed transform faults of the SW-NE direction. They dissect a new Jurassic-Cretaceous lithosphere of the South Caspian. The Araks fault separated the Lesser Caucasian and Trans-Caucasian blocks from the Talysh block and the latter was separated from the Central Iranian block by the Lakhijan fault. J.Golonka (2000) associates the separation of the South Caspian microcontinental block (i.e. Godin's massif) from the Iranian exactly with the Lakhijan fault.

Microcontinental blocks like Godin's uplift in the SCB exist throughout all recent marginal and internal seas. They are identified in the form of underwater uplifts-plateau and divided deep-water depressions of different ages (graben-troughs) in these seas. Such are protrusions-plateau Erotosphen and Gerodot in the Ionic - Lewantian basin in the Mediterranean Sea, Yamato and Ullandy in the Japanese Sea, Okhotiya (or named after the Academy of Sciences of the USSR) in the Okhotsk Sea, Kyusyu-Palau - in the Philippine Sea. They and Godin's uplift in the South Caspian are characterized by 15-20 km subcontinental crust and are separated from the thin (up to 7-10 km) oceanic crust in the rift depressions by faults or by suture zones. The above mentioned underwater uplifts separated from the microcontinent (island arc) as a result of the rift opening in their bodies. After the displacement into the marginal sea and with the widening of the trough they were between two deep-water depressions of different ages.

Positive Bouguer gravitation anomalies (about + 40 $\div$ 60 mGal) are typical for the underwater uplifts in the marginal seas. They are identified in the background of a relatively calm and weak gravitation field of these seas. The same situation exists in the South Caspian where the uplift is overlapped by 13 km sedimentary cover and forms anomaly + 20 - 25 mGal in the background of a weak negative (- 10 $\div$ 15 mGal) gravitation field.

The underwater uplifts in the marginal seas are characterized by a rather weak heat flow or by its complete absence. The same situation exists above the South Caspian uplift, whereas south of it there were fixed area with increased values of the heat flow. The heat flow is indicator of the basin's age: high heat flow indicates young basins. The underwater uplifts are characterized by a weak magnetic field as well. Thus, protrusion Yamato and plateau Okhotiya are distinctly identified among a complex and mosaic magnetic field in the Japanese and Okhotsk seas with a weak and nearly "zero" anomaly. The same or close situation exists above the protrusion of the base in the South Caspian. Being placed in the basin in the tensions field the protrusion of the metamorphic basement suffered recycling and crushing. Its south periphery became decrystallized due to contact with a melted magmatic material of a new crust of the graben-trough. Its north periphery contacted with hard stable crust of the Great Caucasian Sea and with the Mesozoic series accumulated above it. Due to this having penetrated into the Great Caucasian depression in the Late Eocene-Oligocene it formed in the Pribalkhan region a tectonic huddling during the extension of the initial trough of the compression fold. Erratic configuration of the structural contours on the structural maps, isovels on maps of equal velocities and isoanomalous on the gravitational schemes opposite the uplift's north side show the late intrusion of the uplift into the structure of the Mesozoic trough. It is quite possible that above the consolidated crust of the protrusion there were preserved Pre-Paleogene deposits inherited from the North Iran as they could not be completely divided during riftogenesis.

Seismic stratigraphy demonstrates that the Turkmenian structural terrace above the uplift was stable tectonic zone with a conform occurrence of sedimentation complexes during the whole Cenozoic (**Fig. 2.1.12**).

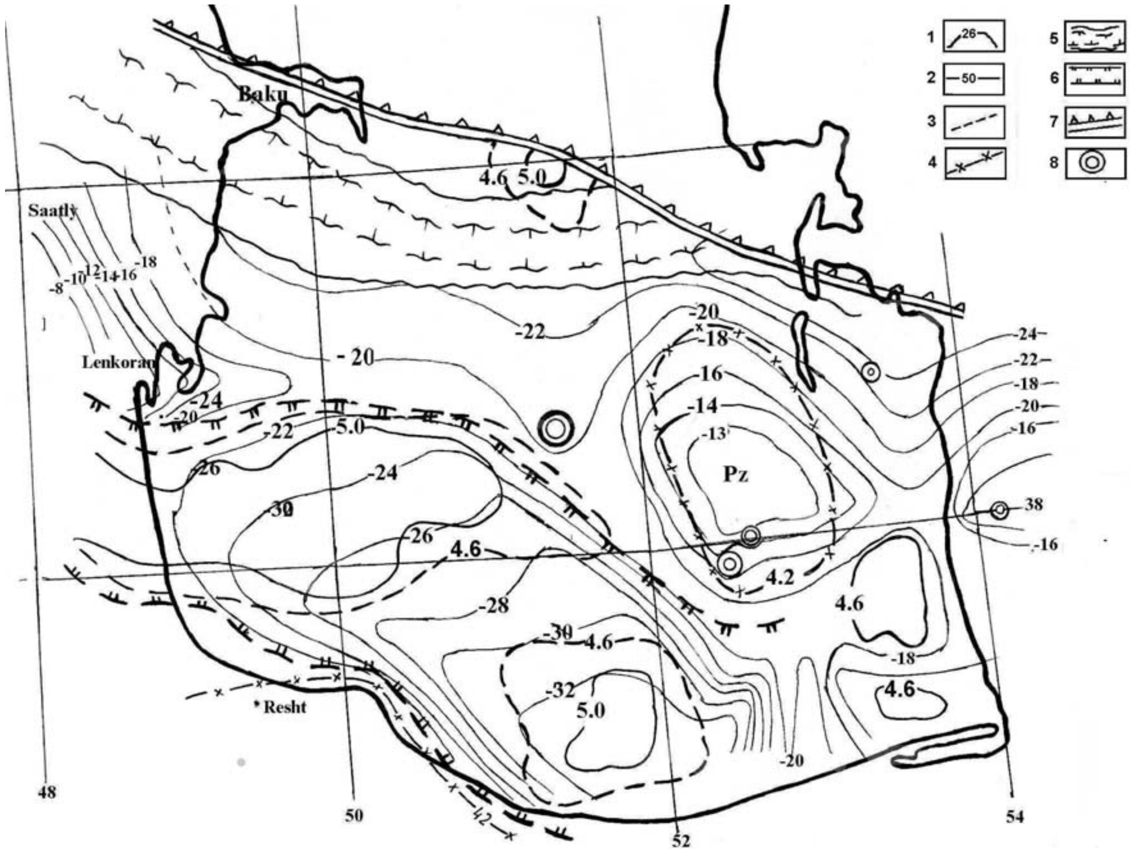


Fig. 2.1.12. Structural map on the top of the sedimentary cover

Compiled by: P.Z.Mamedov (Azerbaijan State Oil Academy) according to materials of J.K.Knopp, C.Diaconesku, J.Connor (Cornell University; Chevron), A.N.Yakobson (Department of Earth Physics Institute); Pavlenkova N.I., Rajabov M.M. (AzNIIGeofizika); L.P.Zonenshain et al; S.I. Dotduyev; G.N. Aksenovich et al; P.Z.Mamedov; M.I.Lodjievsky and F.M.Kadirov; E.N.Khalilov; V.E.Khain et al; Shneider et al.

1 - isolines of basement depth; 2 - mantle diapers - zone with increased mantle velocities at the basin basement; 3 - zones with basalt velocities: figures show the thickness of consolidated crust; 4 - zones with reduced values (“granitic”) of velocities; 5 - border of the Middle Jurassic shelf and rift; 6 - borders of the Paleocene-Eocene rift; 7 - zone of subdiction of the oceanic (basaltic) crust; 8 - remnants of the "granitic" layer.

In conditions of subplatform stabilization there probably occurred process of the crust continentalization. According to Moshashvili (1982) the east shelf and the littoral zone in Turkmenia are the zone of the Early Kimmerian folding where the continental crust were formed in the Jurassic. Probably the west of the West Turkmenian depression (onshore) with a thin "granite" layer in the beginning of the Cenozoic was in a stage of continentalization being adjacent to the Turanian plate margin. Currently the whole Turkmenian shelf is at later stage of geological evolution that the west of the SCB which still suffers geosynclinal stage with movements of microplates of different directions and differentiated downwarping of the basin floor. Here the island arc regime stopped and transformed into the shelf regime and the earth became subcontinental.

Thus, geologic-geophysic studies demonstrate that Godin's uplift is a fragment of the Iranian microcontinent and not the morphologic element formed as a result of tectonic huddling of the oceanic crust. Its contours and location of suture zones and faults limiting it, where the reason of later structural reconstructions such like the formation of folded lines (Abych, Tchikishlyar, Pribalkhan) south-west and submeridional variations in Kopetdag. The sedimentary cover above the metamorphic substrate of the uplift was characterized by rather weak deformations and conform occurrence of sedimentation sequence.

2.1.5. Passive structural elements and sedimentation bodies in the north continental margin of the Greater Caucasus Sea

In the rift and mature stages of the Greater Caucasian marginal sea evolution in the margin of the Scyth-Turanian platform its north continental slopes and shelf developed. In the Pre-Caucasian and Middle Caspian seismic sections one can observe traces of the Jurassic riftogenesis considered as a genetic core of the old marginal sea and its relict - the SCB. In the seismic sections the rift structures of the extension and subsidence of the continental crust blocks have a direct morphologic expression in the surface of the consolidated crust. One can clearly see ruptures between the blocks, horsts and grabens, and also consedimentation overlying of layers of the sedimentary cover in the inter-block spaces (**Fig. 2.1.15**).

The presence of the latter witness to the fact that the filling by the sediments of narrow and parallel lakes on the tops of the blocks occurred during a slow sliding of the blocks towards a deep graben - trough.

Rather interesting structures in the north flank zone of the trough are buried protrusions of the Paleozoic substrate which are identified in the seismic materials as acoustic basement without any reflecting element. Their surface is sometimes identified as a rough boundary with erosion features and underwater denudation. Such are the Paleozoic protrusion (massif) in the Karabogaz arc, Agzybirchala and Khudat-Khachmaz protrusions.

Protrusions of the basement played the role of marginal uplifts separating the deep-water depression of the marginal sea from shallow-waters epicontinental basins (ECB) in the margin of the platform, which formed in vast shelf spaces during the Late Mesozoic and Early Paleogene transgressions. Arising of marginal protrusions and ECB was determined by the evolution of the north continental margin of the ocean Mesotethys. Marginal protrusions occurred as a flank framing of the epirift Greater Caucasian marginal sea were transformed into margins of the platform peneplene. For a long time there remained uplifted elements and suffered erosion and washout.

Thus, the largest marginal uplift Karabogaz arc (KBA) till the beginning of the Late Cretaceous was an uplifted element of the Paleozoic basement and was the source for the basins located in its peripheries. The Agzybirchala protrusion according to data of the drilling and seismic sections was a paleoland as long as the Lower Pliocene. The East - Pre-Caucasian uplift and the other protrusions in the Mesozoic were below the sea level but in different epochs they existed in the form of isles and were structural-uplifted elements between the Greater Caucasian Sea and ECB in the margin of the platform.

Later on due to the extension of the rift depression and the downwarping of its floor the above mentioned protrusions were involved into the subsidence and their outward steep slopes turned into continental slopes in the north of the marginal sea. Between the Agzybirchala - Khudat - Khachmaz group of protrusions and the Karabogaz arc in the Middle Caspian there was formed a not deep trough going towards the Kazakh bay. In the Late Jurassic - Eocene period there occurred an active downwarping of the Paleozoic basement there.

Analysis of seismic material shows that in the Mesozoic and in most of the Paleogene relatively steep continental slopes were formed in the outward flank of marginal uplifts.

Steep (up to 16^0) and high (3-4 km) continental slopes are very well read in the seismic sections in the south of the KBA (**Fig. 2.1.13b**). Plane shears, broken clinoforms and bodies of the collapse are fixed there. Such a slope were formed for a long time - from the Late Jurassic till the Oligocene. Absence if deposits in the slope demonstrates that it was a transit zone. Surface of the slope was washed out as deep as the base and was broken by a system of canyons. Sequences of the same age are identified at two levels: in the shelf and at the base of the slope. The main regulating mechanism of the replacement of the sedimentary cover were cyclic decrease of the sea level.

Outward slopes of marginal uplifts in the Agzybirchala protrusion directed towards the Caucasus geosyncline (**Fig. 2.1.13a**) appeared as a result of the platform block destruction along the listric fault due to the extension of the earth crust. The above mentioned continental slopes by their morphology and attitude (up to 3-4 km) are similar to those in the south marginal zone in the Scyth-Turanian plate determined by seismic survey. This witnessed to the fact that these old slopes were steep morphostructures of a regional scale. They existed along the north flank of a unique marginal - sea depression.

Relatively gentle slopes existed in conjugation zones of active shelves with deep-water depression without the marginal uplift. In such zones the outward shelf gradually transforms into a gentle slope. One of such zones was located between the KBA and the Agzybirchala protrusion. In different epochs of the Mesozoic-Paleogene there occurred dagger transgressions there and there were formed gentle carbonaceous clinoforms / platforms. Seismostratigraphic sections for the Middle Caspian and the adjacent land give nice ideas about the evolution of continental slopes and shelves at different fluctuations of the sea level (P.Z.Mamedov, 1992).

Analysis of the distribution of the deposits thickness shows that during the Jurassic and the Cretaceous periods the marginal part of the epihercyan platform was characterized mainly by the downwarping. In these periods there occurred the separation of independent shelf basins along the margin of the platform.

Carbonaceous shallow-sea formations best of all illustrate the shelf sedimentation of the platforms margin. Nearly monolithic limestones sections of the Upper Jurassic (up to 0.8 km thick) and the Upper Cretaceous (up to 1.4 km thick) complexes in the areas adjacent to the Middle Caspian - in the Pre-Caucasus (Bairak, 1985) are identified in seismic sections by a specific macrolayered portray. Carbonaceous series in the section of the Middle Caspian possess comparatively the same portray (**Fig. 2.1.13a**). They framed marginal basin in the Late Jurassic - Neocomian and Late Cretaceous - Early Paleogene periods. By sigmoidal surfaces with the application of a special method (Kunin, 1989) we assessed the depth of the sea basin beyond the shelf margin - 300-400 m.

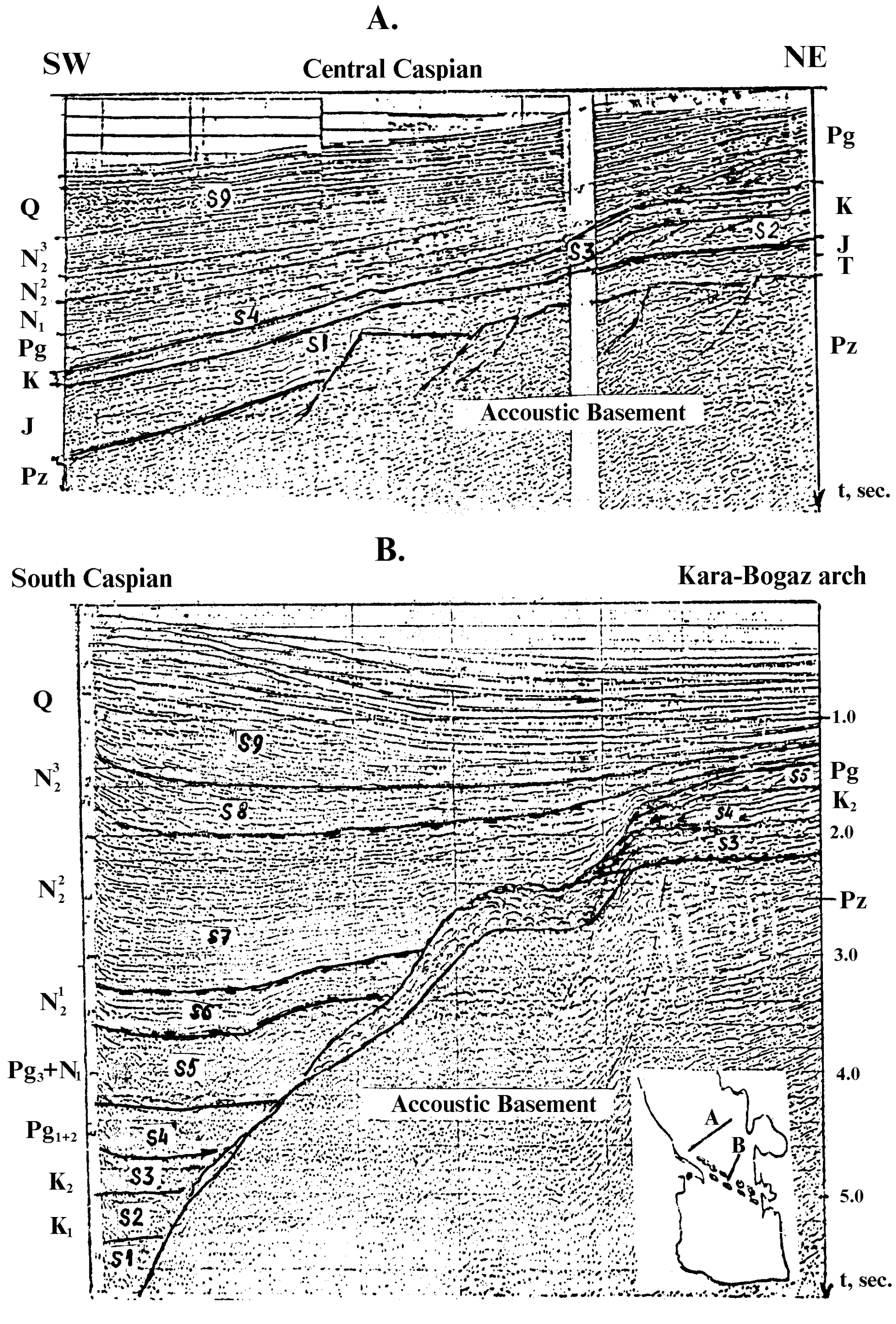


Fig. 2.1.13 Two models of old continental slopes on the north flank of deep-water depression: A - Model-II; B-Model-I

Marginal uplifts stretched along the platform margin, ECB and shelf basins, vast carbonaceous platforms (clinoforms) are typical passive structural elements and formation complexes in the continental margins). While studying structural and morphological peculiarities of the marginal zone of the Scyth-Turanian platform within the Middle Caspian and the adjacent land there was determined that it obeys the general classic model of a passive margin of the marginal seas. The active margin developed on the opposite side belonging to the island arc - in the north slopes of the Trans-Caucasian and the Iranian and the other microcontinents. Two models of continental slopes of the marginal sea are identified on the base of results of the seismostratygraphic analysis.

- Model-I - includes a relatively steep continental slope which here and there is washed out as deep as the base and the broken clinoforms of sediments of the same age (Mesozoic - Paleogene) in the shelf and at the base. The slope is the zone of the washout and transit of sediments (**Fig. 2.1.13b**);
- Model-II - includes a gentle flexure slope formed both by bodies of the lateral increase of the clastic sediments and by the carbonaceous clinoforms. Such slope was the zone of a localized sedimentation (**Fig. 2.1.13a**).

Both models are typical structural flanks of the non-compensated deep-water basins of the rift genesis.

Now let's consider main models of the slope sedimentation in the continental margin of the Greater Caucasian basin.

In the relatively steep south and south-west slopes of the KBA the plane underwater erosion played an important role in the formation of the sedimentary cover. In these slopes the plane erosion resulted in the formation of a steeply dipped natural screen where the deposits did not remain. Existence of deposits of the same age (SSC-2, 3, 4 and 5; **Fig. 2.1.14**) in the shelf and in the continental base and their absence in the slope demonstrate that the latter was the transit zone. The whole sedimentary material from the shelf margin gathered at the slope basin and the surface of the base here and there was completely washed out and was broken by a system of valleys and canyons. In the time section the lanslide seismic facies are shown very well in the upper relatively gentle part of the slope too (**Fig. 2.1.13 b**).

Seismic stratigraphy analysis demonstrates that the formation of thick sedimentation complexes at the base of the slope was due to the supply of abundant watered sediments from the shelf. The main regulating mechanism of the transportation of the sediment material from the shelf to the lower level are cyclic relative fall of the sea level (SL). During the fall of SL the erosion basis moved downwards and the vast territories of the shelf were in the zone of denudation. They were moved to the base of the slope by the movements of the waters. The sedimentation bodies which were formed in the lower parts of the ancient slopes due to the dense and turbidity flows were buried by young sediments and preserved they "flow" structure in a recent section during the increase of the SL. They form hilly formations at the base of the slope. The top of the latter is moundy and the internal reflections possess a configuration of the crushing. The belonging of the "flow" seismofacies in the slope to the sedimentary bodies of the dense (turbidity) flows is determined by the presence of the dislocated and broken layers (configuration of "the crushing") and by typical erosion ditch under them (**Fig. 2.1.13**).

A thick complex (up to 0.5-0.7 km) of a lateral increase in the Lower Cretaceous SC-2 fills a narrow submeridional graben of the base in the margin of the platform. By some indication features it may be related to the turbidite formations coming from more uplifted areas of the platform. In the conjugation zones of the shelf with a large continental slope in the south-west slope of the KBA in the seismic sections together with the pinching out of some complexes here and there one can observe broken series and layers (**Fig. 2.1.14**).

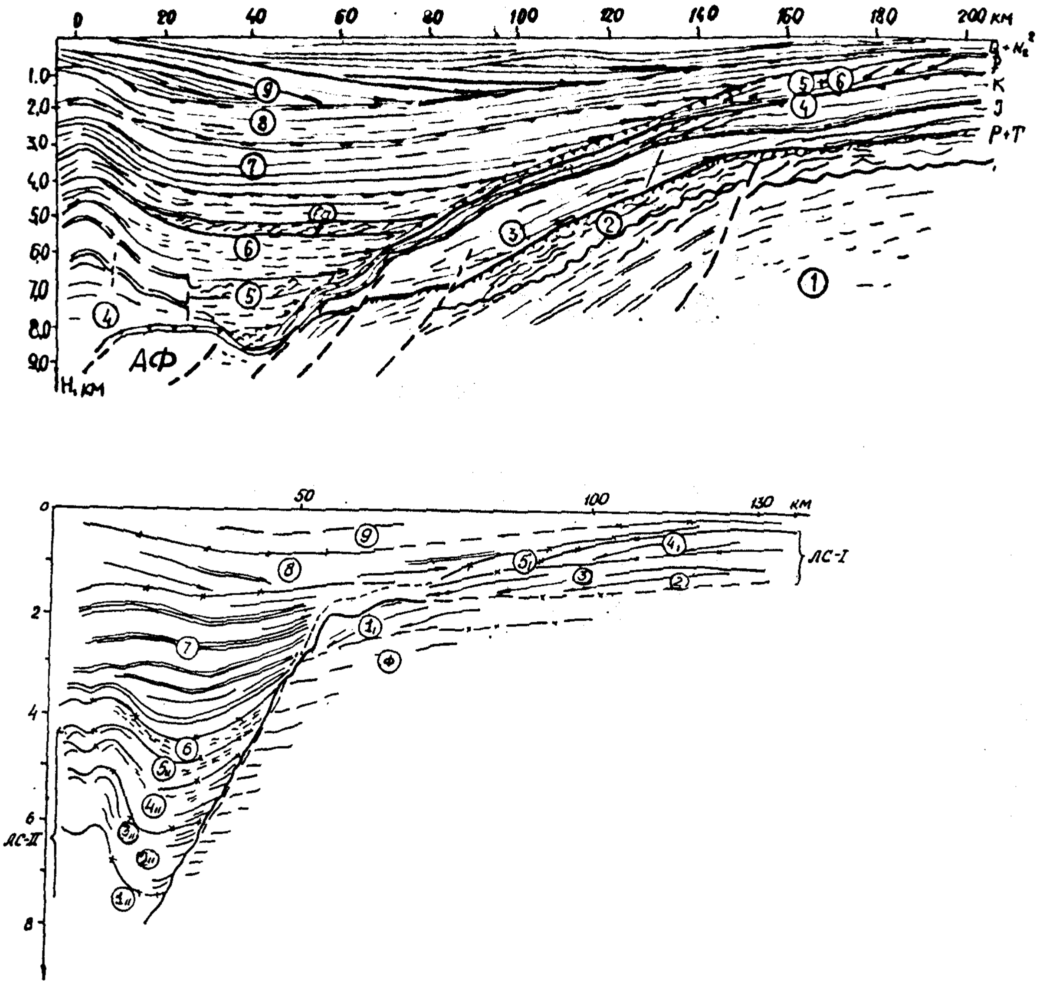


Fig. 2.1.14 Seismostratigraphic sections of zone of conjugation of Epihercyan platform and Alpine mobile belt (compiled by P.Z. Mamedov, 1989); 1-Pre-Jurassic substratum; 2-3,…, 9-sedimentary complexes: 1-Jurassic, 2-3-Cretaceous, 4-Lower Paleogene; 5-Oligocene; 6-Miocene; 7-Lower Pliocene; 8-Upper Pliocene; 9-Quaternary; indexes I and II - quasisynchronous bodies of avalanche sedimentation of the lower (AS-I) and upper (AS-II) levels.

Below in relatively gentle terraces of the slope we can identify bended, moundy and hilly seismogfacies which are seismic images of sedimentary bodies formed as a result of the rupture of the layers and landslides in the margin of the shelf.

In relatively gentle slopes the underwater plane erosion was replaced by a linear erosion. Canyons dissecting the slope and entering territory of the shelf in the upper parts were the canals of the transportation of the great masses of the deposits coming directly from the shelf in the margin of the Turanian plate. This transportation was carried out by the bear-bottom flows, gravities and by the turbidite flows. The canyons and the dead paleobeds of the dense flows is wider and deeper from the erosion cut. Seismofacies filling them are characterized by a simple or hilly superposition of the coherency axes. In the foot slope the turbidites have a complex structure and the corresponding wavy picture becomes worse. Here the filling seismofacies of the canyons are identified by a complex and chaotic reflection configuration. The SSA shows that despite the existing ideas about the belonging of the turbidite formations to the foot of the slope they reach even the upper slope and the margin of the shelf.

The initial south-west continental slope in the West Caspian horst in the Central Caspian probably was quite gentle. Consedimentation occurrence of SSC-2 layers (Jurassic) shows that during the earth crust extension there existed shallow-sea or the lake state. A system of Cretaceous clinoforms (Late Cretaceous ?) formed large secondary sedimentation slopes. The latter are transformed into vast shelves. The Mesozoic-Eocene macrosequence decreases from the east westwards there and forms a large flexure 100-120 km long and with amplitude 5-6 km.

Thus, the boundary structures of the basement in the margin of the epihercyan platform played an exclusive role during the formation of the continental slopes and specific forms of sedimentation bodies in the north flank zone of the marginal sea.

2.1.6. Morphostructural elements of the Trans-Caucasian island arc and features of the slopes on the south flank of the marginal sea

After examining the riftogenous structures on the north continental margin and features of the consolidated crust of the South Caspian lets study the ancient buried morphostructural elements on the south island arc side of the marginal sea.

According to mobilistic plate-tectonic conception the opening of the marginal sea in early-middle Jurassic time on the Mesothetis active margin is connected with the oceanic crust subduction under the Trans-Caucasian and Iranian microcontinents and further formation of the Lesser Caucasus volcanic island arc (IA) in bodies of the latter ones. The arc stretched from the Crimea till the Caucasus in further to Iran (Zonenshain et al., 1990; Lomize, 1987; Dotduyev, 1986 et al). At the same time the geodynamic situation was similar enough to those which take place on the active margin of the Pacific Ocean.

In the region recent structure the relicts of the Mesothetis oceanic crust in autochthonous occurrence had been preserved as Sevano-Akerin ophiolitic suture. The important morphostructures of the pre-arc area, namely the deep water trench, the outward slope of the arc are completely destroyed as a result of the plates convergence.

But in Cenozoic the morphostructures of IA, formed in the Mesozoic on the sialic socleplate of the microcontinental fragments, IA morphostructure are subjected to relatively weak tectonic influences. Thus, they had preserved good in the section and clearly seen on the seismic sections (**Fig. 2.1.15**).

According to researches of V.G.Kazmin (1989), Ostroumova and Tsenter (1990) et al two volcanic arcs were developed in the studied region in the middle Jurassic - Cretaceous time. These arcs were related with a united back-arc basin. One of them – frontal-arc - were developed on the south peripheries of the Trans-Caucasian and Iranian microcontinents. L.P.Zonenshain with his co-authors (1990) doesn't exclude that it was one arc splitting into two arcs at the Middle Jurassic end. After the crack the frontal part of the arc was moved southward towards the Mesothetis ocean and, probably, was obducted on the oceanic lithosphere, and the residual arc had felt the submersion.

Since in the recent structure the Jurassic volcanites are given in direct contact with the ophiolitic suture, Lomize (1987) suppose that the subduction was accompanied by the tectonic erosion of the southern continental side of the Trans-Caucasian microcontinent. At the same time the axis of the volcanic belt gradually displaced northward.

According to data of the petrochemical studies and geophysical fields' analysis the Pre-Lesser Caucasus zone of volcanites is corresponded to the frontal volcanic arc. According to reconstruction this zone felt the elevation in the Late Jurassic and the Early Cretaceous and had split into two parts.

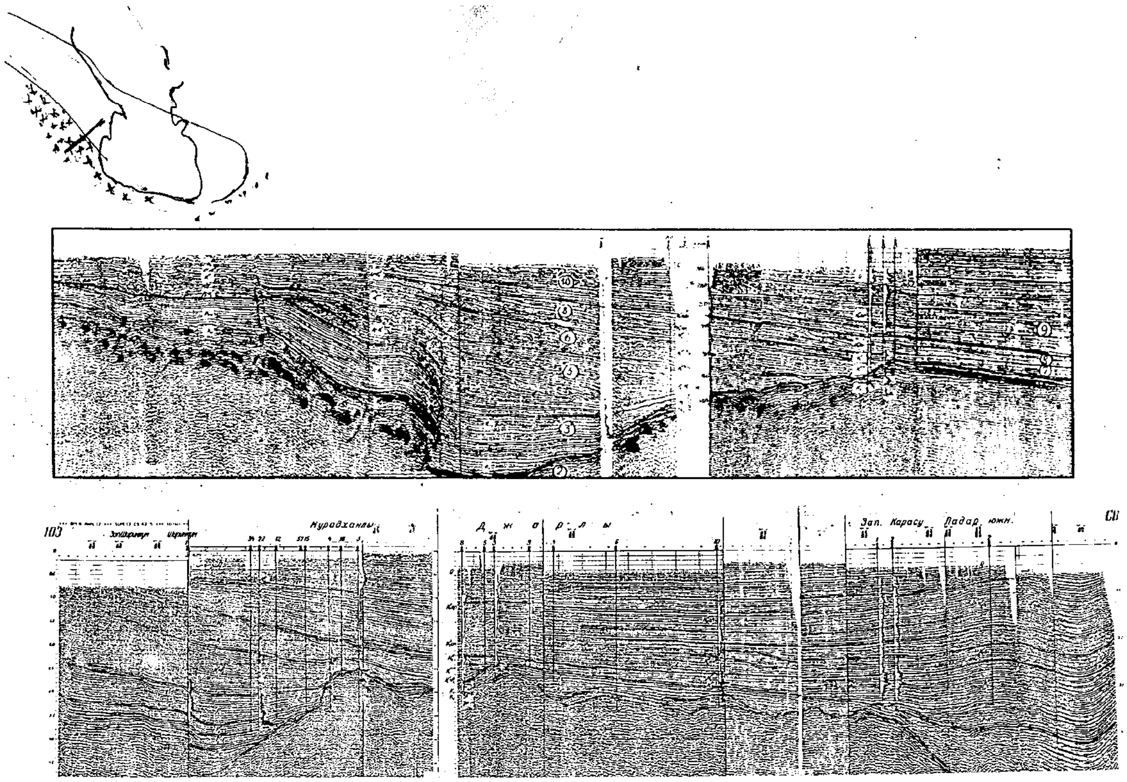


Fig. 2.1.15. Image of the buried volcanic arc on the seismic sections

At the same time the outlines of Mingechavir-Mugan inter-arc trough were drawn up. Further within this trough there were developed Evlakh-Agjabedi and Khyrmandalin troughs.

Within Samkheto-Karabakh length of IA the researchers V.G.Zaseev and I.I.Abramovich (1993) had revealed its fragmentary, established the stage manifestations of volcanism, spatial-time distribution of basalt-andesite-rhyolitic series and zoning of potassium concentration areal which are very typical for all recent IA.

In Shamkir, Murovdag, Karabakh and Agdam-Khojavend fragments of the arc the most extensity of magmatic eruptions is determined in the Late Jurassic and the late Cretaceous stages. Simultaneously the location and orientation of the arc fragments were changing, new volcanic centres had appeared. After each stage the volcanic centres moved to the arc rear, i.e. northeastward for 20-30 km on average.

In Dalmamedli-Begmanlin zone of uplifts the Jurassic-Cretaceous section is composed of series of the volcanoclastic rocks and calcareous-tufogenic material (R.N.Abdullayev et al., 1984). At the same time within this zone there is the greatest thickness (up to 800-900 m) of the sedimentary rocks, carbonaceous mainly, of the Cretaceous age. Northward the thickness of carbonates reduces gradually and they pinch out near the opposite flank of Evlakh-Agjabedi trough.

The great thickness of the Mesozoic effusives of basalt-andesite-rhyolitic formation in flank zones of Evlakh-Agjabedi trough shows a significant activation of volcanic activity in the Jurassic-Cretaceous time. On the northeast from Evlakh-Agjabedi trough the researchers had reconstructed Saatly-Kyurdamir-Geokchay-Mingechavir arc. Developing beyond the arc in the Cretaceous time the rear Greater Caucasus back-arc basin reached the maximal sizes - about 2000 km in length and 600 m in width. Volcanites of this arc form an extended morphostructural unit as a ridge with width 30-70 km. This sharply dislocated volcanogenic-tectonic zone Alazan-Gyzylagach zones of the buried Mesozoic uplifts. The reached thickness of the volcanites on Muradkhanly field is about 2 km, on Saatly field - 5 km. But no one drilled well had reached the foot of the mentioned fields. The content and character of rare and rare-earth elements distribution in volcanic rocks of Saatly ultradeep well are corresponded completely to such in volcanites of the recent IA.

Studying the materials of the seismic prospecting of Kura depression we came to conclusion that here the seismic sections give data about the volcanic noses, tectonic ruptures related with extension and disintegration of the Lesser Caucasus IA to the outward (south) and inner (north) segments (conventionally called by us as Pre-Lesser Caucasus and Mingechaur-Geokchay-Saatly segments). For example, in IA the thick cover of the Jurassic and Cretaceous volcanites in the basement of Pre-Lesser Caucasus trough and the Middle Kura depression is distinguished on the seismic sections as acoustic basement the erosion and uneven surface of which scatters seismic energy. Chaotic and uneven reflection are recorded lower the mentioned surface. High enough (up to 3-5 km) and wide (from 20 to 70 km) volcanogenic ridge of the general Caucasian orientation is clearly traced on the seismic sections in the Middle Kura, Alazan, Upper Kura depressions beginning from Pre-Talysh till Dzirul massive.

The typical sliding of acoustic basement blocks on the listric faults towards Lower Kura - South Caspian depression and fan-like divergence of the synrift deposits on blocks' tops are observed on the northeastern slopes of the IA inner segment (**Fig. 2.1.16**). There is an absolute identity of the observed wave fields with the known literary specific seismic images of IA systems.

Seismic images together with the petrophysical characteristics (the belonging of volcanites of basalt-andesit-rhyolitic formation, the presence of rare earth elements typical for IA volcanism) are the additional and objective indicators of IA genesis of the examined volcanic noses.

Carbonate series (up to 800-850 m) covering the volcanogenic formations of the Jurassic and the Lower Cretaceous on the inner segment of IA system formed on the southwestern near-flank zone of the Greater Caucasus sea. Due to sharp fall of sea level at the Late Cretaceous (nearly 50 mln. years before the Middle Miocene end) the continental regime prevailed there. Later the eroded scarp of the Upper Cretaceous carbonate rocks served for a long time (Late Cretaceous-Paleogene) as the shelf-edge of the marginal sea. On the seismic sections the slope height was 3-4 km according to thickness of adjacent layers. It completely corresponded to such ones on the northern continental margin of the Greater Caucasus basin.

A steep submersion of the island slope is pointed on the eastern sides of the

Mesozoic uplifts on Jarly - Sor-Sor - Karajaly line. The consedygenic ruptures are recorded in some places. These ruptures are connected with relief of the underlying volcanogenic formations. The sharp fall of sea level at the Cretaceous end promoted the formation of deep erosion wedges and development of the denudational processes on the exposed shelf (peneplain) and paleodepressions' steep slopes. The fill seismic reflection configuration and terrigenous clineforms of the Paleogene-Miocene sequence complex shows the deep water genesis of the paleobasins.

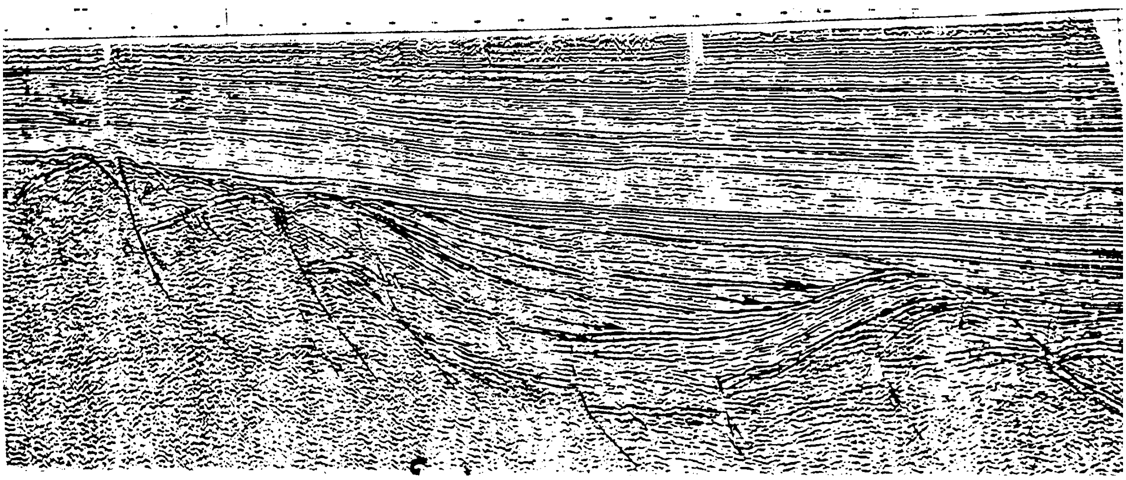


Fig. 2.1.16. Sliding of IA blocks towards the deep-water depression (Kyurd area)

Relatively gentle northeastern sides of Mugan anticlinorium served the island slopes of deep basin in Pre-Talysh zone. Here the slope was forming for a long time too, beginning from the Paleocene till the Upper Pliocene. The slope surface is cut by the turbidites and gravitites flowing down the steeply slop shelf.

Thus, seismic-stratigraphic analysis allows coming to the following conclusions about the formation of the southwestern island slopes of the Lower Kura - South Caspian depression. The surface of erosion of the Mesozoic volcanogenic-carbonate massive of IA served as the southwestern paleoslope of depression up to the Upper Miocene in Jarly-Saatly region and up to the upper group of the Lower Pliocene in Pre-Talysh zone. As far the warping and subsidence of the interbasin zone more younger layers of filling sequence contacted with its surface. The secondary accumulative slop (Middle Sarmatian and Lower Pliocene) formed during the Middle Miocene and Lower Pliocene stages. But on the background of the general transgression the primary slope determined the main morpho-genetic peculiarity of the depression's southwestern flank.

2.1.7. Regional seismostratigraphy of South Caspian Megadepression (SCMD)

In scale of the whole SCMD the regional seismic-stratigraphy is aimed to precise the development history and general regularities of the sedimentary basins' structure and stratigraphic bodies filling them. This research's stage contain the following tasks: tracing of the unconformity and surface of acoustic basement, study of the main structural elements of the sedimentary cover, spatial-time correlation of sequences, discover of sedimentation condition and prognosis of oil-gas prospective zones and objects.

The hiatus determination, tracing and correlation of unconformity surfaces are the main chain of the regional seismic-stratigraphy. The unconformity is widely spread structural form in the sedimentary cover of SCMD. Here the sections differ by the deformation specifics, duration of breaks and scale of unconformities. The success of seismic-stratigraphic analysis in geosynclinal area can be provided with the good development of the methodical bases of unconformity surface determination and establishing of their nature on the seismic time sections. Information on the genetic type and scale of unconformity are in dynamic and morphological characteristics of reflections in contacting sequence. On the seismic sections we were able to distinguish the unconformities related with exogenic, tectonic, sedimentary, eustatic and volcanogenic processes. Basically, two regional unconformity surfaces of the first rank, dividing the macrosequence, are distinguished in SCMD. The first one fills an age sliding and fixes a surface of the Cretaceous sediments, somewhere - Paleocene-Eocene sediments, on which the megadepression is subdivided into zones of troughs and uplifts. The second one - asynchronic surface of unconformity - is corresponded everywhere to the lower border of the Pliocene-Quaternary macrocomplex on which SCMD is fixed as a unite area of the recent subsidence. Depending on contrast of structural and angle unconformities there are changes of character and truth for their tracing on seismic sections.

The tracing of regional surfaces of unconformity on seismic sections has a principal meaning on the historical-genetic analysis. The unconformity surfaces between sequences control the majority of revealed and forecasted non-anticlinal traps in the region outlining the applied aspect of their study.

Seismic sections of regional and composite profiles provide enough space for reconstruction of the main features of the tectonic development and sedimentation conditions. Information obtained from seismic sections and updated by available geologic-geophysical and well information were used by us for compiling of some seismic-stratigraphic sections with length up to 400-600 m. They light up the SCMD structure from flank to flank (**Fig. 2.1.17 and Fig. 2.1.18**).

On the base of precise seismic-stratigraphic analysis we had studied the specific features of the sedimentary sequences. We distinguish 10 sequences in the sedimentary cover of the megadepression.

Jurassic seismic sequence (SC-1). Seismic sections give clear notion about the development of the epicontinental consedimentational basins in Jurassic in the platform marginal part. The transgressive deposits are bordered by sedimentary unconformities of onlap seismic features upthrust of axes of synphase upon Pre-Jurassic surface of unconformity testifies the widening of shallow basin. Here the general thickness of the Jurassic deposits is about 1 km and increases towards the South Caspian, reaching 5-6 km in flysch troughs of the Greater Caucasus. In the Middle Jurassic trough the Jurassic sequence is represented by the volcanogenic rocks.

Cretaceous seismic sequence. Cretaceous sedimentary series are composed of two seismic sequences: SC-2 (Lower Cretaceous deposits) and SC-3 (Upper Cretaceous deposits). These sequences show important variations in thickness and facies between basinward zone, platform areas and island-arc areas. Layers of SC-2 occur conformably on vast paleoshelves on the northeastern near-flank zone of the megadepression. On seismic section the carbonate clineform is distinguished in the near-slope zone. According to it we had revealed sea depth - 300-400 m. The top horizon of the SC-2 is very reflecting surface. Zone of development of carbonate benches on shelf-break is a favourable zone for rifogenic constructions formation. On the base of seismostratigraphic analysis we had revealed and mapped two hill-shaped objects on the Upper Jurassic - Early Cretaceous terrace in region of North-Apsheron - Andreevsky bank structures. According to some seismofacial criteria, data of dynamic and rate analysis these objects are interpreted as barrier reefs.

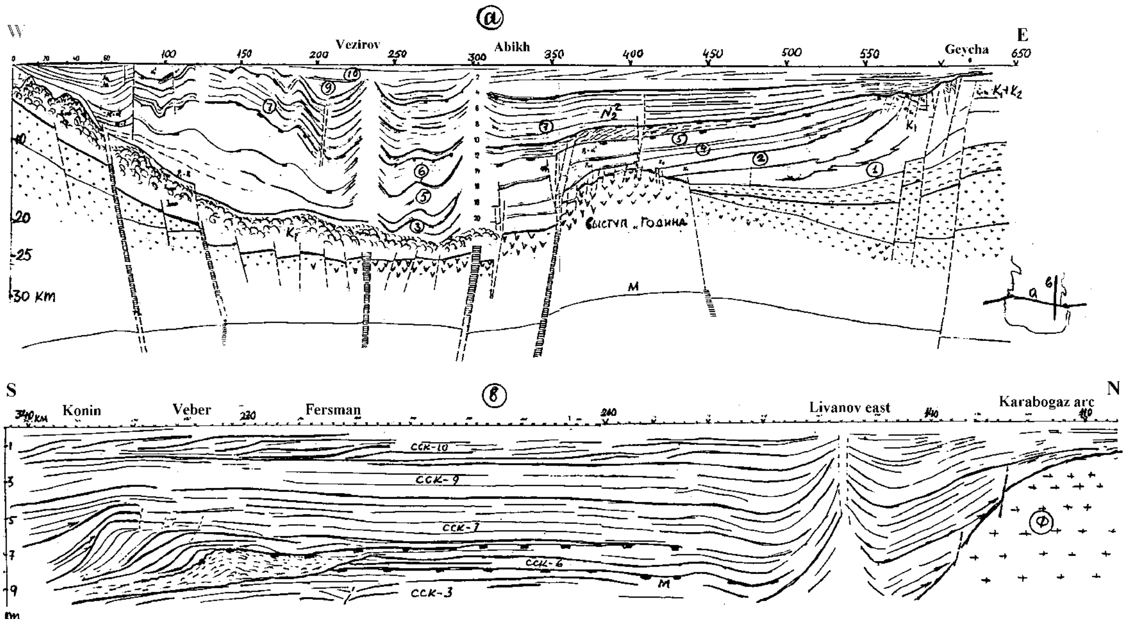


Fig. 2.1.17. Regional seismic-stratigraphic sections along the sublatitudinal (a) and meridional (b) profiles (by P.Z. Mamedov, 1994)

The northwestern part of Apsheron archipelago is characterized by the complex structure of the Cretaceous sequence. Here the Mesozoic benches are distinguished on sections by the uneven and curvilinear configuration of their surface. Inside the benches the reflection configuration is broken and distorted by the diffraction waves.

An intensive multiphase reflection is traced in the section of Turkmenian shelf on 7-8-km depth. This reflection is typical for acoustically hard carbonate rocks. The similar record of the reflection is observed on time section in the Turkmenia on-shore zone. According to drilling data this zone is corresponded to the surface of the Neocomian carbonate series on 4.5-5-km depths. In the Middle Kura depression SC-2 is represented by carbonate series covering the volcanogenic benches.

Paleocene-Eocene sequence (SC-4). In transition (from platform to geosyncline) zone SC-4 differs by transparent macrolayer look typical for homogeneous carbonate series. On the territory of the North-Apsheron trough (NAT) the surface of SC-4 unites with the Mesozoic surface (conventional seismic horizon - III). Here SC-3 and 4 form a great flexure with 100-120-km length and bend amplitude 4-6 km. Northward from anticlinal line Apsheron bank - Arzu - Ashrafi we had revealed for the first time a graben on the Mesozoic-Early Paleogene complexes with 40-50-km length and 17-km width. Graben amplitude is about 1 km. Judging to the stratigraphic band of examined deposits the graben had appeared during the Alpine tectogenesis manifestation. The specific features of tectonics of the graben different sides points to that the latter one had disassociated the sedimentary basins of the geosynclinal and platform areas and caused the autonomy of their further development. In this connection we propose to draw the northern border of the geosynclinal area on the graben.

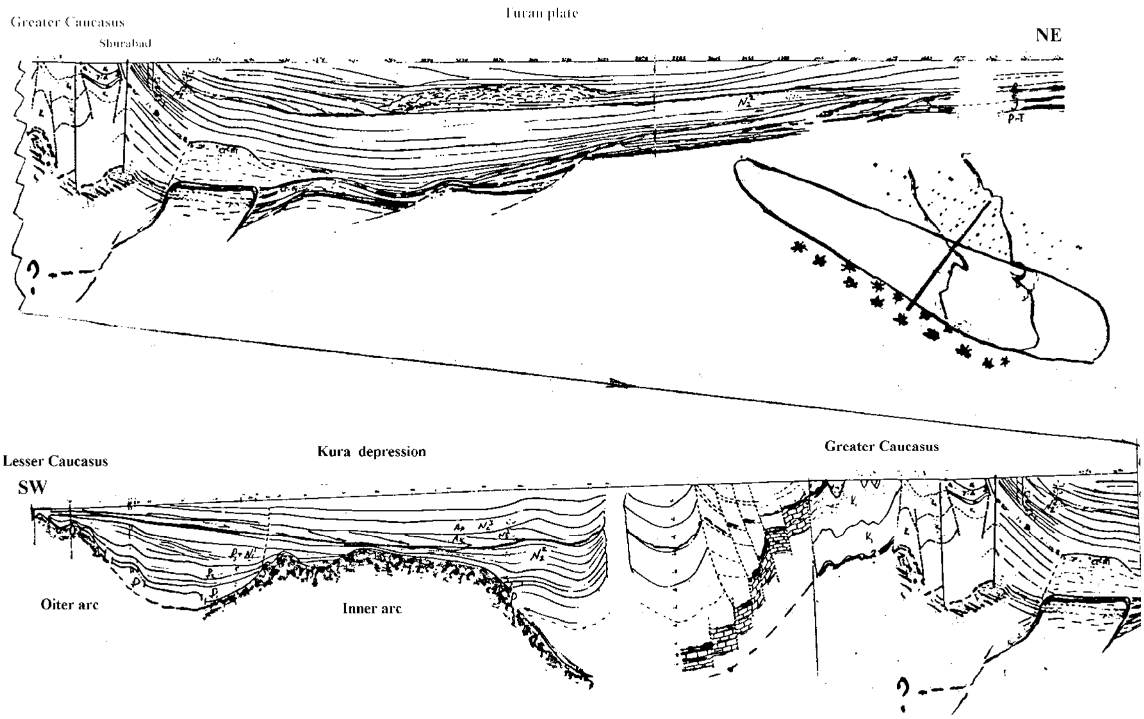


Fig. 2.1.18. Regional seismic-stratigraphic section through Turanian plate, southeastern troughs of the Greater Caucasus, Kura depression and Lesser Caucasus (by P.Z. Mamedov, 1990)

Within Apsheron archipelago the adjoining of subparallel axes of synphase to the Mesozoic benches testifies the deep water conditions of sedimentation in the Paleogene. In the Middle Kura depression the Eocene deposits are isolated into SC-4. The adjoining of SC-4 layers to the Mesozoic substratum surface is observed on the slopes of Satly-Geokchay bench complicated by sharp paleogeomorphological elements.

Seismic sections of the regional profiles give full enough notion about the sedimentary bodies formed on the orogenic stage of SCMD development. From seismostratigraphic analysis it follows that in the Oligocene-Early Miocene time Apsheron trough represented a zone of relative uplift which separated SCB from NAT. Here the Maykop deposits (SC-5) lay trasngressively (with angle and azimuth discordance) upon the Pre-Oligocene unconformity. In the central part of the megadepression on the great depths (13-16 km) the seismic sequence is represented by the pseudo-isotropic series. Contrary to the predictions about the great thickness of the Maykop deposits here - up to 9 km (L.I.Lebedev, 1987) according to our data its maximal thickness doesn't exceed 3 km.

Owing to specific features of the records the complex of deposits of the Middle and Upper Miocene in the studied region is isolated into SC-6. On the North-Apsheron area SC-6 is represented by sigmoid-progradational seismic facies looks like flow condition. The southern border of this seismic facies has tortuous form with gulf-like areas entering towards the interstructural lowers. Probably, the anticlines of the northern belt Apsheron archipelago, not came out to the Late Miocene from under the sea level, had played a role of barrier for dense flow from the north and reduced their penetration into SCB. In the central part SC-6 is represented by weakly laminated body of cover type with thickness up to 2 km.

Due to small thickness (up to 100-200 m) the deep water sediments of the Pontian stage don't isolate into the independent seismic sequence.

The Lower Pliocene SC-7 is distinguished among other complexes by the greater thickness, abundance of dynamically expressed regular reflections and quasi-isotropic intervals of section. Time of this sedimentary complex formation (productive - red bed series) is about 2.2-2.5 mln. years, it makes 1% of geological time of Alpine megacycle. In that period a great mass of coarse fragmental material with maximal thickness 6.0-6.5 km had accumulated. That is to say 25-30% of general thickness of the sedimentary cover of SCMD falls to SC-7. The calculation of sedimentation rate even without accounting the rocks' compaction and frequent breaks to which 40-60% of time fall gives 2-3 km/mln.years. By itself it is somewhat higher than avalanche rate. In this respect the Lower Pliocene paleobasin has no any analogue among paleo- and recent basins of the World Ocean. Such high rate of sedimentation is typical for deltaic formations of the intermontane depressions (P.Z.Mamedov, 1989).

SC-8 is corresponded to the Upper Pliocene deposits of Akchagyl stage. In the central part of SCB the complex has a character of the condensed cover with 60-80 m thickness and expressed by one quasiregular wave. Westward the SC-8 thickness increases and reaches 400-600 m in the Lower Kura depression. In the Middle Kura depression the seismic sequence consists of oblique-progradational facies, typically high energy in updip portions. Possibly that formation of such bodies in Akchagyl age took place under the predominant influence of shore-along flows in the uncompensated depression.

SC-9 corresponded to the Apsheron stage of the Lower Pliocene differ by the layers' conformable occurrence. The upper border of the seismic sequences is represented by strongly eroded surface of unconformity. Sigmoid-progradational facies of SC-10 (Anthropogene) are characterized by gentle sigmoid reflections along depositional dip. The reflections downlap at the base and are concordant with the top of the unit. These sigmoidal layers were formed in the condition of uncompensated sedimentation. The presence of progradation cline forms in the western and eastern near-flank zones of depression point to that a great phase of submeridional downwarping took place in the Quaternary age. As a result a recent structural plan of the Caspian sedimentary basin was formed.

Thus, the revealed on the geologic-geophysical, mainly seismical data, rift structures of extension, mantle mega-arc and thinned oceanic crust underling the SCB, the character of its joint with the Paleozoic metamorphic basement of the Scythian-Turanian platform, morphostructural peculiarities of continental and island arc slopes as well as similarity of other geonomic peculiarities of the crust and sedimentary cover allow conforming that SCB territory including its Kura and West-Turkmenian centroclines was included into the marginal sea on the Mesotethys ocean active side begging from the Middle Jurassic till the Oligocene. Thus sea had isolated mainly by the unite of two back arc riftogenic troughs which had lived through to that moment three cycles (stages) of the geodynamic development: 1) riftogenic; 2) mature (with stages of widening and isolation of back arc trough) and island arc (with stages of volcanism development, processes of compression and subduction). Traces of both troughs are preserved in the structure of consolidated crust and basal series of SCB. The unite of these troughs completed in the Oligocene. Driftage of Afro-Arabian platform led to collision of the microcontinents with each other

(Anatolian-Iranian block with the Trans-Caucasian) and at last with the Eurasia margin. In Late Oligocene the Iranian microcontinent moved eastward from coming Arabian bench and collided by its eastern side with Turanian plate margin. As a result it made a support originating a collision process in Kopetdag region. The Trans-Caucasian microcontinent was compressed to Scythian plate and had played a role of buffer forming a compression structure in the Greater Caucasus region.

Thus, to the Oligocene end the basin of the eastern Paratethys with hard oceanic crust and developed continental slopes, partially isolated from the World Ocean, was developed on the Trans-Caucasian and South Caspian territories. In the same form it preserved in the Post-Oligocene stage of compression and reduction of basin size.

The fold systems of the Greater and Lesser Caucasus, Greater and Lesser Balkhan, Kopetdag Talysh and Alborz began to grow in the Middle - Late Miocene. These orogens have epicontinental structure of origin on the place previos marginal sea during the period of its closure. It proves by that these orogens are located there where the moving of lithospheric plates or two continents' collision take place. At that time on the territories of the South Caspian and partially Kura and West-Turkmenian depressions, compressed from both sides, a downwarping and deepening of basin bottom took place. Area of shelf spaces, configurations of continental slopes and foot changed but the topographic deep water depression in the South Caspian stayed uncompensated. The most important structures proving the deep water feature of the South Caspian relict of the marginal sea are its early continental slopes.

The morphostructural peculiarities of the continental slopes and specific forms of the sedimentary complexes overlapping them and read well on seismic time sections are documented proofs of the deep water basin constancy in the South Caspian which did not fill completely and stayed in relief beginning from the Middle Jurassic till present time. Even in those periods of the sea level sharp decrease (regressive phases) when in conditions of avalanche and deltaic sedimentation the bottom relief smoothed out on the greater part of the sedimentary basin (e.g. Lower Pliocene), all the same a narrow uncompensated relict trough stayed. Clearly distinguished clineform bodies of the lateral addition of the Miocene-Pliocene age are good markers of displacing of the trough continental slopes with time. During the further periods of sea level increase (transgressive phases) more wider deep water depression originated in other outlines (e.g. Akchagyl basin).

On the background of intensive reduction and compression of the Earth crust the Caucasus segment had felt a complete isolation and continentality at the final stage (Late Miocene - Quaternary). The lithosphere bending and extrusion of sedimentary material to a side took place by the sublatitudinal compression caused by the Arabian cline pressure. In the Pliocene-Quaternary the South Caspian and its Kura and West-Turkmenian centroclines turned out to be geodynamic shelter where material excess accumulated extruded out the Caucasian and Kopetdag syntaxes (Kopp, 1988). Cross folded structures of Shemakha-Gobustan, Baku archipelago Okarem-Gograndag, etc. had formed under a significant role of material extrusion from places of great compression.

Thus, due to partial and diachronic closure of the initial marginal sea its East-Caucasian, Apsheron-Prebalkhan, Kopetdag cells were on the different stages of development in Late Cenozoic. When the area of Caucasus and Kopetdag embodied the collisional stage the areas of future Kura and West-Turkmenian depressions and most part of the South Caspian neither closed completely nor compensated by the sediments, they passed into the stage of fading (reduction) of preserved segment of the marginal sea.

In the Quaternary the SCB turned into the intracontinental basin. So, its sections differ with considerable thickness and stratigraphical sequence whereas long-term breaks in sedimentation are recorded on its peripheries. The variety of formational series is differed respectively.

Reduction of sizes and areas of shelf sedimentation is typical for the SCB in the Late Cenozoic. Because of the extreme reduction of the Earth crust the crystallic basement of the depression is separated into blocks and the sedimentary series are crushed into folds. The lowering of the Pliocene and Early Quaternary shelves takes place on the depression periphery. It is especially typical for the eastern and western borders of the South Caspian depression.

Thus, highly informative material obtained for last years, together with available geologic-geophysical information proves the platetectonic conception of presence of marginal-sea basin in the region with typical crystallic crust of oceanic type, morphostructures of flanks and sedimentary complexes. The geological interpretation of this material points to inherited development of vast deep water depression in the Caucasus - South-Caspian region in the Mesozoic-Paleogene stage. It isolated by the unity of two back arc riftogenic troughs the traces of which stayed in the structure of consolidated crust and basal layers of the sedimentary cover. The recent deep water depression of the South Caspian is a relict of the Mesozoic-Paleogene uncompensated depression. This depression had lived through three main cycles to the orogenic stage: 1) riftogenic, with location of deep trough of the Greater Caucasus sea; 2) mature with stages of widening and isolation of marginal sea; 3) island arc with stages of volcanic arcs development, processes of compression and subduction.

Beginning from the Oligocene and especially in Neogene-Pleistocene the sea basin had lived through the fourth stage - fading - with its conversation into the intracontinental basin.

The obtained new data on seismometry, seismotomography and other geophysical methods contradict completely to fixing interpretation of kinematics of the Alpine deformations of the whole region and require principally new interpretation from late tectonics viewpoint.

2.2. Numerical gravity data analysis and results interpretation

Gravitation field of Azerbaijan

The carried out detailed gravimetric measures within Azerbaijan allow to compile the summary map of Bouguer anomalies in scale 1:500000. The summary gravimetric map of Azerbaijan territory and the south part of Caspian Sea was compiled by R.M.Gajiyev by material of trust "Caspmorneftgeofizika", Azerbaijan scientific-research institute for oil production, AzNIIGeofizika and Geology institute. The Bouguer summary map taken as a basis for compilation of gravitational model of Azerbaijan was made accounting the values of density of rock of intermediary layer. For plain areas of Azerbaijan where not high mountains and uneven relief mainly formed by low-compacted sedimentary rock of Neogene, density of intermediary bed is 2,3 g/cm^3. For highly-mountainous areas of the Greater and Lesser Caucasus where compacted and partially metamorphised rock of cretaceous and Jurassic age are outcropped is 2,67 g/cm^3.

Gravimetric map of Azerbaijan and Caspian sea compiled by VNIIGeofizika was used as well. Gravimetric map in Bouguer reduction compiled with a value of density of intermediary slab is 2,67 g/cm^3. Normal value of gravity was calculated according to Gelmert formula 1909 accounting the corrections was -14 mGal. Topography (R=200 km) was taken into consideration when calculating Bouguer anomalies. For sea areas gravimetric map was compiled accounting the amendments for surrounding relief and topography of sea bottom.

The compiled map of Bouguer anomalies of Azerbaijan is not differed from the similar maps of other geosynclinal areas. There a vast areas of intensive minimums and maximums of gravitational field are distinguished (see **Fig. 2.2.1**).

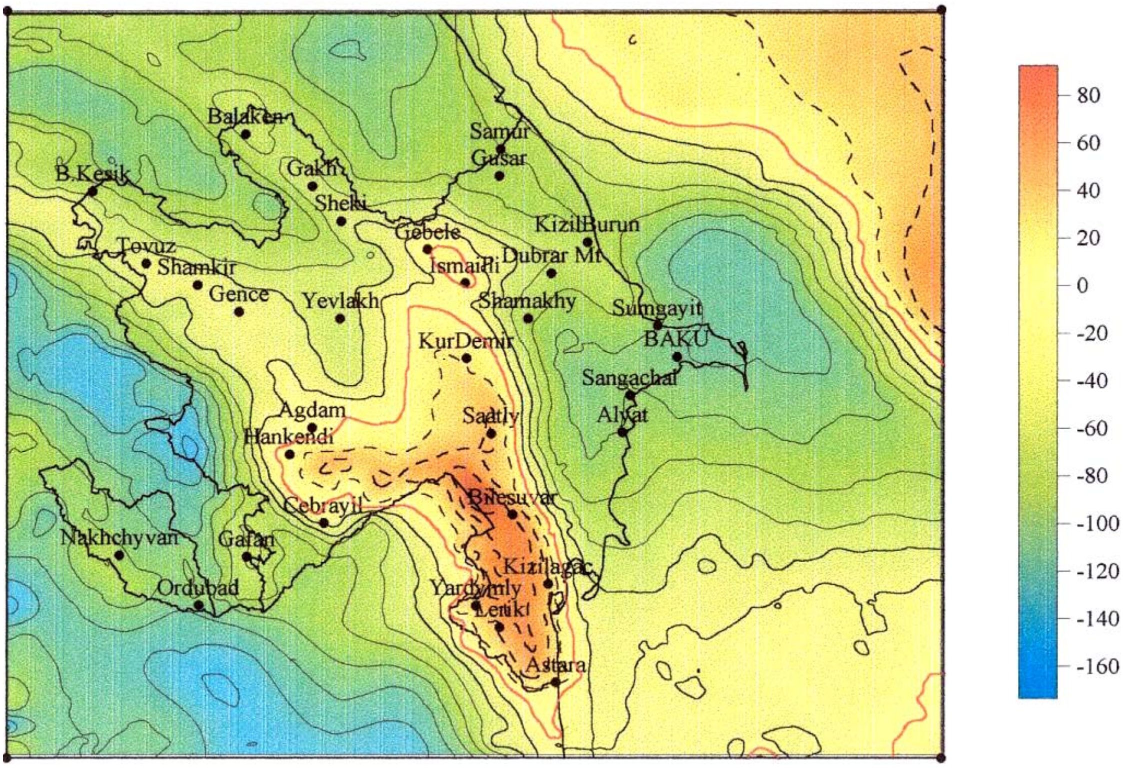


Fig.2.2.1. Scheme of gravitational field of Azerbaijan.

On the map of gravitational anomalies of Azerbaijan in Bouguer reductions two main strips of negative anomalies linked with elevations of the Greater and Lesser Caucasus and separated by strip of positive and weak negative anomalies are distinguished. Through the lower zones of the Western Azerbaijan stretches Alazan - Middle Kura minimum. Alazan Middle-Kura minimum within Kura, Gabyrry and Alazan interfluve has the most width. On the map of gravitational anomalies of Azerbaijan in Bouguer reductions within the Absheron peninsula, Absheron threshold, Gobustan, Low-Kura area, Baku archipelago, sea continuation, Pri-Caspian-Gobustan area and Cheleken isle, are called Eastern-Azerbaijan (by R.M. Gadjiyev this minimum is called as South-Caspian). In plainer words the Eastern-Azerbaijan minimum covers the south Caspian and framing it offshore areas. The considered anomaly through the occupied area is considered to be one of the largest among gravitational anomalies of Azerbaijan. The northern border of Azerbaijan minimum coincides with Makhachkala - Krasnovodsk gravitational degree, separating he minimum from maximum of Middle Caspian (maximum of Derbent depression). From the west the area of Eastern-Azerbaijan minimum is limited by Azerbaijan maximum [39, 87, 90]. Minimal value of anomalies is in the sea northward from Absheron peninsula. Value of anomaly here reaches to -125 mGal, is quite unusual for areas of the earth crust with not-high relief.

Minimum of Pri-Caspian-Guba area I.V. Kirillova, E.N. Lyustih, V.A. Rastvorova, A.A. Sorski, V.E. Khain and R.M. Gajiyev are included into the Dagestan minimum which cover the territory of Dagestan republic and Grozny area. For that reason R.M. Gajiyev writes: "Obviously the given name of the described minimum is to some extent irrelavent" as on the territory of Azerbaijan coincides with area of Pre-Caucasian trough and on the north-west is traced through the high-mountainous area of Caucasian ridge" [39]. That's why the more suitable name of that minimum is Pri-Caspian-Guba. Within the Lesser Caucasus there stretches a zone of strong negative anomalies (-160 mGal). Isolines describes the arc protuberant to the north and reiterative in outline the arc-shaped outlines of this fold-zone. But the axle of minimum doesn't coincide with a more elevated part of the ridge it passes southward the main elevations of the Lesser Caucasus. By intensity of anomalies the Lesser Caucasian minimum takes the first place. The axle zone of that minimum stretches in the direction of Caucasian over 30 km from Geicha lake. The north-eastern border of Lesser Caucasian minimum passes along the line of the most intensive on Caucasus Ardebil - Lachin Dilidjan gravitational step. Azerbaijan minimum with values of gravity varying from zero to 90 mGal, mainly linked with Talysh mountains. This maximum (anomaly from zero to 50 mGal). One of them stretches northward and connected woth Alazan zone and the other north-westward continuing through the Gyanja to Tbilisi and cover the narrow strip of lavations by the north-western margin of the Lesser Caucasus. Azerbaijan maximum is separated into various by its nature three parts delimited by narrow zones of relative minimums. The first of them Khodjavend-Tbilisi maximum stretching from Nagorny Karabagh to the north-west through basins of right tributaries of Kura river to the Gori latitude. The second one - Talysh-Vandamian maximum located between the north-western spurs of Talysh mountains and area of Geichai river - Karamaryam. Talysh-Vandamian maximum established since 1926-1929 according to the data of the pendulum observations was named as "Kyurdamir gravitational bridge". This anomaly stretching in the meridianal direction forms the bridge between two stretching relative maximums in the sublatitudinal direction located on the South slope of the Greater Caucasus and on the Northern slope of the Lesser Caucasus (Shamkir-Talysh maximum).

The third one -Dyubrar-Sheki (Eastern-Caucasian) maximum territorially confined to the Eastern Caucasus, starting from the Caspian Sea to Sheki city. This maximum is stretched by narrow strip north-westward to VladiCaucasus. On the west and particularly on the east restrictions of Azerbaijan maximum are very rare. A bit westward the profile of Guba-Shamakhy-Salyan, Azerbaijan maximum is separated from the Eastern-Azerbaijan minimum almost by rectilinear zone. Area of positive anomalies (40 mGal and higher) corresponds to the Central-Caspian. Along the eastern margin of Azerbaijan maximum gravity varies on the 120 mGal in a distance of 30 km. Shamkir-Talysh maximum occupies the north-eastern part of the Lesser Caucasus and its northern-eastern slope including the Talysh mountainous area where positive anomalies reach 100 mGal and more. The most gravitational steps are Makhachkala-Krasnovodsk, Lagich-Gyzylgadja and Ardebil-Lachin-Dilidjan step. Amplitude of these steps is more than 150 mGal. each of the six mentioned anomalies of the first order is complicated by anomalies of the second order-anomalies of the third order etc. Some results of geological interpretation of the mentioned anomalies of Azerbaijan are presented in the proceedings of I.O.Tsimelzon and R.M. Gajiyev.

2.2.1. Complete horizontal gradients of gravitational filed of Azerbaijan

Scheme of high gradients location for Caucasian region was compiled and studied by I.V.Kirrilova etc. It had been established, that these zones are mainly located along the borders between maximums and minimums. Regional gravitational steps of Azerbaijan were analyzed by R.M.Gajiyev. Schematic maps of zones of large gradients of gravitational field were compiled by these authors. It had been considered, that sharp gradients can testify to the concealed tectonic projection of a sharp flexure or fault. It is supposed, that various anomalies of gravitational field correspond to various blocks of the earth crust, separated by abyssal faults. Studies of these authors were confirmed by comparison of schemes of large gradient of gravitational field with a scheme of deep faults.

During the comparison of scheme of large gradients of Azerbaijan calculations were made in the same places where visually gradient zone of gravitational field distinguished. During calculations values of gradients were chosen perpendicularly to axle step direction and gradient was calculated along his direction or calculation were made in the direction of earlier chosen axle. Of course, such calculation of gradient values are not identical. Calculations along the chosen axle do not allow to reveal parallel to this direction gradient zones.

For simultaneous determination of longitudinal and cross vertical borders of two geological environment in the given work gravitational field is transformed in the anomaly of complete horizontal gradient.

The complete horizontal gradient of gravitational field G(x, y) is determined by formula

$$G(x,y)=\left[\left(\frac{\partial g(x,y)}{\partial x}\right)\right]^2+\left(\frac{\partial g(x,y)^2}{\partial y}\right)^{\frac{1}{2}}, \tag{2.1}$$

where g(x,y)-values of gravitational field [Blakely R.J., 1995; Mironov, 1980].

During task of gravitational field on the knot points of rectangle net horizontal gradients are calculated using simple finite relationship method. Vertical and sharply-falling boundaries of geological mediums of various thickness or faults can be presented by bodies, limited by flat verge. The experiments conducted with such models showed that on verges of rectangle parallelepiped one can observe maximums. These properties are successfully used by many authors to determine contacts of two geological mediums by the measured gravimetric data [Blakely R.J. and Simpson R.W. (1986), Edwards D.J., Lyatsky H.V. and Brown R.J., 1996].

Distribution of complete horizontal gradients of USA were studied in the work [Blakely R.J. and Simpson R.W., 1986].

Fault scheme and block structure of the Western Canadian basin is studied in the given work [Edwards D.J., Lyatsky H.V. and Brown R.J., 1996]. It had been proved, that maximums of horizontal gradients allow to distinguish geological bodies and main structural elements of USA. Effectiveness of horizontal gradients method is proved during studies of vertical boundaries.

Map of Bouguer anomalies of Azerbaijan was divided by square net aimed at studying of the complete horizontal gradients of gravitational field. The beginning of coordinate system is located in the south-western angle of study area. X axle is directed Eastward, and Y axle northward. Number of elements on the X (Nx) axle and Y (Ny) axles there were chosen Nx=17, Ny=90. On the **Fig. 2.2.2.** map of distributions of complete horizontal gradients of gravitational field of Azerbaijan.

Section of isolines was made by means of 0,5 mGal/km. Value of complete horizontal gradient of gravitational field of Azerbaijan varies within 0-5,63 mGal/km. Maximal values of horizontal gradients for Azerbaijan are gmax >1,5 mGal/km. Value 5,63 mGal/km is obtained on the local area within Shakhdag ridge on the Lesser Caucasus. On the Lesser Caucasus closed isolines of complete horizontal gradient of gravitational field of Azerbaijan with values 3 and 4 mGal/km form the chain. Within Jabrail zone of maximum of complete horizontal gradient of gravitational field is branching off. One line with maximal values stretches to the Saatly area and the other line in the direction of Talysh mountains.

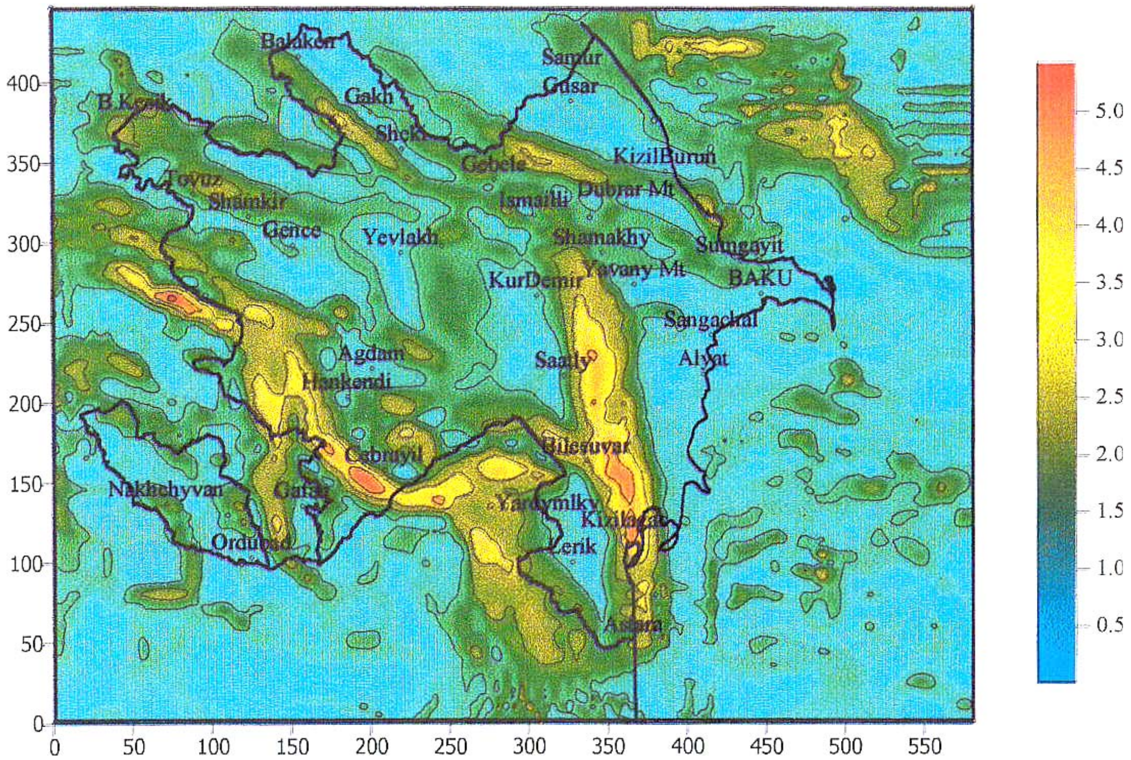


Fig. 2.2.2. Bouguer gravity gradients map of Azerbaijan

The second zone with large values of complete horizontal gradient of gravitational field is observed along the Astara - Kyzylagage - Ismaili profile. Here G(x, y) values reach to 4mGal/km. Along the South slope of the Greater Caucasus there stretches the 3-d zone of large gradients (3mGal/km). This zone of large gradients within Ismaili -

Shamakhy is crossed with the Astara -Kyzylagage -Ismaily zone. The following known faults were revealed on thenew scheme: Siazan, Main Caucasian, Kainarsk- Zangin, North-Adjinaur, Adjichai - Alyat, Kura, Lachin-Bashlybel, Precaucasisn, Nakhchyvan. Numerous cross faults are distinguished on the scheme.

2.2.2. Digital analyze of gravitation data.

Gravity data acquired in the Kura-South Caspian basin were using analized a Hartley transform (HT) The HT originally introduced by Hartley (1942) is an integral transform method similar to the Fourier transform (FT) with a number of properties being similar to the properties of FT. The HT transform is a real transform. It is an alternative procedure to the discrete FT since one complex operation is equal to four real operations. The experiments show that the discrete HT is twice as fast as the discrete FT. The power spectrum of the HT analysis of the Bouguer gravity values in the KSCB suggests that gravity field may be separated into long and short wavelength components.

Theoretical Formulation

The 2-D HT of a real function f(x,y) is defined as

$$H(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)Cas(ux)Cas(vy)dxdy, \qquad (1)$$

where

$Cas(ux)Cas(vy) = \cos(ux - vy) + \sin(ux + vy)$.

The inverse transform can be obtained by interchanging the positions of f(x,y) and H(u,v) in equation (1) and replacing dxdy with dudv as below

$$f(x,y) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} H(u,v)Cas(ux)Cas(vy)dudv. \qquad (2)$$

Let $H(u,v) = E(u,v) + O(u,v)$, where E(u,v) and O(u,v) are even and odd functions defined as:

$$E(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\cos(ux - vy)dxdy = \frac{H(u,v) + H(-u,-v)}{2} \qquad (3)$$

and

$$O(u,v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)\sin(ux - vy)dxdy = \frac{H(u,v) - H(-u,-v)}{2}, \qquad (4)$$

where

$$H(-u,-v) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} f(x,y)Cas(-ux)Cas(-vy)dxdy. \qquad (5)$$

2D Hartley and Fourier transforms are related by (Bracewell, 1986; Mohan et al., 1994; Saatcilar et al., 1990):

$$F(u,v) = E(u,v) - iO(u,v), \qquad (6)$$

$$H(u,v) = \mathrm{Re}\,F(u,v) - \mathrm{Im}\,F(u,v), \qquad (7)$$

Where F(u,v) is the FT of f(x,y). The amplitude and phase spectra associated with the HT are both physically and mathematically similar to those of the FT but differ numerically. In general, the amplitude spectra of the FT and HT give the same information. The 2-D discrete HT of an image f(x,y) represented by a (M×N) matrix is defined in accordance with equation (1) as below (Sundararajan, 1995),

$$X(u,v)=\frac{1}{MN}\sum_{x=0}^{M-1}\sum_{y=0}^{N-1} f(x,y)\,Cas(ux)\,Cas(vy)\,. \tag{8}$$

Its inverse is given as below,

$$f(x,y)=\sum_{u=0}^{M-1}\sum_{v=0}^{N-1} H(u,v)\,Cas(ux)\,Cas(vy)\,. \tag{9}$$

The results obtained from (8) are rearranged to get the 2-D HT by (Rao et al., 1995),
for u ≠ 0, 1v ≠ 0

$$H(u,\ v)=\frac{1}{2}\left[X(u,\ v)+X(M-u,v)+X(u,\ N-v)-X(M-u,N-v)\right]$$

and (10)

$$H(u,v)=X(u,v),\quad \text{for}\ \ u=0\ \ \text{and}\ v=0\,.$$

The Hartley amplitude coefficients are calculated from positive and negative coefficients as given below,

$$A(u,v)=\left[\frac{H^2(u,v)+H^2(Nu,Mv)}{2}\right]^{1/2} \tag{11}$$

for Nu and Mv is defined as

Nu = u
Mv = v for u = 0 and v = 0,
Nu = u
Mv= M-v for u = 0 and v ≠ 0, (12)
Nu = N-u
Mv = v for u ≠ 0 and v = 0,

With these coefficients, even and odd Hartley coefficients can also be calculated.

$$E(u,v)=\frac{H(u,v)+H(Nu,Mv)}{2}$$

and (13)

$$O(u,v)=\frac{H(u,v)-H(Nu,Mv)}{2}\,.$$

E(u,v) and O (u,v) are even and odd Hartley coefficients respectively. Hartley amplitude and phase spectrum values can be calculated with these coefficients as shown below,

$$A(u,v)=\left[E^2(u,v)+O^2(u,v)\right]^{\frac{1}{2}} \tag{14}$$

$$\theta(u,v)=\arctan\left[-\frac{O(u,v)}{E(u,v)}\right],$$

where A(u,v) and θ(u,v) are amplitude and phase spectra of the HT.

To separate regional and residual anomalies of the Bouguer gravity field HT and Butterworth filters are used (Kulhânek, 1976). The ideal low-pass Butterworth filter is given by,

$$H_B(k) = \frac{1}{\sqrt{1+\left(\frac{k}{k_c}\right)^{2n}}}, \tag{15}$$

where $\mathbf{k} = \frac{2\pi}{\lambda}$ is the wavenumber, $k_c = \frac{2\pi}{\lambda_c}$ is the cut-off wavenumber and n is the degree of the filter. In this study n was taken equal to 1. The procedure of filtering is: using the HT transform the gridded gravity data are converted to space-frequency Hartley domain. In this domain, row by row followed by column by column Butterworth filter are applied using suitable cut-off frequency. Then the produced filters are multiplied by the spectrum of data in Hartley domain. Finally, by taking the inverse transform we return to space domain.

Application to real data

Shamakhy-Gobustan and Absheron area. The HT was applied to the gravity data grid of 32×32 in dimensions with grid space at 5 km in the study area (**Fig. 2.2.3.**).

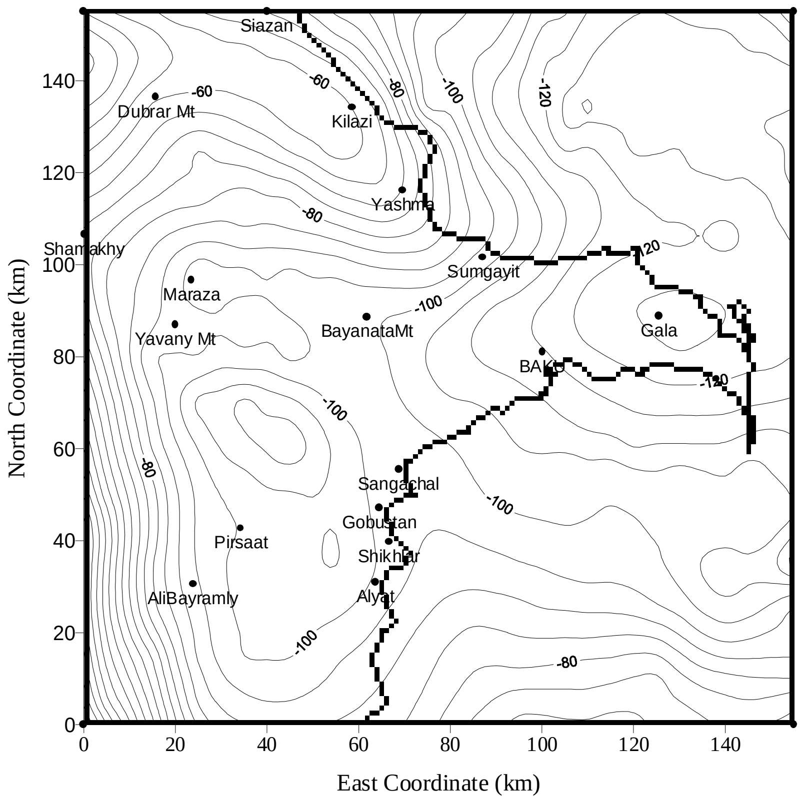


Fig. 2.2.3. Bouguer gravity map for the Shamakhy-Gobustan and Absheron area. Contour interval is 5 mGal.

The calculated power spectrum curve is displayed in **Fig. 2.2.4.**

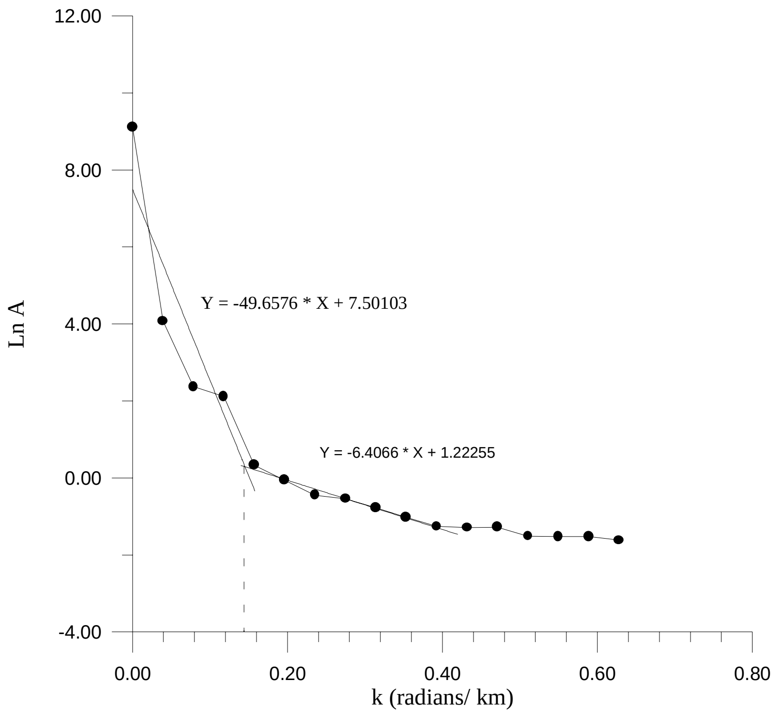


Fig. 2.2.4. Power spectrum of the Bouguer gravity anomaly in the Shamakhy-Gobustan and Absheron area.

The power spectrum of the gravity data shows a cut-off wavenumber separating two domains with high and low wavelength information. The low and high wavenumber parts of the power spectrum, associated with deep and shallow gravity sources, were taken as representing the regional and residual anomalies, respectively. Two linear segments shown on the plot are suggestive of the existence of discrete density boundaries, the slopes being estimates of their mean depth (Bhattacharyya, 1966; Spector and Grant, 1970). The present power spectrum indicates a depth of 24.5 km for the long wavelength component and a depth of 3.2 km for the short wavelength component. These depth values are well correlated with the results of seismic studies previously carried out in the region. The regional anomalies are interpreted to be related with elevation and sinking of crystalline basement.

The cut-off wavenumber is determined by the crossing point of fitted straight lines approximating the power spectrum data in high and low wavelength domains. A cut-off wavenumber of k_c=0.142 km^{-1} is found from the power spectrum.

Fig. 2.2.5 shows the results of low-pass filtering arranged for a k_c=0.142 km^{-1} wavenumber.

The gravity low north of Absheron is preserved in the regional Bouguer anomaly map. The results of the high-pass filtering process are presented in **Fig. 2.2.6**.

A large positive anomaly is evident in the north-west of the region (from Sumgayit to Siazan), the so called Dubrar positive anomaly. A maximum local anomaly value at 7 mGal is noted in Kilazi locality. Another extensive positive anomaly lies in parallel with the Great Caucasus axis covering an area from the Yavany Mt to Sangachal, where the highest value is equal to 3 mGal. In the south-west a large positive anomaly located within Kura Plateau is noted. The Absheron-Central Gobustan negative anomaly (at as low as –7 mGal) is seen to east and south of Dubrar Mt positive anomaly region. The Absheron negative anomaly extends towards the north. A row of closed negative anomalies begins from Gobustan and goes towards Shamakhy.

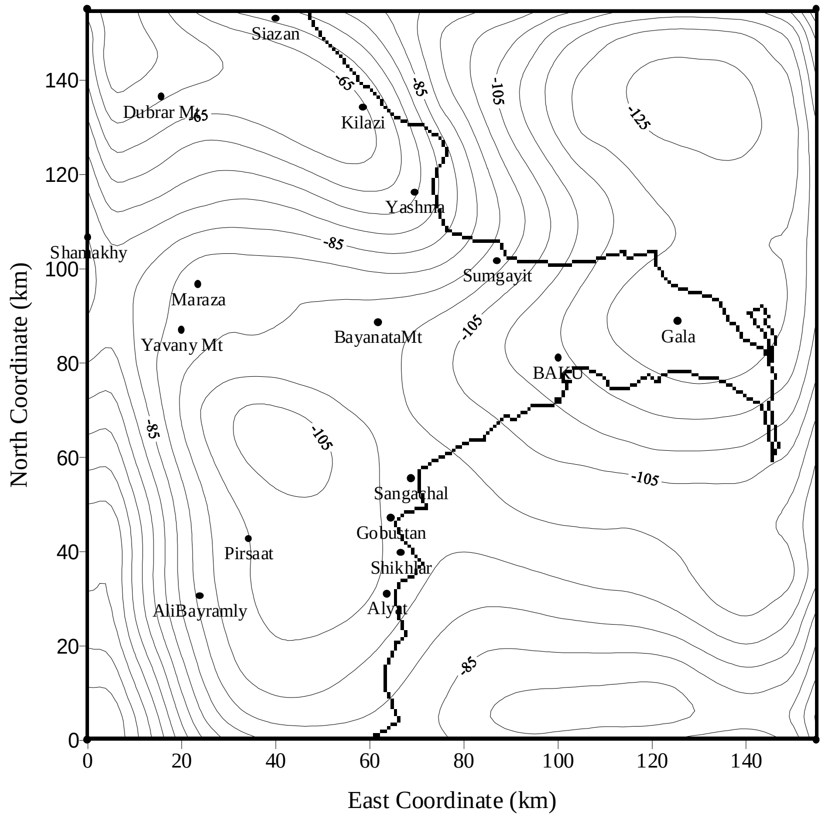


Fig. 2.2.5. Results of low-pass filtering of the gravity data on the Shamakhy-Gobustan and Absheron area with using 2D HT.

The Kura intermontane trough. The Hartley transform was applied to the gravity data from the Kura intermontane trough, specified at the nodes of a 32x32 with 5 km square grid (**Fig. 2.2.7**). The power spectrum of the Bouguer anomalies is presented in **Fig. 2.2.8**.

The cutoff frequency separating the regional and local regions is determined by the intercept of the straight lines approximating the power spectra in a long-and short wave intervals. In the case under consideration the cutoff frequency (wavenumber) is k_c =0.228 km^{-1}.

The depth of anomaly - producing boundaries determined from the long and short-waves slopes are 11,8 and 1,5 km, respectively, [Spector and Grant, 1970; Bhattacharyya, 1966; Serkerov, 1991].

The results of the low- and high-frequency filtering with the cutoff frequency k_c =0.228 km^{-1}, using the Hartley transform are shown in **Fig. 2.2.9 and 2.2.10**, respectively. The Saatly-Kyurdamir maximum appears on this map of **Fig. 2.2.10**. as an N-S trending area.

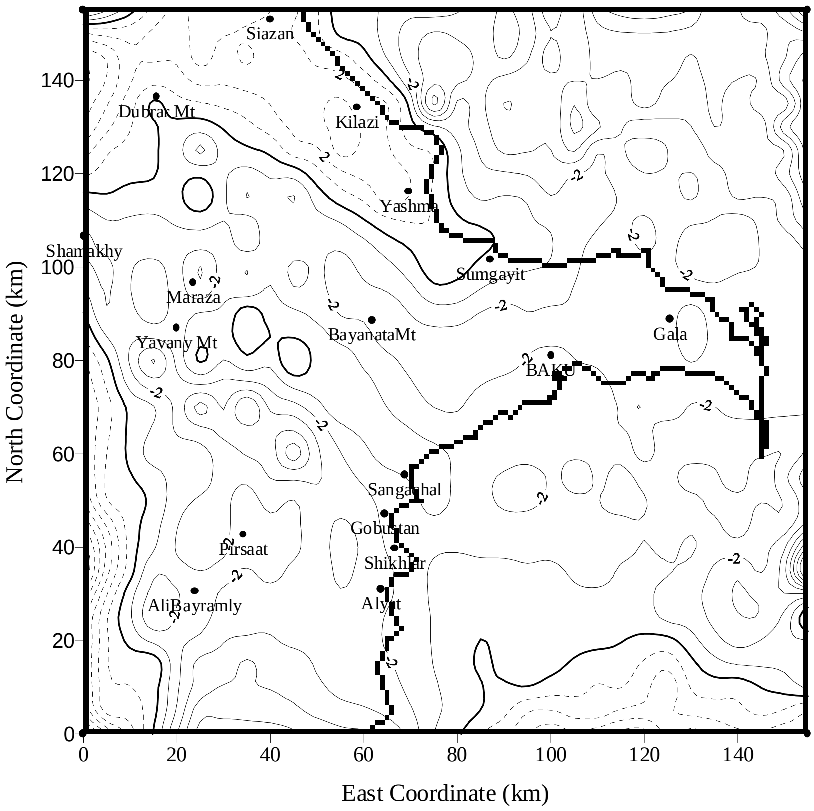


Fig. 2.2.6. Results of high-pass filtering of the gravity data on the Shamakhy-Gobustan and Absheron area with using 2D HT. Dashed and solid lines show positive and negative local anomalies, respectively.

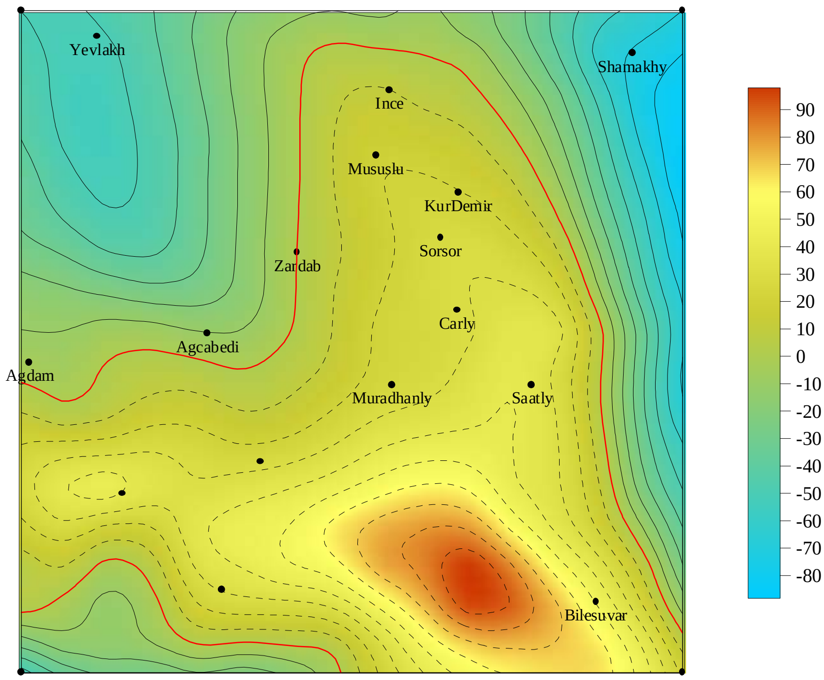


Fig. 2.2.7. Bouguer gravity map for the Kura intermontane trough. Contour interval is 5 mGal.

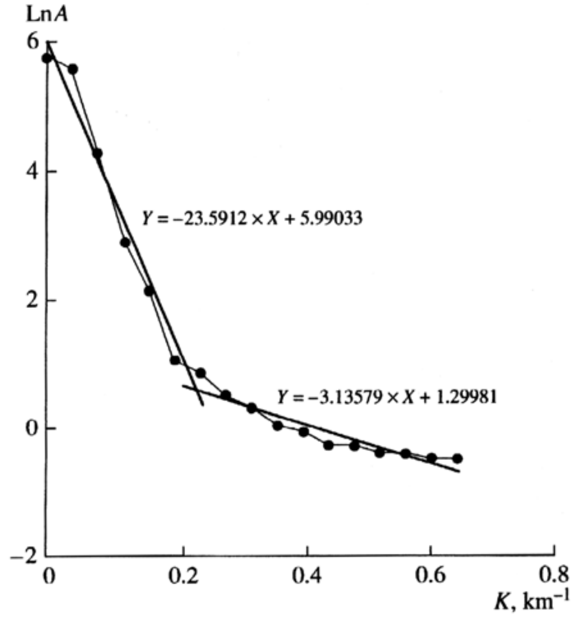


Fig. 2.2.8. Power spectrum of the Bouguer gravity anomaly in the Kura intermontane trough

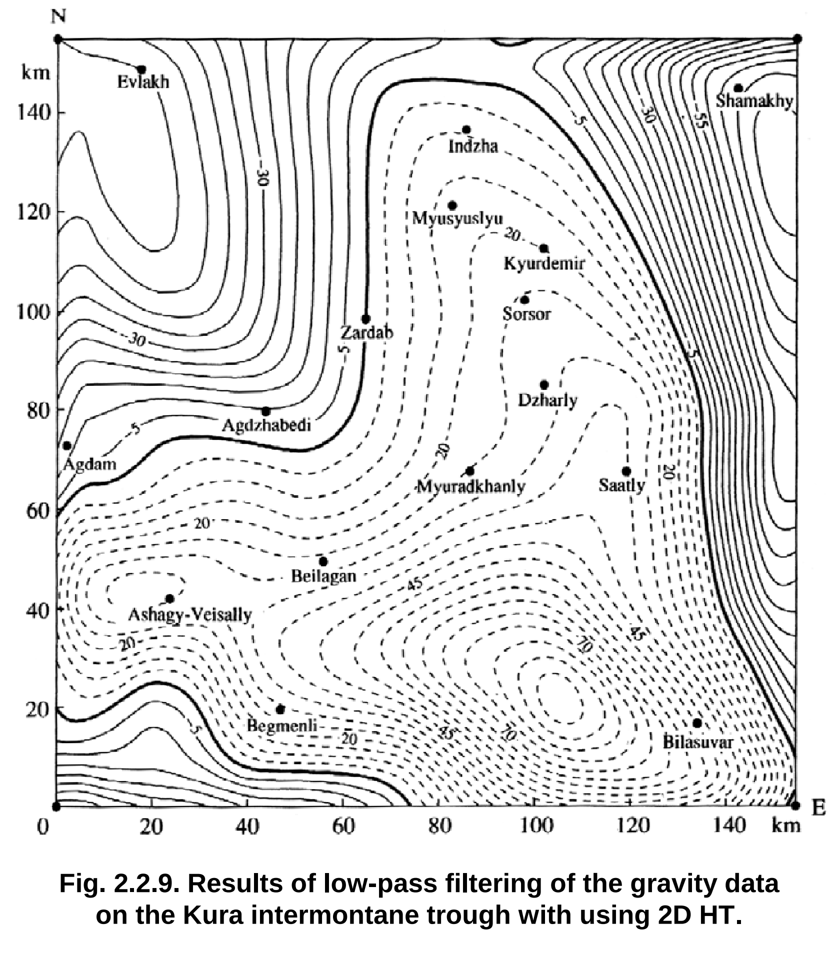


Fig. 2.2.9. Results of low-pass filtering of the gravity data on the Kura intermontane trough with using 2D HT.

Its maximum reaches 4mGal. The Myusyuslyu positive anomaly occupies a separate area. Two positive anomalies are observed north and south of the Ashagy-Veisally positive anomaly. A positive anomaly in the Agdam area is weak. The Evlakh-Agjabedi minimum revealed on the map of local anomalies has a value of-3mGal. Note that the inferred anomalies agree with the anomalies determined by using master curves [Gajiev, 1965; Tsimel'zon, 1965].

The depth of anomaly-producing bodies determined from the power spectrum slope are consistent with seismic and borehole data. According to DSS data, the depth to the crystalline basement is 7-8 km in the zone of the Saatly-Kyurdamir maximum and 14-15 km in the zone of the Evlakh-Agdzabedi maximum [Akhmedov et.al.,1972]. The 11.8-km depth is asocited with the crystlline basement surface and the 1,5-km depth, with a surface within Cenozoic deposits.

The analysis of the power spectra of the gravity field in the Kura intermontane trough revealed anomaly-producing bodies at mean depth of 11.8 and 1.5 km. The 11.8-km depth is associated with the surface of the crystalline basement and the 1.5-km depth, with a surface within Cenozoic deposits.

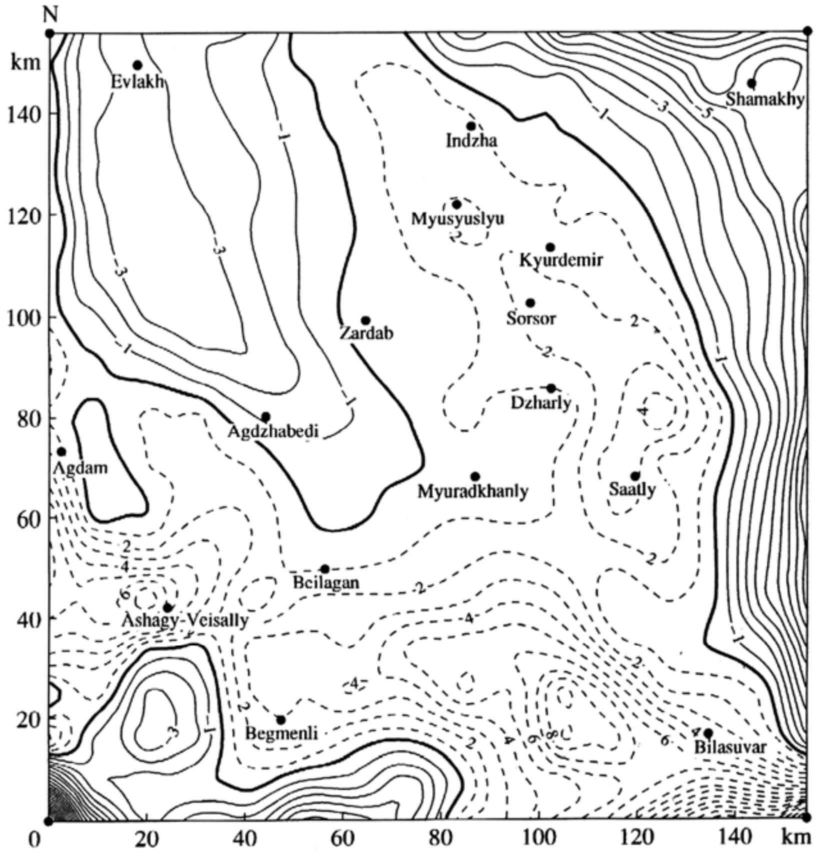


Fig. 2.2.10. Results of high-pass filtering of the gravity data on the Kura intermontane trough with using 2D HT. Dashed and solid lines show positive and negative local anomalies, respectively.

The South Caspian sea (within Azerbaijan). A scheme for gravitation field of study area with Bouguer reductions is given in **Fig. 2.2.11**. It also indicates well known oil and gas fields. Negative gravitational field values are characteristic for this region.

Hartley transform was applied to gravitational data obtained for the study area at nodal points of a grid of 42 x 61 size with 5km spacing. The power spectrum of the Bouguer anomalies is presented in **Fig. 2.2.12**

The cutoff frequency separating the regional and local regions is determined by the intercept of the straight lines approximating the power spectra in a long-and short wave intervals. In the case under consideration the cutoff frequency (wavenumber) is k_c =0.115 km^{-1}.

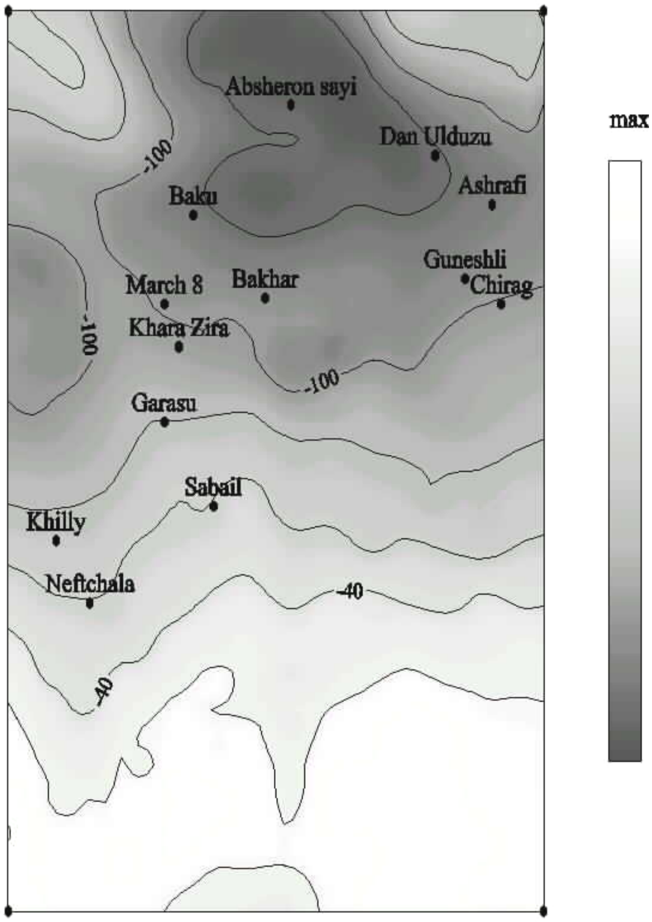


Fig. 2.2.11. Bouguer gravity map for the South of the Caspian sea (within Azerbaijan).

The slope of the curve at long-wave frequency range represents the depths of anomaly causing boundaries equal to 22 km and at short wave frequency range – 4.8 km. Depths of bedding of anomaly causing objects determined by slope of intensity spectrum are in agreement with seismic and well data. **Fig. 2.2.13** displays the results of low frequency filtration with $\mathbf{k_c= 0.115\ km^{-1}}$ cut off frequency.

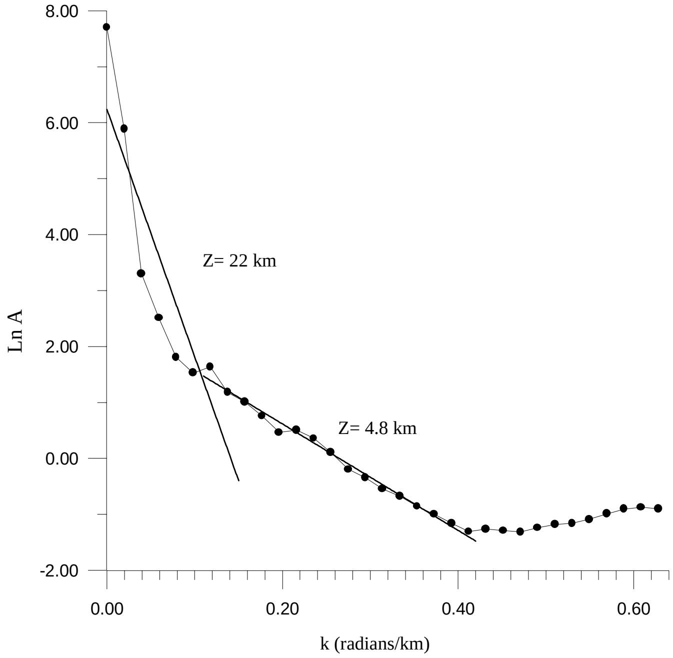


Fig. 2.2.12. Power spectrum of the Bouguer gravity anomaly in the South of the Caspian sea (within Azerbaijan)

As it can be seen, in the areas with known oil and gas fields such as Absheron sayi, Dan Ulduzu, Ashrafi, Chiraq and Bahar deep minimum is observed within the regional field. To the north the regional anomaly values reduce and closed anomalies are observed. **Fig. 2.2.14** shows the results of high frequency filtration with **k_c= 0.115 km^{-1}**.

Many of the closed anomalies marked on the map of local anomalies are possibly conditioned by structural forms in Cenozoic complex.

Seismic survey conducted at the central part of the Caspian Sea through deep seismic sounding (**DSS**) method [9] revealed the following:

1. Three basic seismic boundaries are distinguished at the central part of the Caspian Sea which coincide with the surface of crystal basement (bedding depth from 2 to 20 km), the surface of basalt layer (bedding depth between 15 and 30 km) and Makhorovichich surface (bedding depth from 30 to 50 km).

2. In the east of the sea where epihertzian platform is located, the earth's crust has typical continental structure and it composed of thin (2-3 km) sedimentary layer, granite (about 10 km thickness) layers. The depth of the earth's crust in this region varies between 35 and 40 km.

3. Within Caspian trough, the earth's crust is composed of two layers: thick (over 20 km) sedimentary rocks with low velocity (3.5-4.0 km/s average velocity) and a layer attributed to "basalt" bearing one with boundary velocity equal to 6.6 km/s. there is a transition zone between platform and the trough, in which from east to west the sedimentary layer sharply gains in thickness and granite layer loses it. Depth boundaries of the earth's crust have smooth relief within the platform and complicated one in transition zone and the trough. The Mokhorovichich surface has smooth relief too. Correlation of gravitational data and calculated gravity effects of depth boundaries for **DSS**

sections in the central parts of the Caspian Sea shows that the gravitational fields are mostly affected by "granite layers" which are limited on top by the surface of crystal basement. Within the trough, where "granite" layer is absent, "basalt" layer masses have the strongest effect. Within transition zone from platform towards the trough, cumulative effect of sinking crystal basement and basalt masses is observed. The effect of Mokhorovichich surface on gravitational field at the central part of the Caspian Sea is incomparable smaller than that of layers limited by the boundaries of crystal basement and "basalt". Allowing for **DSS** results obtained for study area in the central Caspian and based on spectrum of depth thickness, one can state that 22 km depth and regional anomalies are conditioned by the relief of "basalt" surface. 4.8 km depth coincides to average depth of Miocene surface and local anomalies are conditioned by structures within sedimentary system.

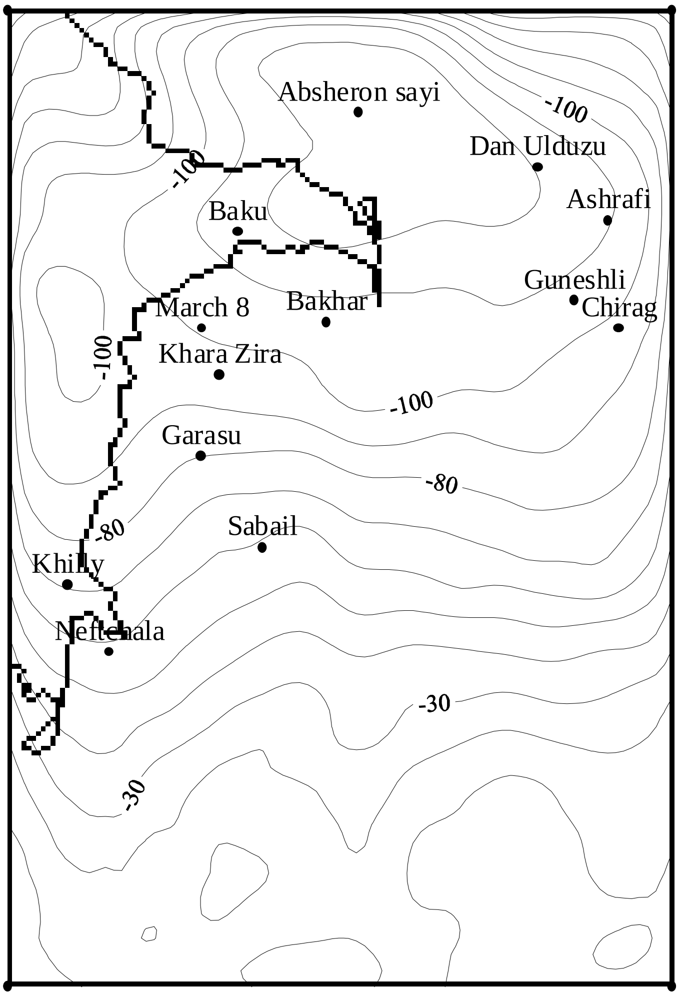


Fig. 2.2.13. Results of low-pass filtering of the gravity data on the South of the Caspian sea (within Azerbaijan) with using 2D HT.

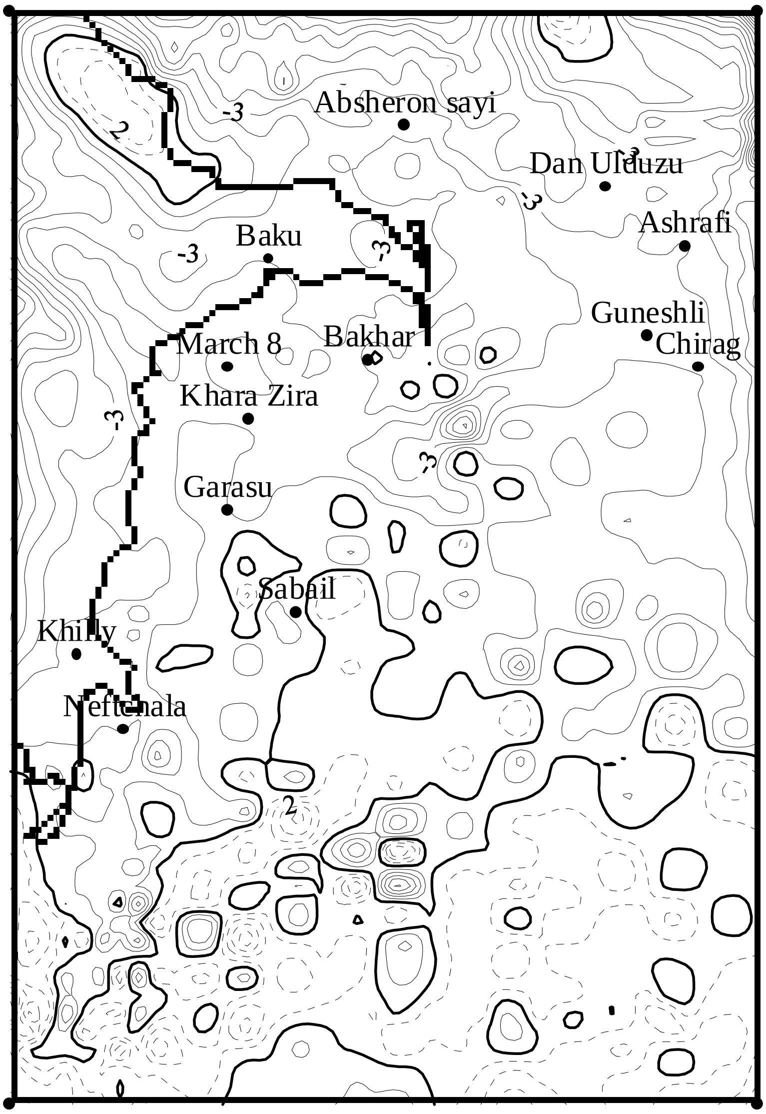


Fig. 2.2.14. Results of high-pass filtering of the gravity data on the South of the Caspian sea (within Azerbaijan) with using 2D HT.

The Lower Kura-Talish region. Study area is in the northern-east of Azerbaijan and it contains Salyan, Jalilbad, Bilesuvar, Yardymly, Lerik, Lenkeran, Astara and Baku Archipelago partly. Talish mountain region which is tectonic element of Lesser Caucasus and Lower Kura Depression region which is east part of Kura Megacynclinorium are the elements of the study area. In Talish Mountain and outskirts of the mountain Astara, Brover and Mill-Mugan anticlines which are lying from south to north were discreted. All three are in the direction of northwest and southeast and they subduct to Caspian in southeast and to Araz river in west. In the Lower Kur depression region third revolution anticlines take place in the direction of northwest-southeast (Gajiyev, 1965).

When the study area is taken into consideration for oil-gas; it was classified as Baku Archipelago with oil-gas, Lower Kura prospected for oil-gas, Jalilabad still being prospected and Mill-Mugan prospection of which hasn't been done yet. Lower Kura and Talish regions are seen as Azerbaijan maximum and East Azerbaijan minimum on gravity map.

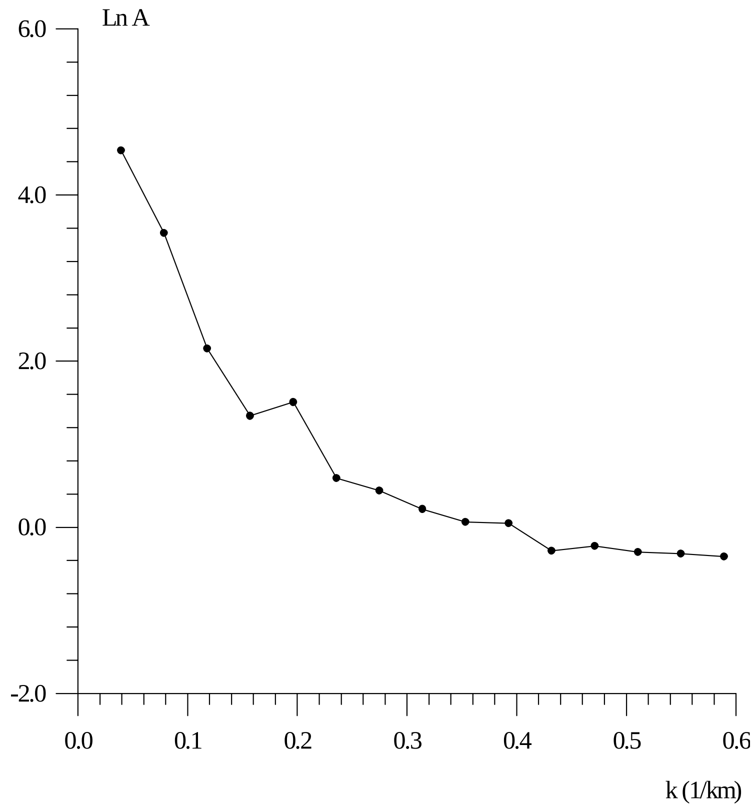


Fig. 2.2.15. Power spectrum of the Bouguer gravity anomaly in the Lower Kura-Talish region.

The Hartley transform was applied to the gravity data from the Kura intermontane trough, specified at the nodes of a 32x325 km square grid. The power spectrum of the Bouguer anomalies is presented in **Fig. 2.2.15**. The cutoff frequency separating the regional and local regions is determined by the intercept of the straight lines approximating the power spectra in a long-and short wave intervals. In the case under consideration the cutoff frequency (wavenumber) is k_c =0.08 km^{-1}.

Figure 2.2.16 shows the results of lowpass filtering arranged for **k_c=0.08 km^{-1}** wavenumber. So intensive positive and negative anomalies are seen on the regional gravity anomaly map obtained from the region. Isogals of the both anomaly regions are the distorted circles lying in the direction of northwest-southeast. The highest values of positive anomalies take place in the north of study area. In the direction of east and west, in the sub-boundary of the earth-crust firstly a rising and then a falling were observed.

To find the depth of the boundary which consistute the regional anomalies appearing in the study area, power spectrum of regional values was calculated in the direction of east-west from 10 km north of Bilesuvar. Power spectrum curve was given in **Fig. 2.2.17**.

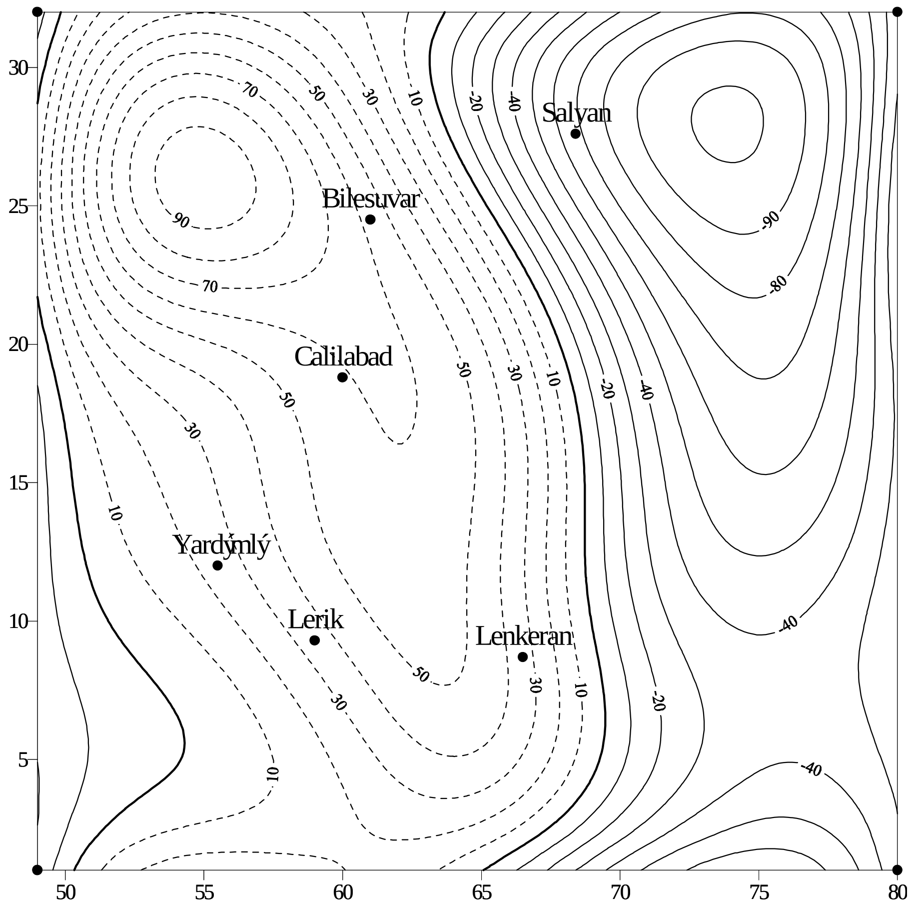


Fig. 2.2.16. Results of low-pass filtering of the gravity data on the Lower Kura-Talish region with using 2D HT.

The present power spectrum indicates a depth of $\overline{h_1}$ =25.5 km (the slope of the line on the left) for the long wavelength component and a depth of $\overline{h_2}$ =9.2 km (the slope of the line on the right) for the short wavelength component (**Fig. 2.2.3**.). Calculated $\overline{h_1}$ and $\overline{h_2}$ depths show the depths of earth crust for Bazalt-surfaces in Lower Kura basin and near Bilesuvar respectively.

The results of high pass filter were shown in **Fig. 2.2.18**.

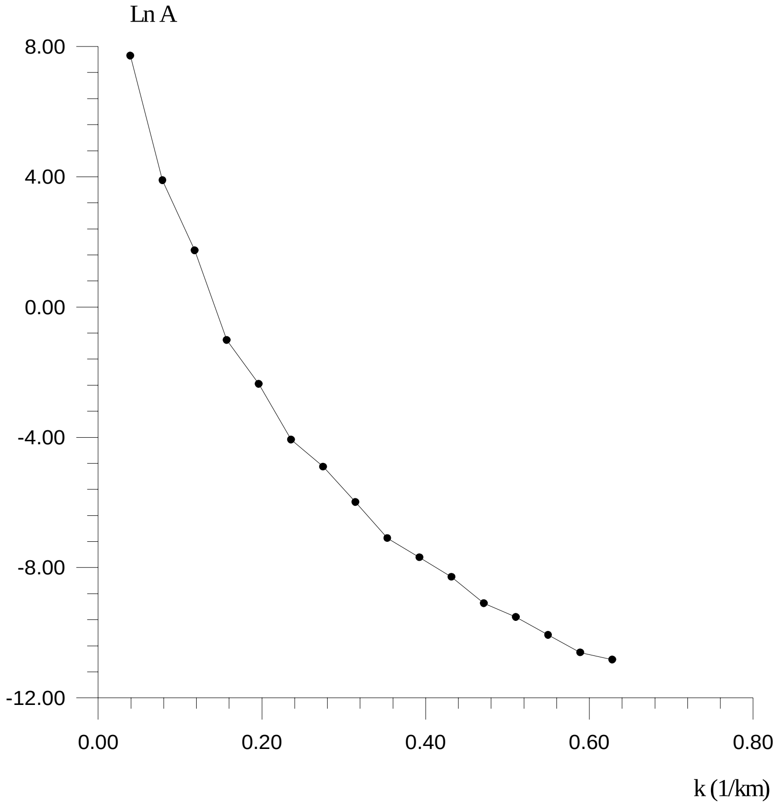


Fig. 2.2.17. Power spectrum of the regional gravity anomaly in the Lower Kura-Talish region.

The positive anomaly region is seen in the northwest of the study area. This positive anomaly region shows two directions. One of them is in the direction of northwest-southeast and constitutes Bilesuvar-Karadonlu maximum. The maximum value of the anomaly is 12 mGal. Other way of the anomaly is in the direction of northwest-southeast and its maximum value is 10 mGal. Second positive anomaly component lies to Kizilgach from the southeast of Bilesuvar to the northeast-southeast. This positive anomaly is called Uzuntepe (Novogolvka)-Kizilgach positive anomaly. In the extreme. In the extreme parts of the anomaly two important isoanomalies are seen. Maximum anomaly value on the northwest edge is 10 mGal. Near Jalilabad maximum anomaly region appears in the southwest part of Bilesuvar-Kizilgach maximum anomaly region. Its anomaly value is 8 mGal. The third important positive anomaly lies in the direction of northwest-southeast from 20 km away Yardimly. Then this positive anomaly contains a large part of Baku Archipelago. This positive anomaly is Yardimly-Astara anomaly. The highest value of anomaly is 6 mGal. Other important anomalies in the region are negative anomalies. A negative anomaly the value of which is - 10 mGal is seen in a part 30 km near Jalilabad. This anomaly is threehills negative anomaly. The second negative anomaly is in the direction of northwest-southeast and takes place in the north of Lenkeran. This anomaly the maximum value of which is -8 mGal is Masally negative anomaly. Other two local anomalies the values of which are-6 mGal and -10 mGal appearing in the southwest and south of Lerik. Another important negative anomaly appeared in the region of Lower Kura (Salyan) and Baku Archipelago between the important instantaneous rising of radial power spectrum of the study area in **Fig. 2.2.15**. and the local anomaly in **Fig. 2.2.18**. The results of bandpass Butterworth filter the cut-off wavenumber interval of which is 0.156-0.22km^{-1} were given in **Fig. 2.2.19**.

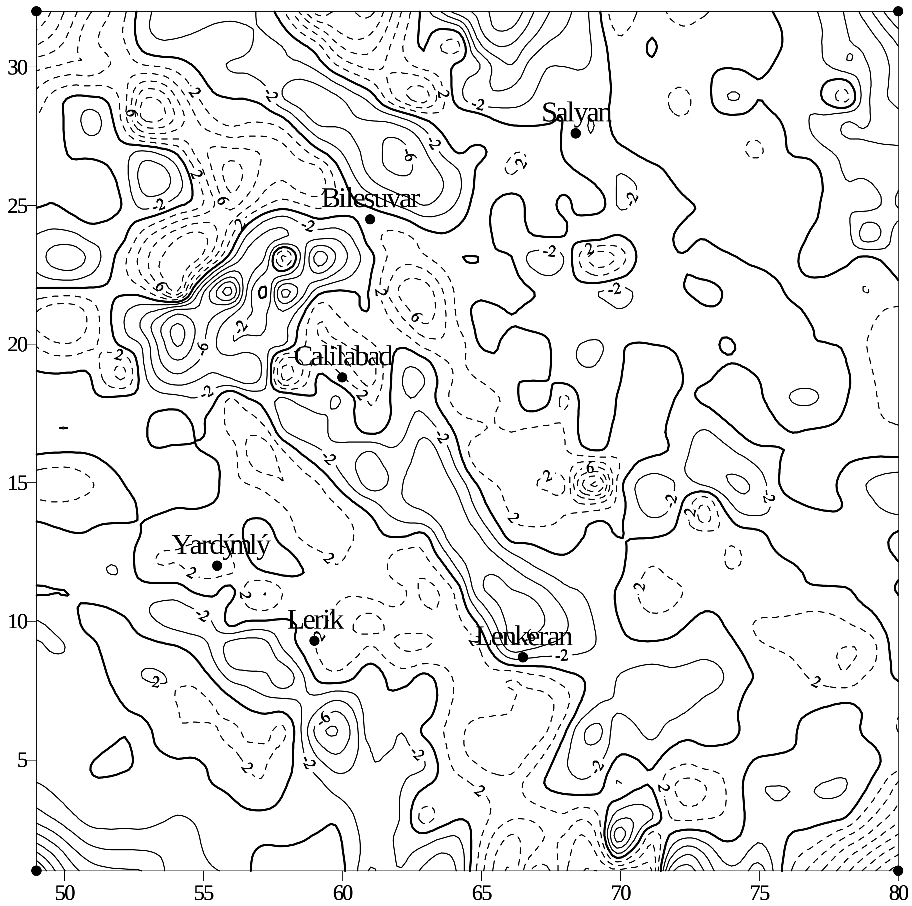


Fig. 2.2.18. Results of high-pass filtering of the gravity data on the Lower Kura-Talish region with using 2D HT.

Here posiive and negative anomalies mentioned above can be seen more clearly. Generally, the extension of the anomalies are in the direction of northwest-southwest.

By applying the Hartley transform to Lower Kura-Talish region gravity data, the structures which caused local and regional anomalies were tried to be determined. The regional gravity map obtained in this way shows that Lower Kura basin as an inseparable element in south Caspian basin. The regional anomaly obtained from the result of lowpass filtering determine the topography of earthcrust and the local anomalies obtained from the results of highpass filtering determine the topography of crystalline base. It was concluded that determined positive anomalies were developed depending on rising of crystalline base and negative anomalies depending on falling crystalline base. In the given examples, we used fast Hartley transform for both (column and row), without depending on data size. We are not faced any memory space and computational time because of fast Hartley transform. These advantages promote the use of smaller computers to process larger geophysical data sets using frequencydomain techniques. Using of the obtained results with the seismic and petrophysics studies is supposed to contribute to investigating of the region for oil-gas and directing studies.

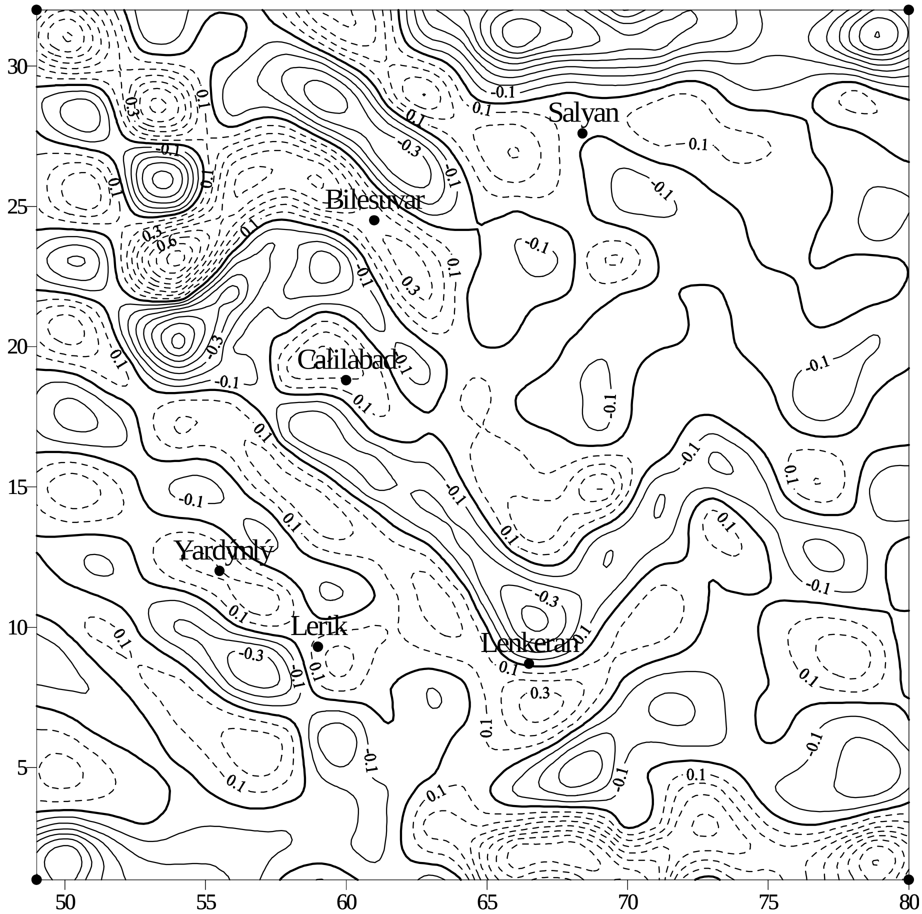


Fig. 2.2.19. Results of band-pass filtering of the gravity data on the Lower Kura-Talish region with using 2D HT.

2.2.3. Model of basement and its gravity effects in Absheron and Shamakhy-Gobustan regions

Depth occurrence of the pre-Mesozoic crystalline basement surface have been studied with the aim of interpreting the gravity anomalies in Absheron and Shamakhy-Gobustan regions. Density-versus-depth relationship in the part of the Earth's crust overlying crystalline basement can be approximated by a quadratic function (Bhaskara, 1986)

$$\Delta\rho\,(z) = a_0 + a_1 z + a_2 z^2\,, \qquad (16)$$

where z represents the depth measured positive in downward direction, a_0 represents the extrapolated value of density contrast at the surface, and a_1 and a_2 are the constants of the quadratic function. The constants are first solved by the least squares method on the data of density available from borehole profiles (to 5km) and other geophysical information sources.

The geological, geophysical and borehole information available suggest a general four-layer structure of the Earth's crust in the area: a first layer of Cenozoic deposits with a density of =2.20-2.40 g/cm^3; a second one of Mesozoic deposits, =2.60 - 2.72 g/cm^3; a third one of metamorphic and granite rocks, =2.66-2.85 g/cm^3; and fourth one of basaltic rocks, = 2.90 g/cm^3 (Gadjiev, 1965; Volarovich and et al. 1966). Thicknesses of these layers vary substantially over the region, making up around 42 km in total.

In the study area a considerable density contrast of -0.35 g/cm^3 at a 2 km depth within the Neogene complex is documented by borehole survey. The next density contrast of -0.27 g/cm^3 occurring at Cenozoic and Mesozoic boundary is located at an average 5 km depth. At the boundary of crystalline basement occurring at an average 15 km depth, density contrast is taken equal to -0.15g/cm^3. Besides the layered model included density contrast at the boundary of low-velocity zone (-0.40g/cm^3).

Taking mean thicknesses of the Cenozoic and Mesozoic as equal to 5 and 10 km, respectively, with density contrast between them at -0.27 g/cm^3 and -0.15 g/cm^3 at the surface of crystalline basement, a density-versus-depth quadratic relationship has been established. The values so obtained are a_0 = -0.4009, a_1 = 0.03091, and a_2 = -0.00094. This approximation function is graphically shown in **Fig. 2.2.20**.

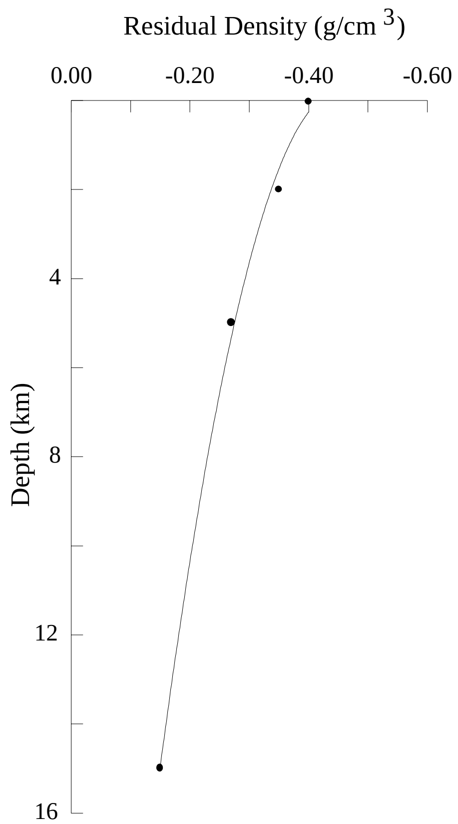


Fig. 2.2.20. Approximation of density versus depth data for the Shamakhy-Gobustan and Absheron area by a quadratic function.

Deep sounding of the subsurface with seismic methods shows that from the north Absheron Peninsula to the south, marine continuation of the Jeirankechmez depression, thickness of the Pliocene deposits progressively increase. These deposits have the lowest density, being within 2.0-2.2 g/cm^3 on average. Such a north to south trending in thickness, with quiescent bedding of underlying strata, must be accompanied with decrease of gravity field in the same direction. At a distance of 50 km thickness of the Pliocene unit grows to as large as 7 km. With an average 0.3 g/cm^3 density difference between the Pliocene and underlying strata 7km-thick unit must provide negative gravity field at 89 mGal. However, observed anomalies of the gravity field in Bouguer reduction in indicated direction increase. Negative gravity effect due to the Pliocene complex are compensated for by positive gravity effect caused by southward elevation of the denser rocks (Gadjiyev, 1965). Thus, increase in thickness of young deposits is accompanied by elevation of denser and older complexes. Subtracting linear regional effect of 30 mGal due to elevation of denser and older rocks from the map of gravity field anomaly in Bouguer reduction we obtain "residual" gravity map for study area. The depth map of basement (**Fig. 2.2.21**) is estimated from the inversion of the "residual" gravity field constrained with the density model by using the GR3DSTR program (Bhaskara and Ramesh, 1991).

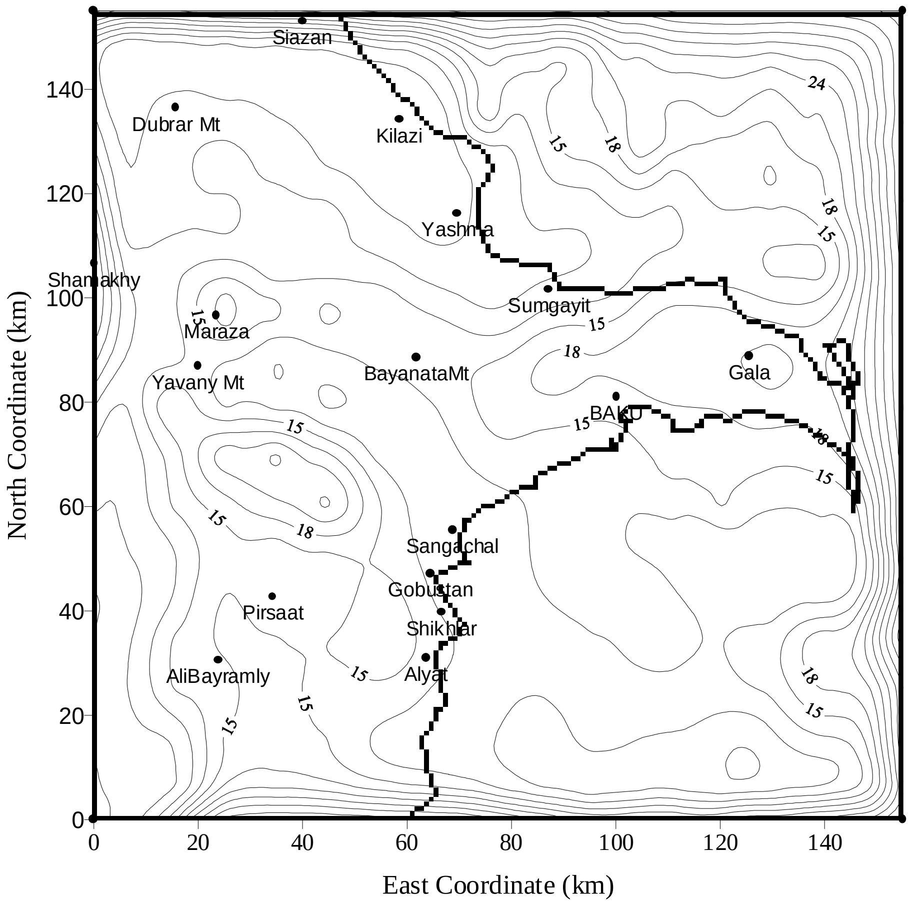


Fig. 2.2.21. Basement contour map of the Shamakhy-Gobustan and Absheron area derived from 3D modelling of gravity anomalies using a quadratic density function. Contour interval is 3 km.

Calculations for basement depth maps were performed at specified 10 iterations. The recalculated gravity effect based on the depth to basement map (**Fig. 2.2.21**) is displayed in **Fig. 2.2.22**.

Apart from the regional shift of 30 mGal the map agrees well with the regional anomaly map. As can be seen higher values on the map correspond to the Yavany Mt-Alyat area where the mean depth is around 23 km. The mean depths in the Absheron peninsula and Dubrar zone are 20 and 6 km, respectively. The data presented are well correlated with the results of seismic exploration (Gajiev, 1965; Aksyonovich and et al. 1962; Rajabov, 1978). Comparison of the Bouguer gravity anomaly maps, regional anomaly map and calculated gravity anomalies with regard to the above reduction shows that major part of the regional anomaly is due to the crystalline basement.

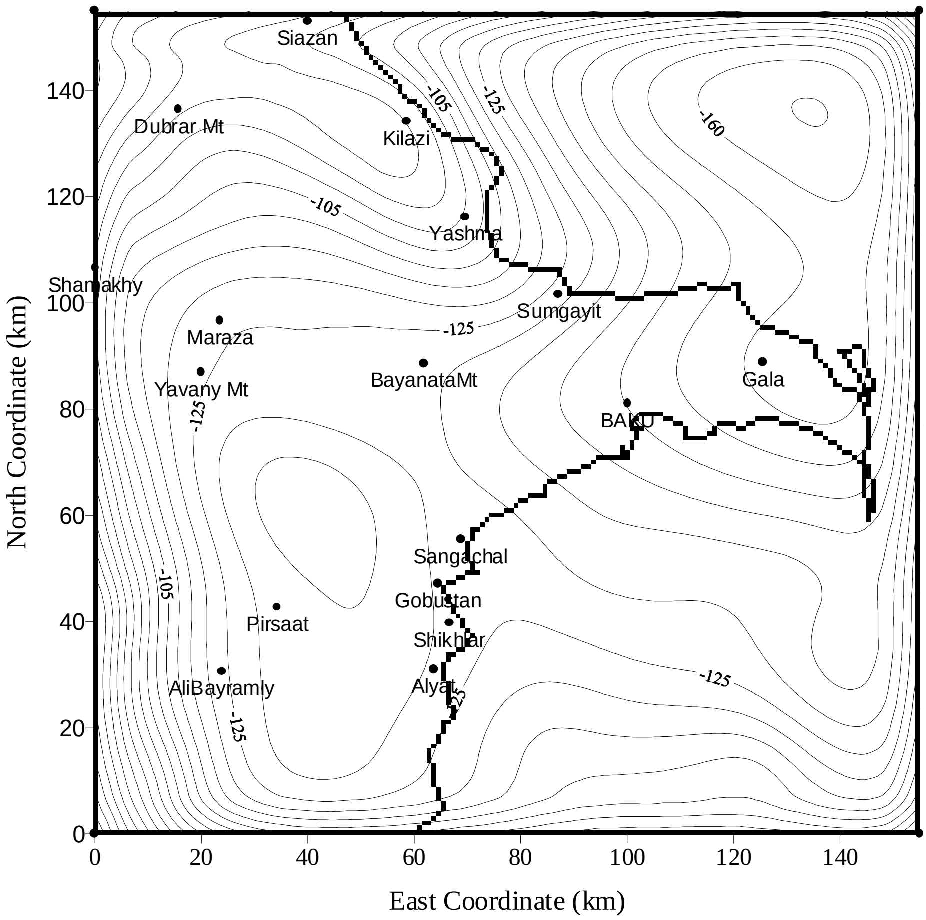


Fig. 2.2.22. The calculated gravity anomalies of the sedimentary basin with the 3D prism program in the Shamakhy-Gobustan and Absheron area. Contour interval is 5 mGal.

2.2.4. Gravity model of the Hekery river-Fuzuli-Carli-Maraza profile

Gravity modeling was made along the Hekery Rive-Fuzuli-Carli-Maraza profile in SW-NE direction for investigating of depth structure and tectonic evolution of Kur Intermontane Basin. The investigated profile starts at Karabagh Plateau to the SW, passing through

Karabagh-Mil piedmont flats, Mil-Shirvan planes, Gobustan region and ends at Dubrar area at the Great Caucasus, to the NE (**Fig. 2.2.23**). For gravity modeling, observed gravity value and geological-geological structure diagram of investigated profile make up initial data. Initial structure model of the profile was obtained by using seismic data, well informations, geological informations, density-depth distribution of major rocks units along the profile and another profiles which cuts the profile.

Gravity modeling was made by a selection method, which is minimization condition of multi-parameter functional by formed parameters of initial structure model. The parameters of modeling obtained at the beginning are changed such that, the difference between observed and computed fields doesn't be large from deformed values (Strakhov, Bulakh, 1976).

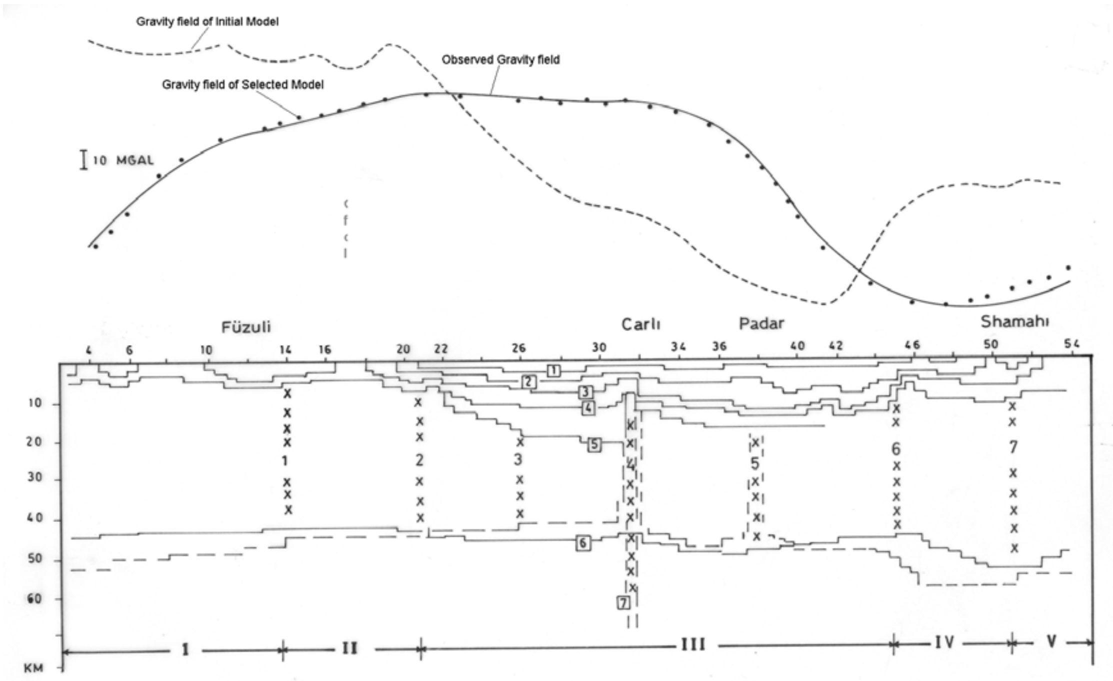


Fig. 2.2.23. Gravity model of the HekeryRiva-Fuzuli-Jarli-Maraza profile. The faults: 1-Lesser Pre-Caucasus fault, 2-Kura fault, 3-Kabala-Chakirli fault, 4-Mingechevir-Lenkeran fault, 5-West Caspian fault, 6-Hachinchay-Alet fault, 7-Hermiyan fault. The density boundaries: 1-Bottom surface of Akchakil Unit, 2-Lower surface of the production unit, 3-Boundary in Upper Mesozoic, 4- Interface separations sedimentary and consolidated complex, 5-Upper surface of Basalt, 6-Moho surface, 7-The new determined boundary of Mantle-Lithosphere bodies. I-Karabagh Plateau, II-Karabagh-Mil piedmont flats, III-Mil-Shirvan planes, IV-Gobustan region, V-Dubrar area.

The six important density boundaries have been determined in section of initial profile. Starting from uppermost boundary, they represent bottom surface of Akchakil Unit, lower surface of the productive horizon, seismic boundary in Upper Mesozoic, interface separating sedimentary and consolidated complex, upper surface of Basalt and Moho-surface. Density changes across the upper four boundaries are 0.1 gr/cm^3, across the Basalt and Moho-surfaces are assumed to be 0.15 gr/cm^3 and 0.3 gr/cm^3 respectively.

Three uncompensated zone have been identified in the whole profile, as a result of comparison of observed gravity-values with gravity effect on initial structure model, calculated by dividing the interval-zones lying in between seimic-boundaries which are accepted to be contact surfaces, into columns. A difference of - 60 mGal has been determined, in between observed and calculated gravity field, along the 90 km central part of this profile which represent section across Yevlakh-Agjabadi Mesa-Cenozoic depression zone and Talish-Vendam graben. This segment reflect mass-deficiency. Northeast segment (Gobustan and Dubrar zone) and southwest segment (Lesser Caucasus Graben) of the profile with 165 mGal gravity differences, represent regions of excess-masses. The negative difference representing deficient-mass, at the central segment is compensated by two mantle-lithosphere bodies and a new boundary rising from 80 km depth. Two mantle-lithosphere bodies coincide to the intersection zones of the profile with Mingechevir-Lenkeran and West Caspian faults.

Mantle-lithosphere body associated with Mingechevir-Lenkeran faults (Western Intrusion) had broken the Basalt boundary and caused upraise of Moho up to 12 km. This intrusion raising up the three upper boundaries (except Akchagil) had formed Carli Uplift. Mantle-lithosphere body with 10 km width is estimated to have 2.9 gr/cm^3 density. The other mantle intrusion is situated at Padar Anticline area, 35 km Northeast of the Carli intrusion. Here, Padar Mantle-lithosphere body caused upraise of Moho up to 18 km, but not reached to consolidation boundary. Positive differences at both ends of the profile reflecting excess-mass is compensated by 52 km Moho depths at Lesser Caucasus Graben and 57 km Moho depths at Dudrar zone, respectively.

2.3. Active tectonics of the Caucasus/Caspian region: deduced from GPS, gravity and seismically date.

Measurements using the Global Positioning System (GPS) have yielded velocities of horizontal motions in the Lesser Caucasus, the Talysh Mountains, the southern slope of the Greater Caucasus, and the Caspian region. Large NE-oriented velocity vectors (9–12 mm/yr) are observed in the southeastern Lesser Caucasus and Talysh Mountains. A decrease in the velocity and a significant accumulation of elastic energy are observed in the southern Absheron Peninsula. Geological activity (seismicity, mud volcano eruptions, and so on) is attributed to horizontal motions. The Belokan–Sheki area is a mobile sector of the Greater Caucasus. The GPS stations in the Lesser Caucasus (field of negative gravity anomalies) and Talysh Mountains (field of positive gravity anomalies) yield the same horizontal motion velocity vectors, which do not correlate with the gravity anomalies. These facts allow us to state that the Lesser Caucasus and Talysh Mountains participate in horizontal motion as a unified plate.

Very strong earthquakes that took place in 1986, 1989, and 2000 (Caspian Sea; M = 6.5, M = 6.5, M = 6.2, and M = 6.4), in 1988 (Spitak, Armenia; M = 6.8), in 1990 and 1997 (northern Iran; M = 7.4 and M = 6.5), in 1991 (Racha, Georgia; M = 7.0), and in 1992 (Erzincan, Turkey; M = 7.2), as well as the occurrence of moderate earthquakes in focus zones with an energetically weak seismic prehistory, suggest an activation of the Caucasus–Caspian region. The seismic activity of the Caucasus–Caspian region is related to a persistent tectonic motion of the Arabian and African plates toward the Eurasian Plate (Smith, D.E., et al., 1994; McClusky, S., et al., 2000; Shevchenko, V.I., et al., 1999; Philip, H., et al., 1989).

An intricate geological structure of the Earth's crust in Azerbaijan and the existence of numerous seismically active faults here make urgent the problem of the investigation of deformational processes. The main question in this case is whether the tectonic stress accumulated in deep-seated faults of the general Caucasian strike is discharging through weak tectonic events or if it is accumulating and can lead to a discharge in the form of a disastrous earthquake.

Distribution of epicentres of earthquakes (M>4) occurred for the season(term) of 1980-2001 East Caucasus / SouthCaspian region is shown in a **Fig. 2.2.24** (IRIS date). In a **Fig. 2.2.25** the distribution hypocentre of these earthquakes designed on a line having a direction west east is given.

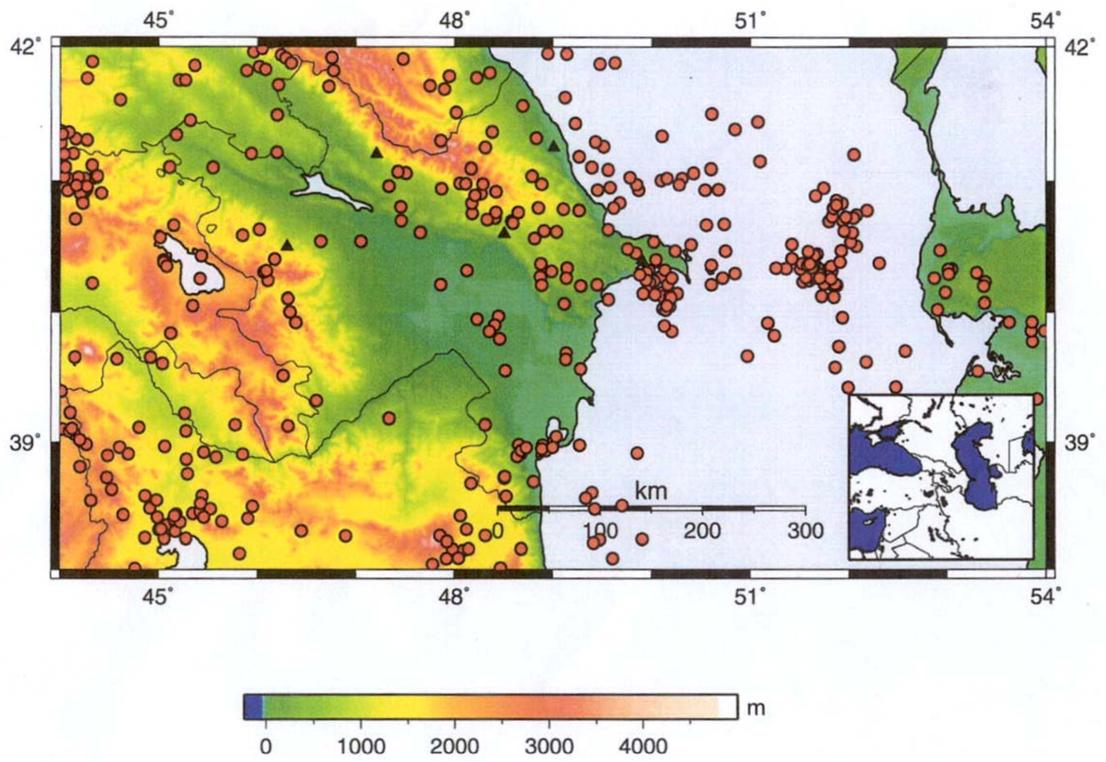


Fig. 2.2.24.Seismic activity of the Caucasus region between 1980- 2001, (M>4).

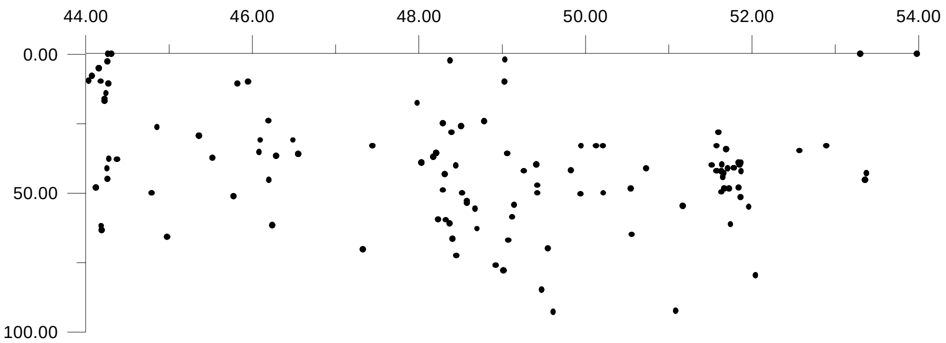


Fig. 2.2.25.Distribution hypocentre of the earthquakes of the East Caucasus-Caspian region between 1980- 2001, (M>4) designed on a line west east direction.

Figures 2.2.26 shows focal mechanisms (lower hemisphere projection) for shallow (<100km), major earthquakes (M>5.0) is compilation with using the published by Dziewonski et al. (1981), Jackson and McKenzie (1988) and Harvard CMT determinations Caucacuc/Caspian region.

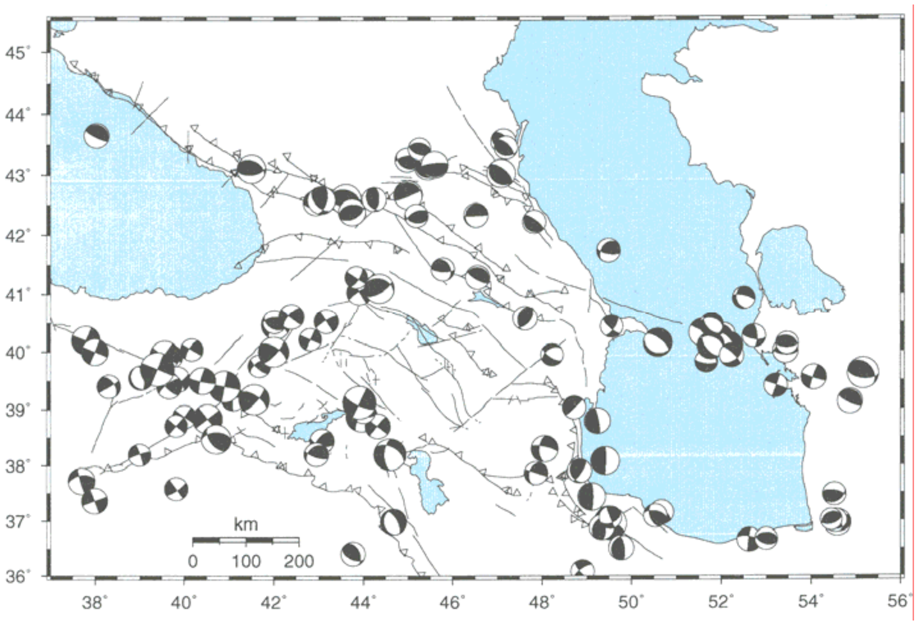


Fig. 2.2.26. Focal mechanisms major earthquakes (M>5) in the Caucasus region.

At the present time, GPS measurements are the main instrument for the investigation of deformations within mountain structures and global motions of lithospheric plates (Hager, B.H., 1991). Such measurements were initiated for geodynamic purposes in the mid-1980s in Europe and the United States. In 1988, GPS measurements were commenced in Turkey, Greece, Egypt, and Israel. Within the Caucasian Mountain System, such investigations and measurements began in the territories of Georgia, Armenia, and Russia in 1991.

In 1998, the Azerbaijani GPS-measurement network was established by the Institute of Geology, Azerbaijan Academy of Sciences, and the Massachusetts Institute of Technology (R. Reilinger, United States) based on previously existing geodynamic sites in Azerbaijan.

The network incorporates 14 GPS stations in the Azerbaijan territory with the following conventional designations: KATE (Katekh), SHEK (Sheki), KEBE (Gabala), SAMU (Samur), SIYE (Siazan), MEDR (Medrasa), SHIK (Shikhlar), GOSM (Gosmalion–Lerik), YARD (Yardymly), BILE (Bilyasuvar), KURD (Kyurdamir), and YEVL (Evlakh). The network also includes two stations in the Yukhary-Karabakh region: KASP (Agdere) and SHOU (Shusha). The first measurements were performed in September 1998 at the ten first-listed stations. Repeated measurements were carried out in September 2000, at 12 stations. Results obtained in 1998–2000 were processed in cooperation with the Massachusetts Institute of Technology with the use of GAMIT/GLOBK software (King, R.W. and Bock, Y., 1998; Herring, T.A., 1998; Oral, B., 1994).

Figure 2.2.27 presents a schematic map in the Eurasian coordinate system showing the distribution of velocity vectors of horizontal displacements of the GPS geodetic stations and their 95%-confidence probability ellipses over the Caucasian area for the 1998–2000 period. Based on instrumental data, the obtained velocity vectors make it possible to present a relatively complete pattern of recent horizontal displacements of some structures in Azerbaijan.

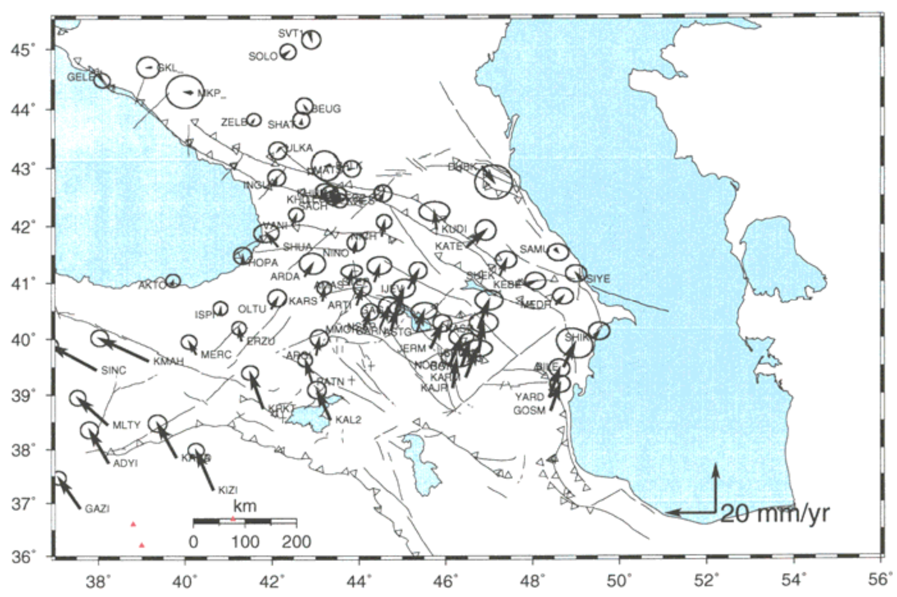
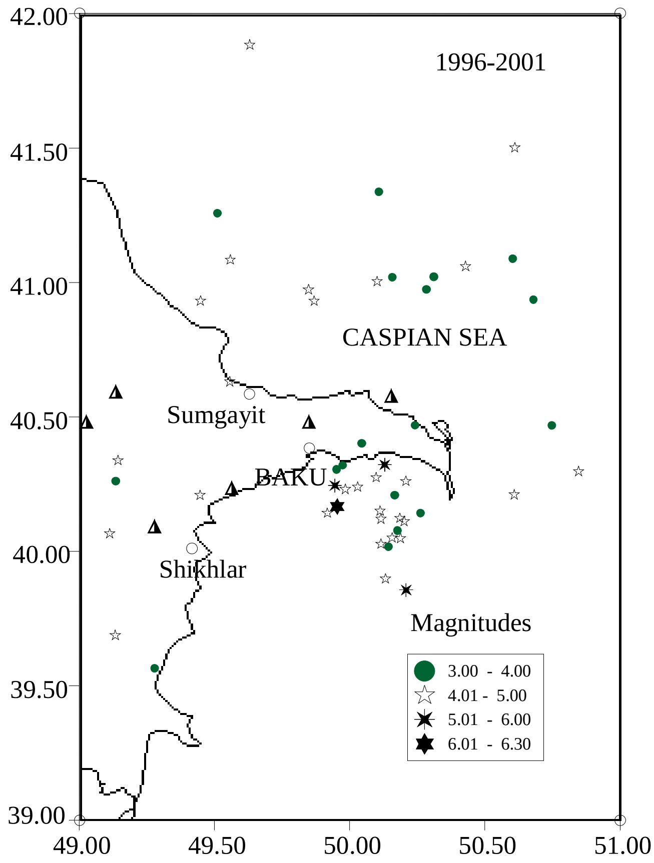


Fig. 2.2.27. GPS horizontal velocities and their 95% confidence ellipses in a Eurasia-fixed reference frame for the period 1988-2000.

Large NE-oriented velocity vectors (9–12 mm/yr) are observed in the southeastern segment of the Lesser Caucasus. Analogous velocity vectors are also observed at the GOSM and YARD stations situated in Talysh. The same velocity vector is typical for the BILE station.

In the Greater Caucasus, intense motions are registered at the KUDI, KATE, and SHEK stations. At the KATE station, a large velocity (12 mm/yr) is also observed, but it deviates further to the northeast. At the SHEK station, the velocity is approximately 8 mm/yr, and the vector is oriented parallel to those at the stations in the southeastern Lesser Caucasus. Almost zero velocity vectors are observed at stations KEBE, SAMU, SIYE, MEDR, and SHIK, suggesting that significant deformational energy is accumulated here along the northern boundary.

A decrease in the velocity and a significant accumulation of elastic energy are observed in the southern Absheron Peninsula. This phenomenon may be responsible for the activation of seismic events and of mud volcanoes in this region. **Figure 2.2.28** presents a schematic map showing the distribution of epicenters of earthquakes that took place during the 1996–2001 period (based on the IRIS catalogue), and of mud volcanoes that erupted during the 1998–2001 period in the Absheron and Shamakhy–Gobustan areas. The strong earthquake in the Caspian Sea at the end of 2000 and its aftershocks probably represent a response to the deformational processes which continue in recent years, and the related stress accumulation at foothills of the Greater Caucasus and the Absheron Peninsula and middle Caspian regions.



-Mud volcanoes that erupted within the 1999–2001 period.

Fig. 2.2.28 Distribution of earthquake epicenters over the 1996–2001 period.

It is impossible to exploit GPS stations within marine areas. Therefore, we cannot make unambiguous conclusions on the nature of this earthquake. However, the tendency of horizontal motions in the Azerbaijan territory suggests an activation of seismic processes in adjacent zones of elastic stress accumulation.

Comparing the GPS measurement data (**Fig.2.2.27**) with the regional gravity anomalies (**Fig. 2.2.1**) demonstrates that the stations situated within the intense negative gravity anomaly zone in the southern Lesser Caucasus (–160 mGal) and the Talysh Mountains zone (100 mGal) are almost identically displaced toward the northeast. Hence, from the viewpoint of horizontal motions, distinguishing the Talysh Mountains as an individual block is contrary to the evidence.

In other words, the southeastern Lesser Caucasus and Talysh Mountains are not separated but displaced as a unified structure from the south to the north over the viscous asthenosphere under the action of the northward drift of the Arabian Plate. To confirm this conclusion, however, we should increase the number of GPS stations and obtain a more detailed image of the recent horizontal-motion distribution.

III. Sedimentary cycles, depositional environment, architecture of Lower Pliocene reservoirs in the South Caspian basin

Cyclicity of development of any geodynamic system including sedimentary basins is a wide known fact. However the duration of cycles and scales of occurring processes are unambiguous for different basins. Sufficiently good studied the link of transgressions and regressions of the World Ocean with global epochs of tectogenesis and climatic changes. Periodicity of these events is dozens, hundreds, thousands and millions years. The Caspian Sea being the unique largest isolated basin in the world with hyper-unstable sea level regime represents the beautiful model area for studying of dynamics of sedimentary systems' evolution in a short period of time.

The sedimentary cover in the South Caspian basin (SCB) according to modern data reaches up to 30-32 km in thickness. It was determined the wide stratigraphic diapason of deposits in SCB from Aalenian stage of Middle Jurassic to Holocene sediments. But the majority of reservoirs and hydrocarbons reserves (about 90%) are concentrated in Lower Pliocene Productive Series in the Western flank of the basin and its analogue in the Eastern flank- Red color Series.

Sedimentation in the Early Pliocene occurred in conditions of closed basin, formation of which was caused by intensive orogenic movements, uplifting of the adjacent areas of land, subsiding of central part of the South-Caspian depression and fall of the Caspian sea level reached according to some estimations to 1500 m (Reynolds et al.). It led to final isolation of the Caspian Sea from the Eastern ParaTethys in Messinian and progradation of several large river systems. It is generally accepted now, that the hydrocarbon accumulations in Lower Pliocene of the South Caspian basin are concentrated in fluvial-deltaic deposits of the Paleo-Volga, Paleo-AmuDarya and Paleo-Kura rivers.

However, exploration for new fields and exploitation of existing ones in the South Caspian basin are hampered by the lack of good models of depositional environment in Early Pliocene and reservoirs geometry. Existing models are limited due to misunderstanding of very important circumstance- hyper instability of the Caspian Sea level regime like any isolated basin. Amplitude of small-scale Caspian Sea level fluctuations (decades, centuries) can be compared with long time (thousands, tens of thousands of years) World Ocean oscillations. For the example, the last high frequency cycle of the Caspian Sea level fluctuation (1929-1995) led to formation of sedimentary sequence of a high order with regressive and transgressive system tracts and sequence boundary corresponding to time of the lowest sea level (Kroonenberg et al., 2000). Herewith amplitude of sea level fluctuation reached 3 m. At the same time for the last 6 Ka the level of the World Ocean wasn't changed within a large range, than 10 m (Shepard, 1956, Fairbrige, 1961).

Thus, the sedimentation in the Caspian Sea undergoes the great influence of sea-level changes of smaller amplitude. More over the latter played a key role in change of depositional environment, facial shifts, formation of architecture of reservoirs and, possible, source rocks. Some failures which took place last time during the exploration of some structures on the western shelf of the South Caspian basin are mainly related with poor understanding of influence of facial types of the sediments upon the formation of reservoirs, absence of model of reservoirs architecture in various parts of the basin.

3.1. Lithofacies types of Lower Pliocene sediments

3.1.1. Productive Series

Productive Series (PS) consisting of 9 suites (Kala, PreKirmaki, Kirmaki, PostKirmaki sand, Post Kirmaki clay, Pereriva, Balakhany, Sabunchi, Surakhany) occurs is a great area -Absheron peninsula, Absheron and Baku archipelagos, Jeyrankechmyaz depression, Alyat ridge, Pre-Caspian region. Several facial types of deposits-Absheron, Lower Kura, Gobustan, Pre-Caspian, South-Caspian are distinguished. Lithologically this type of deposits is composed by quartz sands and siltstones. Accumulation of thick terrigenous series, lack of macrofauna and scarcity of microfaunal composition are common features for all Productive Series lithofacial zones..

Absheron type

Absheron type of PS sediments spreads along the whole territory of the Absheron peninsula, Absheron archipelago and covers the northern part of Baku archipelago. The typical features are quartz composition and presence of disthene and staurolite. The thickness of sands, silstones and clays composing the section of Absheron type of PS sediments varying within wide ranges from several cm to several meters and in a total 7000 m. Productive gas-oil sand beds the number of which reaches to 40-50 in some fields are distinguished in the section. The basic part of terrigenic material was supplied by a large water artery - PaleoVolga, flowing into the northern zone of the basin.

Gobustan type

Within this type of sediments 2 subtypes are distinguished – Donguzdyk and Eastern-Gobustan.

Donguzdyk series is developed along northern-western margin of Jeirankechmez depression and is characterized by alternating of calcareous sandy shales with coarse pebbly sands in the basal part of the section and brown loams, conglomerates and pebbles in the section upper part. Thickness- 200-400 m.

To the south this type of PS deposits replaced by Eastern-Gobustan type covering the south-eastern zone of Gobustan coinciding with Jeirankechmez depression and zone of Alyat ridge.

Eastern-Gobustan series is represented by a thick sandy-silty-clayey series of rocks, rudaceous rocks which are widely developed in the marginal zones of basin. On some areas the thickness of the this type of PS sediments is 2500-2800 m.

The basic lithological features are alternation of clayey-sandy-silty rocks through the section without any definite regularity and large presence of fine grained material in comparison with Absheron type. A big input of terrigenous material was provided by PaleoPirsagat river.

Lower Kura type

This type of sediments was formed in the backarch basin. Clasts material is predominate in the section and had been supplied from Lower Kura depression, Greater, Lesser Caucasus, Talysh. The occurrence of silty-sandy-clayey deposits is observed in the central part of the basin. The belt of coarse grain rocks intercalating with fine-grained ones which are oil-gas-bearing on some structures is developed along the northern border of basin (Lengebiz zone). The boundary between sediments of Lower Kura and Gobustan types stretches out between Boyuk and Kichik Kharami ridges.

The total thickness of Lower Kura type of sediments is 3500-4000 m. It was formed mainly by terrigenous material supplied by PaleoKura, PaleoAraks and other small fluvial systems.

A small content of quartz in this type of deposits indicates to insignificant role of quartz-containing rocks in the Lower Kura PS type provenance. According to high content of feldspar, pyroxenes and hornblende one can make a conclusion about the significant input from effusive rocks in the sourceland.

Pre-Caspian type of sediments

Along the northern-eastern slope of the Greater Caucasus one can observe the development of deposits of PS of Pre-Caspian type which is lithologically represented by silty-sandy rocks and series of pebbles and conglomerates. The northern-eastern slope of the Greater Caucasus served as a basic PS provenance in this area.

Comparative increase of quartz content and the presence of disthene-staurolite in the deposits composition in the northern part of Pre-Caspian-Kuba region indicates to influence of the northern sources during PS accumulation and poor sorting - to proximity of sourceland.

The thick series of conglomerate alluvial fans developed in the western part of Pre-Caspian region was formed by several mountainous rivers. Paleo-Samur river is appeared to be the largest supplier of terrigenous material. In the eastern part of the region the clayey-sandy rocks are predominating.

3.I.2. Red color Series

It is widely developed in Turkmen oil-gas bearing area represented by terrigenous Red color Series.

This type of PS deposits occurs within the Pre-Caspian plain of the Western Turkmenistan covering the vast intermountain depression. Discharging of large PaleoAmu-Darya river and other small fluvial systems into PS basin led to accumulation of Red color sediments composing almost all hydrocarbon structures in the Western Turkmenistan.

Turkmen type is represented by intercalation of conglomerates, sands, silstones and clays. Thickness is 2500-2800 m.

Close to the mountain systems of Kubadag and Greater Balkhan (south eastern part of Turkmenbashy peninsula) this type of sediments consists of conglomerates course-grained sandstones. In the central part of the basin lithological composition of deposits changes to fine-grained sediments.

3.2. Architecture of PS reservoirs

As it was above mentioned the most hydrocarbon deposits in the Southwest Caspian basin are located in Lower Pliocene Productive Series (PS) consisting of 9 suites – Kala, Pre-Kirmaki, Kirmaki, Post-Kirmaki Sand, Post-Kirmaki Clay, Pereriva, Balakhany, Sabunchi, Surakhany.

Combined outcrops observations (Kirmaki and Yasamal valleys located on Absheron peninsula) and subsurface data interpretation (gamma ray and SP logs) from Bahar field (Baku archipelago) have been used for paleoenvironment reconstructions and elaboration of model of reservoirs (**Fig. 3.1**). Comparison of log diagram of some other oil-gas bearing fields – Kirmaki, Gum adasi, Bahar, Shakh-deniz had been also carried out.

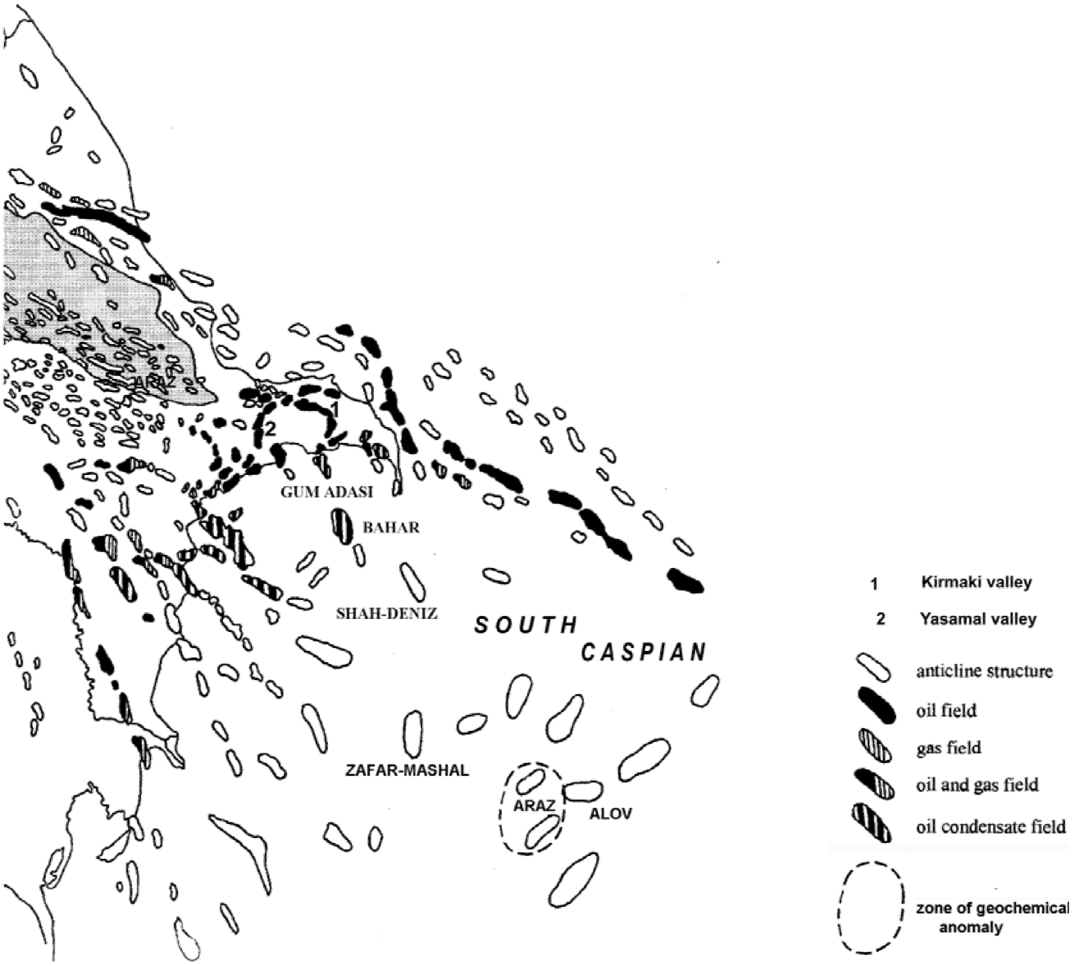


Fig. 3.1. Scheme of location of oil-gas fields in the South Caspian

Elaborated 3D model of PS sediments in Bahar field clearly shows existence of braided fluvial system in Lower Pliocene (**Fig. 3.2**).

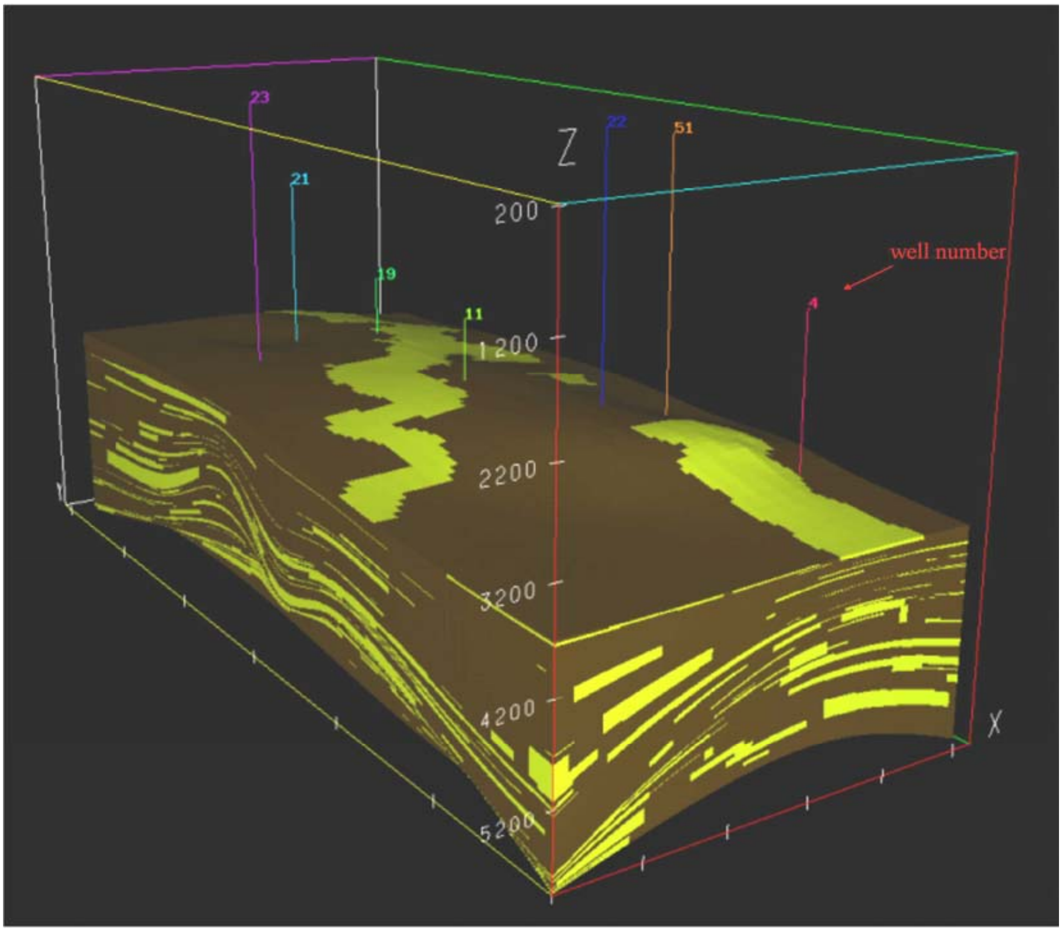


Fig. 3.2. 3D model of Productive Series reservoirs in Bahar field (made up by Ibragimov B., Kroonenberg S., Aliyeva E.)

The profile trending roughly NW-SE along Bahar field was chosen for logs data acquisition (**Fig. 3.3**)

Our palaeoenvironment interpretations had been started form Kirmaki suite of the lower part of PS. One can observe a facial heterogeneity of Kirmaki Suite's sediments along the NW-SE profile - complete absence of stacked shallow channel bodies that is observed in outcrop in Kiramaki valley and development in Bahar field sheet-like laterally extending mudstone beds. Coarsening upward series in Bahar field transiting in the south-eastern direction into monotonous clayey units are mainly distinguished. Small individual channel bodies one can observe extremely rarely in the north-eastern part of the field (**Fig. 3.4**). Interpretation of depositional environment both in exposure and oil filed assumes the sharp change in lateral direction of depositional setting and basinward facial shift from Volga river delta plain-delta front setting with short term accumulation of lacustrine sediments in the middle part of suite in Kirmaki valley (central part of Absheron peninsula) to distal delta front –lacustrine environment in Nothern part of Baku archipelago (Bahar field).

In the vertical section of Kirmaki suite depositional environment in Bahar field changes within distal delta front –lacustrine settings with most distal facial conditions in the middle part of the suite. One can observe only two cycles of the sea level fluctuations not following by any considerable facial shifts.

Transition to the next suite –Post Kirmaki Sand (PKS) occurred under conditions of the sea level fall that led to the gradually progradation of delta which in separate stages of PKS formation was located southward the Bahar (**Fig. 3.4**).

One can observe extended incised one into another fluvial channels filled by sand material. However, as compared to PKS in Kirmaki valley deposits of this suite in Bahar had been formed in the more distal depositional setting. Fluvial channels are shallow and characterized by a good vertical communication but restricted lateral one during sea level low stand. One can observe two such periods during time of accumulation of PKS sediments.

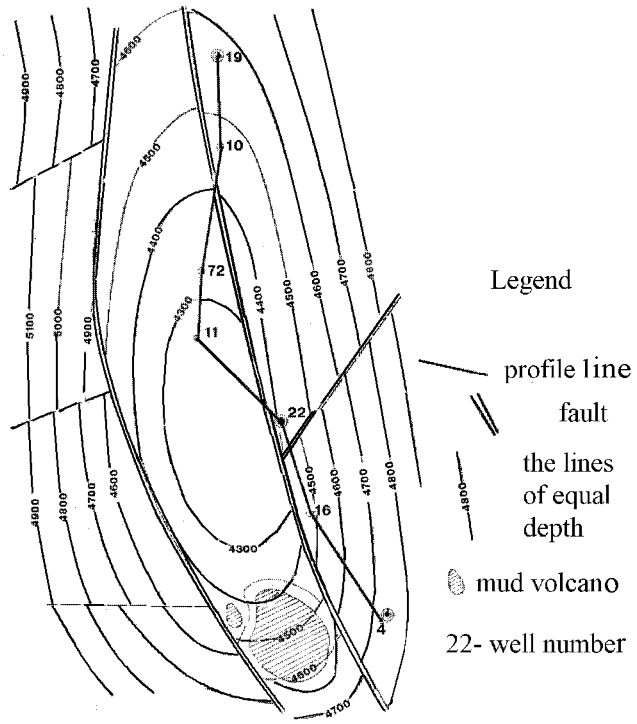


Fig. 3.3. Structural map on the top of horizon X of Balakhany Suite, Bahar field

The following then sea level rise was accompanied by change of depositional environment in Bahar field to delta plain setting with formation of shallow vertically and laterally isolated distributary channels.

One can observe one full cycle and one semi-cycle of the sea level fluctuations, low stand of which were followed by formation of erosional surfaces.

Transition to the most clayey suite in the lower part of PS - Post Kirmaki Clay (PKC) took place under conditions of the sea level rise (**Fig. 3.4**). According to interpretation made by Hinds (verbal information) depositional environment of PKC represents by periodically desiccated floodplain. In our opinion such conditions could take place in the middle of suite.

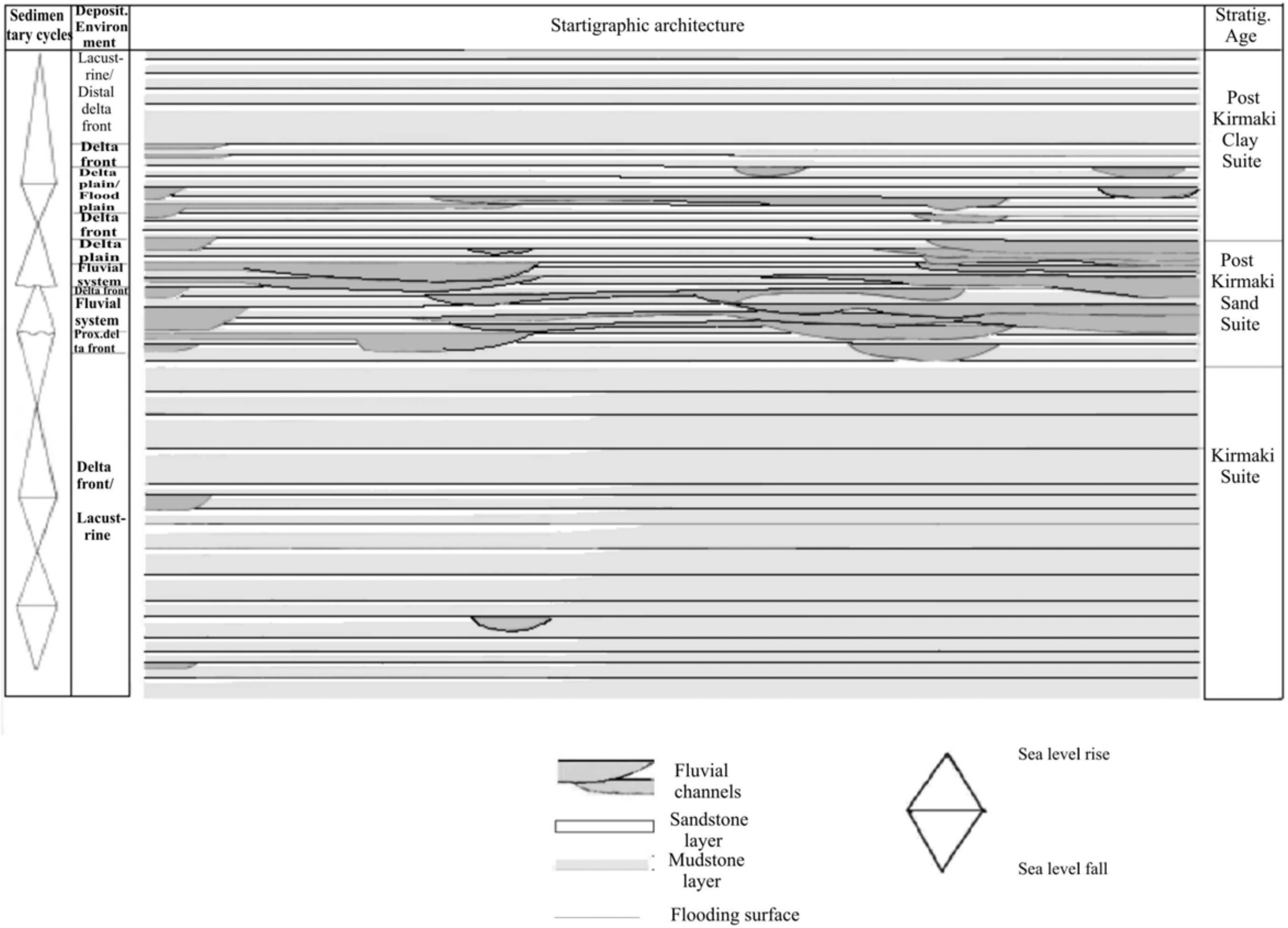


Fig. 3.4. Sedimentary cycles, depositional environment and reservoirs architecture of Kirmaki, Post Kirmaki Sand.

The observed along profile laterally extended broad shallow scours not having lateral and vertical connection can be formed under conditions of poorly channelised floodplain. Findings of numerous desiccation cracks in deposits of PKC in Kirmaki valley proves the existence of such setting in the middle time of PKC accumulation. However, to our view one can not say about existence of such conditions during whole time of PKC formation within Bahar field. Up the section amount of channels and their dimensions decrease significantly. In the upper part of the suite coarsening upward series take place with thick clayey interlayers.

Post Kirmaki Clay Suites, Bahar field. Such changes in stratigraphic architecture represent to our view transition from flood plain setting to delta front - lacustrine. On the whole within PKC one can observe a complete cycle of the sea level fluctuations with low stand in the middle of suite. Low stand sediments comprise approximately 1/3 of total suite thickness that testifies to a rather long duration of this stage of sea level fluctuations.

Formation of the next lithostratigraphic complex of PS - Pereriva Suite takes place under repeatedly sharp fluctuations of the sea level and facial shifts along the section. One can observe 3 stages of sea level low stands following by significant delta progradation, formation of broad fluvial system with amalgamated channel bodies. (**Fig. 3.5**). Sometimes it is possible to observe the intervening of overbank sediments into stacked channel sands and repeating coarsening upward series obviously testify to the presence of crevasse splay deposits.

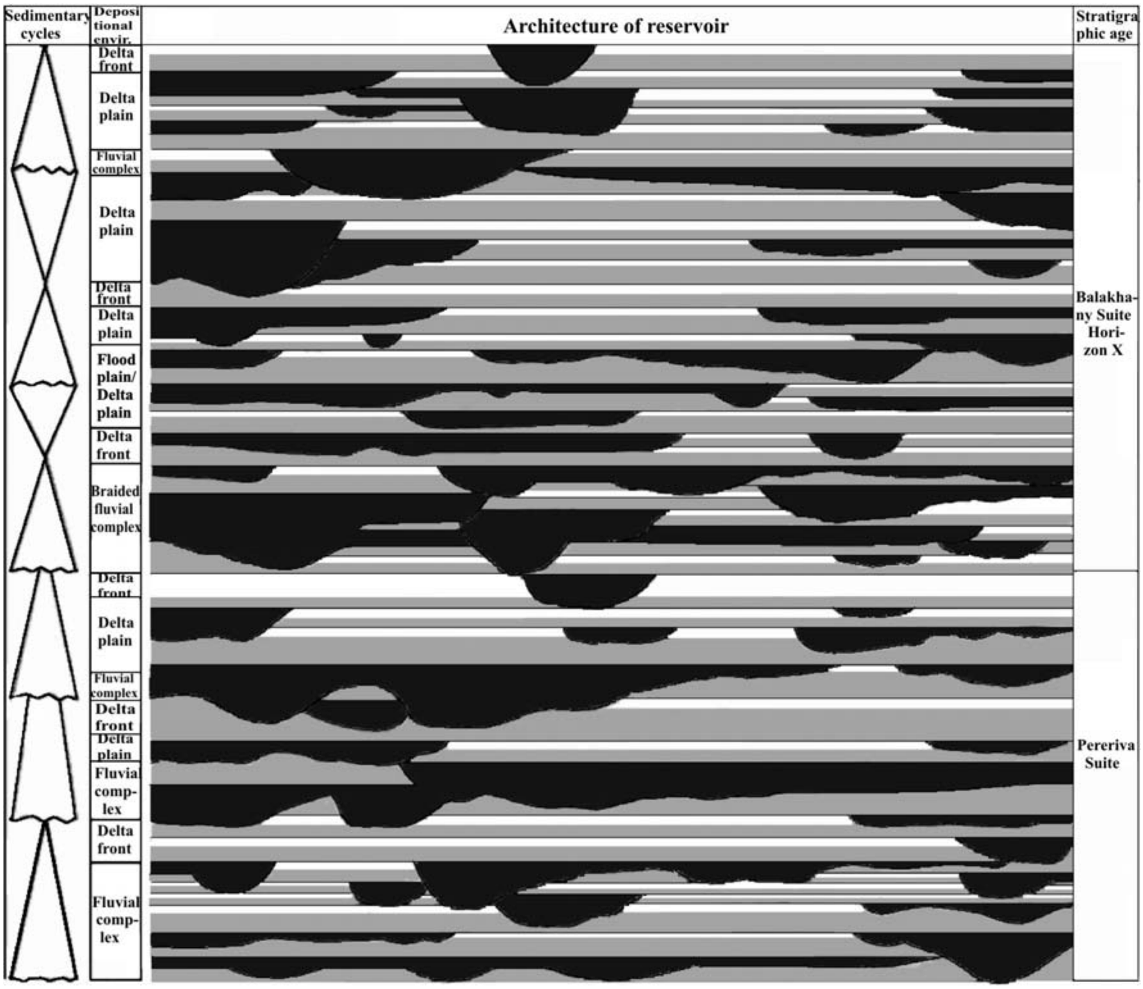


Fig. 3.5. Sedimentary cycles, depositional environment and reservoir architecture of Pereriva Suite and Horizon X of Balakhany Suite

The first cycle of the sea fluctuation during accumulation of Pereriva suite had been terminated by sharp sea level rise of and transition to facies of delta front with extended clayey beds. Following then rapid sea drop was followed by formation of highly amalgamated broad fluvial system changing up the section into deposits of delta plain with restricted isolated channel fills. Successive sea level fall again led to the significant basinward facial shift with development of broad deep sandy filled channels transiting up the section into sediments of delta plain –delta front.

Thus, at total thickness of Pereyva suite on the Bahar field 135 m here one can observe 3 semicycles of very sharp sea level fluctuations.

Sea level high-stand with formation of delta front depositional environment on the Bahar area represents the transition to the next suite of PS - Balakhany suite. However, the duration of that phase of basin evolution is characterized by its short-term and rapidly changed by significant sea level fall led to the backward facial shifts and return to major fluvial system on Bahar field in the lowers of X horizon (**Fig. 3.5**). Fining upward series, probably, represent fluvial channels or bank attached point bars and coarsening upward units may be considered as crevasse splay or sheet flood deposits. The following series of laterally continuous sandstones and mudstones represent transition to facies of delta front. Then one can observe return to fluvial environment represented on Bahar by deposits of floodplain. Laterally traced thin fining upward series represent channel avulsion onto floodplain. Then up to the section of X horizon facies of delta front become dominating within the whole field.

Thus, it should be pointed out, that sea level oscillations during accumulation of Pereriva suite and basal part of horizon X of Balakhany suite were of dramatic nature with a sharp change of trend of sea level fluctuations and development of semicycles. In the middle and upper parts of horizon X depositional environment did not changed so sharp though amplitude of sea level fluctuations was large and facies changed in wide rang. The following 4-th high-frequency depositional cycle in lowers of horizon IX of Balakhany suite is characterized by low amplitude of sea level fluctuations with development of delta front facies during high stand and delta plain during low stand **(Fig. 3.6**). Following sharp sea level drop led to the delta progradation. The delta this time was located toward SSE of Bahar area. On the Bahar field there were deposited highly amalgamated sandstones representing fluvial channels with small intervals of mudstones transforming upward in sheet-like sands, representing, obviously, crevasse splay or sheetfloods deposits.

Up to the section one can observe successive change of depositional setting and the fifth cycle (semicycle) is terminated by rather thick mudstone unit deposited in delta front environment. The section of IX horizon is terminated by a short 6-th cycle characterized by small-amplitude sea level fluctuations

7-th cycle, developed within horizon VIII, represents return to the regime of sharp contrast sea level fluctuations and development of incomplete sedimentary sequences when transition from sea high stand to low stand are sharp and deposits of sea level falling stage not observed. Three sharp changes of sea level, which led to the formation of major broad fluvial system on Baharfield as well as sharp basinward facial shifts are observed.

Up to the section – horizon VII- the amplitude of sea level fluctuations significantly becomes smaller environmental changes were not so dramatic. In the upper portion of Balakhan suite- horizon V, one can observe floodplain facies that testify re-establishment of fluvial environment. Frequent laterally extended fining upward series are obviously interpreted as channel avulsion and coarsening upward ones and as crevasse splay deposits or prograded sheet flood lobes. Results of study Balakhany suite on the Absheron peninsula shows the increase in the section the share of reddened clays, which were formed under aerobic conditions. This fact testifies to formation of floodplain facies within V horizon on the Absheron peninsula that was of general character. In the SSE direction displacement by the more distal facies of delta plain or delta front that were formed during short-term rising of the sea level further changed by phases of its low stand and wide development floodplain depositional environment.

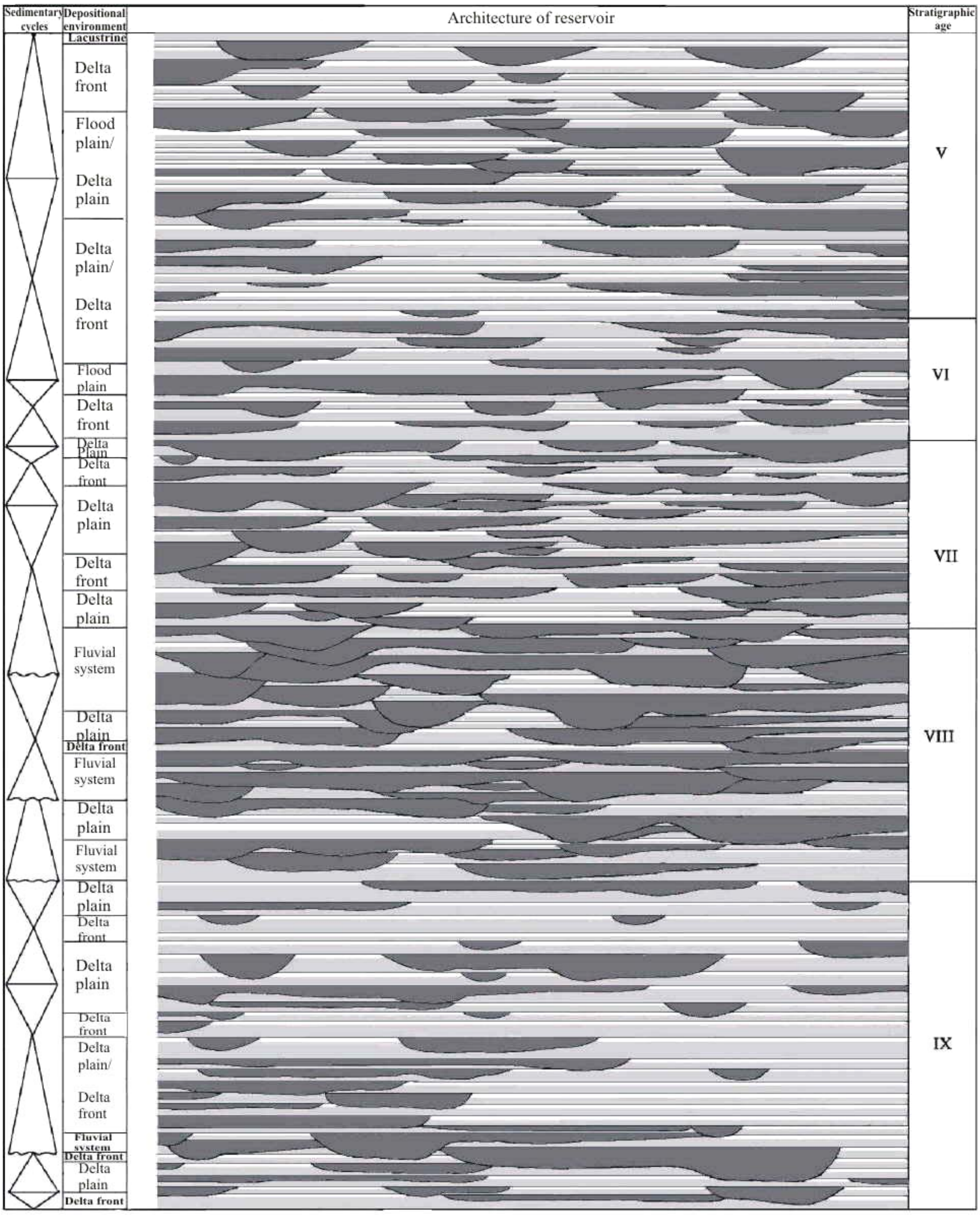


Fig. 3.6. Sedimentary cycles, depositional environment and reservoirs architecture of Balakhany Suite, Bahar field.

Thus, within about 900 m series of Balakhany suite one can observe 13 small scale sedimentary cycles characterizing by different amplitude and duration. At the same time rapid and contrast sea level fluctuations took place in the lower portion of Balakhany suite horisons X and VIII. Up to the section intensity of the sea level fluctuations decreases and from 13 cycles, distinguished within Balakhany suite, only 4 cycles fall on the upper horizons-VII, VI, V.

Prevailing type of depositional environment of Sabunchi Suite is to our view floodplain facies (**Fig. 3.7**). Laterally extended isolated from each other channelised sandstones represent avulsion of fluvial system onto flood plain. Such conditions repeatedly took place during accumulation Sabunchi Suite sediments. Sometimes one can observe lateral replacement of facies, in particular, shifts from flood plain depositional environment to delta plain facies. In the middle of 5-th sedimentary cycles within Sabunchi Suite one can observe rather thick, extended through the whole field, fining upward sandstones packages. These sandy beds are rather deeply incised into underlying intercalating sheet-like layers of mudstones and sandstones. Probably, there is occurs a recurrence to major fluvial system. Fluctuations of water table led to subsequent change of floodplain facies by delta plain environment with small isolated distributary channels separated by coarsening upward interdistributary bay fill series. High stand of each cycle represents deposition in delta front environment. However, extension of these phases was small that testifis to short-term of sea level rising and prevalence of stages of its low stand.

Comparison with exposure of Sabunchi suite in Yasamal valley also testifies to the sedimentation of the most part of Sabunchi suite in proximal depositional environment. Presence of dessication cracks and reddened clays indicate to it.

On the whole, within Sabunchi suite one can distinguish 7 full cycles of sea level fluctuations. In the low half of suite cycles are shorter and characterized by a more high frequency.

Thus, from 27 sedimentary cycles distinguished within Kirmaki, Post Kirmaki Sand and Clay, Pereriva, Balakhany and Sabunchi suites only 11 ones correspond to stages of dramatic sea level drop from high-stands to low stands, basinward facial shifts and establishment of major fluvial system.

Summarizing all above mentioned one can say that various types of depositional environment are distinguished within the defined cycles - from typical fluvial to the facies of delta plane, delta front and lacustrine. Sea level fall was followed by progradation of Paleo Volga delta, formation of broad fluvial system with well laterally and vertically communicated sand bodies. These stages of basin evolution were characterized by the greatest rate of sedimentation and formation of thick sand beds being good reservoirs.

The following sea level rise led to retrogradation of delta and change of fluvial environment to delta front characterized by accumulation of laterally traced mudstones layers and restricted isolated sand bodies or lacustrine setting represented by continuous mudstone intervals. These fine grained sediments may be considered as caps.

Thus, one can observe the great impact of short-term cycles of Caspian Sea fluctuations in Lower Pliocene upon the formation of sedimentary series and architecture of PS reservoirs.

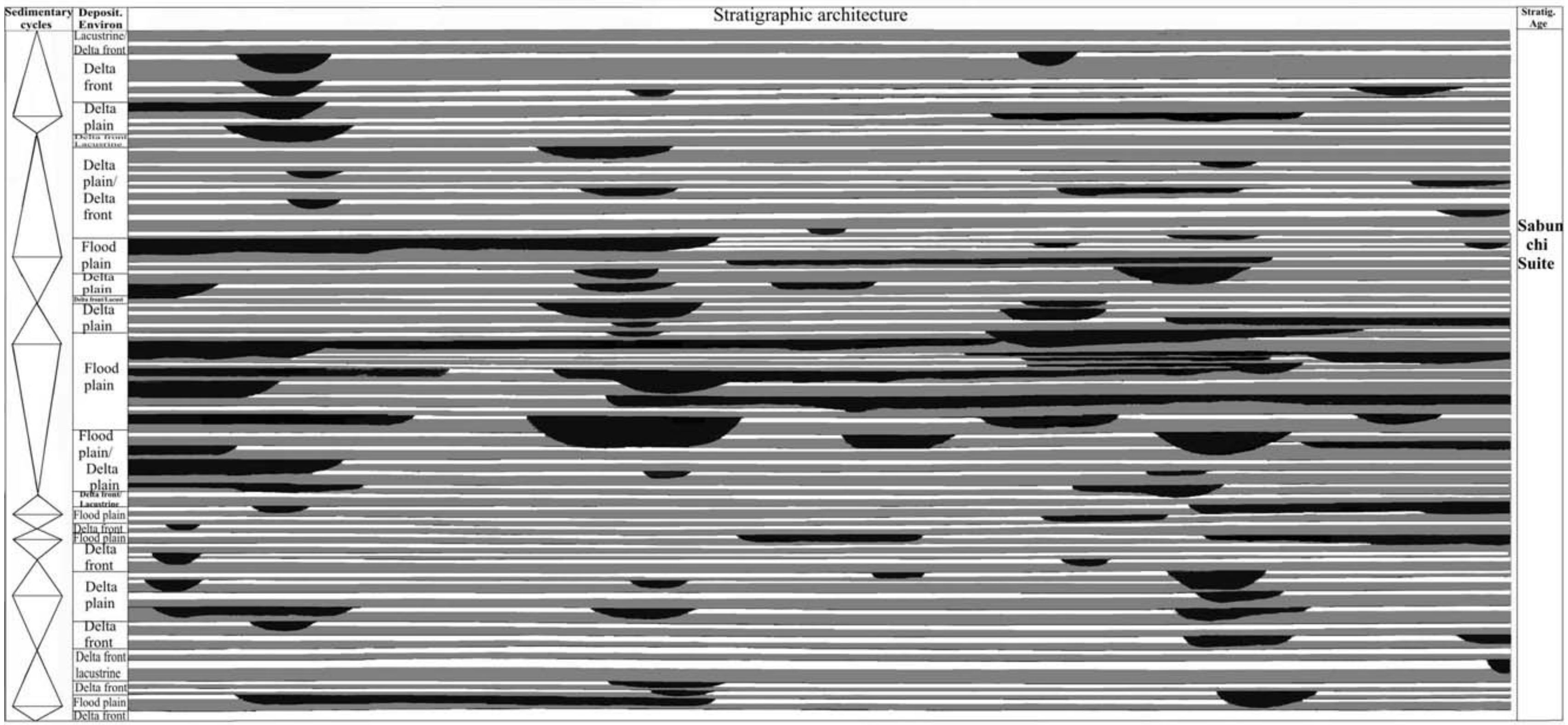


Fig. 3.7. Sedimentary cycles, depositional environment and reservoirs architecture of Sabunchi Suite, Bahar field.

Comparison with data of study of some trace elements in sediments, which are sensitive to environmental changes shows a good correlation of highly-frequency sedimentary cycles with variations of elements content. So, the amount of peaks of maximal values Sr/Ba ratio in separate suites coincides with number of cycles: in Sabunchi-7, Balakhan suite-13, Pereiva suite –3, Post Kirmakinian Clay-1, Post Kirmakinian sand-2 (Huseynov, verbal information) (**Fig. 3.8**). It counts in favor of climatic control for small scale sea level fluctuations, which play a significant role in character and rate of sedimentation, formation of sedimentary series and reservoirs architecture.

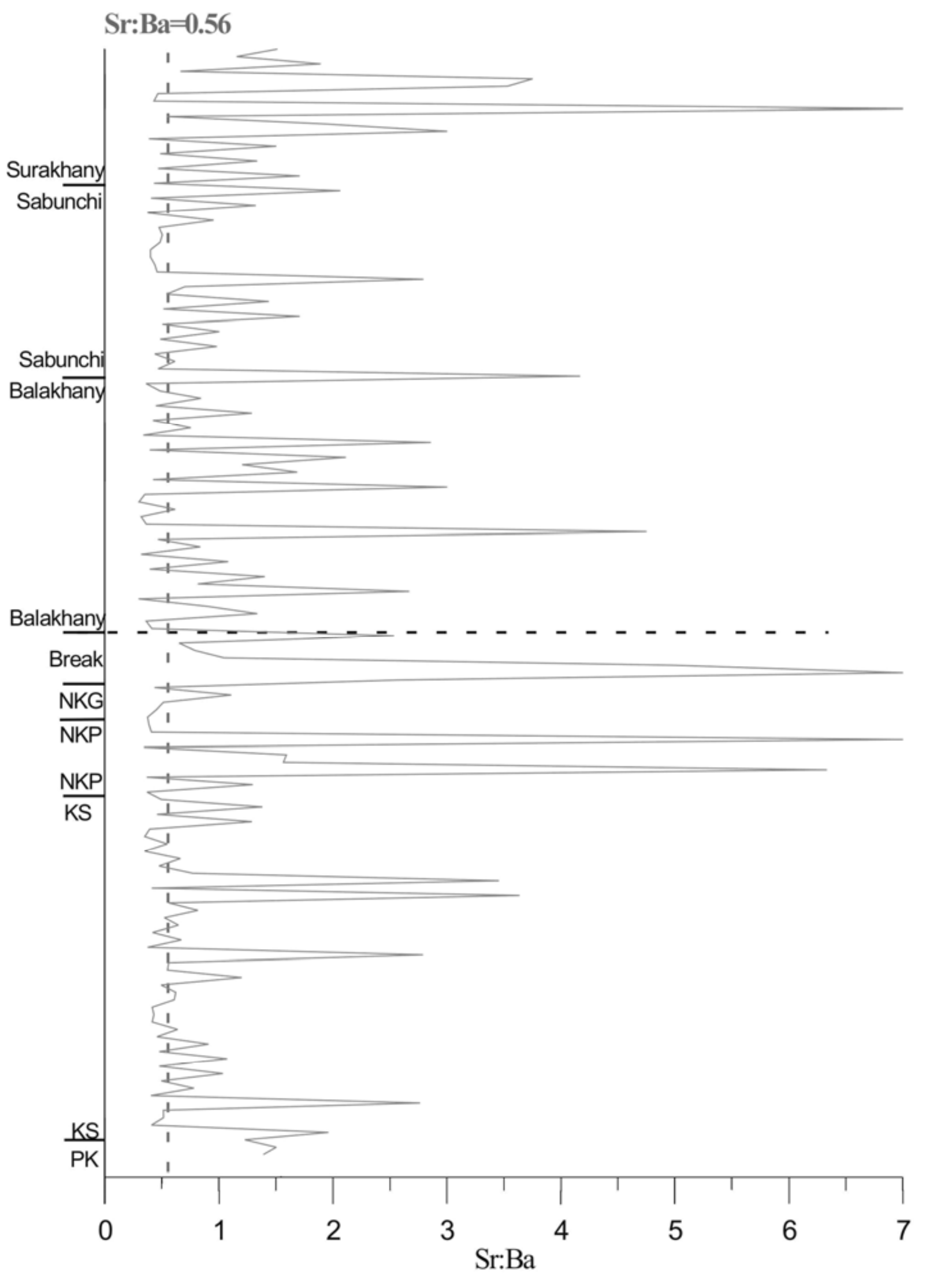


Fig. 3.8. Sr/Ba ratios in Productive Series sediments, Kirmaki, Yasamal valleys (with use of data of Huseynov D.).

IV. RESERVOIR QUALITY

In contrast to other basins in the South Caspian Basin depths below 5 km, down to 6.7 km, have been drilled in many fields. A number of fields under development are pierced by mud volcanoes with roots occurring at deep subsurface. Ejected on the surface rock fragments represent valuable samples for studies of different age reservoirs buried at inaccessible depths, 7 km and below.

The present study is based on analysis of downhole material collected at deep wells. In addition, the Late Cretaceous and Paleocene-Miocene ejectas from mud volcanoes situated in the southeastern Gobustan and the Lower Kura Depression have been used to characterize the lower part of the sedimentary cover.

Results of study over 2500 Neogene samples from both sides of the Caspian sea, both on- and offshore are summarized in the form of histograms of porosity, permeability and carbonate content for sands, silts and clays from 1-km depth intervals down to 6 km, forming **Fig. 4.1**.

There is a slight decrease in the poroperm values of both sands and silts with depth down to about 4 km, after which they remain relatively stable down to 6 km (the approximate depth of the deepest available samples). Thus, within the first 4 km the bulk of sands have porosities of 2-26% and permeabilities of 0.1-800 mD, whereas from 4 km to 6 km average porosities remain at about 15-20%, with permeabilities up to 250 mD (**Table 4.1**). Siltstone values are only slightly less. Mudstones (which may still contain a significant sand proportion) have a wide range of porosity values at all depths (typically 0-24%), but low permeabilities (averaging less than 0.5 mD).

Although core material is not available from below 6.5 km, and silts derived from depths of down to 10 km and ejected from mud volcanoes,

although of Late Cretaceous and Miocene age rather than Pliocene, still have porosities of 19% and permeabilities of 70 mD (typical values). Mudstones from around 6 km depth commonly have porosities of up to 29%, and permeabilities may be as high as 8 mD and, less commonly, up to about 90 mD.

Data for samples within the first kilometer of depth give an indication of initial values of porosity and permeability. The porosity of sands in this interval is up to about 26%. Within the first kilometer of depth the maximum permeability is about 160 mD, with 87% of samples below 80 mD. In the 1-2 km depth interval, however, over 20% of samples have permeability in excess of 650 mD, values as high as this are likely to be associated with relatively clean, friable sands.

The poroperm data for siltstones illustrated in **Fig. 4.1** show remarkably high values of porosity for such fine-grained facies, with 68% of samples within the first kilometer having values in about the 15-28% range. Permeability values are also high, with 50% of samples exceeding about 50 mD. This is even more suprising considering that over 80% of siltstone samples are recorded as containing in excess of 15% of carbonate cement. Such values for siltstones, if correct, would indicate an unusually high degree of sediment sorting.

Figure 4.2a presents the porosity distribution for the onshore producing horizons, indicating a typical porosity around 17-25%, while the corresponding porosity distribution for offshore fields, depicted in **Figure 4.2b** shows a broader range varying from around 10-28% but with a peak value around 23% - very close to the peak for the onshore statistics.

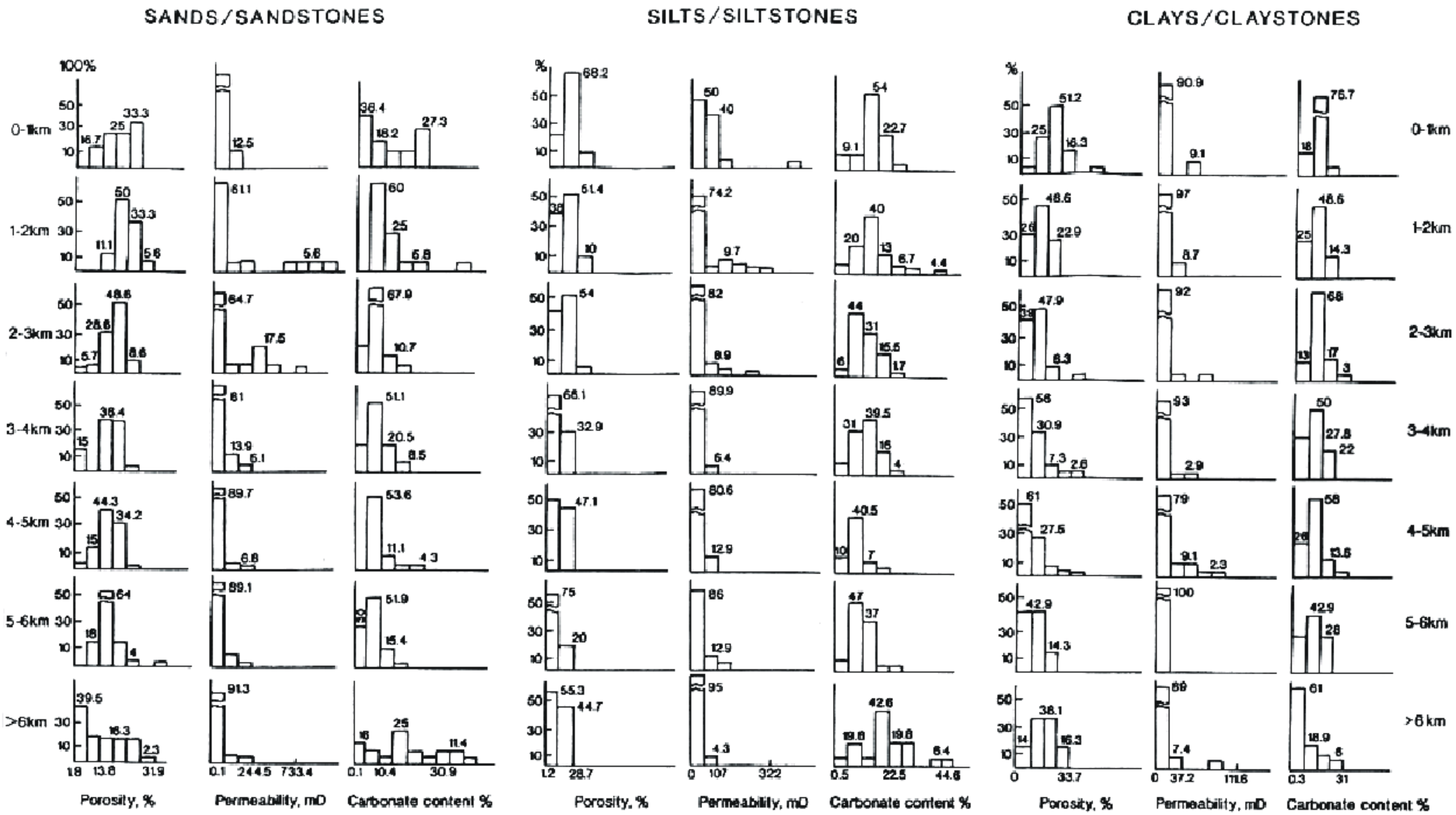


Fig. 4.1. Variations in porosity, permeability and carbonate content with depth in over 2500 Neogene samples from the South Caspian basin.

Table 4.1. Reservoir properties of the deeply buried Middle Pliocene deposits in the South Caspian Basin.

Area	Well #	Depth interval, m	Porosity, %	Permeability, $10^{-15}m^2$
The west flank of the South Caspian Basin				
Bulla-Deniz	527	5416-5421	18.3	82.1
Duvanny-Deniz	549	5589-5582	13.0	128.0
	505	5305-5307	14.2	93.5
	565	5589-5590	18.6	58.2
	533	5228-5231	18.4	94.0
	1	5444-5449	12.3	111.1
	1	5951-5954	10.1	129.9
	1	5778-5783	16.6	121.8
Janub-2	3	4991-4996	28.9	152.1
Seyyar	7	5171-5176	19.9	116.2
The east flank of the South Caspian Basin				
Ogurchinski	3	4929-4934	16.4	48.0
West Erdekly	2	5148-5153	24.4	12.5
	11	5412-5414	18.1	126.0
	1	5470-5480	21.8	32.8
	1	5670-5675	19.2	48.9
	3	5301-5303	24.4	286.8
	3	5565-5570	18.5	77.0

There is very little correlation of porosity with increasing sedimentary burial depth for either the onshore (**Fig. 4.3a**) or offshore (**Fig. 4.3b**) statistics. Certainly one could argue for a slight decrease in porosity with increasing burial depth for the offshore statistics but deeper that about 4000 m one is, perhaps, limited by the paucity of the statistics.

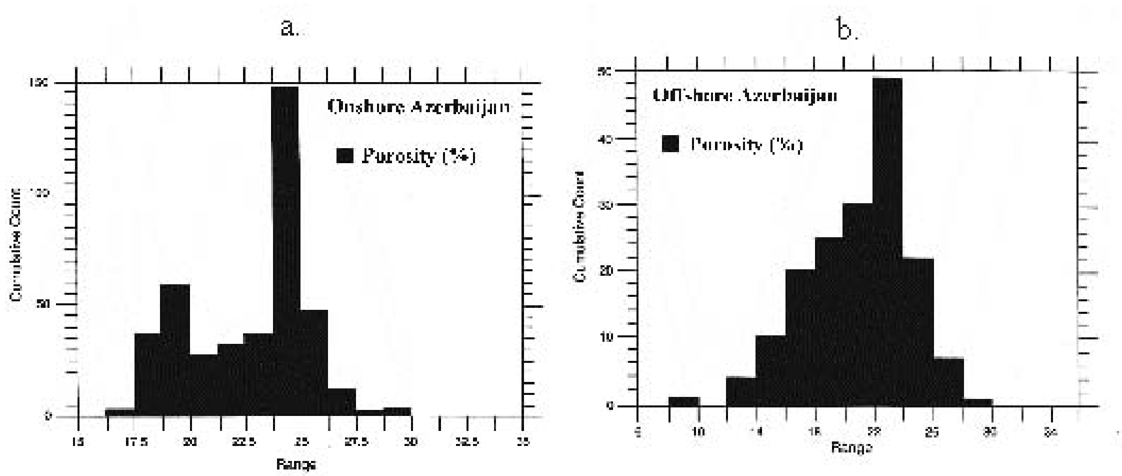


Fig. 4.2. Reservoir porosity distribution: (a) onshore fields; (b) offshore fields.

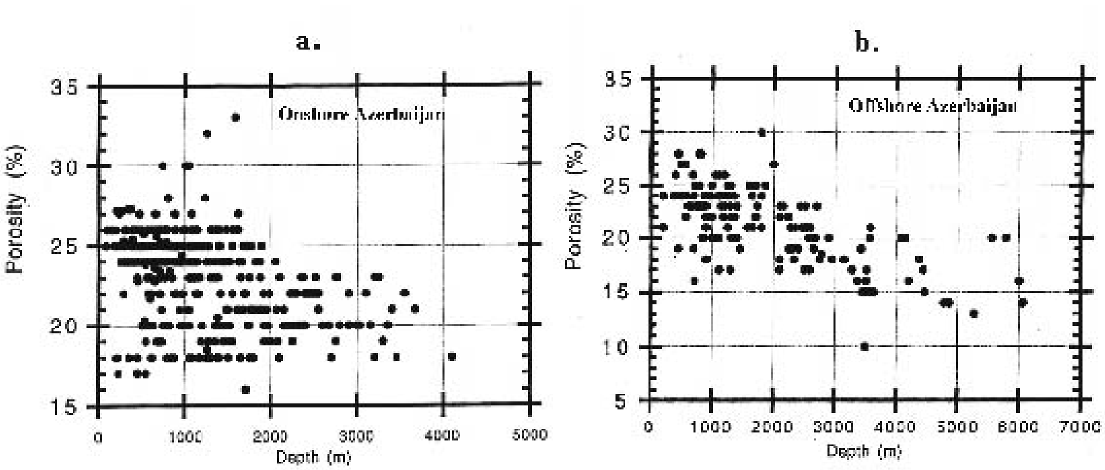


Fig. 4.3. Reservoir porosity variation with depth below sediment surface:
(a) onshore fields; (b) offshore fields.

The variation of permeability for the onshore and offshore fields are displayed in **Fig. 4.4a.** (onshore) and **Fig. 4.4b** (offshore), respectively. There is a slightly larger mean permeability (~300 mD) for the offshore distribution than for the onshore situation (~200 mD), but both distributions are exceedingly broad, making the mean of less than statistically sharp worth.

There is no discernible variation of permeability with burial depth either, as exemplified in **Fig. 4.5a** (onshore data) or **Fig. 4.5b** (offshore data).

Pore morphology, mineral composition and post-depositional alterations of clastic reservoir rocks, sandy siltstones, argillaceous, and poorly sorted facies were studied. The most important properties of reservoir rocks, open porosity, permeability, carbonate content, and grain-size composition have been examined as well as SEM-analyses performed (**Fig. 4.6**). Mineralogical composition of grains were examined on thin-sections of the rocks. X-ray analyses of clays and argillaceous cements in sandy and silty samples were performed by M. B. Kheirov (1979).

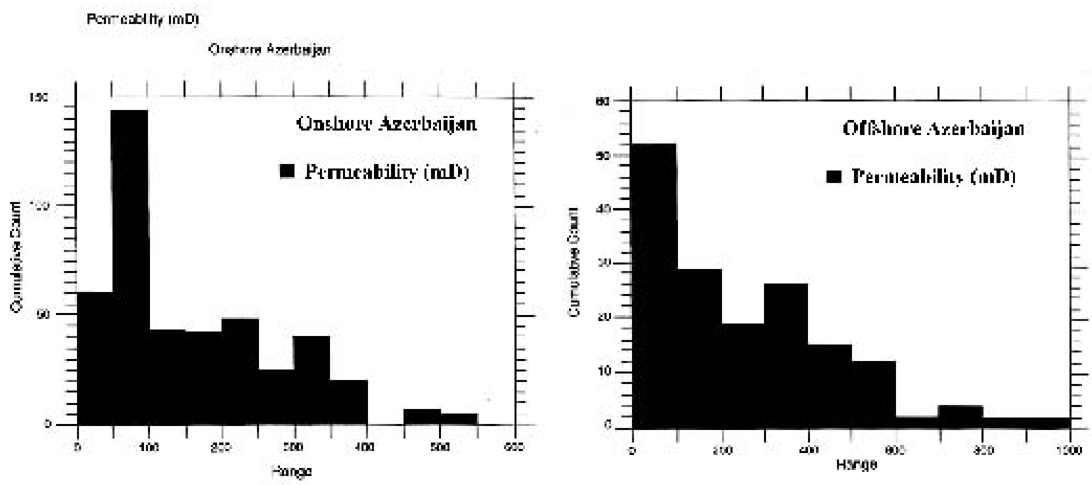


Fig. 4.4. Reservoir permeability distribution:
(a) onshore fields; (b) offshore fields

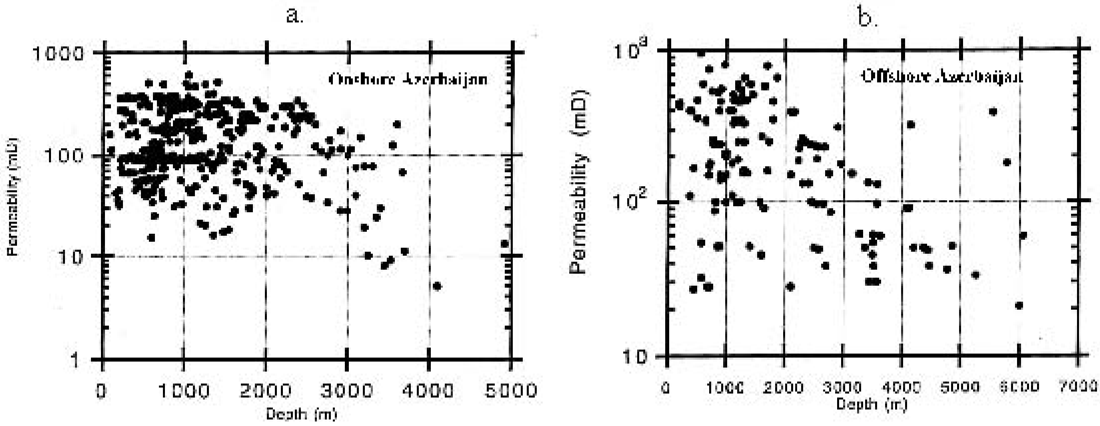


Fig. 4.5. Reservoir permeability variation with depth below sediment surface: (a) onshore fields; (b) offshore fields

The deeply buried PS sandstones studied on thin-sections suggest moderate catagenic alteration. However, sandy and silty rocks at depths below 4 km often have traces of brittle deformation resulting in the textural alteration of rocks.

On the western flank of the South Caspian Basin and Lower Kura Depression smectite content in clays is relatively high (up to 60%) and decreases with depth. The contents of the other clay minerals are : illite - to 45%, kaolinite - to 10%, and chlorite - to 5%.

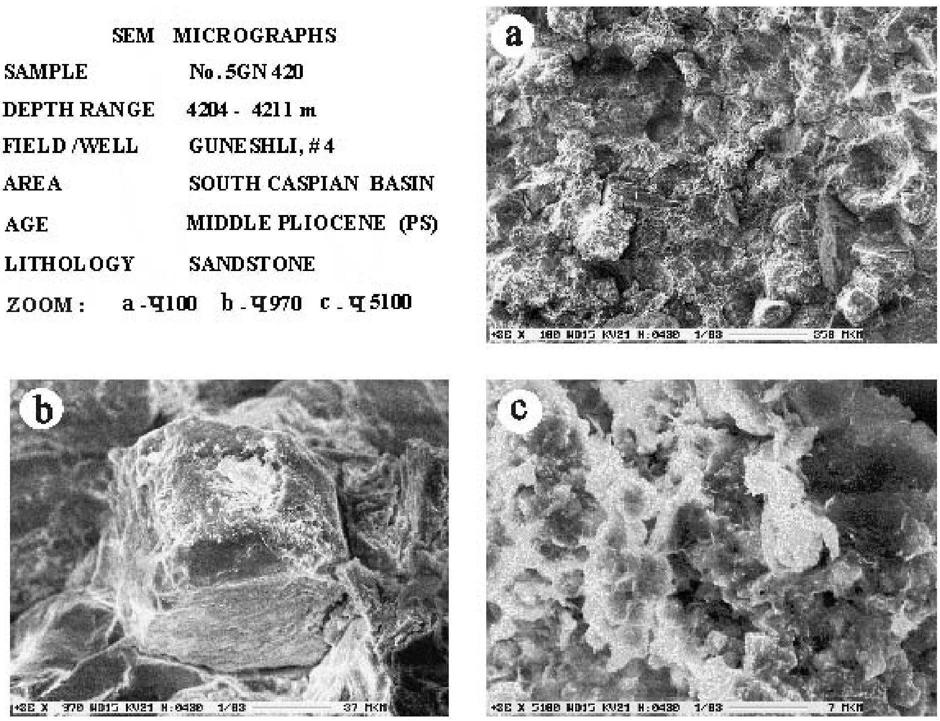


Fig. 4.6. SEM-photographs of core sample from a reservoir in Guneshli oilfield, the South Caspian Basin.

The composition of clays on the eastern flank of the South Caspian Basin is characterized by predominance of illite (50-60%), with subordinate montmorillonite (2-17%), kaolinite (10-25%) and chlorite (5-10%). Some amounts (5-10%) of mixed-layered components, illite-chlorite, montmorillonite-chlorite and vermiculite-montmorillonite are present.

The distinctions in composition between the clay minerals from the sedimentary sequences of the west and east flanks of the basin are due to the different provenances, and post-depositional alterations affected them in much less degree.

V. THERMOBARIC CONDITIONS

5.1. Formation temperature and heat flow

These and more recent investigations have clarified the important trends in three-dimensional temperature variations in the area of Azerbaijan's oil deposits and revealed the relations of temperature distribution to the geological structures and to the oil and gas contents in local structures. The work that had been carried out during the long period of time produced necessary information for evaluating the heat flow distribution over the territory of Azerbaijan. The general results are shown in the **Fig. 5.1** (S.Aliyev and A.Aliyev, 1995). Along with the basic information on the representative heat flow values each depression zone, the **Fig. 5.1** exhibits geoisotherm at the 2000m depth as well as major abyssal fractures and mud volcanoes (**Fig. 5.2**).

The basic data for the Chart is provided by the temperature observations in deep wells in the oil and gas fields as well as by the laboratory results on the thermal conductivity of rock core samples taken from the wells.

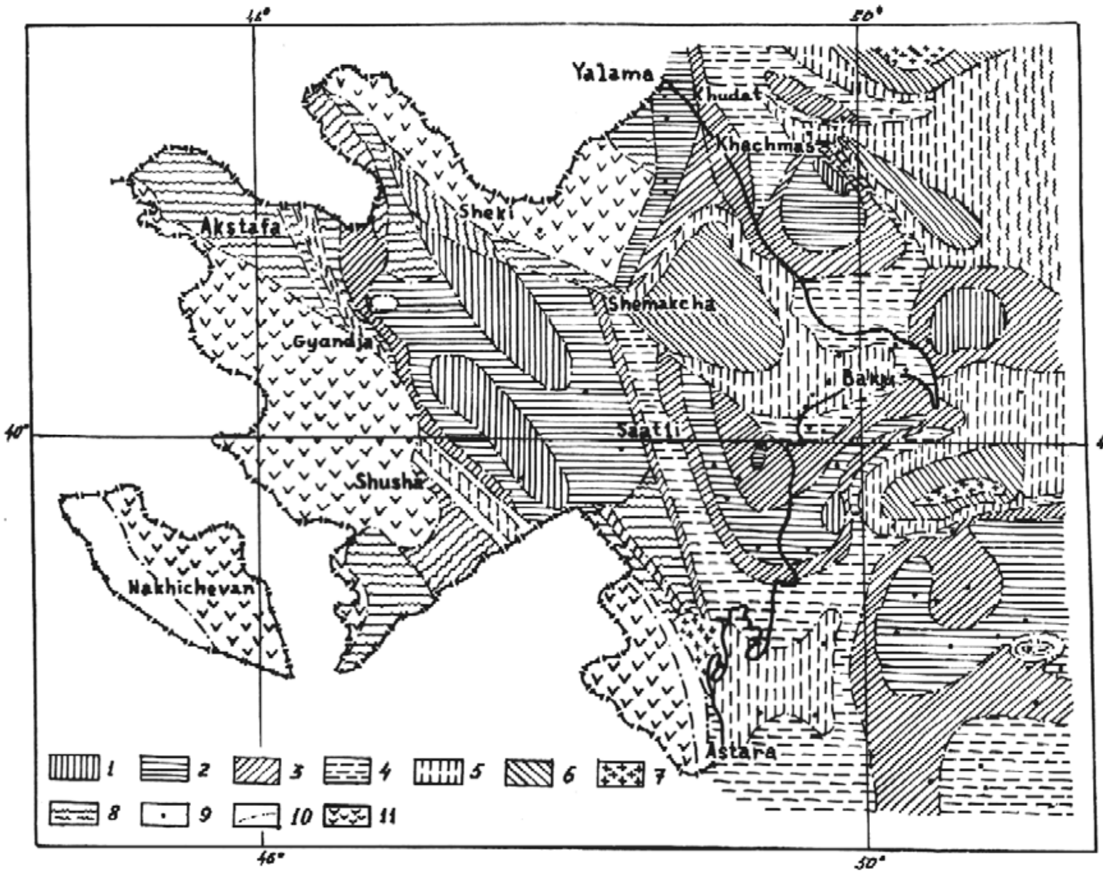


Fig. 5.1. Sketch map of heat flow of Azerbaijan. Heat flow in mWm^{-2}: (1) 0-29; (2) 20-30; (3) 30-40; (4) 40-50; (5) 50-70; (6) 70-90; (7) 90 and higher; (8) uncertain; (9) heat flow measurement points; (10) heat flow zone boundaries; (11) folded mountain structures.

The temperatures were measured by geological surveys and production organizations generally in the course of well logging with the aid of maximum mercury and electric thermometers. The total number of temperature measurements exceeds 6000. Most of the data cover the depth interval of 1000 to 2000m and the interval of 4000 to 6000m deeper are least investigated (**Fig. 5.3**).

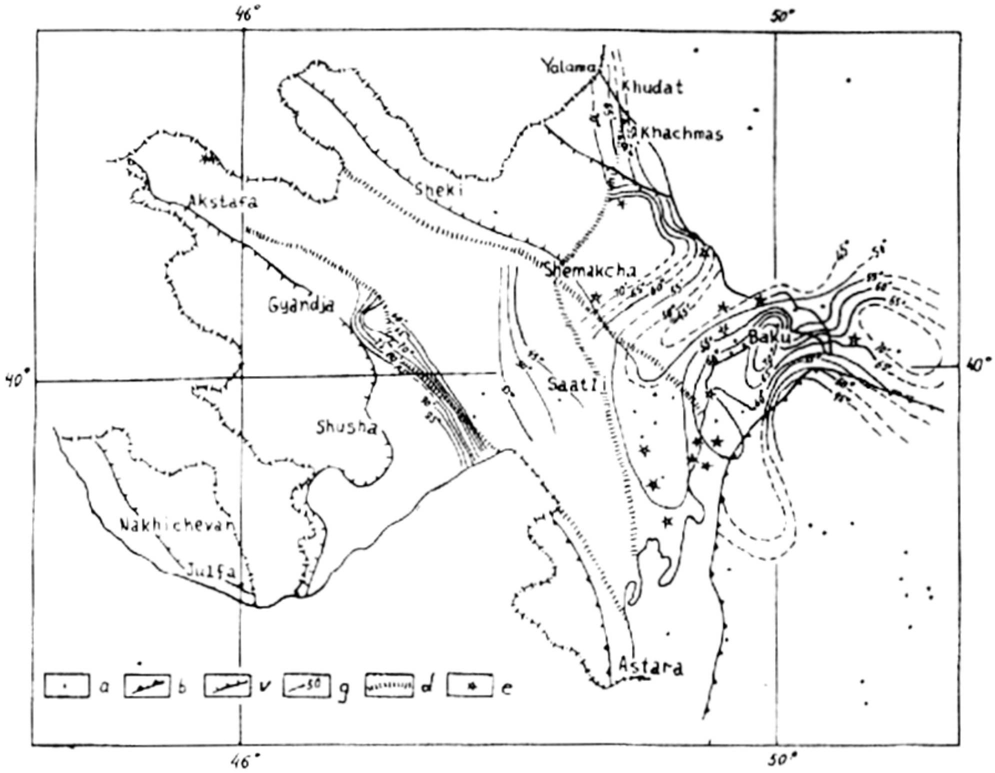


Fig. 5.2. Sketch map of distribution of temperature at depth - 2000m and major geologic features: (a) heat flow measurements points; (b) anticlinorium: (c) geoisotherm; (d) abyssal fractures; (e) mud volcanoes.

Heat flow.values were calculated from the data at about 500m depth section. The selection of this section is primarily dictated by the geological structure of most region of Azerbaijan under investigation. On one hand, majority of large-scale geological structures occur in the sediments lower than 500m depth; on other hand , this depth horizon is sufficient to completely eliminate the effects of external factors. In the cases where the data for calculating heat flow for individual areas were insufficient or not available, the heat flow was estimated from its horizontal gradients within a single anticlinal zone.

It is seen from **Fig. 5.1** that the thermal field of Azerbaijan is characterized by considerable variability. On one hand , this is due to the presence of regional abyssal fractures limiting the dimensions of large blocks with different basement depths. On other hand, the variation may be due also to the converctive mass and heat transfer in the sedimentary series and to the presence of oil and gas fields with local thermal anomalies.

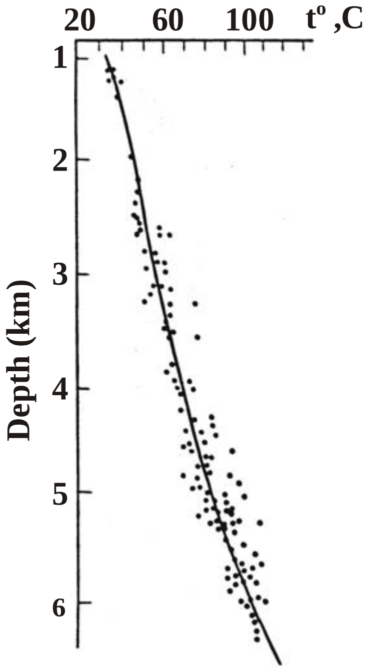


Fig. 5.3. Temperature conditions in the Middle Pliocene deposits of the South Caspian Basin (Bagir-zadeh et al., 1988).

The South Caspian depression, which includes several oil and gas-bearing areas, is the most explored region in Azerbaijan. The western slope of the South Caspian depression is regionally low in heat flow which, however, vary over a considerably wide range from 20 to 90 mWm^{-2}. A number of possible thermal anomalies appear to correspond to the oil reservoirs contained in the structure. Distribution of heat flow values in South Caspian depression is believed to be determined mainly by that sedimentary cover and by the history of geological development. The thermal regime of South Caspian depression appears to be formed by the convective component of heat flow which caused by vertical migration of weakly mineralized water underlying the Productive Series of the deposits. Another factor responsible for the formation of local thermal anomalies is mud volcanism. A thermal anomaly of a sub-latitudinal strike characterized by values of 90mWm-2 and more can be ascribed to the effected of mud cones (**Fig. 5.1**).

The inspection of the **Fig. 5.1** discloses certain trends in the heat flow distribution. The low heat flow is characteristic of the whole western part of Azerbaijan. Intermediate heat flow prevails in the deep-water part of the South Caspian, the Lower Kura depression, the Absheron peninsula and the adjacent archipelago. Low heat values are also characteristic for the inner part of the South Caspian depression where the heat flow tends to decrease towards to maximum downwarping region and for the littoral area of the Middle Caspian where the heat flow values tend to increase in the eastern direction. Zones of high heat flow generally correspond to the areas with large oil and gas deposits and zones of mud volcanism.

It is indicated in many recent studies that there is clear cut correlation in many areas between heat flow values and the depth of crystalline basement (or equivalently sedimentary cover thickness). Higher heat flow values are observed in the areas where the crystaline basement is close to the surface (thin sedimentary cover) and vice versa. These fact may be related to the generation of radiogenic heat in the basement rocks and its conductive transfer through the sedimentary series.

It is evident from the foregoing that heat flow distribution in the territory under investigation is basically determined by the following factors: (1) depth of the crystaline basement (sedimentary cover thicness) in the area where conductive heat transfer is dominate; (2) convective heat and mass transfer in the areas where oil and gas fields are developed; (3) neotectonic movements and mud volcanism; (4) location of abyssal fractures which are in most cases good conductors of plutonic heat.

5.2. Pressure

The numerous actual materials on the manometric measures of initial formation pressures of reservoirs and determinations of pore pressures in clays conducted by the geophysical methods allowed to reveal the regularities of distribution of abnormal high formation pressure (AHFP) in the sections of the South Caspian depression northwestern flank. The average values of gradients of initial formation pressures in reservoirs and pore pressures in clays in the studied intervals of depths are, MPa/m: for Absheron archipelago - 0.0107 and 0.0126; for the South-Absheron water area zone - 0.0117 and 0.0145; for Baku archipelago and Low Kura depression - 0.0126 and 0.0181. Most significant difference between initial formation pressures in reservoirs and pore pressures in clays (over 1.5 times) takes place in Baku archipelago where thickness of clayey series is greater (**Fig. 5.4**). Generally, the intensity of AHFP growths with increase of relative content of the clayey rocks as on the section and in layers as well, occurring in reservoir horizons. The highest values of pore pressures are typical for clayey series of Baku archipelago and Low Kura depression preserved exclusive high porosity and the structure of pore space.

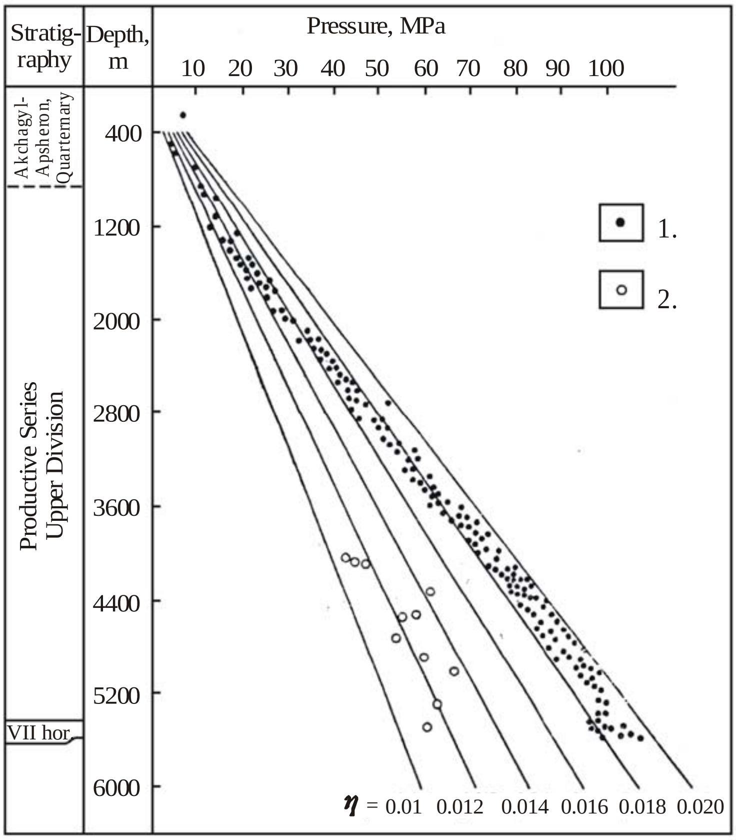


Fig. 5.4. Changing of the porous pressure in the clays (1) and formation pressure in the reservoir sands (2) with depth in the Baku archipelago oil fields (η - pressure gradient, MPa/m).

VI. HYDROCARBON OCCURRENCE, RESOURCES AND TYPES OF ACCUMULATIONS

Within the Kura - South Caspian Basin, oil and gas accumulations have been found in sediments that range in age from Middle Jurassic to Upper Pliocene. The majority of commercial oil reserves, however, are located in the Lower Pliocene in the Productive Series (>70 %), the Miocene - Palaeogene (about 15 %) and the Upper Cretaceous (about 10 %). More than 300 structures have been identified in the basin and more than 100 of these have oil and/or gas deposits, with over 700 individual oil pools. One of the main features of this hydrocarbon province is the multibedded nature of the hydrocarbon accumulations.

In the Productive Series at least 30 commercial horizons have been identified and many have been enumerated (**Fig. 6.1**).

Generally about 70 oil and gas fields were discovered during the whole period of oil industry development. At present 37 onshore and 18 offshore (Caspian Sea azeri sector) fields are in development process.

In the Lower Kura and South Caspian areas, the hydrocarbon accumulations occur from the surface down to 8200 m, although the main fields currently exploited are generally in the depth range 500 m - 2000 m. Below 3500 m, the hydrocarbons are more likely to be gas or gas condensate.

The subdivision of the basin into hydrocarbon areas generally follows the tectonic framework. Also the basin can be divided according to the stratigraphic occurrence of hydrocarbons, i.e. in the Lower Kura-South Caspian, the Productive Series are the main oil and gas bearing strata, whereas in the Middle Kura Depression, older sediments are the main reservoirs. Where formations of the Productive Series occur in the Middle Kura Depression, they have unfavourable facies for hydrocarbon accumulation. In the Middle Kura Depression, four main oil and gas bearing complexes are distinguished:

- Upper Cretaceous - Paleocene terrigenous and carbonate sediments;
- Eocene sediments;
- Oligocene-Lower Miocene terrigenous sediments;
- Upper Miocene sediments.

The main interest centers around the offshore possibilities. The offshore extension of four anticlinal trends was recognized by marine seismic surveys. Many offshore fields have been found and a whole new hydrocarbon-bearing region is now being developed. The first discovery was made in 1963 at Sangachaly-Duvannyy offshore testing 5.2 MMcfd of gas from the Balakhany Beds; deeper production was also established in the Pereryva Beds (SP) in a well which was drilled down to 5.260 m.

Garasu was discovered on the Pirsagat - Nakhchivan trend. the Azeri geologist have great hopes on the Pirsagat - Nakhchivan on the Mishovdag - Inam and the Kyurovdag - Neftechala trends. During the seventies interesting developments have taken place offshore to the Southwest of Baki, related to the structural trend which starts North of kala on the Absheron Peninsula; it can be followed offshore over some 100 km or more. Developments have taken place at Bakhar where deep production is being established from depths between 4.500 and 5.000 m. Several pipelines have been laid and the field is producing a sizeable part of the Caspian sea offshore gas production.

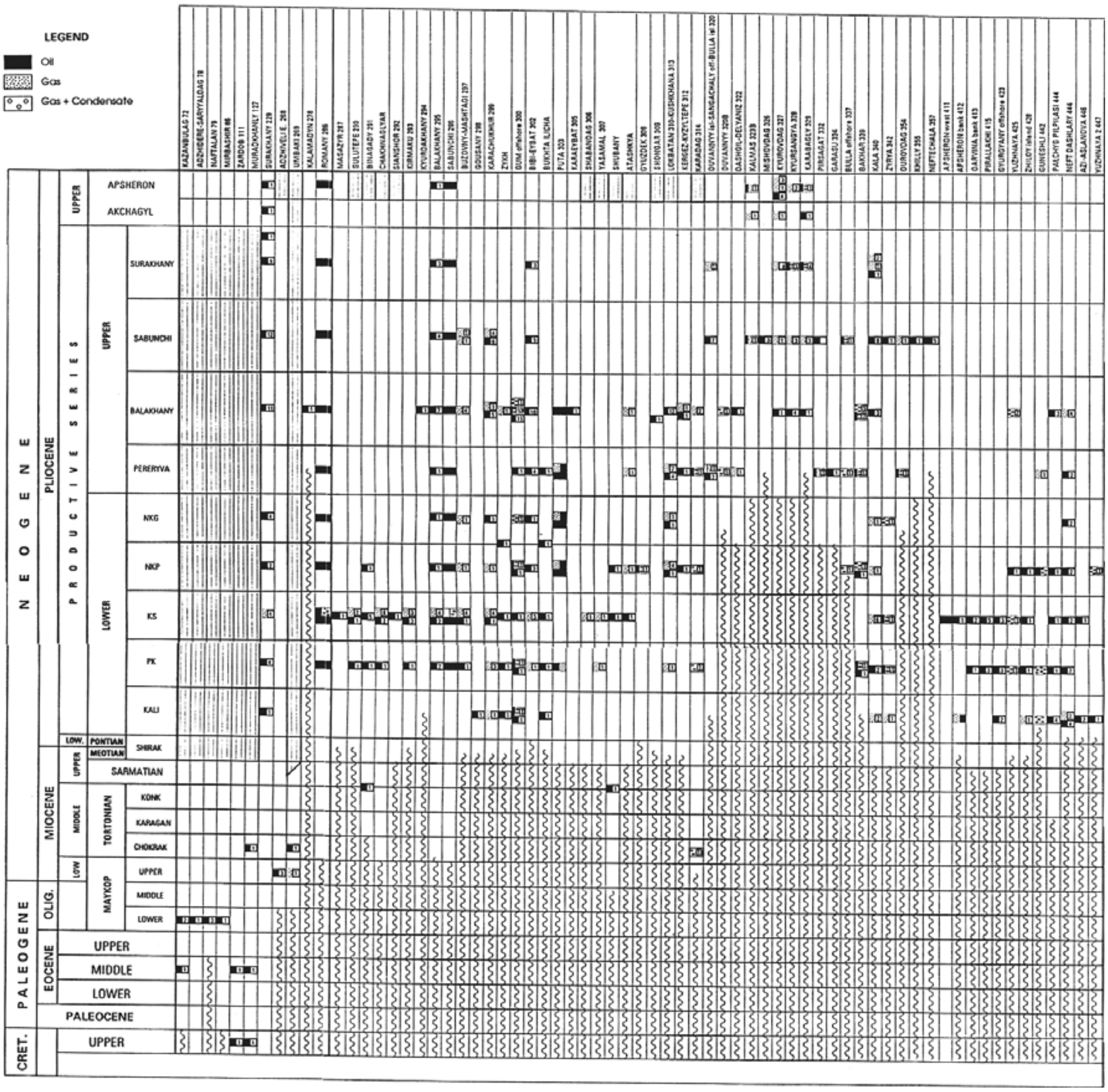


Fig. 6.1. Hydrocarbon distribution in the stratigraphic section.

A similar successful search started about the same time in the Absheron Archipelago. All islands there are surface expressions of folds at depth. Neft Dashlary or "oil rock", was drilled in 1951 on a faulted structural feature, and found the "Productive Series" oil-bearing. Since then more than 1.200 wells have been completed in the field which is one of the major producers in the Absheron offshore area.

In recent years, onshore exploration in Azerbaijan was concentrated on the following plays:

- the Miocene-Paleogene and Mesozoic sections of the Yevlakh - Agjabedi Trough and in the area between the Iori and Kura Rivers, Muradkhanly 1971, Zardob 1981. Tarsdallar
- the Middle Pliocene section in the Lower Kura Depression and Absheron Peninsula, Kalamadyn 1979, Durovdag 1978, Masazyr 1980.

Some lesser exploration was targeted at the Miocene-Paleogene section on the Absheron Peninsula and in the Terek-Caspian Foredeep. No significant new exploration results were obtained in the Mesozoic exploration recently. Only a few wells were drilled at Bozgobi (where only a few tens of meters of Upper Cretaceous were penetrated) and Agjabedi (where the drilled Upper Cretaceous reached a few hundred meters).

In N.E. Azerbaijan commercial hydrocarbons have been discovered only on the Siazan monocline, at the junction between the SW margin of the Kusar - Divichi Trough and the NE slope of the Tengi - Beshbarmak Anticline. First, oil was discovered in 1939-1940 in a wide stratigraphic range (Siazan and other fields).

Although the entire area under discussion has been abundantly drilled, no commercial discoveries have been made except on the Siazan monocline.

More than 40 fields have been found as of today in the Caspian Sea. The largest of these are in the Azeri sector: Neft Dashlary, Guneshli, Azeri, Chirag, Sangachaly-Duvanny-Khere-Zire, Bulla-deniz and Bakhar,

Exploration in the late 1980's was rewarded by the following discoveries: Kapaz field, West Absheron field, Guneshli field, one oil pool in the Supra Kirmaki (NKP) pay, Chirag field, one oil pool in the Balakhany IX pay. Commercial gas-condensate flow rates were tested from the Supra Kirmaki Fm. Commercial oil was tesred from the Pereryva Fm on the NE flank of the structure.

Alyaty offshore field, one oil accumulation each in pay VIII of the "Productive Series" in the "crestal" and NE faulted blocks.

Bulla Island field, one gas pool in the VII pay of the "Productive Series" in the SSE faulted block of the field.

March 8th field, one gas-condensate pool in the VII pay of the "Productive Series". Bakhar field, one gas-condensate accumulation in the Sabunchi Fm.

Azeri field (1987), oil was tested from the Pereryva Fm and Pay X of the Balakhany Fm. Gas condensate was tested from the Supra Kirmaki (NKP) Fm.

A gas discovery was made at wildcat Nakhichevan-1 on the Azeri shelf the July 1993. Gas and condensate was struck, presumably in the Pliocene "Productive Series". Gas reserves are preliminary estimated at 25 billion cu m (860 BCF).

This is the first offshore discovery on the Azeri shelf in almost five years. It is the first discovery along the anticline trend which runs north of and parallel to the prolific Absheron trend. Water depth is approximately 100 m. The field could be developed in three years.

Of great importance is the fact that commercial oil flow rates from the Pereryva Fm on the NE flank of the Chirag field shows that this pool is connected with the Pereryva oil pool of the neighboring Azeri field. In November 12, 1997 the first oil was obtained from well Chirag-1 with test rate over 1 ths. tons per day.

The following structures - Shakhdeniz, Karabakh, Dan Ulduzu, Ashrafi, Lenkoran-Talysh-deniz, Oguz, Absheron, Nakhchyvan, Inam and others were involved into the prospecting during last years. Such companies as BP/Amoco, Exxon/Mobile, Chevron, Pennzoil, Unocal, Agip, Itochu, Lukoil, Shell and others take pare there. According to estimated calculations these prospective structures contain about 1.6 milliard tons of produced oil reserves and 1 trillion m^3 of natural gas. All these allow growing the oil production and bring it in 2005 to 50-60 million tons per year, and gas - to 14-15 milliard m^3 per year (Aliyev N.A., 1998).

Altogether 1.4 milliard tons of oil and over 450 milliard m^3 of gas were produced from the depths. The output degree of the initial produced oil reserves onshore is 87, offshore - 59%. The majority of oil and gas fields are in the late stage of development.

Now concerning the estimation of HC reserves in the SCB. They vary but similar in that the main HC resources are concentrated here in azeri sector of the Caspian Sea of 78.8 th.km^2. At present there had been revealed 145 prospective structures, including 40 structures on sea depths up to 60; 33 structures - on depths 60-200 and 72 structures - on depths over 200 m (Aliyev N.A., 1998). Deep water part is one of more poorly studied zones where the predicted resources are not clarified.

In this zone the productive horizons occur on depths over 5500-6000 m in complex thermobaric conditions.

According to experts' estimations from different countries the HC reserves in azeri sector are expected from 4 up to 8-10 milliard tons of conventional fuel. So, more high valuations of oil and gas resources on the whole Caspian region belong to Department of Energetics, USA. The conducted estimations give the results up to 200 milliard barrels, i.e. about 30 milliard tons (Efrimov I., 1999).

According to estimations made by Centre GEON (Russia) jointly with AzNIPINeft, GIA (Azerbaijan) (Levin L.E. et al, 2000) (**Fig. 6.2**) the primary percentage of the South Caspian hydrocarbon resources is concentrated within the Pliocene-Miocene deposits, whereas that of the Middle Caspian one is within the Cretaceous and Jurassic ones. Among large-scale component features typified with high-dense resources concentration within the South Caspian basin there is Absheron-Pribalkhan sill (Caspian "golden belt") with the most resources explored, and vast area of high-potential large offshore features south off Absheron peninsula (Nakhchyvan, Absheron, etc.).

As for hydrocarbon type percentage of forecast estimates, then liquid hydrocarbons (oil + gas condensate) in the South Caspian basin will probably amount to 55-60%.

K.M. Kerimov et al. (1999) had made the estimations in different ways. The average arithmetic value of HC resources in the Kura - South-Caspian megabasin was 85.6 milliard tons; the limits of change 85.6±9 milliard tons of balance and 30.8±8.2 milliard tons of the produced reserves. Up to depth of 7 and 10 km the HC resources of the megabasin are estimated accordingly as 55.8 and 64 milliard tons of balance and 21.7 and 25 milliard tons of the produced ones (see **Table 6.2**).

International oil encyclopedia gives data on the Caspian reserves as 4.0 milliard tones.

More cautious numbers are given in Russian sources. In work (4) with reference to the Ministry of Natural Resources of the Russian Federation the Caspian region resources are estimated as 15-18 milliard tones, and 3.7-4.0 milliard tones for Azerbaijan. Mass media give another numbers - reserves on the Caspian region and Azerbaijan are: 2.7 milliard tons, 0.3895 milliard tons of oil accordingly; resources on the Caspian - 17-20 milliard tons and Azerbaijan - 1.611 milliard tons. The experts from Monument company, UK, had estimated the Caspian reserves - 8-10 milliard tons, Azerbaijan - 2.5 milliard tons; resources on the Caspian - 8-10 milliard tons, Azerbaijan - 3.0 milliard tons. The estimation as 6.0 milliard tons (Aliyev N.A.,1998) was given in Internet. In one of the supplement the "Nezavisimaya gazeta" newspaper considers that in XXI century the Caspian region will became the main supplier of the energetic resources for the world market and estimates its (Caspian region) reserves as 24 milliard tons; in other supplement the newspaper comes to a conclusion that the great Caspian oil is a myth and predict a crash of Baku oil policy; in the third one it suppose that at the beginning of the XXI century the whole region can take the third place in the world after Middle Asia and Siberia. Referring to the latest officially stated data the authors declare that oil and gas reserves in Azerbaijan are 3.5 milliard tons of oil and 600 trillion m^3 of gas.

Mode of types of accumulations in the SCKB are determined by the features of its geological structure and development history. Among those are frequent change of tectonic regime accompanied by transgression and regression of the basin and change in geographical range, rate and character of sedimentation, development of both magmatic and mud volcanism (diapirism), formation of great number of faults complicating fold structures etc.

The common character for all oil accumulations in Azerbaijan is that they occur in bed reservoirs confined between weakly permeable strata. Within the beds the accumulations are bounded with edge and bottom water.

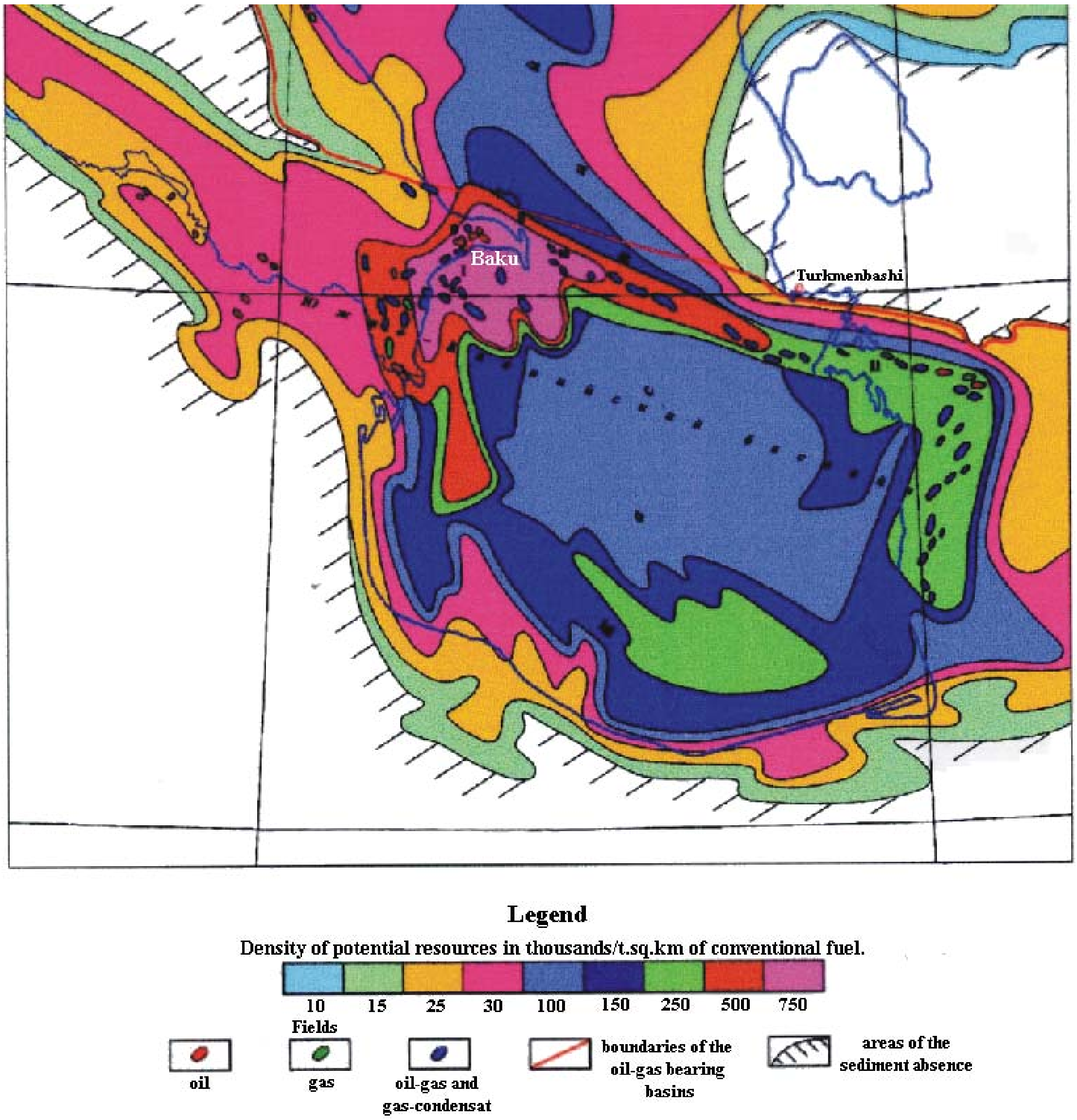


Fig. 6.2. The map of distribution of the total hydrocarbon resources in the Mesozoic-Quaternary deposits of the KSCB (after Levin L.E. et al., 2000).

Table 6.2.

Regional oil-gas bearing complexes	Up to depth, km		
	7	10	basement
N^1_2	44.3/18.7	44.3/18.7	44.3/18.7
$P+N_1$	8.8/2.2	15.6/3.9	15.6/3.9
MZ	2.7/0.8	7.1/2.4	31.1/11.4
Totally	55.8/21.7	67.0/25.0	91.0/34.0
Coefficient of prospecting	11.23/14.7	9.35/12.76	7.31/10.56
Coefficient of mastering	10.1	8.8	6.4

Note: numerator - balance resources, denominator - produced resources

The most characteristic feature of the oilfields found in the PS in Azerbaijan is their multilayer structure (to 40 oil and gas bearing objects) and presence of diverse accumulation types not only within the same field and even within the same bed (Babazadeh, 1960).

Especially widespread are oil and gas accumulations formed in traps produced by deformation of flat beds into anticlinal (brachyanticlinal) folds (**Fig. 6.3**), with insignificant influence of lithological or other factors. Typical representatives of anticlinal accumulations are those in the PS at Surakhany, Gala, Bibiheybet, Balakhany-Sabunchu-Ramany fields.

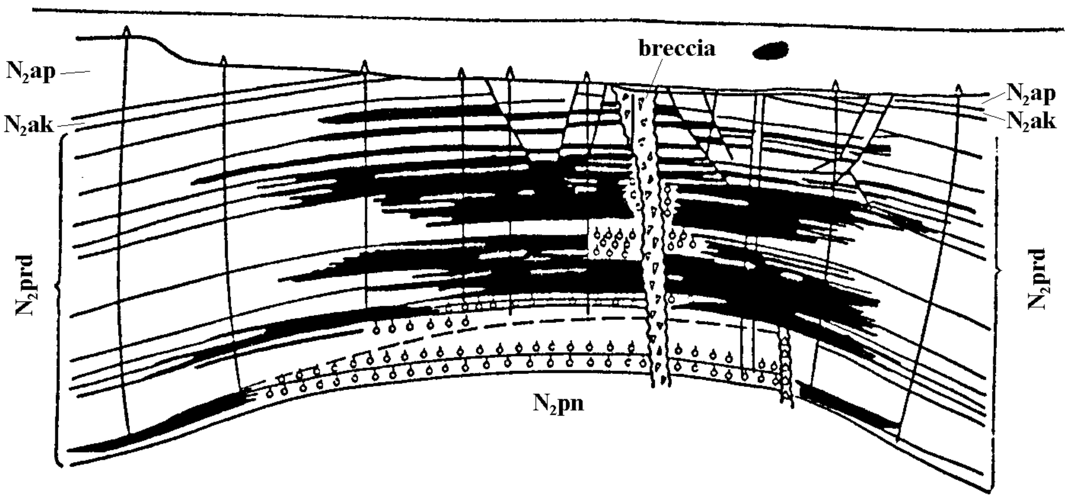


Fig. 6.3. Geological section across the Bibiheibat oil field.

The second large group consists of tectonically screened accumulations, that form along tectonic dislocations (normal and reverse faults) complicating anticlinal folds. The majority of accumulations in the PS within the Absheron Peninsula (Garachukhur, Buzovna-Mashtaga, Lokbatan fields (**Fig. 6.4**), Absheron Archipelago (Darvin-Kyupesi, Chilov-Adasy), Baku Archipelago (Bulla-Deniz, Khere-Zire) and the Lower Kura (Kalmas, Mishovdag) OGBRs, and also those in Maykop Suite in Gobustan (Umbaki) fall into this group. The tectonically screened accumulations in Azerbaijan fields are characterized by large height (300-2400 m), considerable extension (to 6000 m) and width to 2000 m. Unlike accumulations in anticlinal traps they do not have gas caps.

Stratigraphically screened oil accumulations associated with beds updip pinching out in Azerbaijan for the first time were revealed in 1938-1939 in the west part of the Absheron Peninsula (Chakhnaglar, Binagadi, Sulutepe). The relation of the PS with underlying sediments is an important factor in formation of this type of accumulation.

At the early stage of formation the PS basin occupied a relatively small area. Progressively from the lower horizons to upper ones this area increases and the uppermost horizons of the PS reach maximum extension.

For this reason in the direction of regional elevation of strata, from SE to NW, both in the Absheron Peninsula and Gobustan area sequential pinching-out of individual horizons and suites, from the lowermost to overlying, and their convergence onto the Pontian deposits are noted. These regional pinching-out zones are favorable for formation of hydrocarbon accumulations (Palchyg-Pilpilesi, Kohne-Gala).

Lithologic oil pools have wide occurrence in the Absheron area (Gushkhana-Garadag, Hovsan) and within the Lower Kura Depression (Neftchala).

The most favorable zone for development of non-anticlinale traps are continental shelves and slopes of troughs, tectonic steps and terraces, pinch-out zones, erosion cuts, deltaic and fluvial sequences, offshore bars and marginal reefs (**Fig. 6.5)**.

In the north-west part of the Absheron archipelago discovered and predicted a number of stratigraphic traps located in the areas of reef structures in the Low Cretaceous sequence and turbidities on the slopes of Paleogene troughs as well as in the pinch-out zones of the Gala and Sub-Kirmaki suites of the Productive Series, in Pliocene paleo-deltas and in the zones of clinoform bodies on the Turkmenian shelve.

Among structural, tectonically screened and stratigraphic oil pools often are encountered so called hanging pools representing irregular, shifted on limb or pericline oil bodies with tilted oil-water contact. This mode of occurrence is widespread on the Absheron Peninsula (Surakhany, Bibiheybet, Balakhany-Sabunchu-Ramany, Garachukhur).

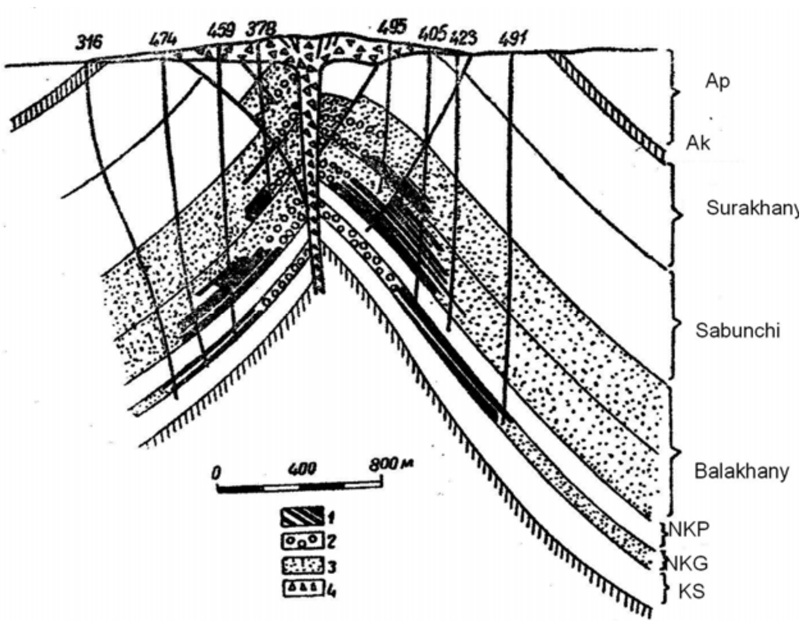


Fig. 6.4. Geological section across the Lokbatan oil field.

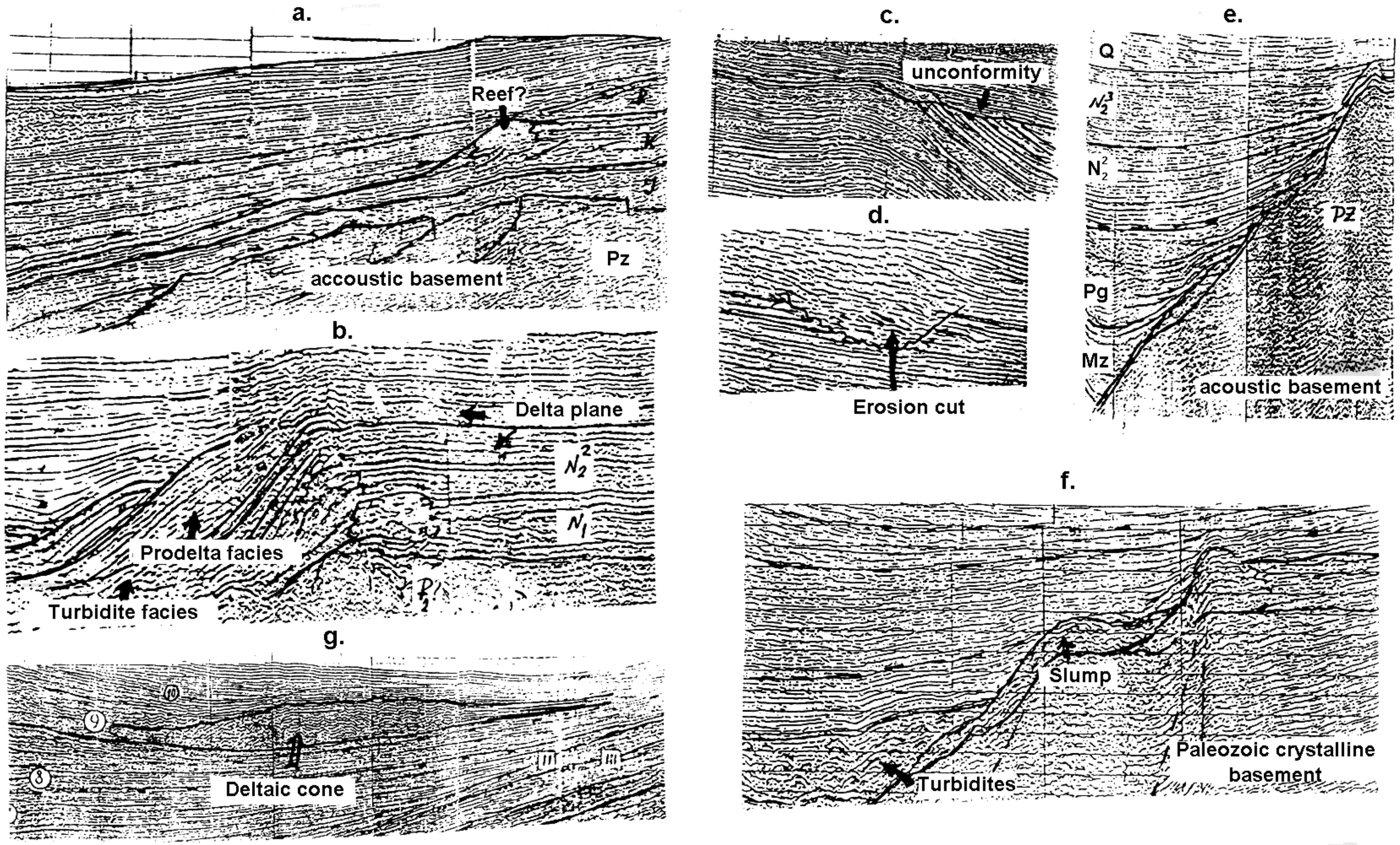


Fig. 6.5. Seismic sections showing favorable zones for non-anticline traps in the South Caspian basin: reef structure (a), aggredational shelf and progradational slope (b), erosion cut (c, d), lap-out and pinch-out (e), slump (f), deltaic cone (g).

Wide occurrence of mud volcanism and diapirism in the SCKB promotes formation of uncommom oil accumulations at the contact of reservoir with surface of diapiric body (oil accumulation in the Kirmaki Suite of the PS in the SE part of the Buzovna oilfield).

In 1981 at the Muradkhanly field in the Middle Kura Depression for the first time an oil accumulation confined to eroded surface of the Upper Cretaceous effusive rocks was found (**Fig. 6.6a**).

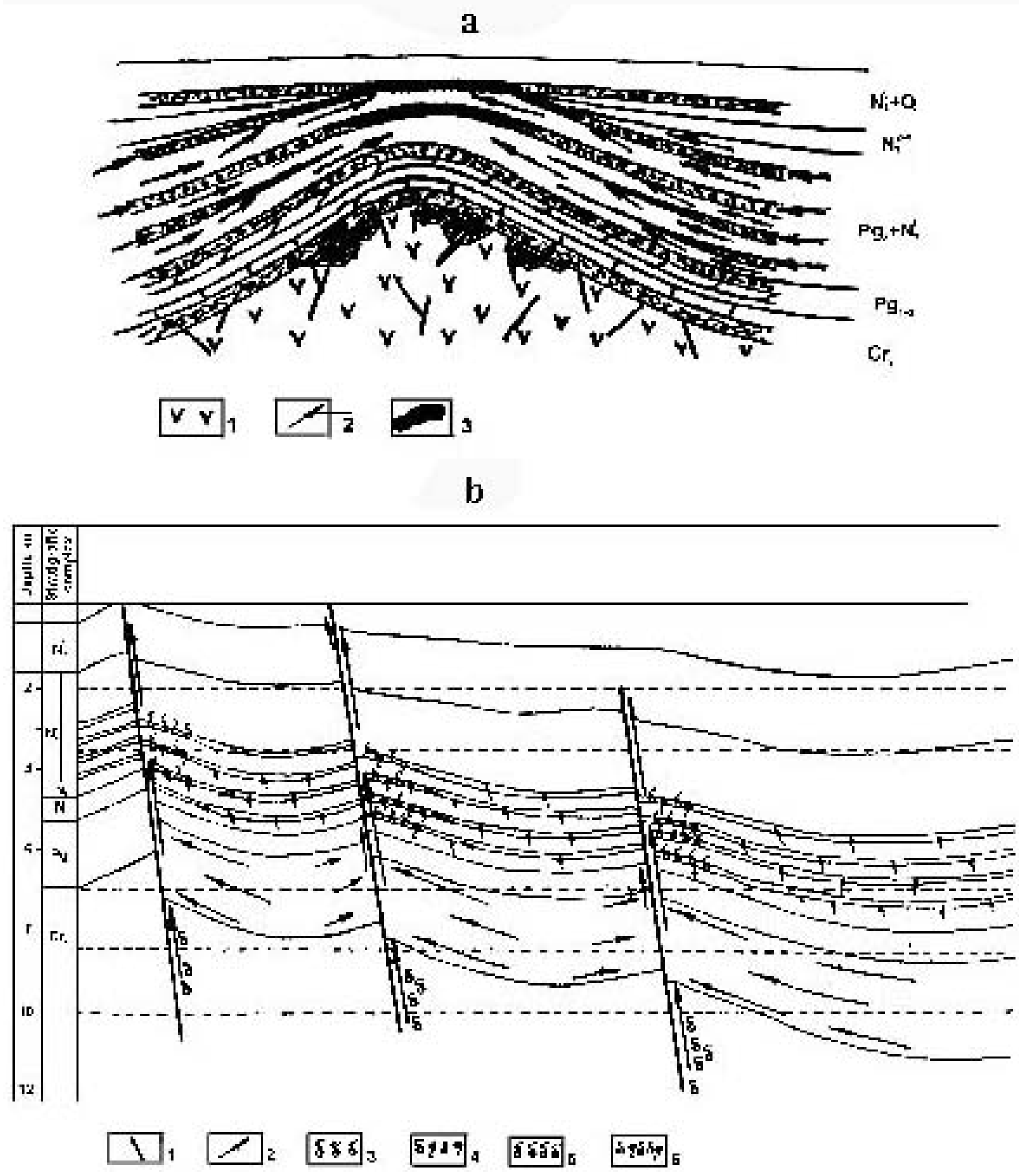


Fig. 6.6. Sketch of formation of hydrocarbon accumulations in different structural settings in the South Caspian-Kura Basin (Kuliyev, 1991) : (a) in the Middle Kura OGBR lateral migration of oil was likely to take place via the Paleogene-Late Miocene strata, with accumulation in crest part of a structure and subsequent injection into the bulge of the Upper Cretaceous fractured volcanogenic rock below; 1 - volcanogenic rocks; 2 - direction of hydrocarbon flow; 3 - oil accumulations; (b) in the South Caspian Basin (the Baku archipelago OGBR) formation of accumulations in the Middle Pliocene reservoirs was likely to take place in the way of combined lateral-vertical migration. 1- tectonic fault; 2 - direction of hydrocarbon flow; 3 - gas; 4 - gas condensate; 5 - oil.

VII. GEOHEMISTRY OF ORGANIC MATTER AND HYDROCARBONS

7.1. Source rocks.

7.1.1. Samples and methods

A stratigraphic range from Middle Jurassic to Lower Pliocene in the SCB has been covered by source rock studies. Analyses were performed on over 500 rock samples collected from over 50 localities, including outcrops, mud volcanoes (ejecta) and boreholes (**Fig. 7.1**). The bulk of samples were taken at natural exposures of rocks (37 localities). The extent to which different units were covered by the sampling was determined by their surface outcrop distribution. In this respect the Maykop Series was the most extensively studied formation, the Chokrak unit was represented by a limited number of samples, and Lower Eocene, Lower Jurassic and Pontian units were not studied. Organic geochemical study of the Lower Pliocene unit has been conducted mostly using core samples collected from offshore oilfields, with a few samples from outcrops.

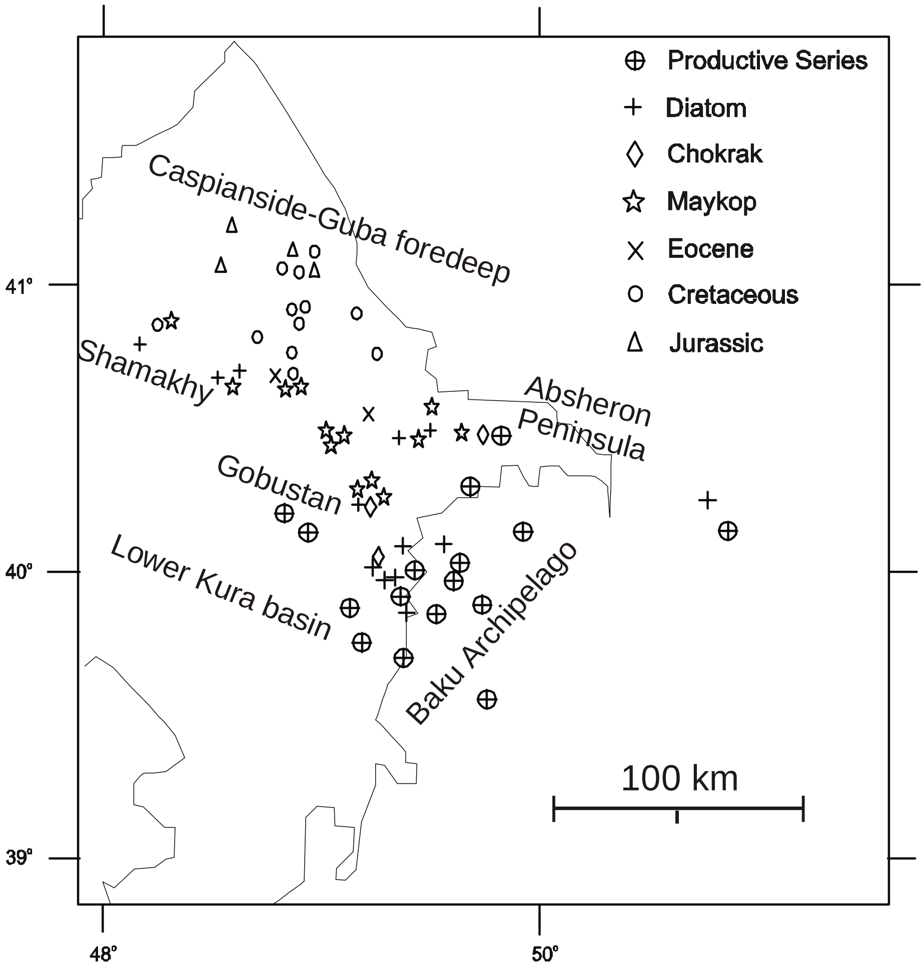


Fig. 7.1. Distribution of sample collection localities (outcrops, oilfields and mud volcanoes)

Sampling was selective related to the lithological character of the particular section and aimed to make the most coverage of argillaceous intervals differing in colour and thickness. The number of samples taken from an outcrop varied between 5 and 56. To minimize the impact of exogenic factors on samples, they were collected after removal of an upper 20-50cm layer of rock.

The laboratory studies of organic matter (OM) included optical examination, pyrolysis, determination of total organic carbon (TOC) content and carbon isotopic composition of kerogen and individual fractions of the extrac **Table 7.1** OM. Optical data included measurements of vitrinite reflectance, TAI (thermal alteration index) and SCI (spore colour index).

Table. 7.1. Data summary for pyrolysis-derived geochemical parameters for the stratigraphic intervals of the South Caspian Basin

		Number of samples	*Minimum*	Mean	Maximum	Std.Dev.
Productive Series (L.Plio.)	**TOC (wt.%)**	95	0.02	0.47	2.71	0.56
	HI (mgHC/g TOC)	28	15	147	334	107
	S1 (mgHC/g rock)	28	0.08	4.94	29.78	7.95
	S2 (mgHC/g rock)	28	0.14	1.94	7.28	1.98
	Tmax (^{o}C)	28	333	408	437	28
	Ro (%)	14	0.31	0.58	0.90	0.17
Diatom (M.-U. Mio.)	**TOC**	88	0.05	0.63	2.19	0.44
	HI	54	12	105	427	82
	S1	54	0.06	0.39	1.45	0.31
	S2	54	0.07	1.20	9.35	1.72
	Tmax	50	408	429	441	8
	Ro	21	0.25	0.48	0.89	0.2
Chokrak (M. Mio.)	**TOC**	10	0.09	1.10	2.44	0.70
	HI	8	73	204	541	158
	S1	8	0.1	0.39	0.65	0.21
	S2	8	0.74	3.21	10.88	3.55
	Tmax	6	426	431	435	4
	Ro	4	0.33	0.38	0.45	0.05
Maykop (Oligo.-L.Mio.)	**TOC**	174	0.07	1.86	15.1	1.79
	HI	141	11	146	612	97
	S1	141	0.08	0.88	6.51	0.87
	S2	141	0.02	4.06	74.04	8.60
	Tmax	139	400	423	464	10
	Ro	48	0.21	0.39	0.76	0.13

Eocene	**TOC**	16	0.02	0.46	0.90	0.35
	HI	9	13	19	29	5
	S1	9	0.04	0.12	0.20	0.06
	S2	9	0.08	0.14	0.23	0.06
	Tmax	9	406	422	437	5
	Ro	4	0.26	0.53	0.67	0.18
Cretaceous	**TOC**	84	0.05	0.22	1.84	0.22
	HI	23	15	83	220	66
	S1	23	0.05	0.32	1.92	0.41
	S2	23	0.06	0.39	3.82	0.77
	Tmax	22	398	429	460	16
	Ro	14	0.38	0.62	0.80	0.11
Jurassic	**TOC**	59	0.05	0.76	3.41	0.66
	HI	36	22	87	413	94
	S1	36	0.00	0.17	0.57	0.11
	S2	36	0.23	1.39	13.57	2.78
	Tmax	36	431	479	543	33
	Ro	12	0.26	0.98	1.96	0.64

TOC was determined on a LECO CS444 device using the decarbonated residue of powdered samples. Programmed pyrolysis was performed on powdered whole rock samples using a LECO THA-200 device. This technique provides the following parameters: S1 (mg of free and adsorbed hydrocarbons per gram of rock), S2 (mg of hydrocarbons per gram of rock, obtained by thermal decomposition of kerogen), T_{max} - (the temperature corresponding to maximum rate of S2 yield), and the hydrogen index (HI), a measure of hydrocarbon generative potential of kerogen and its preservation state (mgS2/gTOC).

The isotopic composition of kerogen and individual fractions of extracts were analyzed using a VG 602C and CJS Sigma masspectrometers.

Vitrinite reflectance measurements were made on polished surfaces of whole rock samples.

7.1.2. Source potential of the different stratigraphic complexes

The data on source properties of rocks produced through pyrolysis indicate that among different age units of the South Caspian basin the Oligocene-Miocene has the highest potential for petroleum generation (**Fig. 7.2**). A considerable amount of data has been summarized to provide a quantitative notion of the distribution and variation range of geochemical parameters (**Table 7.1**). Geochemical features of the sedimentary units are individually discussed below.

Middle Jurassic. The studied sequence (about 1500m thick) is Aalenian to Callovian and consists mainly of clayey lithofacies interbedded with fine-grained sandstones, siltstones and argillites. The colour range is dark gray to black. In the lower part of the section (Aalenian) clayey and sideritic concretions nearly 2m in diameter are present. Within the Late Bathonian - Early Callovian interval 10 m of good quality source rock is overlain by a further 10 m of very good oil source rock.

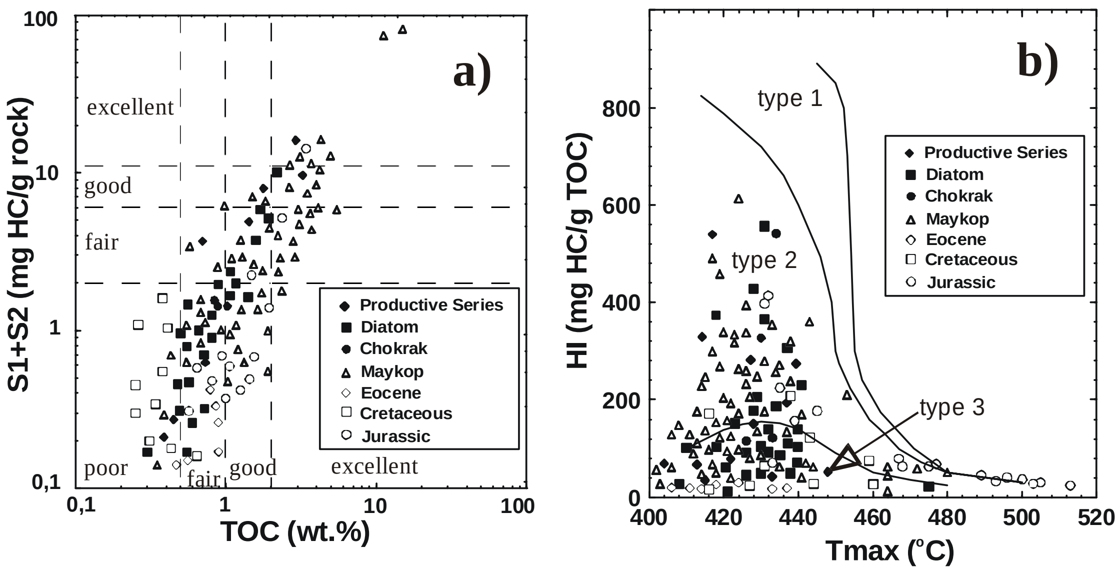


Fig. 7.2. Annotated diagrams of pyrolysis parameters.
(a) source rock potential classified according to categories of Peters (1986);
(b) qualitative source characteristics of organic matter in rocks
of different stratigraphic units

From the palaeogeographic data available it can be suggested that during Late Bathonian-Early Callovian a closed basin with reducing environment and possibly increased water salinity was in existence. The Pr/Ph ratio spans the range 0.39 - 1.41. The composition of the OM is mixed, with amorphous algal, inertinitic woody and herbaceous input, corresponding to kerogen Type 2 and Type 3. TOC content has a mean value at 0.76% and varies in the range 0.05-3.41%. The oil source potential of the Jurassic rocks is not high (HI : 22-413, mean 87).

Cretaceous. Few Hauterivian samples were obtained for this study, most emphasis being placed upon the Aptian-Cenomanian interval and upon the Maastrichtian. Generally, the Cretaceous is characterized by poor source rocks. The TOC content in the studied samples varies from 0.05 to 1.84% with the low mean value of 0.22%. HI shows values characteristic of gas-prone source with the average value of 83.

Palaeocene. This is the poorest unit with respect to OM content. The studied samples (N=11) showed TOC values in the range 0.01-0.08%, averaging 0.03%.

Eocene. These strata contain inertinitic and woody OM and are poor in TOC content and genetic hydrocarbon potential. With an average TOC of 0.46%, the HI for the samples analyzed does not exceed 29.

Oligocene-Lower Miocene (Maykop Series). Earlier organic-geochemical studies of the Maykop formation documented these strata as a potential source rock for oil in the area (Zhabrev & Mehtiyev 1959; Ali-zadeh et al. 1975; Korchagina et al. 1988). The present study has allowed us to verify the conclusion on the basis of a large volume of modern analytical data.

OM in the Maykop sediments consists chiefly of amorphous algal organic material. Good source rocks are best developed in the Upper Maykop in the east of the study area towards the Caspian Sea. Offshore these sediments are likely to be richer and more uniform but onshore there are significant variations both vertically and laterally, recording short and long-term differences in the environment of deposition. Sediments of the Maykop Series are distinguished by their high TOC content, which reaches 15.1%, with a mean of 1.86%. HI values vary between 11 and 612, with an average of 146.

Middle Miocene. The Chokrak formation was studied in a limited number of samples (N=10). HI values suggest that the source potential of the sediments is favourable to generate liquid and gas hydrocarbons (TOC: 0.09-2.44% and HI: 73-541). The thickness of the Chokrak unit is less than those of the Maykop and Diatom strata.

Middle-Upper Miocene Diatom Series. This is considered to be one of the principal source rocks in the SCB. Most of the claystones in the studied Diatom sections are of fair source quality, though, in some sections there are several intervals, each a few meters thick, of good source quality. Thus, on the whole, the sediments of the Diatom Series in the Shamakhy-Gobustan area are not rich in organic matter (average TOC=0.63%). HI ranges from 12 to 427 mg HC/g rock, while the mean value is 105.

Down the regional dip of the strata, the quantity and quality of OM in the Diatom Series increase and become more favourable with respect to oil generation. This is seen from the results obtained on the Diatom rocks ejected by mud volcanoes located in south-east Gobustan and on core samples from wells drilled on the Baku Archipelago (**Fig. 7.3**). The kerogen in this unit of the sedimentary complex for the most part corresponds to type 2. A higher content of TOC (0.09 - 7.8%; mean 1.03) and HI values (107-708; mean 308) point to the good hydrocarbon forming potential of this unit in the deepest parts of the basin.

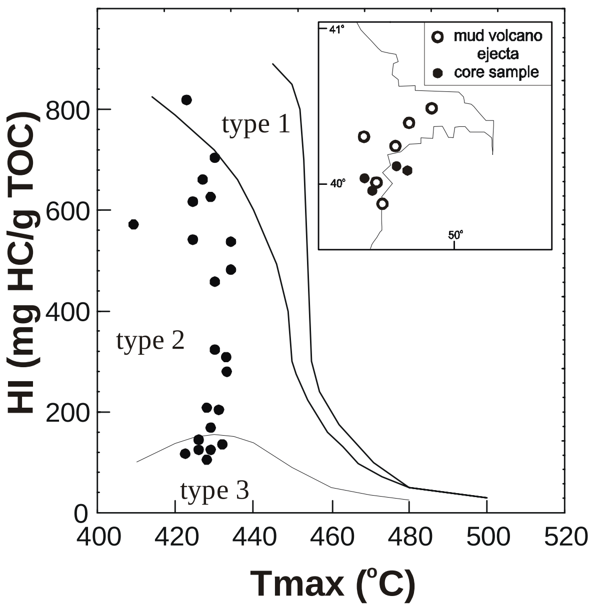


Fig. 7.3. Annotated diagram indicating improvement of source quality of organic matter in the Diatom sediments towards the basinal deeps

Lower Pliocene. Claystones of the Productive Series have been examined in core samples from oilfields. The sediments of the Productive Series were deposited in deltaic and near-shore/marine environments (Reynolds et al. 1998). OM in this unit has poor source quality, with kerogen of Types 2/3, composed largely of reworked and woody material with minor amorphous and algal input. TOC values lie in the range 0.02-2.71%, (mean

0.47%), with HI variable from 15 to 334 (mean 147). The hydrocarbon generative potential and the organic maturity of shales contained in the Productive Series are inadequate to have formed the observed great petroleum resources. It should be noted that in the generally thermally unaltered sediments of the unit the majority of samples have PI values considerably exceeding 0.2, thereby suggesting an inflow of allochthonous hydrocarbons from underlying units.

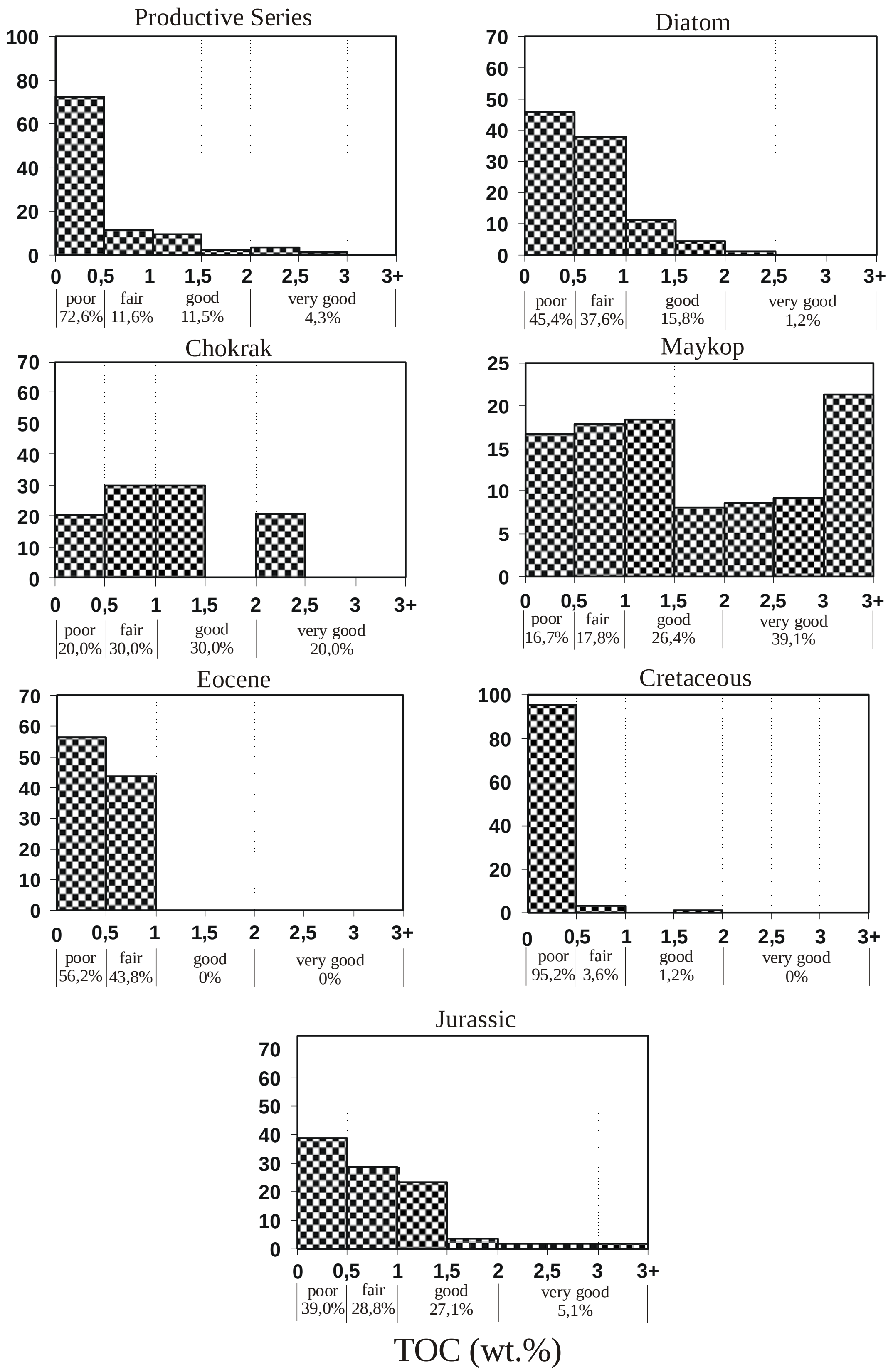
Summary. To compare the distributions of TOC content in the different stratigraphic units histograms were plotted (**Fig. 7.4a**), annotated with categories of source quality and corresponding percentages of samples.To obtain more realistic HI distribution for the stratigraphic units studied a way was needed to indirectly estimate HI values for those samples which showed TOC values below a pyrolysis cut-off value (0.5wt.% in our case). For this purpose, linear fit functions found on the measured pairs of TOC and HI values were used. Using the measured and the predicted HI values together, new histograms were plotted and annotated with percentages of oil and gas to be generated (**Fig. 7.4b**).

Summing up the results of the pyrolysis study it should be noted that none of the considered sedimentary units can be placed into a source rock category based only on average geochemical parameters. However, oil generative horizons (from TOC and HI values) are most frequent in the Oligocene-Miocene interval.

On the whole the relatively modest source potential of the sediments in the SCB is compensated for by their great thickness and predominant shaly content (up to 90%), as well as by the high oil expulsion efficiency due to formation of large volumes of gas concurrent with oil generation. These circumstances appear to explain the great hydrocarbon resources discovered here.

7.1.3. Maturity

Detailed evaluation of OM thermal conversion was beyond the scope of the present paper. However, taking into consideration that without these data source rock information would be incomplete, a generalized appraisal of organic maturity is given based on the parameters of Tmax, Ro, TAI and SCI. The most representative among datasets is that of Tmax (N=272), though a considerable number of determinations were available of Ro (110), TAI and SCI (92). Analysis of the data from individual stratigraphic intervals graphically (**Fig. 7.5**) revealed a good agreement between the maturity parameters. All intervals except for the Jurassic have undergone thermal stress inadequate for decomposition of OM, i.e. are immature with respect to HC generation. It should be noted that Jurassic samples came from the north slope of the Greater Caucasus, an area in a geological province outside the limits of the SCB – the Caspian margin - Guba foredeep. The younger sediments were sampled within the Shamakhy-Gobustan superimposed trough. Vitrinite reflectance versus depth profiles were examined on core samples collected from the Miocene interval of two fields, West Duvanny and Solakhay (located close to the coastline); they demonstrate the immature state of the sediments down to as deep as 4500m (**Fig. 7.6**) and probably deeper with respect to oil generation. In earlier work (Wavrek et al., 1996) we have documented the immaturity of the penetrated offshore Productive Series section, with Ro values at 5300m of less than 0.6%.


Productive Series
poor 72,6%
fair 11,6%
good 11,5%
very good 4,3%
Diatom
poor 45,4%
fair 37,6%
good 15,8%
very good 1,2%
Chokrak
poor 20,0%
fair 30,0%
good 30,0%
very good 20,0%
Maykop
poor 16,7%
fair 17,8%
good 26,4%
very good 39,1%
Eocene
poor 56,2%
fair 43,8%
good 0%
very good 0%
Cretaceous
poor 95,2%
fair 3,6%
good 1,2%
very good 0%
Jurassic
poor 39,0%
fair 28,8%
good 27,1%
very good 5,1%
0 0,5 1 1,5 2 2,5 3 3+
TOC (wt.%)

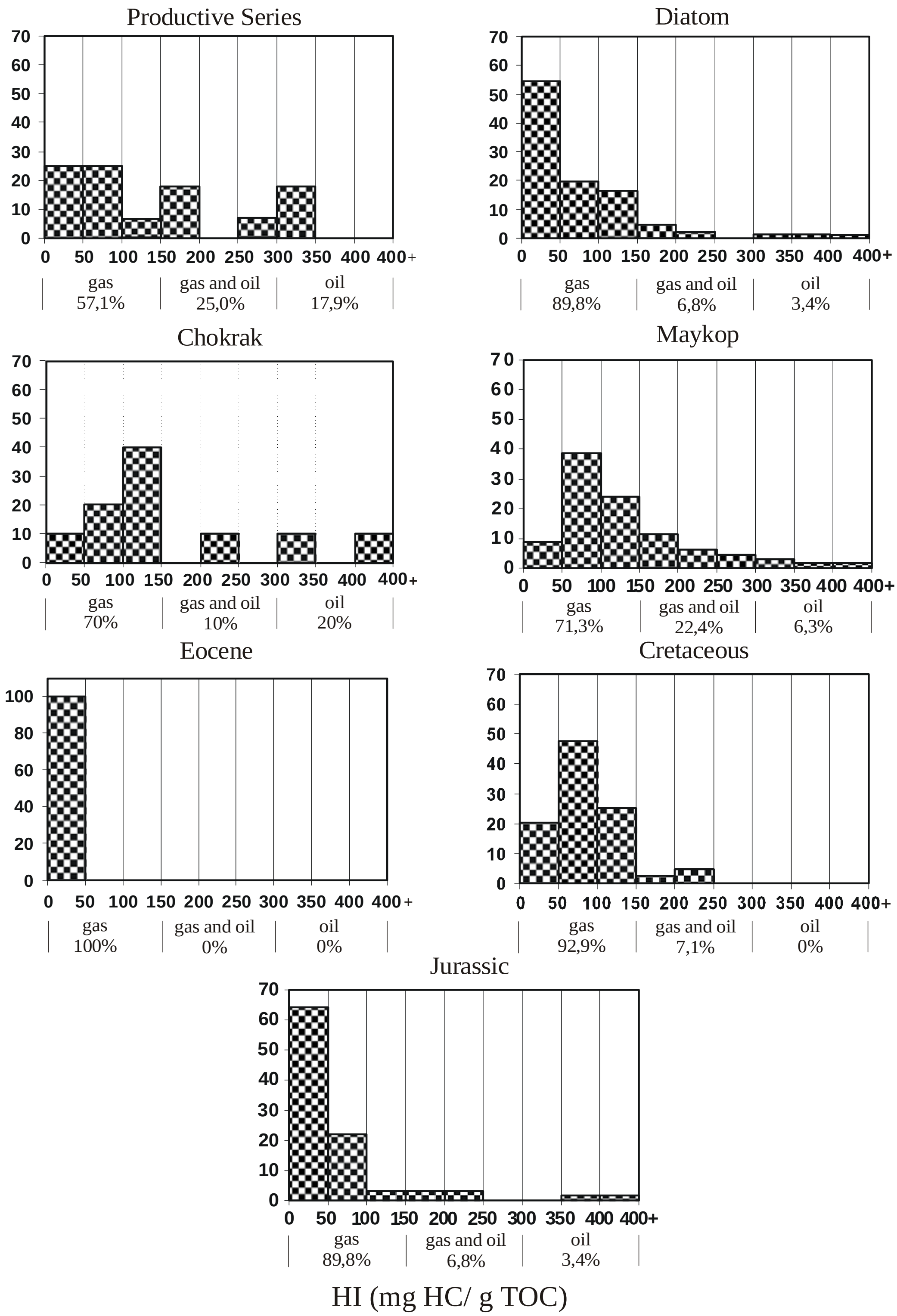


Fig. 7.4. Histograms of (a) TOC, and (b) HI for different units of the sedimentary fill. Vertical scales: frequency %. Classification of organic matter according to categories of Peters (1986).

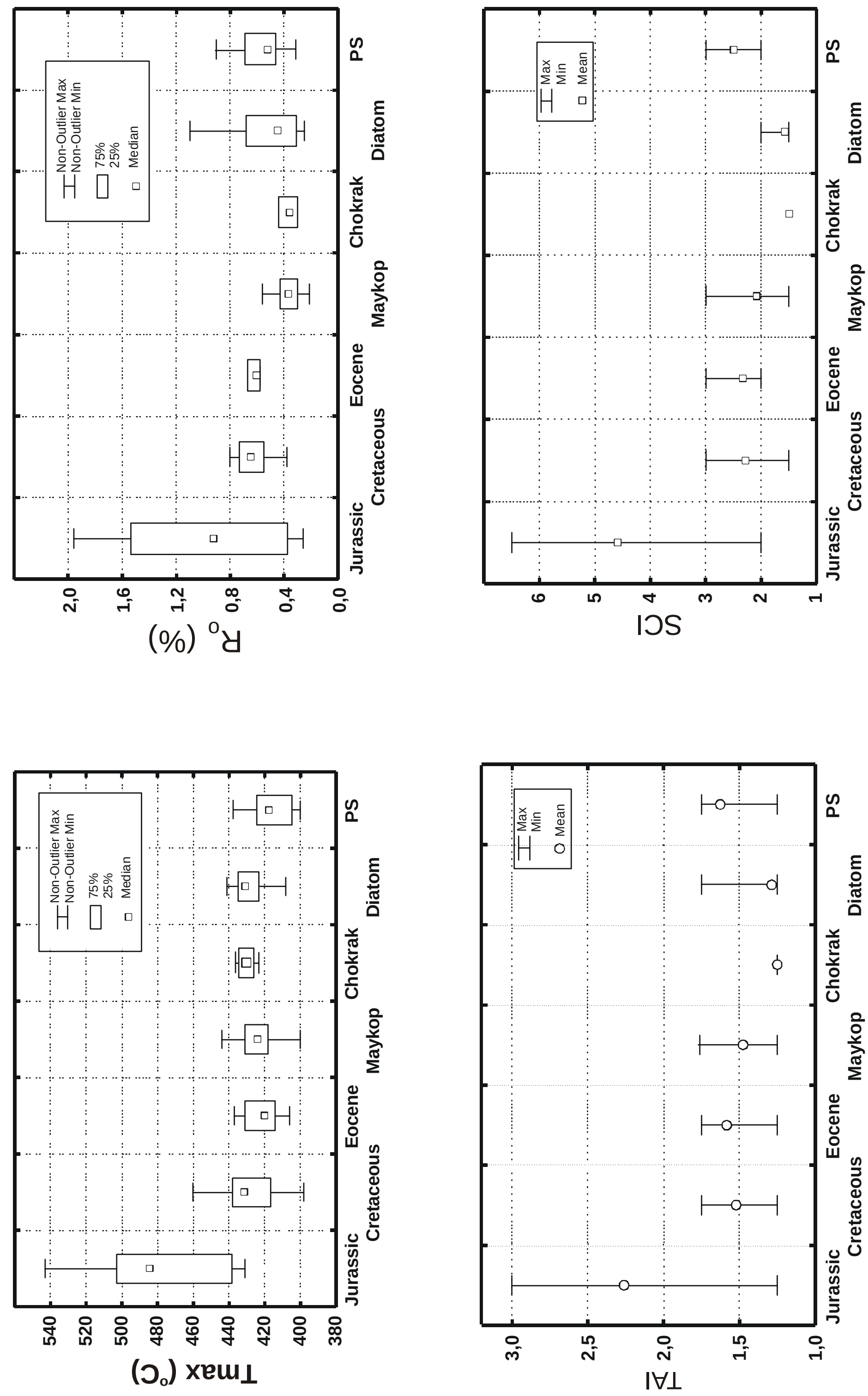


Fig. 7.5. Maturity status of organic matter in different units of the South Caspian Basin for pyrolysis-based (Tmax) and optical (Ro, TAI, SCI) parameters.

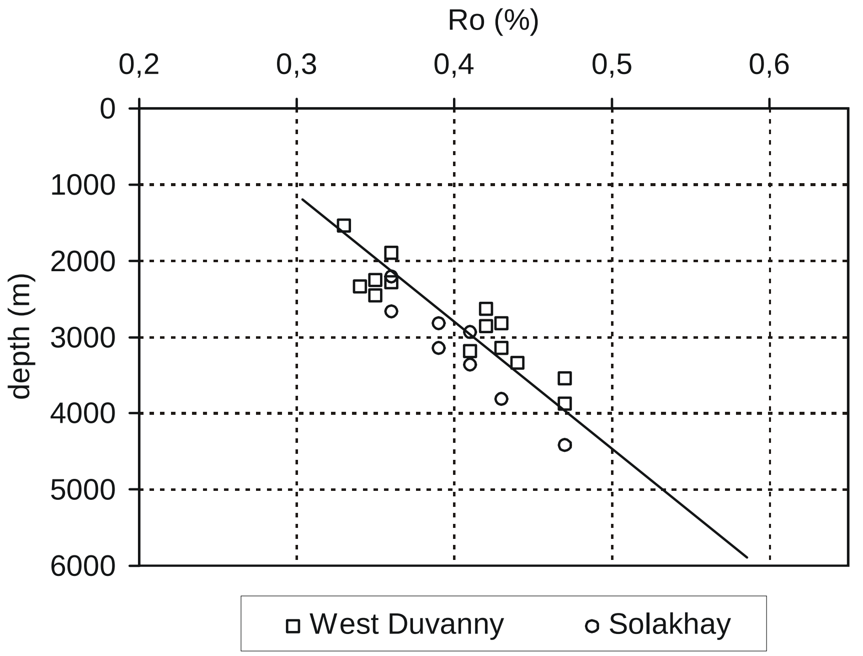


Fig. 6. Vitrinite reflectance versus depth profile for the Miocene rock samples from the West Duvanny and Solakhay oilfields, documenting the immature state of the organic matter with respect to oil generation.

7.2. Oils and hydrocarbon gases

7.2.1. Oil samples studied

Oils were studied from 53 fields in the Absheron, Evlakh-Agjabedi, Shamakha-Gobustan and Lower-Kura oil and gas regions in the Baku and Absheron archipelagos and in the interfluve of the rivers Kura and Gabyrry, comprising reservoirs from Upper Cretaceous to Upper Absheron levels. A list of the oil fields and the studied samples is given in **Table 7.2**. The isotope composition of oils from 20 natural oil seepages associated with mud volcanoes in the Absheron, Shamakha-Gobustan and Lower-Kura regions was studied as well. The studied mud volcanoes are listed in **Table 7.3**. The locations of the studied seepages (mud volcanoes) are shown on the **Fig. 7.7**.

Table 7.2. Studied oil field samples

No on the map (Fig.1.)	Oil field	Well number	Depth top-bottom (m)	Reservoir age
Absheron peninsula				
1	Puta	2128	482-500	Productive Series
		805	728-801	
		1162	858-878	
2	Bibieibat	2565	1504-1578	Productive Series
		3818	1883-1886	
		2566	1508-1564	
		2681		
3	Zykh	314	2219-2278	Productive Series
4	Buzovna	1057	1820-1902	Productive Series
		1324	1942-1957	
		1324	2013-2030	
5	Gala	1300	1975-1987	Productive Series
		1494	2118-2194	
6	Gousany	1701	3537-3562	Productive Series
7	Ramany	3312	1417-1446	Productive Series
		3683	1919-1935	
		3805	2315-2323	
8	Surakhany	945	2574-2590	Productive Series
9	Garachukur	64	2418-2444	Productive Series
		927	2510-2542	
10	Binagady	1167	615-638	Productive Series
		1448	665-787	
		2464	762-801	
		2464	853-910	
		2759	626-654	
11	Sulutepe	2696		Productive Series
		2597	1199-1201	
		2599	1190-1201	
12	Kushkhana	1862	352-414	Productive Series
13	Masazyr	105	90-204	Productive Series
		104	122-258	
		111	82-290	
14	Balakhany	1016	312-358	Productive Series
		21036	241-295	
		1107	240-266	
		3548	272-295	
		3178	728-759	
		3230	841-879	
15	Sabunchi	3728	1358-1374	Productive Series
		2345	1066-1114	
16	Kergez	263	1661-1759	Productive Series
17	Guzdek	210	2024-2060	Productive Series
18	Garadag	511	3100	Diatom
		352	2606-2640	Diatom
		508	2812-2906	Diatom
		1		Productive Series
		73	1945-2003	Productive Series
Absheron archipelago				

19	Gunashli	170	3144-3188	Productive Series
		182	2835-2891	
		2	2994-3039	
		257	2690-2751	
		118	2749-2884	
		81	2913-2930	
		260	2705-27053	
		189	2329-2368	
		16	3310-3430	
		124	3004-3068	
		258	3030-3050	
		122		
20	Azeri	1	2447-2489	Productive Series
21	Pirallahi	654	570-655	Productive Series
22	Absheron kupesi	4		Productive Series
23	Kapaz	3	3628-3682	Productive Series
24	Janub	57	2981-2987	Productive Series
25	Neft Dashlary	2001	385-404	Productive Series
		3	383-389	
26	Gum	348	2656-2682	Productive Series
27	Bahar	148	4500-4572	Productive Series
		182	4660-4700	
		3		
Baku archipelago				
28	Duvanny	320	3548-3614	Productive Series
29	Sangachal	551		Diatom
		9		
30	Garasu	122		Productive Series
Shamakha-Gobustan OGBR				
31	Astrakhanka			Up. Cretaceous
32	Adjiveli	12		Maykop
33	Umbaki	135	682-710	Chokrak
		308	308-327	Chokrak
		101	1334-1380	Chokrak
		34	424-482	Chokrak
		114	960-990	Maykop
		196	1567-1648	Maykop
		11	1314-1396	Maykop
		21	1055-1121	Maykop
34	Dashgil	15	2629-2630	Productive Series
35	Kanizadag	29	4175-4200	Productive Series
		25	2398-2532	
Lower Kura OGBR				
36	Pirsagat	204	1740-1747	Productive Series
		85	4110-4130	
		111		
37	Kalamadyn	161	1380-1400	Productive Series
		72	1728-1783	
		24	1674-1693	
		126	1619-1637	
38	Kichik Kharami	3	1900-2000	Productive Series
39	Kurovdag	958	843-852	Upper Pliocene

		1008	258-263	Upper Pliocene
		918	1118-1242	Upper Pliocene
		127	1936-1955	Upper Pliocene
		148	2238-2278	Upper Pliocene
		934	2020-2030	Productive Series
		517	2511-2556	Productive Series
		889	2789-2790	Productive Series
		1263	2919-2936	Productive Series
40	Kursanga	401	4119-4135	Productive Series
		4	4884-4924	
		298		
41	Garabagly	144	2784-2797	Productive Series
42	Hilly	15	1665-1728	Productive Series
	Hilly	418	1128-1180	Upper Pliocene
43	Neftchala	1083	1170-1256	Productive Series
		709	1821-1956	
		3001	3249-3254	
44	Mishovdag	276	1176-1203	Upper Pliocene
45	Kalmas	416		Productive Series
OGBR of the interfluve of the Kura and Gabyrry				
46	Demir Tepe	7	4200	Eocene
47	West Gurzundag	1	4230-4450	Eocene
48	Palantekan	2	5112-5129	Eocene
49	Tarsdallar	1		Eocene
		24	4236-4256	
Evlakh-Agjabedi OGBR				
50	Zardob	7	4093-4175	Eocene
51	Shaftakhal	250	4200	Eocene
52	Muradhanly	37	4135-4189	Up.Cretaceous
		247		Eocene
		232	4168	Maykop
		246	4110-4140	Maykop
53	Djafarly	21	4030	Eocene
		28		

Table 7.3. The studied oil and gas seeps related with mud volkanoes

No on the map	Mud volcano	Type of studied sample	Location area
1	Cheildag	oil	Shamakha-Gobustan
2	Airantekan	oil, gas	‘’-‘’
3	Bahar	oil, gas	‘’-‘’
4	Matrasa	oil	‘’-‘’
5	Demirchi	oil	‘’-‘’
6	Melikchobanly	oil, gas	‘’-‘’
7	Djengi	oil	‘’-‘’
8	Kirkishlag	oil	‘’-‘’
9	Kirdag	oil	‘’-‘’
18	Kyrlykh- Enikend	oil, gas	‘’-‘’
16	Perekishkul	gas	‘’-‘’
20	Shikhzagirly	gas	‘’-‘’
10	Charagan	oil, gas	‘’-‘’
11	Umbaki	oil	‘’-‘’
12	Shorbulag	oil, gas	Absheron
13	Kirmaki	oil	‘’-‘’
14	Zigilpiri	oil	‘’-‘’
15	Kyrlykh lake	oil	Lower Kura
17	Kyrlykh- Kharami	oil	‘’-‘’
19	Akhtarma Pashaly	oil	‘’-‘’

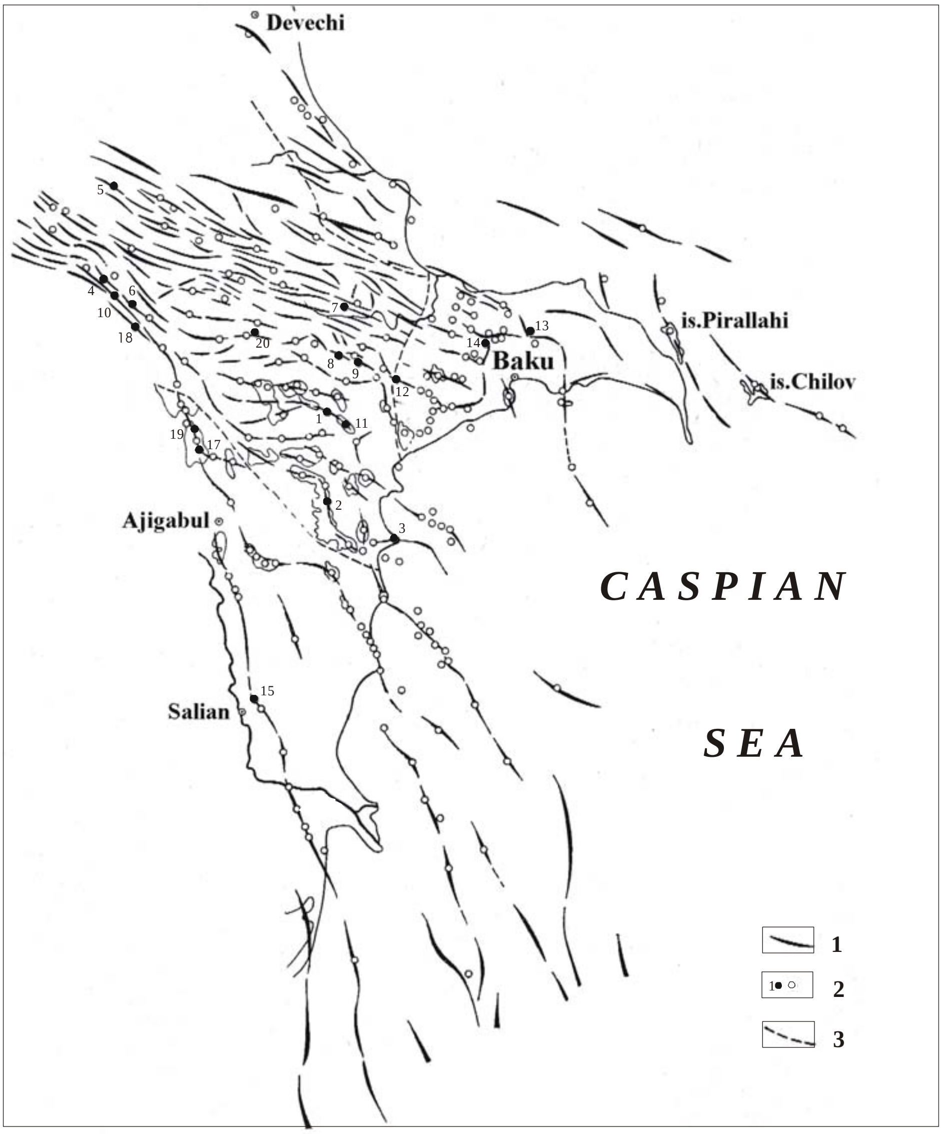


Fig. 7.7. Location map of mud volcanoes. 1-anticline structure; 2-mud volcanoes (black circles are studied mud volcano seep); 3-boundary between OGBR.

7.2.2. Methodology

The most difficult task in evaluating oil source rocks is the determination of direct genetic associations between oils present in reservoirs and specific oil source rocks. The determination of these associations will help solve a number of important problems, e.g. the origin of the oil, analysis of conditions and facies favourable for oil generation, assessment of hydrocarbon reserves and potential of the oil and gas basin. The task can be studied in two ways. The first is the comparative analysis of some compounds and their correlation in oils and in the organic matter of rocks, e.g. normal alkanes, isoprenoids, steranes, triterpanes, some groups of aromatic hydrocarbons etc. The second approach is based on the study of the isotopic composition of the matter, principally the isotopic composition of carbon. We prefer the isotope method of the study of the organic matter and oil, for it is not limited to certain compounds and structures but derives from the characteristics of the chemical element which makes up the basic mass of the matter. Moreover, isotope relations are less exposed to changes determined by secondary alteration. This article presents results of studies of the stable isotopes of the total carbon of oils and the carbon of the alkane and aromatic fractions on 152 samples (wells).

On the basis of the results of isotope analyses we constructed and interpreted graphs and histograms of frequency of distribution of values of isotope ratios for oils from the Upper Cretaceous – Upper Pliocene reservoirs, for the oils from reservoirs of a particular age and also for the oils of each oil and gas region. The results of isotope analyses of oils from natural seepages were interpreted by the same method.

Studies of the organic matter and oils using molecular fossils (biomarkers) allowed us to conduct oil-oil and oil- source rock correlations and to determine the stratigraphic age of the oil as well as the maturity of oils related to the level of the catagenetic transformation of the producing kerogen.

The following parameters were used: level of isomerization of hopanes, steranes, sterane aromatization, correlation of the aromatic steroids etc. We used the following highly informative and widely applied biomarker parameters: degree of isomerization of sterane {$\alpha\alpha$ C_{29} (20S/S+R)} and aromatization of monoaromatic sterane {C_{28} triaromatic sterane/ C_{28} triaromatic+ C_{29} monoaromatic sterane}.

7.2.3. Results of isotope study
Reservoired oils

The isotopic values of hydrocarbon $\delta^{13}C$ in the oils of the SCB vary widely, from -28.0 $^o/_{oo}$ to -24.34 $^o/_{oo}$ for the oils and from -29.1 $^o/_{oo}$ to -24.8 $^o/_{oo}$ for the alkane fraction. The oils in the SCB can be grouped into two classes: 1) isotopically-light - with $\delta^{13}C$ values of -28.0 $^o/_{oo}$ to -27.0 $^o/_{oo}$ for the total carbon and -29.1 $^o/_{oo}$ to -27.0 $^o/_{oo}$ for the carbon of the alkane fraction and 2) isotopically heavy, with values of -26.5 $^o/_{oo}$ to -24.0 $^o/_{oo}$ and -26.5 $^o/_{oo}$ to -24.5 $^o/_{oo}$ for the total carbon and the alkane fractions, respectively (**Fig. 7.8**). Mostly the oils in the SCB are represented by the oils of the second group (58-69% of the examined samples), whereas the isotopically-light oils make up 31-42% of the samples. An important observation is that there is a distinct, regular change in the isotopic values through the stratigraphic section. So, the isotopically lightest oils are typical for the Upper Cretaceous reservoirs, which have values corresponding to $\delta^{13}C$ in alkane fraction and in the whole oil carbon of –28.15 $^o/_{oo}$ (-28.0 $^o/_{oo}$)). Isotopically light oils occur in these reservoirs: Eocene -28.32 $^o/_{oo}$ (-27.86 $^o/_{oo}$); Maykop (Oligocene- Lower Miocene) -28.05 $^o/_{oo}$ (-27.64 $^o/_{oo}$) and Chokrak (lower Middle Miocene) -27.95 (-27.52 $^o/_{oo}$). Isotopically heavy oils occur in these reservoirs: Diatom suite (Middle-Upper Miocene) -26.45 $^o/_{oo}$ (-26.13 $^o/_{oo}$) and Pliocene age -26.36 $^o/_{oo}$ (-25.75 $^o/_{oo}$) (**Fig. 7.8 and Fig. 7.9**). At the same time the range between the upper and lower limits of the $\delta^{13}C$ values increases in the same direction. Oils in Pliocene reservoirs are distinguished by the largest variation in isotope values: 22.6% of the alkane fraction are isotopically light and 9.68% isotopically heavy, whilst the main mass (67.7%) are of intermediate value.

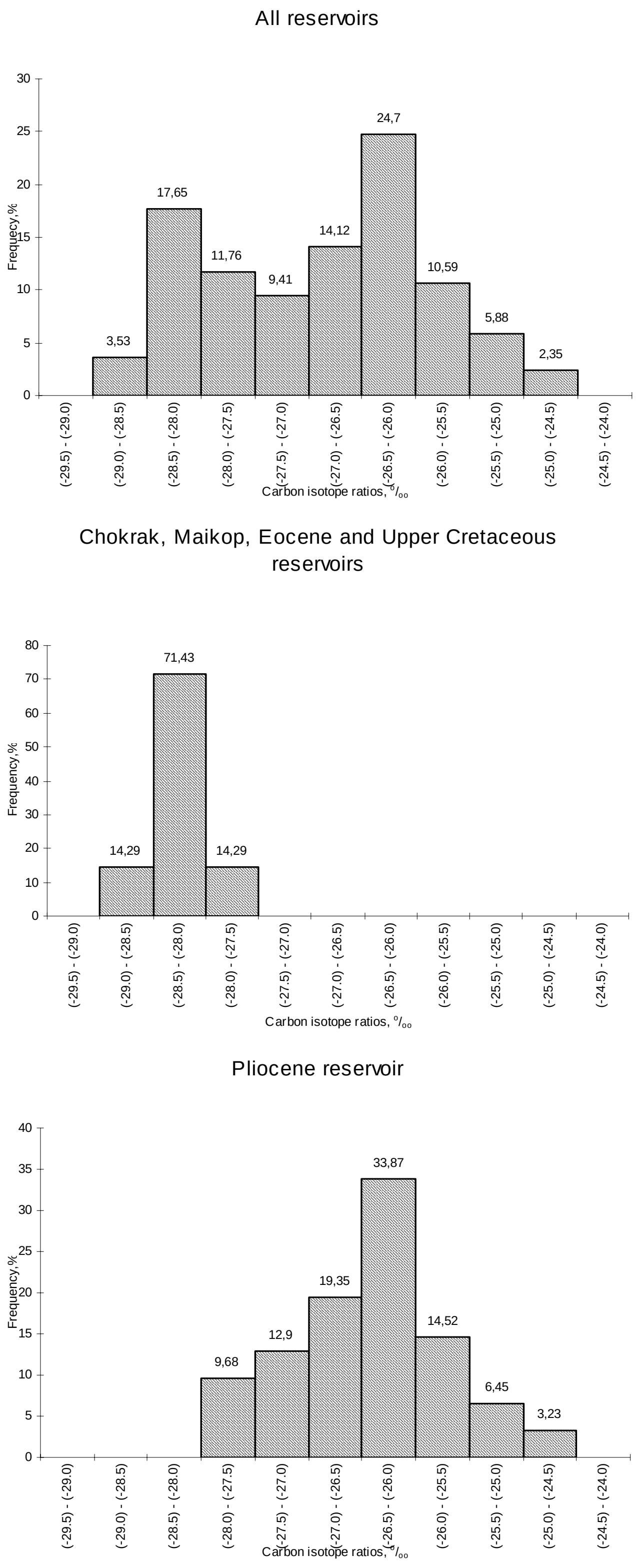


Fig. 7.8. Frequency distribution of carbon isotope ratios of alkane fraction of oils from different age reservoirs in the South Caspian basin.

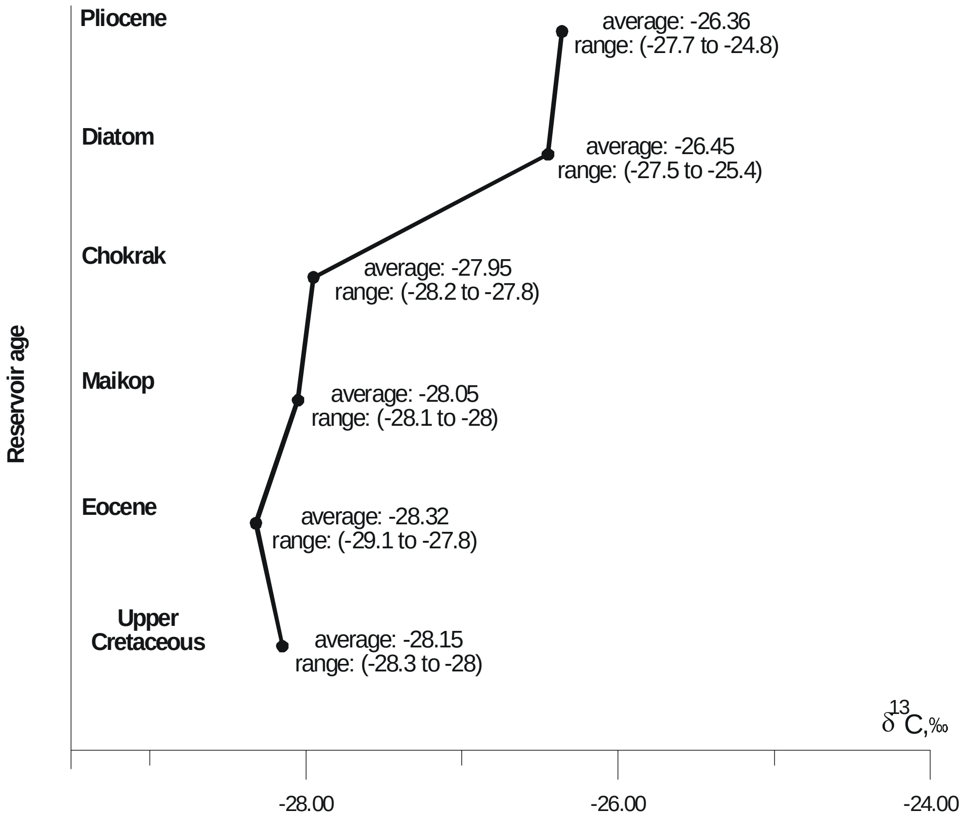


Fig. 7.9. Average values and ranges of carbon isotope ratios in the alkane fraction of oils

7.2.4. Oil seeps

Isotopic studies of oil seeps associated with mud volcanoes has allowed two oil groups to be differentiated: oils with a typical Paleogene-Lower Miocene carbon isotopic signature and those representing mixed oils generated from both Paleogene-Lower Miocene and Diatom sources. **Figure 7.10** illustrates the correlation of mud volcano seeps according to the isotopic composition of carbon in the saturated fraction. It is inferred from the figure that about 50% of the mud volcanoes release Paleogene-Lower Miocene sourced oils. Around 17% of the mud volcanoes largely release oils sourced from the Diatom complex and 33% of them release a mixture having approximately equal share of oils from the Paleogene- Lower Miocene and Diatom sources.

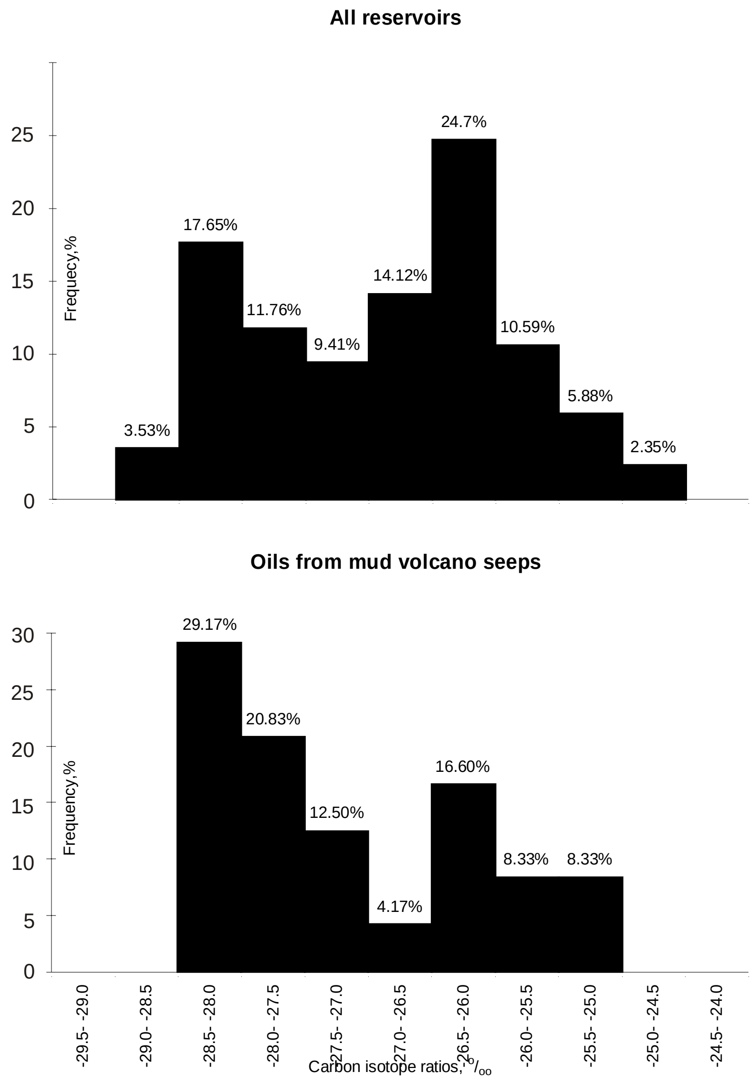


Fig. 7.10. Frequency distribution of carbon isotope ratios of alkane fraction of mud volcano oils, compared with values from all reservoirs.

7.2.5. Geochemistry and formation environment of oils. Oil-source correlation.

All of the studied oils appear to derive from source rocks formed in near-shore - marine and delta conditions. This is indicated by the $\delta^{13}C_{alk}$ versus $\delta^{13}C_{arom}$ diagram (**Fig. 7.11**), where the oils plot in the field of marine organic matter and are positioned along the border line separating continental and marine organic matter types. This suggestion is also supported by the Pr/Ph ratio, only a few of the oils fall in the 1.58-2.12 range, and by sulfur contents not exceeding 0.4%. These results suggest that the initial organic matter had a mixed continental-marine composition, with a predominant sapropelic input (Abrams and Narimanov 1997; Guliev et al., 1997). These conclusions are confirmed by the C_{27}:C_{28}:C_{29} normal steranes and isosteranes correlation (about 33%:35%:32% and 31%:36%:33%, respectively) (**Fig. 7.12**). The relatively high values of the oleanane index suggest a high input of continental organic matter into the paleobasin (Inan et al.1997), whilst the moderate values of the gammacerane index indicate a saline environment in the paleobasin in the area of organic matter accumulation and fossilization. The obtained geochemical data prove that the oils present in Pliocene reservoirs are not syngenetic to the deposits which contain them, as it is known the Pliocene basin was a closed freshwater basin (Kerimov et al. 1991; Lerche et al. 1997; Reynolds et al. 1998), with intensive input of continental organic debris carried together with terrigenous clastic material. If the Pliocene oils had been generated from source rocks deposited in such conditions, the geochemical composition would be different, with for example a high Pr/Ph ratio (> 3), a predominance of sterane C_{29} above sterane C_{27} and C_{28}, an absent or very low gammacerane index, a very high oleanane index, etc.

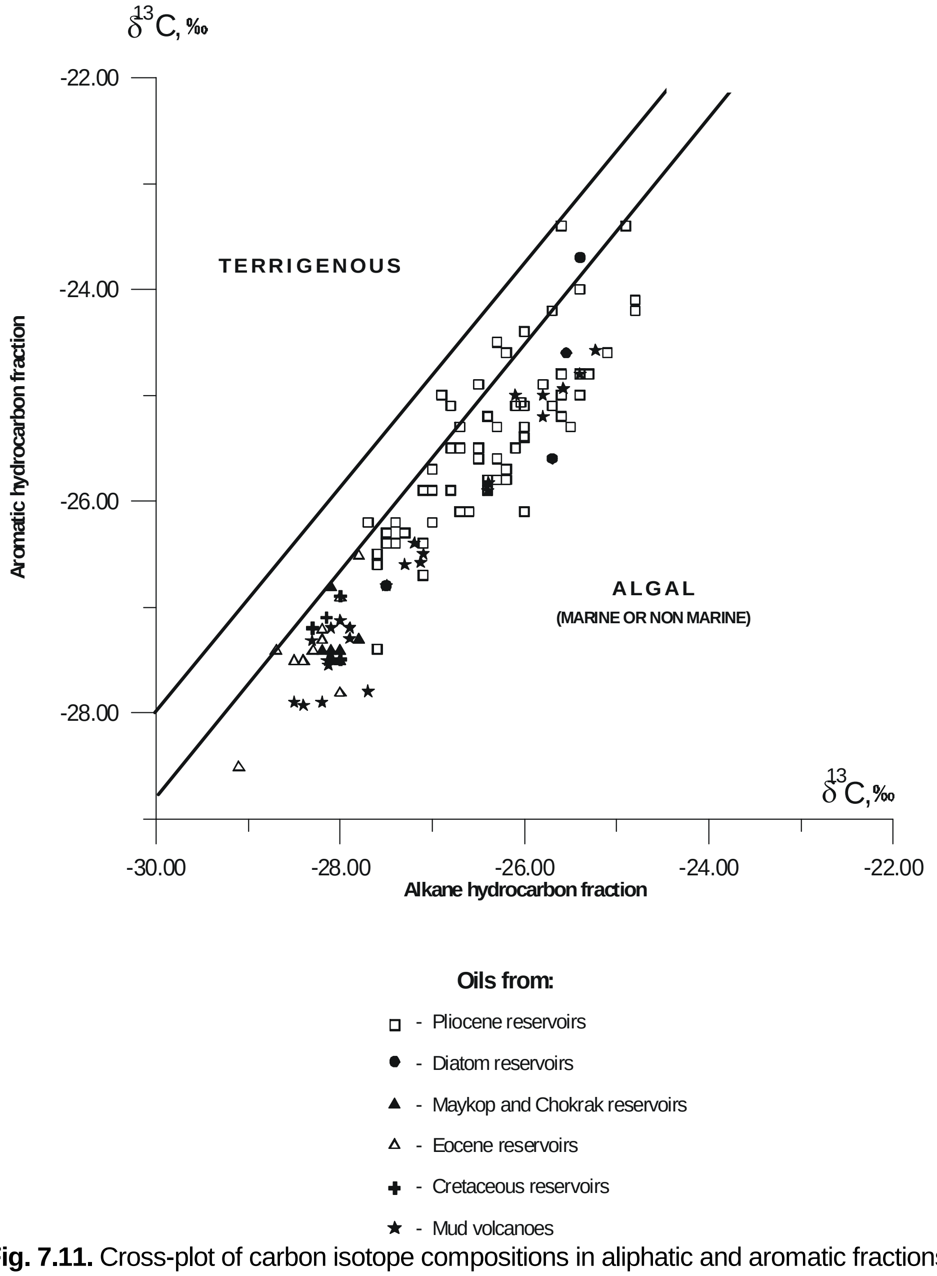


Fig. 7.11. Cross-plot of carbon isotope compositions in aliphatic and aromatic fractions of reservoired and mud volcano oils in the South Caspian-Kura Basin.

The occurrence in the Pliocene reservoirs of both isotopically light and isotopically heavy oils, with a range of $\delta^{13}C$ values of 3-4 $^{o}/_{oo}$, suggest they have been generated from at least two different source rocks (Peters and Moldowan 1993; Chung et al. 1992), e.g. the pre-Diatom (Cretaceous- Lower Miocene) and the Diatom (Middle-Upper Miocene).

The presence of both mixed oils, produced from the Paleogene-Lower Miocene and Diatom sources and of oils derived from a single source is characteristic of the Pliocene reservoirs.

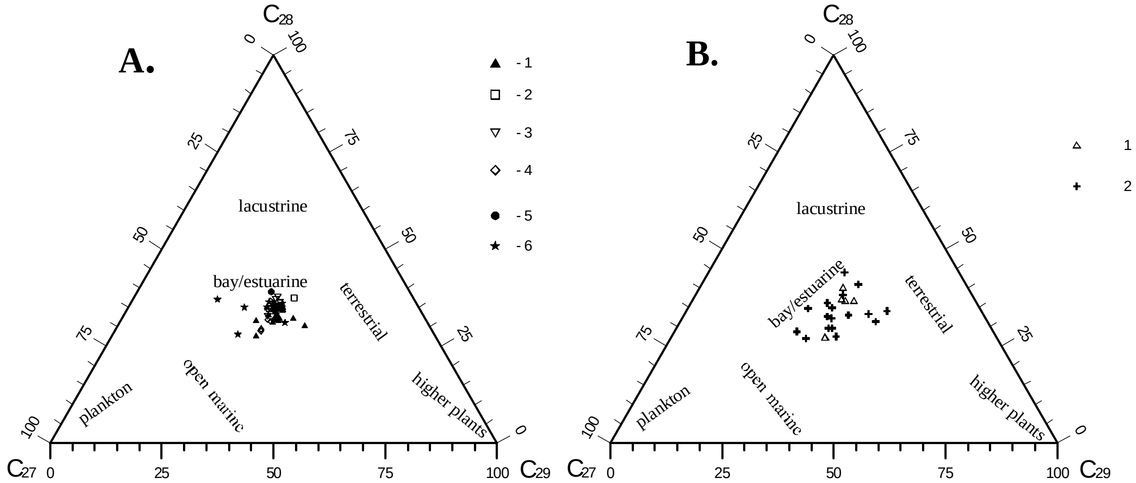


Fig. 7.12. Distribution of normal steranes in oils (a) and sedimentary organic matter occurring in different age strata of the South Caspian-Kura Basin. (a) in reservoired oils from : 1 - the Pliocene; 2- the Diatom; 3 - the Chokrak and Maikop; 4 - the Eocene; 5 - the Upper Cretaceous; and in seep oils from mud volcanoes (6); (b) in organic matter extract: 1 - the Pliocene; 2 - the Oligocene-Miocene.

There is a clear differentiation between the carbon isotope compositions of pre-Diatom and Diatom OM. Kerogen from the Diatom sediments contains considerably heavier $\delta^{13}C$ (less negative) than the respective values for older parts of the sedimentary section. From the Oligocene to Miocene the tendency for an enrichment of OM with ^{13}C is obvious (**Table 7.4** and **Fig. 7.13a**). Abrams & Narimanov (1997) presented similar evidence for saturate and aromatic fractions in rock extracts from the Oligocene-Miocene rocks. Therefore, multiple source intervals within the Oligocene-Miocene sequence will give rise to differing $\delta^{13}C$ values in reservoired oils, as reported in our earlier work (Guliyev et al., 2000b).

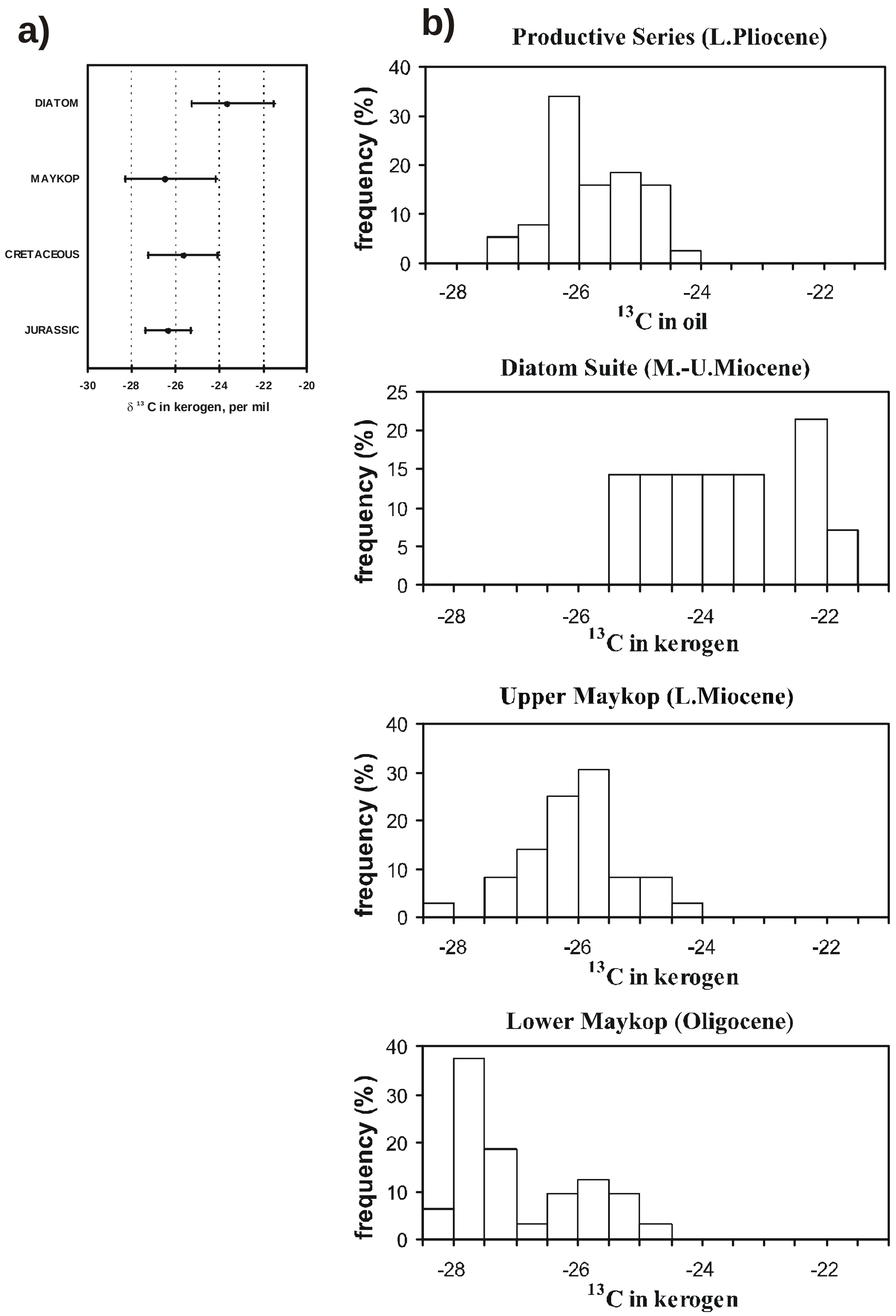


Fig. 7.13. Source-to-oil correlation using carbon isotope ratios : (a) ranges and mean values of $\delta^{13}C$ in kerogen of different age rocks; (b) comparison of the kerogen occurring in different intervals of the Oligocene-Miocene sediments with the Lower Pliocene reservoired oils.

Table. 7.4. Data summary for carbon isotope composition of kerogen (‰, PDB) contained in the stratigraphic intervals of the South Caspian Basin

Stratigraphic Unit	Minimum	Mean	Maximum
Diatom	-25.25	-23.63	-21.53
Maykop	-28.24	-26.48	-24.15
Cretaceous	-27.22	-25.63	-24.05
Jurassic	-27.35	-26.33	-25.27

By isotopically correlating the Productive Series oils with kerogen from different intervals of the Oligocene-Miocene (**Fig. 7.13b**) one can assess the participation of the pre-Pliocene sediments in the formation of the oil pools in the Productive Series. Taking into consideration that oil is normally 0.5-1.5‰ depleted in ^{13}C compared to source kerogen (Omokawa 1985; Peters & Moldowan 1993), OM in the Miocene (Upper Maykop and Diatom Suite) is inferred to have dominant role as a source for the Productive Series oils.

A close source-to-oil relationship between the Miocene rocks (Diatom, Chokrak and Upper Maykop) and oils reservoired in the Productive Series is suggested from a cross plot of carbon isotopic signatures of aromatic and aliphatic fractions in rock extracts and oils (**Fig. 7.14**). A group of the Oligocene points with appreciably lighter isotopic composition on both fractions is distinct from the Lower Pliocene reservoired oils, whereas source samples from the Diatom and Chokrak are the closest to them. This evidence would be suggestive that oils accumulated in the PS have been sourced from Miocene sediments.

Contributions to the oil charge from different stratigraphic levels are variable from one part of the basin to another : towards the basinal deeps the share of oils supplied from the Diatom Suite becomes greater, whereas the share supplied from the Lower Miocene is higher in flank zones (Guliyev et al., 2000a).

7.2.6. Relative contributions of different source rocks in the oil formation

The definition of the limiting $\delta^{13}C$ values which characterize the pre-Diatom and Diatom oils, allows us to estimate the real share of each oil-generating complex (source rocks) in supplying the oils in the Pliocene reservoirs.

Based on the isotopic composition of the oils, Paleogene-Lower Miocene and Diatom source rocks appear to have contributed approximately equally to the oils in the Pliocene reservoirs of the Absheron peninsula. The same is true for the oils in the Pliocene reservoir of Shamakha-Gobustan OGBR and Baku archipelago, although there are slightly more oils sourced from the Diatom complex. Approximately 3/4 of the oils in the Lower Kura OGBR formed from Paleogene-Lower Miocene source rocks. The source rock for two-thirds of the oils in the Pliocene reservoirs of the Absheron archipelago is the Diatom suite (**Fig. 7.15**).

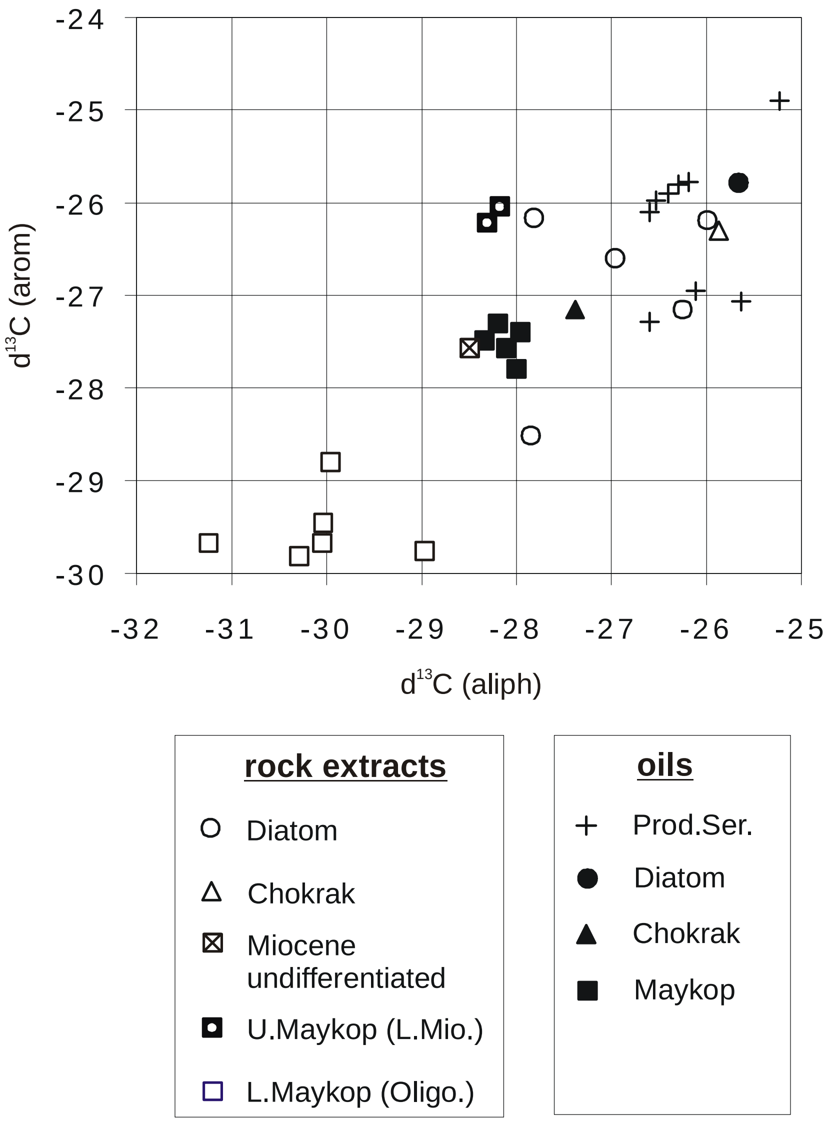


Fig. 7.14. Source-to-oil correlation using carbon isotope ratios: aliphatic vs. aromatic fraction of rock extracts and oils.

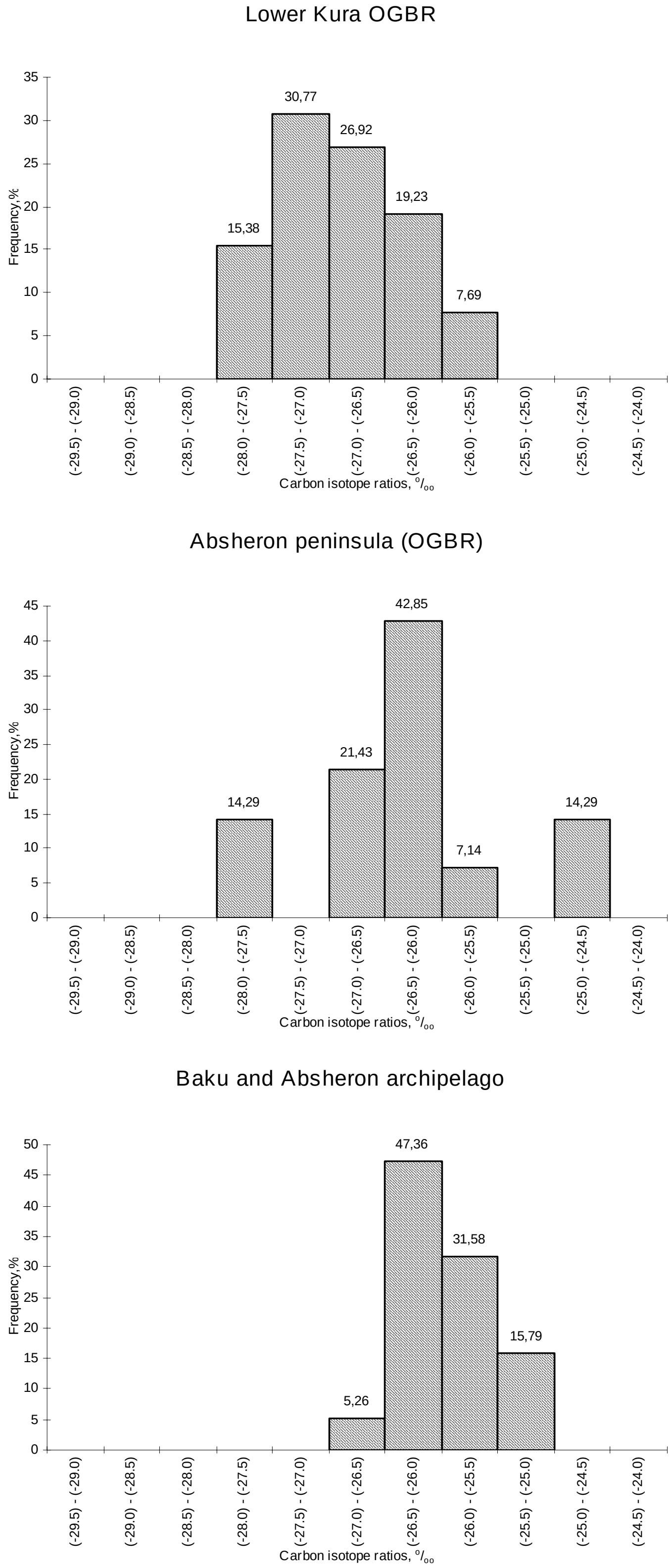


Fig. 7.15. Frequency distribution of carbon isotope ratios of alkane fraction of oils from different OGBR in the South Caspian basin.

The general trend is that from land to sea the oils are isotopically heavier (**Fig. 7.16**). Such regularity can be explained by the "oil window" occurring in younger strata. Offshore there is a considerable increase of thickness of young Pliocene-Quaternary strata and underlying rocks are buried to large depths. However, according to the $\delta^{13}C$ values of methane of mud volcanoes the inverse tendency takes place (Dadashev at al. 1986, Guliev and Feisullaev, 1996).

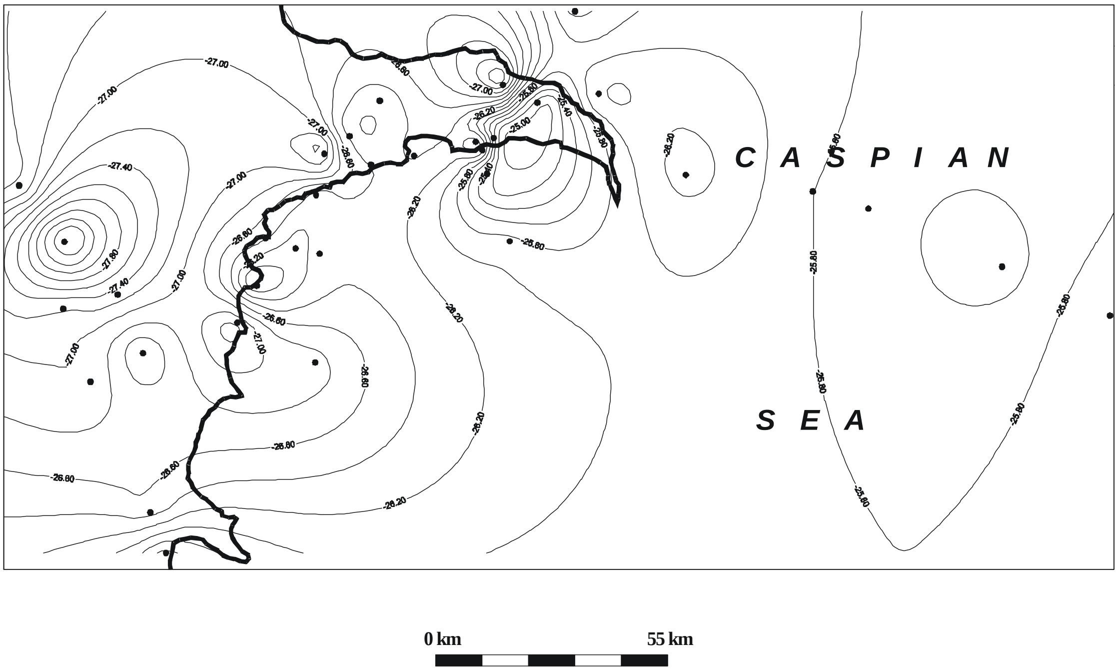


Fig. 7.16. Map of distribution of carbon isotope ratios in oils in the Pliocene reservoirs.

Based on isotopic character, the oils in the Pliocene reservoirs of the SCB consist on average of equal inputs from Paleogene-Lower Miocene and Diatom sources. Taking into consideration the fact that the thickness of the Oligocene-Lower Miocene source rocks in this part of basin increases to twice the thickness of the source rocks of the Diatom suite, we suggest that only part of the hydrocarbons generated from the pre-Diatom source is present in the Pliocene reservoirs. We conclude that 50% of the hydrocarbons generated from Paleogene-Lower Miocene sources remain unrecognized.

7.2.7. Oil maturity from different reservoirs

The level of oil maturity is the important parameter which in complex with other geological-geochemical parameters allows to get necessary information of depth of oil and gas formation zone, stratigraphical correspondence of source rocks, direction and conditions of migration of hydrocarbon fluids, and at last, to access the potential of oil and gas bearing basin. Study of oils' maturity is very valuable for oil and gas bearing basins (OGBB) where several fluid generating complexes are involved in hydrocarbonformation processes. And the example is intensively developed South Caspian megadepression (SCMD) it is unique by its high thickness of filling which reaches 20-25 km, and there are several fluidgenerating complexes - Eocene, Oligocene - Lower Miocene (Maikop), the Middle Miocene (Chokrak horizon), the Middle - Upper Miocene (Diatomic).

The main specific feature of megadepression is strong qualitative geochemical variety of oils of the Pliocene reservoir where oils with different compositions are produced: they are light, heavy weaksulphurous and high resin, methane and naphthene, etc. A wide geochemical spectrum of oils of this reservoir according to our studies is a result of a number of factors of thermocatalitic, genetic (as the participation in oil formation of different age fluid generating complexes), migration, biogradeting nature, etc.

The other specific feature of SCMD is the lower degree of oils maturity from the Upper Cretaceous, Oligocene-Lower Miocene (Maikop) and Miocene reservoirs of Shemakha-Gobustan oil-gas bearing region (OGR) in comparison with oils from reservoirs of the Pliocene, adjacent OGR. As it is known the maturity of oil is the function of temperature regime of the Earth deposits and prolongation of oil producing deposits in zone of oil formation, it's directly related with age of oil generating series, i.e. oil which are generated underlayer series must be more mature in comparison with oils of overlapping complexes.

The third, is a very specific feature - the lowest maturity of oils in known oil and gas-condensate fields and it does not fit in the present ideas of vertical zonality of oil and gas formation, according to which condensates are the products of high catagenetic destruction of organic matter.

High technologic methods of study for organic matter and oils on level of molecular fossils (biomarkers) which are widely used in organic geochemistry, allowed to correlate oil-oil, oil-source rock, to define stratigraphical oil age and, it is very important, to define the degree of oils maturity and exactly the level of catagenetic transformation producing its kerogen. Such parameters as degree of isomerization of hopanes, steranes, aromatization of steranes, correlation of aromatic steranes and steroids, etc. are used for the latter.

We have used such high informative and widely used biomarker parameters as degree of sterane isomerization {$\alpha\alpha\alpha C_{29}$ (20S/S+R)}and aromatization of monoaromatic sterane {C_{28} triarom. sterane/C_{28} triarome+C_{29} monoarom. sterane}.

The results of investigations of the fields of all ORG of the South Caspian megadepression had showed that oil maturity varies from 0.155 to 0.49 on sterane isomerization. More maturated oils concentrate within OGR of the Middle Kura depression with values 0.35-0.49. Histograms of frequency distribution (**Fig. 7.17**) show that in 50% of the objects oils have maturity value 0.45-0.5 on sterane isomerization. It is equal to EVRA R_0=068-0.73%; in 40% - it is 0.4-0.5 or R_0=0.63-0.68%. So, the studied oils characterize low and medium conversation of kerogen of the source rocks. In the stratigraphical interval of the Upper Cretaceous - Eocene - Oligocene - Lower Miocene section their average values are practically unchangeable and make 0.43-0.45 (according to degree of sterane isomerization). Taking into account the correspondence of the studied fields in Evlakh-Agjabedi trough in the Upper Cretaceous part of the section to the effusive formations (Muradkhanli field), their overlaying and covering by the Eocene oil-bearing sandy-clayey deposits and equal catagenic conversation of oils and both reservoirs as well one can judge about interformation migration hydrocarbon fluids from the Paleogenic complex into the volcanogenic Upper Cretaceous one. The identity of oils of the examined reservoirs is confirmed by genetic biomarker parameters: ratios of normal steranes $\alpha\alpha C_{27}$:C_{29}:C_{29}, isosteranes $\alpha\beta C_{27}$:C_{29}:C_{29}, ratio of isoprenoides (Pr/Ph), etc. The most important indicator of their similarity and genetic attribute to the Cenozoic complex is the ubiquitous presence of oleanane molecule in oils.

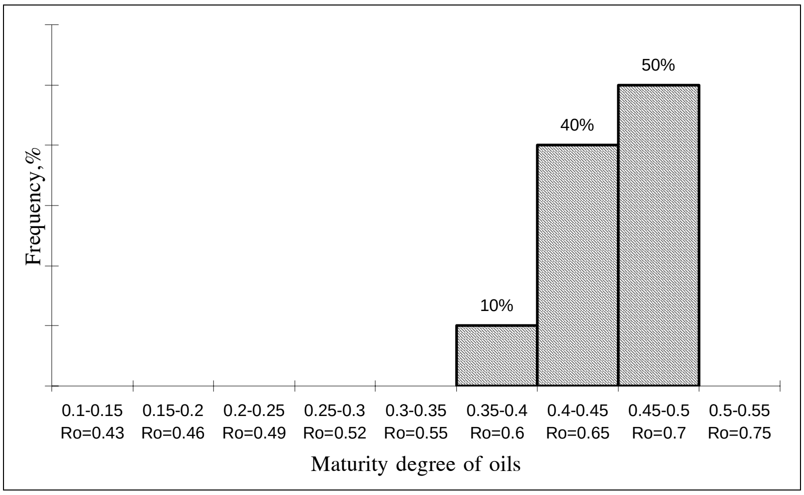


Fig. 7.17. Middle Kura depression:
Frequency distribution of oil fields by maturity degree of oils.

It is necessary to emphasize that relatively low degree of catagenic conversation of Middle Kura depression oils (R_0=0.58-0.75%) correlates well with maturity level of scattered OM of the enclosing Paleogene deposits being in interval of catagenesis gradation MK_1-MK_2 (R_0=0.65-0.85%) (1). This perfectly testifies the syngenesis of oils to the Paleogene complex and allow affirming the high prospective of the Mesozoic oil producing and accumulating deposits which underlay the Eocene complex concerning the discovery of more maturated oils and condensates.

In the Pliocene fields of SCMD concentrated within Lower Kura, Shemakha-Gobustan and Absheron troughs, Baku and Absheron archipelagoes the degree of oil maturity varies within very high limits - from R_0=0.45 up to 0.67%. The main mass of the Pliocene fields (i.e. reservoir age) of SCMD (81.58%) consists of the objects with average values of this parameter within R_0=0.53-0.63%. It shows the low degree of conversation of OM of the source rocks. On this background one can distinguish the fields with very low maturity R_0=0.5-0.53% in volume of 13.16% and insignificant number of fields with relatively maturated oils R_0=0.7% consisting 5.2% of all fields. Histograms of frequency distribution and graphs (**Fig. 7.18 and 7.19**) show visually the qualitative ratios of the Pliocene objects on oils' maturity in oil-bearing regions. Proceeding from the mentioned graphs oils of Absheron peninsula and Shemakha-Gobustan trough are differed by the lowest conversation (R_0=0.43-0.56%).

The increased maturity is typical for oils of Lower Kura depression and the fields of Baku and Absheron archipelago (R_0=0.62%). At the same time the principal difference of the fields of these regions of SCMD is expressed in very opposite ratio of share of the Paleogene - Lower Miocene and Diatomic complexes in reservoirs' saturation.

The maturity of the oils in the mud volcano seeps, expressed as the equivalent vitrinite reflectance (R_0) calculated from the sterane aromatization level (C_{28}triaromatic/C_{28}triaromatic+C_{28}monoaromatic), indicates a low maturity level (R_0=0.46-0.64%). The application of other maturity parameters, like hopane and sterane isomerization ratios, etc. is not possible due to the very high biodegradation and oxidation of the oils. It should be noted that such low maturity is typical for the oils of the fields in the studied region and the Caspian Sea. Those oils very rarely reach the value of R_0=0.68%. As rule R_0 is 0.61% (**Fig. 7.20**).

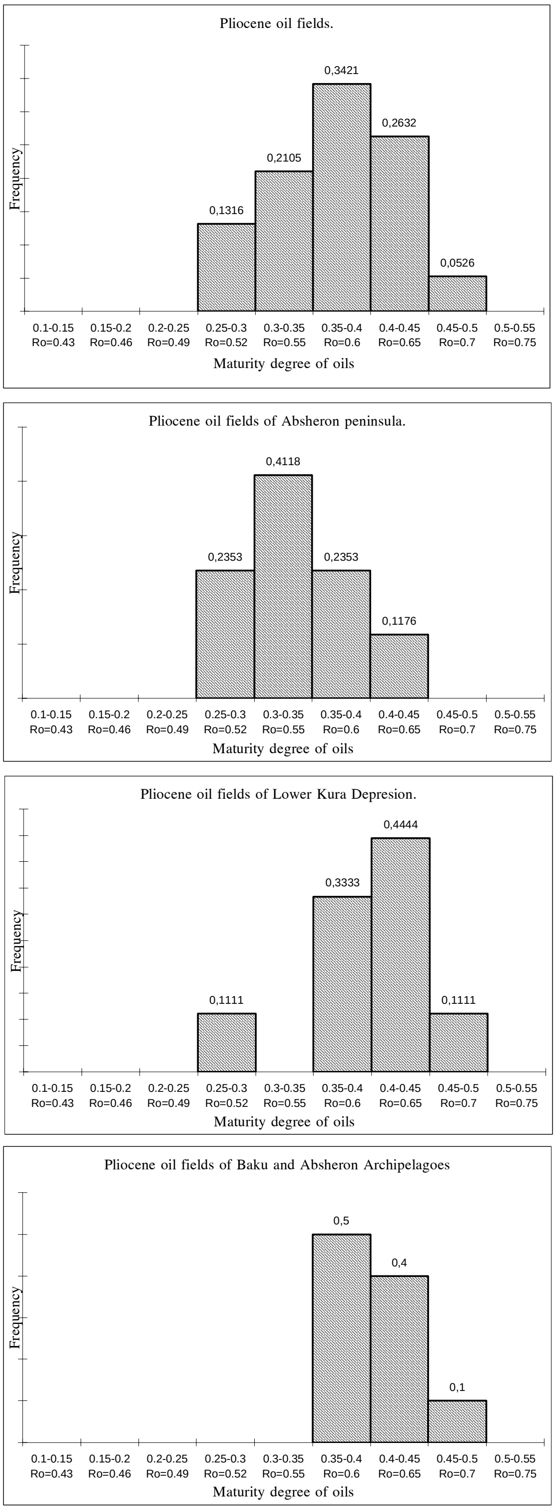


Fig. 7.18. Frequency distribution of Pliocene oil fields by maturity degree of oils.

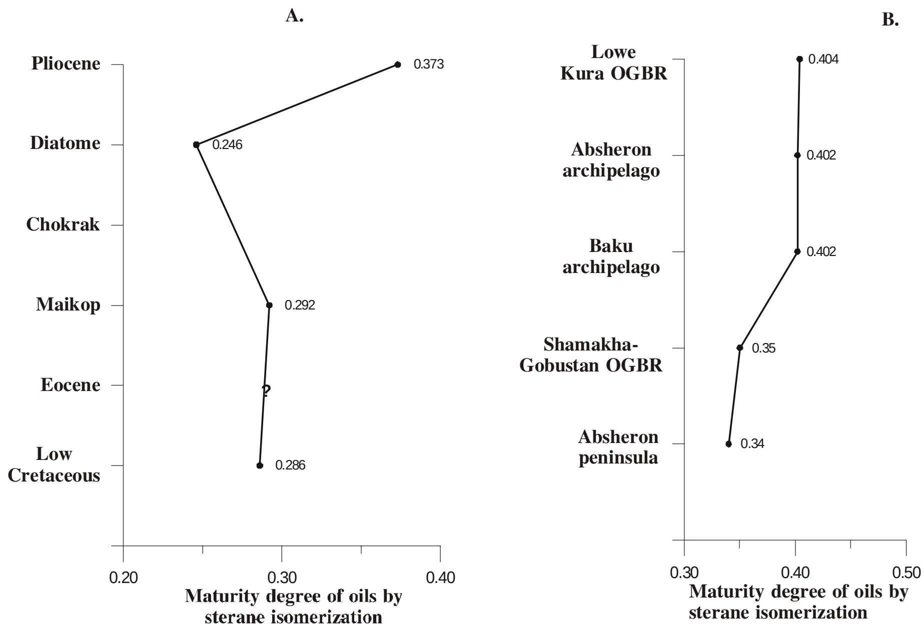


Fig. 7.19. Plot shows changing maturity degree of oils in stratigraphic section (A) and in OGBR (B) of KSCB.

Stages of hydrocarbon generation.

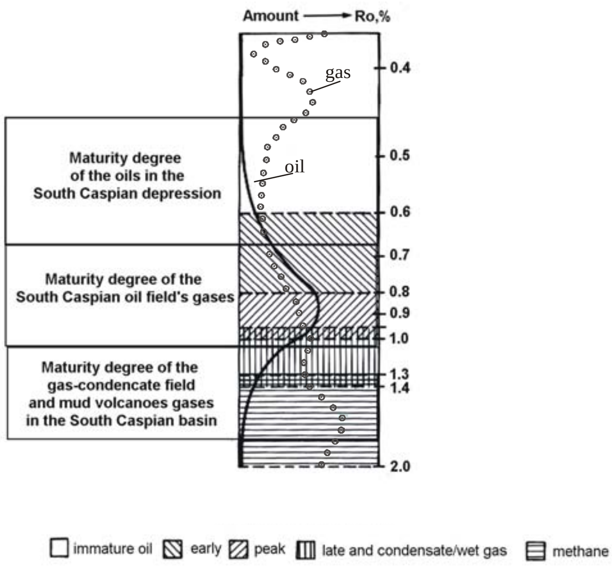


Fig. 7.20. Schematic plot of maturity (in R_o) against intensity of hydrocarbon generation showing vertical zonality of hydrocarbon formation in the SCB..

7.2.8. Hydrocarbon gases.
Isotope-geochemical compositions

Reservoired and mud volcano gases. The Kura-South Caspian Basin and surrounding mountain ranges are favourable for studying natural hydrocarbon gases. Numerous gases of different chemical composition and type occur within a small region (Abikh, 1939; Veber, 1935; Kovalevski, 1940, Dadashev, 1963). This variety is related to the structural contrast between the existing deeper depression of the South Caspian and the folded uplifts of surrounding Greater and Lesser Caucasus, Elburs and Kopetdag mountains. The South Caspian Basin is characterised by a high sedimentation rate (up to 1.3 km/MA), and enormous thickness of sedimentary cover (up to 30 km). The Quaternary - Pliocene complex (up to 10 km thick) consists predominantly of shaly, terrigenouis rocks. A low heat flow (25-50 mW/m^2) and abnormally high pressure (with anomaly ratio up to 1.8), also characterise this basin. Finally, there is considerable faulting and fracturing of the sedimentary cover and tectonic activity. All of these create favourable conditions for the seeping of natural hydrocarbons to the surface, especially the areas associated with mud volcanoes, ground water and faults. The most active gas seepage are within a thick series of Mesozoic and Cenozoic sedimentary rocks that have undergone intensive tectonism (**Fig. 7.21**). The annual production hydrocarbon gases by mud volcanoes is estimated to be $3x10^8\ m^3$. Comparable quantities of gas are discharged from the central Lesser Caucasus mountain and fold range, where intensive volcanism occurred during the Mesozoic and Cenozoic eras. Near-surface gas seeps, which are 90% CO_2, are confined mainly to the highly faulted and fractured areas in various volcanic, metamorphic and sedimentary terranes. Nitrogen gas seeps are confined to the southern and northern slopes of the Greater Caucasus mountain, which are tectonically quieter (Guliyev, 1984).

Free gas of oil/gas and gas/condensate accumulation is HC gas with minor content of CO_2 and N_2 (Dadashev, 1970). Methane is major component in oil and gas accumulation; the most typical concentration of the component is following: methane 85-89%, ethane 1-5%, propane 1-3%, isobutane and normal butane 0.1-0.5%, nitrogen 0.1-2%, carbon dioxide 0.2-2%, helium $(1-2)x10^{-3}$%, argon $(2-4)x10^{-2}$%, hydrogen $(1-4)x10^{-3}$%. Gas of condensate fields are characterised by higher methane concentration (92-96%), low concentration of C_2, C_3, C_4, C_5 (2-4%), CO_2 (0.2-0.6)%, N_2 (1-2)%, He $(1-2)10^{-3}$%. Average composition of gases accumulated in different age reservoirs in the South Caspian Basin is given in **Table 7.5** (Dadashev, 1964).

Table 7.5. Average composition of gases accumulated in different age reservoirs in the South Caspian Basin (in %).

Stratigraphic unit	Sample size	$CH_4+C_2H_6$	C_3H_8	C_4H_{10}	C_5H_{12}	CO_2
Absheron	41	94.62	1.96	1.56	0.56	1.30
M.Pliocene (PS)	350	91.72	0.84	0.64	0.60	6.20
Chokrak	9	95.50	1.19	0.98	0.63	1.70
Oligocene-L.Miocene (Maikop)	48	86.24	3.24	2.09	1.33	7.10
Eocene (Koun)	1	84.62	5.50	6.22	2.96	0.70

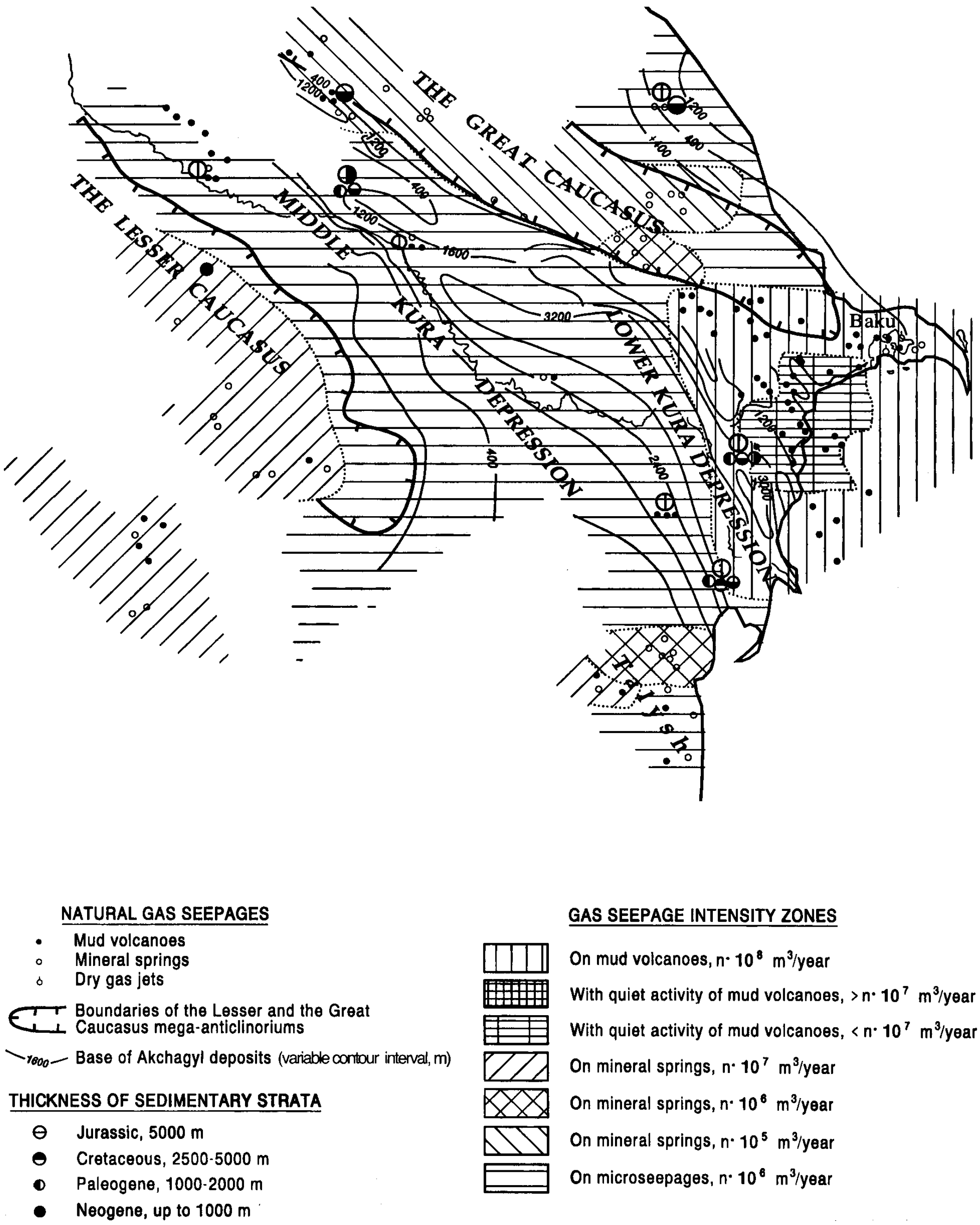


Fig. 7.21. Schematic map of location of surface gas seepages in the western part of South Caspian basin.

Isotopic composition of methane carbon in oil and gas fields widely ranges from -30 to -61‰ ,with mode in the range from -35 to -50‰. Age of reservoirs from the Quaternary to the Upper Cretaceous. In interval of depths 300-4500 m where mainly oil gases are spread the average isotopic composition is about -45.0‰ and by the increase of the depth the content of heavy carbon isotope increases. As a result of analysis there is no correlation between age of rock and isotopic composition of carbon of methane though the tendency of increase for heavy carbon (^{13}C) can be noted here. More distinct dependence is established between δ^{13} C of methane in oil and gas deposits and the depth. It can be confirmed with experimental and theoretical data. The isotopic composition of carbon in methane from mud volcanoes can be observed in **Fig. 7.22**. It is expressed is isolated areas and zones with similar isotopic composition. Thus, the "lightest" methane is found in gases from mud volcanoes in the Lower Kura basin, whereas the gases in the Shamakha-Gobustan region are isotopically heavy. Mud volcanoes in the Absheron peninsula can be divided into three distinct groups on the basis of the isotopic composition of carbon in methane. The first group includes the Abikh, Uchtepe, Akhtarma and Garadag volcanoes - (δ^{13} C: -35.9 to -41.5‰), the secondary group includes the Shorbulak, Gekmaly, Bozdag-Gobu and other volcanoes - (δ^{13} C: -44.6 to -44.6‰), and the third group the Bog-Boga and Kirmaki volcanoes (δ^{13} C: -55 to -60‰).

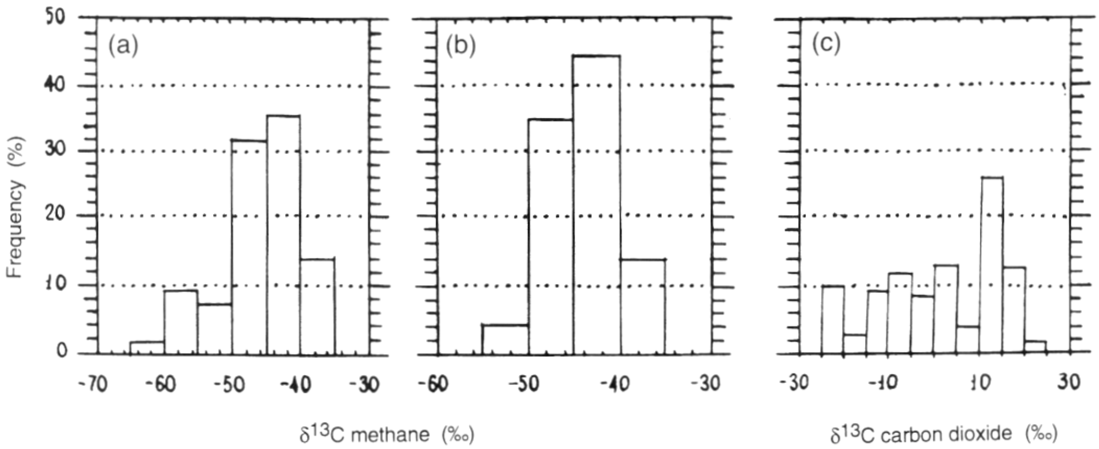


Fig. 7.22. Distribution of methane δ^{13} C in (a) mud volcanoes, (b) petroleum fields and (c) carbon dioxide δ^{13} C in mud volcanoes in Azerbaijan.

Theoretically, where the gas formed is wholly preserved, the section should contain a series of zones of gas generated at different levels, with δ^{13} C values varying from about -70/-75/ to -25/-30‰. In actual geological conditions, the value of δ^{13} C from methane in oil and gas accumulations varies in fact within a narrower range, from about -35 to -50‰, with an average of -44 to -45‰.

One of the possible reasons for the varying isotopic composition of carbon in methane in different areas is the varying degree of preservation of gas; i.e. the degree of degassing of the deposits. Loss from the rock matrix of biogenetic methane or methane from an early stage of organic matter maturation, i.e. isotopically light methane, may lead to the accumulation of isotopically heavy methane; in contrast if these gases are preserved then more isotopically light methane may be present due to the mixing of various generations of gas.

The model proposed for the formation of the isotopic composition of carbon in methane does not deny the possibility of other mechanism operating which may cause significant variations in the δ^{13} C values in methane gases from different regions and fields. Thus, for example, different initial types of organic matter (alinic or arkonic) may lead to variations; or the breakdown of oil at great depths may form methane characterised by an elevated content of isotopically light carbon (δ^{13} C up to -55 to 60‰).

In terms of the theoretical model outlined above, marked variations in the isotopic composition of carbon in methane from mud volcanoes of the Lower Kura basin and the Shamakha-Gobustan region are probably due to different degrees of preservation of gases from different catagenetic levels. This ties in well with the geological development of the region.

Judging from data from isotopic (average δ^{13} C methane -47‰) and chemical (average total heavy hydrocarbons, 2.1%) analyses, the gases from the volcanoes in the Lower Kura basin are the products of an early stage of organic matter maturation, corresponding to the initial and middle stages of catagenesis, whereas gases from the Shamakha-Gobustan region (average δ^{13} C methane -41‰; average total heavy hydrocarbons 0.1%) are mainly represented by methane from late and mature catagenetic stages (**Fig. 7.23**). It is evident that the main reason for the difference in isotopic composition of the gases is the varying degree of degassing of the deposits. Gases generated at an early stage in the Shamakha-Gobustan region, due to their specific geological and tectonic history have been lost. The area is characterised by a complex geological structure, high seismicity, and the presence of a large number of faults. The significant amount of degassing of the deposits in this region is confirmed by the numerous mud volcanoes which erupts frequently, and also by the absence during drilling of major gas and oil accumulations.

The Lower Kura basin is covered by a thick (5-6 km), almost horizontal successions of the Pliocene to Quaternary deposits. The number of volcanoes in the area is considerably less than in Shamakha-Gobustan, and they erupt relatively infrequently. This fact, together with the presence of major accumulations of oil and gas (Kursangi, Garabagly, Neftechala and others) demonstrate that hydrocarbons are preserved better in this region compared to Shamakha-Gobustan.

Correlation of δ^{13} C values of methane with the degree of sediment degassing (i.e. with the degree of preservation of gases generated) is confirmed by data from the isotopic composition of carbon in methane in mineral springs on the southern slope of the Greater Caucasus. Isotopically light methane (δ^{13} C -55 to -69.3‰) occurs within mineral waters which are expelled from rocks of mainly Neogene age, whereas isotopically heavy methane is associated with rocks of Jurassic and Cretaceous age. This shows that organic matter in Cretaceous and Jurassic rocks is generating isotopically heavy methane at a mature catagenetic stage, and methane generated at earlier stages of catagenesis has been degassed. In contrast, organic matter in Neogene deposits lies within the early catagenetic stages, and no methane from mature catagenetic stages is present within the gases from mineral springs associated with the Neogene deposits.

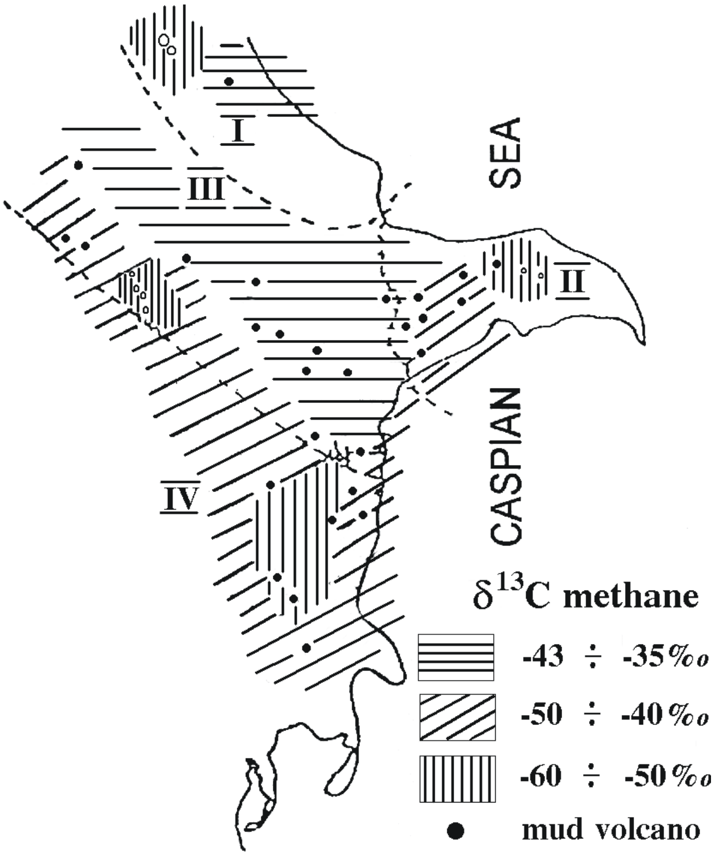


Fig. 7.23. Zonality scheme of isotope composition of carbon in methane from mud volcanoes in onshore Azerbaijan (Dadashev et al., 1986).

The established relationship between the δ^{13} C of methane in mud volcanoes and mineral springs with the degree of sediment degassing may be used for a relative evaluation of the prospectivity for gas of the different regions in which mud volcanoes are developed.

Mud volcanoes are developed in the South Caspian Basin in areas where the thickness of the sedimentary cover varies from 8 to 25 km. In these conditions, as was noted above, virtually the entire range of gas genesis is occurring, from biogenic to apocatagenic gas. The occurrence within the gases of mud volcanoes of isotopically light methane shows that conditions for its preservation at depth are good, and there is also the possibility of isotopiocally heavy methane occurring at great depth.

From the description of mud volcanoes on the western margin of the South Caspian Basin given above, it is possible to recognise three groups according to the prospectivity for gas at great depths. Data from the study of δ^{13} C in methane and carbon dioxide gases from the mud volcanoes of Azerbaijan, set out in, are also taken into account.

The first group includes the volcanoes of Bog-Boga, Kirmaki, Durovdag, Gushchu and others, which have methane isotopic compositions of δ^{13} C = -48 to -60‰ and C in carbon dioxide of -10 to 25‰. These data show that the gases provided initially to the mud volcanism formed at early and middle catagenetic stages, and the carbon dioxide in the gases is genetically related to oil, dispersed organic matter and water-soluble organics. In the deep zones where these volcanoes develop (the destruction of oil is not examined), the gases of precisely the generations mentioned may be found; gases with isotopically heavier carbon in methane are generated at greater depths.

The second group includes the volcanoes of Matrasa, Airantekyan, Sagiyan, Goturdag and others with isotopic compositions of carbon in methane of δ^{13} C = -43 to -48‰, typical of the middle stages of organic matter maturation; and δ^{13} C on carbon dioxide of 10 to -10‰, showing that the carbon dioxide is related to organic matter and oil and, particular, to formation from the decomposition of organic matter in an anaerobic environment.

Finally, the third group includes the volcanoes of Maraza, Pirekeshkyul, Khydyrzyndy, Demirchi, Utalgi and others. These are activated by gases forming at the late catagenetic stages, with δ^{13} C in methane of -35 to -43%, and contain carbon dioxide forming from the destruction of carbonates at great depth and the anaerobic destruction of organic matter: δ^{13} C of carbon dioxide = +10 to +20‰.

Gas Dissolved in Formation Waters. In composition the gases dissolved in formation waters are close to the gases of petroleum fields. The predominant components are: CH_4 - 90%, C_2H_6+ - 2-4%, CO_2 - 0.1-5%. Gas saturation of formation water varies widely: from 100 to 3500 cm^3/l. The most pronounced characteristics of distribution of gas dissolved in water are the increase of gas saturation of formation water, dissolved gas pressure, and dryness factor in the direction of regional subsidence with depth. This trend was identified both for individual anticline zones and for fields and oil/gas region in overall.

Adsorbed Hydrocarbon Gas. Sorbate gases were analysed from cores from the Middle Kura depression, including Saatly super-deep well (SG-1) and its stand-by. HC sorbate gases content in sedimentary rocks is in general not high, up to 1.83 cm^3/kg. The content is lower in volcanic rocks than in sedimentary ones (0.2-0.4 cm^3/kg).

Gases of mineral springs. Mountain / folded structures, framing the Kura depression, were studied with the use of gases from mineral springs. Four types of springs can be identified based on chemical composition of the gases: methane, CO_2, nitrogen and mixed ones.

Isotopic carbon composition of methane from the mineral springs of the Greater Caucasus varies from -25‰ to -70‰, with maximum between -35 and -45‰. Isotopic composition of CO_2 carbon from mineral springs widely ranges from 1.0‰ to -10‰; the distribution has a pronounced maximum within the interval from 0 to -5‰. Isotopic ratio, He^3/He^4 varies for methane and nitrogen mineral springs of the Greater Caucasus from 1.5 to $2.4x10^{-6}$. In carbonic - acid mineral springs of the Greater Caucasus it is slightly higher, $(0.6 \text{ to } 8.5)x10^{-6}$; while high numbers $(8.5\text{-}15.0)x10^{-6}$ are typical for carbonic acid waters of the Lesser Caucasus.

Gas Hydrates. Cases of submarine gas hydrates were accidentally discovered in the southern basin of the Caspian Sea (**Fig. 7.24**) in 1979 during an expedition of the Institute of Geology. Clay deposits with inclusions of hydrates up to 5 cm across were brought up by a bottom grab from a depth of 480 m on the Vezirov anticlinal high (the Shatski ridge) (D-9), Azizbekov's raising (D-6), Abich's bank etc. Inclusion of gas-hydrates were observed along the whole column and that is more interesting in the upper layer (0-10 cm) in the boundary part of nearbottom water. visually a content of gas hydrates in samples varied within 2-3% to 25-35% by core's volume and it varied significantly even within one sediments column.

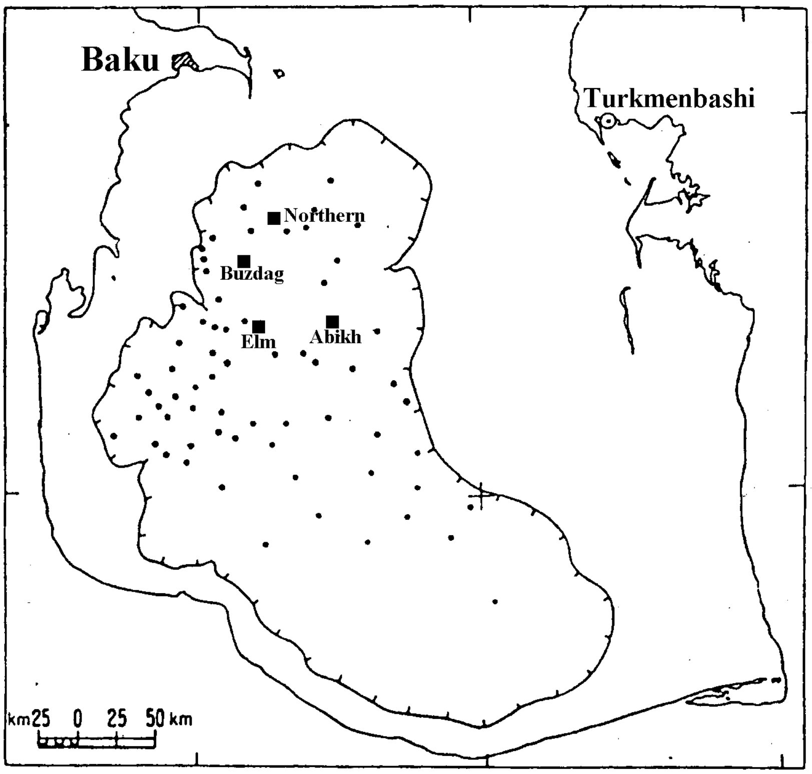


Fig. 7.24. South Caspian gas-hydrate-bearing province.

Gas-hydrates represented ice-shaped formations sometimes right, often irregular of acute-angled form, transparent or color of diluted milk with water, often covered by yellow-green oil film. gas, emanating by hydrates decomposition, was burning by sooty flame. Gas extracted from the hydrate-containing sediments by the thermal-vacuum method contained up to 28% methane homologous, hydrogen sulphide was present, and there were clayey-calcareous nodules and saline pore water with a mineralization of 26.2-30.1 g/l, in the sediment. It was concluded that the gas-hydrate manifestations coincide with a mud volcano. The chemical composition of gases of the revealed hydrates is listed in **Table 7.6**.

Table 7.6. Content of HC gases in aggregates of gas-hydrates

Mud volcano	Sample interval	Content of components, in %					
		CH_4	C_2H_6	C_3H_8	iC_4H_{10}	nC_4H_{10}	C_5H_{12}
On Vezirov's str. (D-9)	0-0,2m	80,8 87,8 74,2 58,7	13,6 10,4 17,0 19,4	4,2 1,8 6,0 15,8	0,3 0,1 0,7 2,5	0,4 0,4 0,9 2,0	0,02 0,06 0,11 0,68
On Azizbe-kov's str. (D-6)	0-0,4m	81,4	15,3	1,6	0,2	0.7	N.O.

Moreover in Absheron area by results of 2D seismic reflection data high velocity zones were revealed which are connected to presence in deposits of gas hydrates.congestions (**Fig. 7.25**) (C.C.Diaconescu, et al.,2001).

In comparison with gases from onshore mud volcanoes of the South Caspian Basin gases from hydrates and sediments of Buzdag, Elm and the mud volcano on Abikh bank are sharply enriched in methane homologues. The high abundance of homologues suggests in particular a catagenic origin for the gas; this is confirmed by the isotopic composition of the carbon in the methane (δ^{13} C $_{CH4}$ = -44.8÷-57.3‰, δ^{13} C $_{C2H6}$ = -25.7÷-28.4‰) and the association of the gas with oil.

7.2.9. Estimation of the hydrocarbon generation focuses

As to Veivreck et. al. the most subsided zone in the Caspian Sea the effective "oil window" is determined at depth 6000-10700 m with a peak of generation in interval 7800-90000 m (Oil and Gas Petroleum System…, 1996).

According to the 12th second regional profile (**Fig. 7.26**) thickness of the sedimentary cover in the most subsided area in the central South Caspian basin (between structures Zafar-Mashal and Alov) is 22 km (Mamedov, 1994).

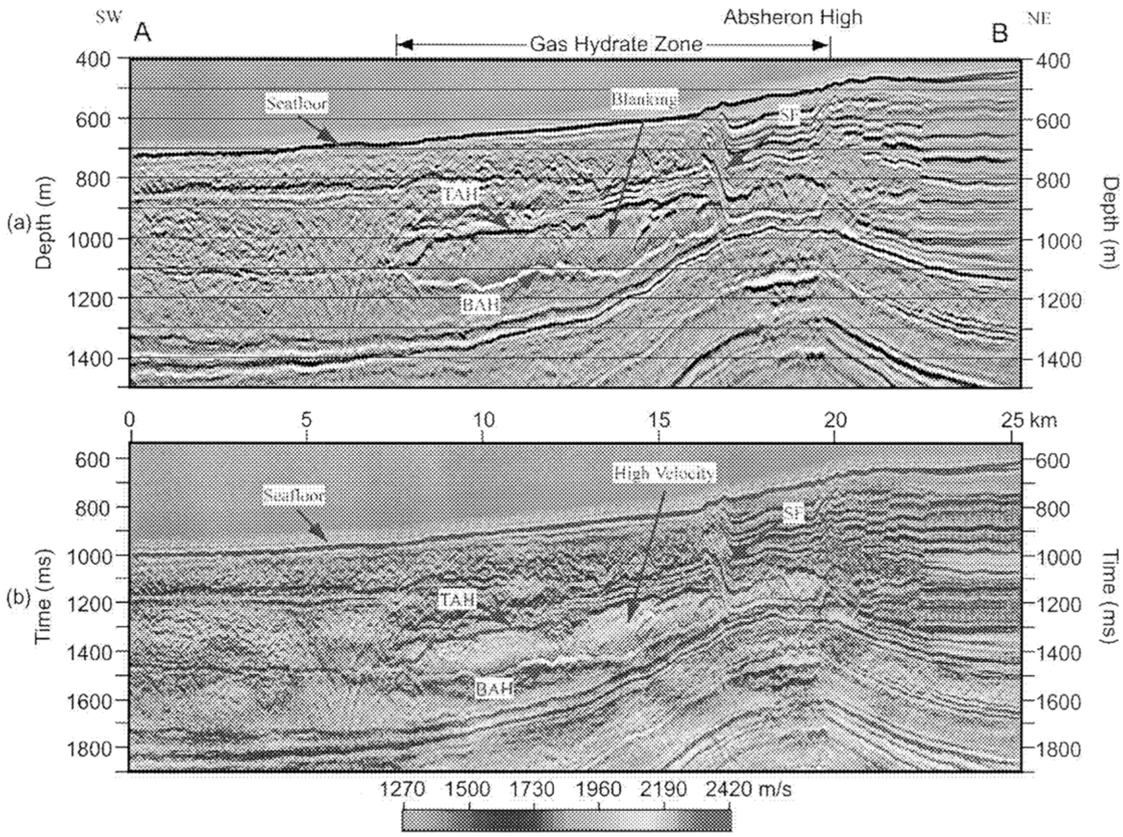


Fig. 7.25. Composite display showing: (a) The inferred top (TAH) and base (BAH) of the Absheron hydrate bound an ι200m thick depth-restricted hydrate layer situated ι300mbsf. Positive polarity (peak) reflection are shown in black (e.g. seafloor and TAH); negative polarity (trough) reflections are shown in white (e.g. BAH); (b) Interval velocity field overlaying the migrated time section. SF stands for shallow faulting. Both seismic section are vertically exaggerated approximately 8:1. (after C.C.Diaconescu, et. al., 2001)

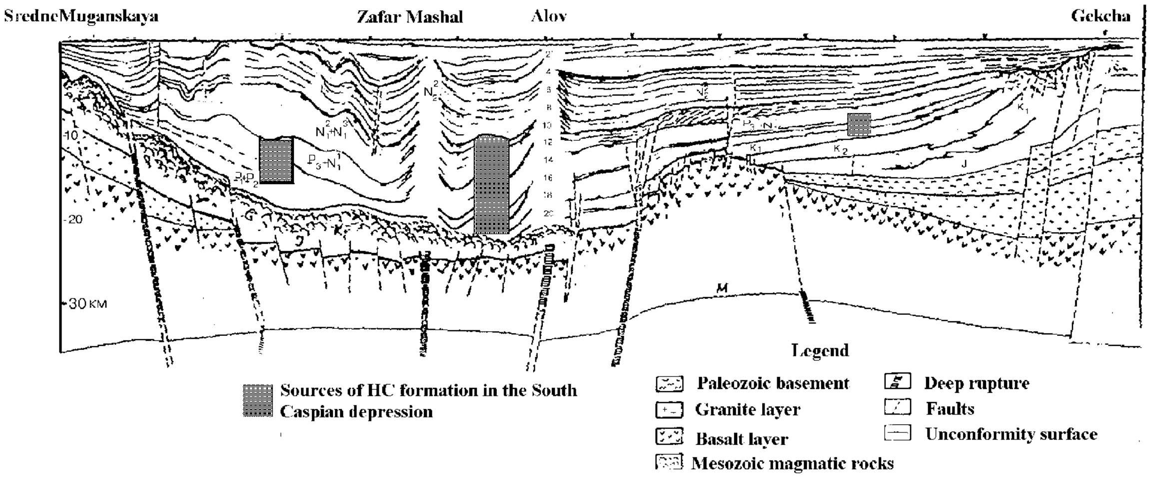


Fig. 7.26. Predicted location of hydrocarbon generation sources on the 12th second regional seismic profile across South Caspian basin

The Oligocene-Miocene deposits (Maykopian suite) - seismohorizon 5, Middle-Upper Miocene (seimohorizon 6) and Productive Series (seismohorizon 7) are the thickest.

The first two complexes have a high hydrocarbon-generation potential. For this reason it is interesting to determine correspondence of the depth of their occurence range to the supposed intervals of the spread of "oil and gas"windows" in the South Caspian basin (SCB).

Lerche et al. (1997) strucructed graphs of paleotemperatures for different areas of the SCB.

According to the prediction models in the area of the Azerbaijan shelf and continental slope located between structures Sabail and Zafar-Mashal, temperature of 60^0 is at depth 3000 m; 100^0-6500m; 200^0-14000 m (**Fig. 7.27**).

The reflectivity of vitrinite R_o reaches threshold values. R_o=0.6 % at 10 km depth; about 0.8 %-10.5 - 11km; about 0/9 %-12 km; 1.3 %-13 km; 1.6%-14 km; 2.0 %-15 km (**Fig. 7.27**).

According to the predicted values of T and R_o in the west shelf and the continental slope of the SCB the zone of the "oil window" is subsided at depth of 10 km with the lower boundary 13 km. Oil-generation peak falls to interval 11-12 km. One can make a prediction that the "gas window" is located in interval 13-14 km (**Fig. 7.27**).

With a prediction like that according to the above mentioned regional profile (**Fig. 7.27**) the main phase of hydrocarbon generation fits the interval of the spread of the Maykopian suite.

According to I. Lerche's et. al. predictions (1997) for the abyssal zone of the South Caspian temperature in the sedimentary section is 100^0 at depth 7-8 km and 200^0 - at depth 15 km (**Fig. 7.27**). It is the most subsided area in the regional seismic profile located between structures Zafar-Mashal and Alov.

R_o=0.6 % is marked in interval 10-12 km; about 0.9 % - 14-15 km; 1.3% - 16 km; 1.6 %-17-18 km (**Fig. 7.27**).

One can suppose existence in the most subsided zone in the central SCB - the site of Zafar-Mashal-Alov structures. "The oil window" zone is located in interval 10-16 km with a peak of oil generation 14-15 km. "The gas window" is located in interval 16-18 km (**Fig. 7.27**). Traditional for the SCB oil source rocks - the Maycopian and the Diatom suites are located in the zone of the “oil window” with a peak of generation which falls to the interval of the spread of the Maycopian deposits (**Fig. 7.26**).

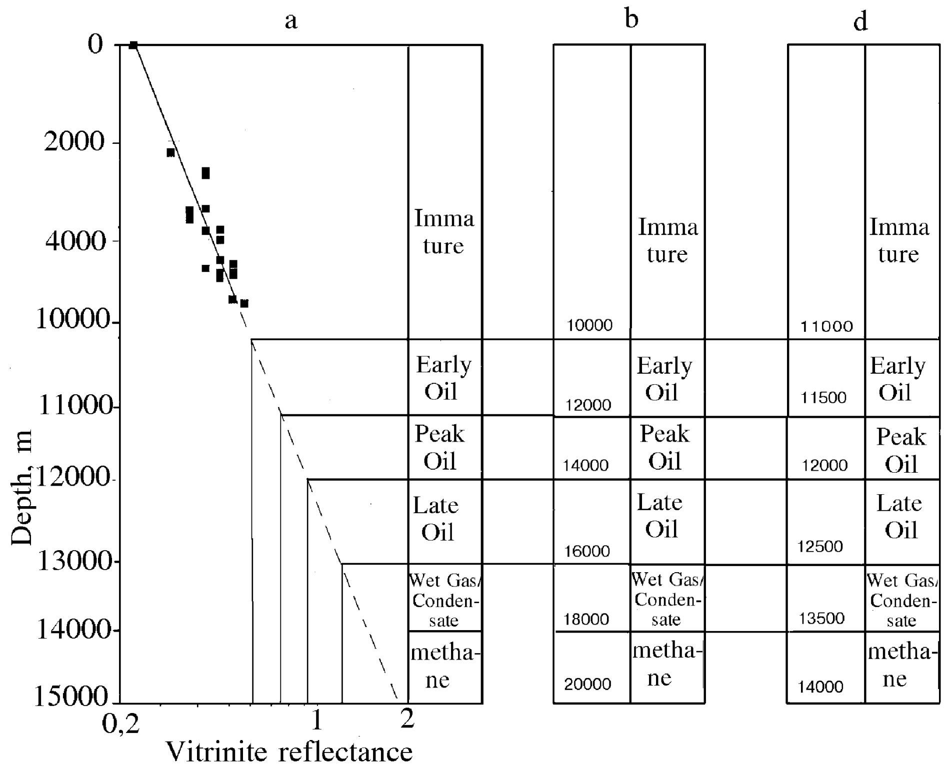


Fig. 7.27. Predicted depth location of HC formation sources in the South Caspian basin
a) Azerbaijan shelf; b) Deep water part of South Caspian; c) Turkmenian shelf

As deep as 20 km one suppose existence of a process of methane generation. Thus, the zone of hydrocarbon generation in the abyssal part of SCB with the thickest sedimentary series extends as far as the basement.

I. Lerche (1997) predicted the location of the main phase of oil and gas generation in the Turkmenian shelf. R_o is 0.6 % there at depth of about 10.5-11 km; 0.77-11.5 km; 0.9-12 km; 1.3-12.5 km; 1.6 %-13-13,5 km; 2.0 %-14-15 km (**Fig. 7.27**). Thus, the upper boundary of the zone of "the oil window" subsides as deep as 10.5-11 km..

One can make a supposition that the main phase of hydrocarbon generation exists in interval 11-13.5 km. This corresponds to the range of the spread of the Eocene-Paleocene and the Upper Cretaceous deposits.

The analysis of the constructed models demonstrates that from the flanks towards the center of the SCB there occurs both a subsidence of the lower boundary of the “oil window” and “gas window” and the decrease of their extension in the vertical section. In the Azerbaijan shelf the range of the occurence of the “oil window” is 10-13 km and of the “gas window” it is 13-14 km; in the abyssal SCB it is 10-16 km and 16-18 km respective; in the Turkmenian shelf it is 11-12.5 km; 12.5-13.5 km. In the central SCB with the thickest sedimentary cover one can suppose existence hydrocarbon window till the upper boundary of the basement (**Fig. 7.26**). The supposed existence of a vast zone of "the oil and gas" windows (up to 10 km) in the central and most subsided SCB allows to predict possibility of the existence of a thick fluid flow in this part of the SCB.

Results of complex geochemical and hydrochemical studies of the bottom sediments, oozy solutions and marine water in the Caspian Sea demonstrated that in the central SCB in the deepwater area of the Azerbaijan sector which can be correlated in space with the most subsided area in the 12 sec regional profile, one can identify a stable multicomponent anomaly accrding to a complex of geochemical, hydrogeochemical and gas indices. The structures Araz, Alov and Amirov are located in this abnormal zone (**Fig. 7.28**).

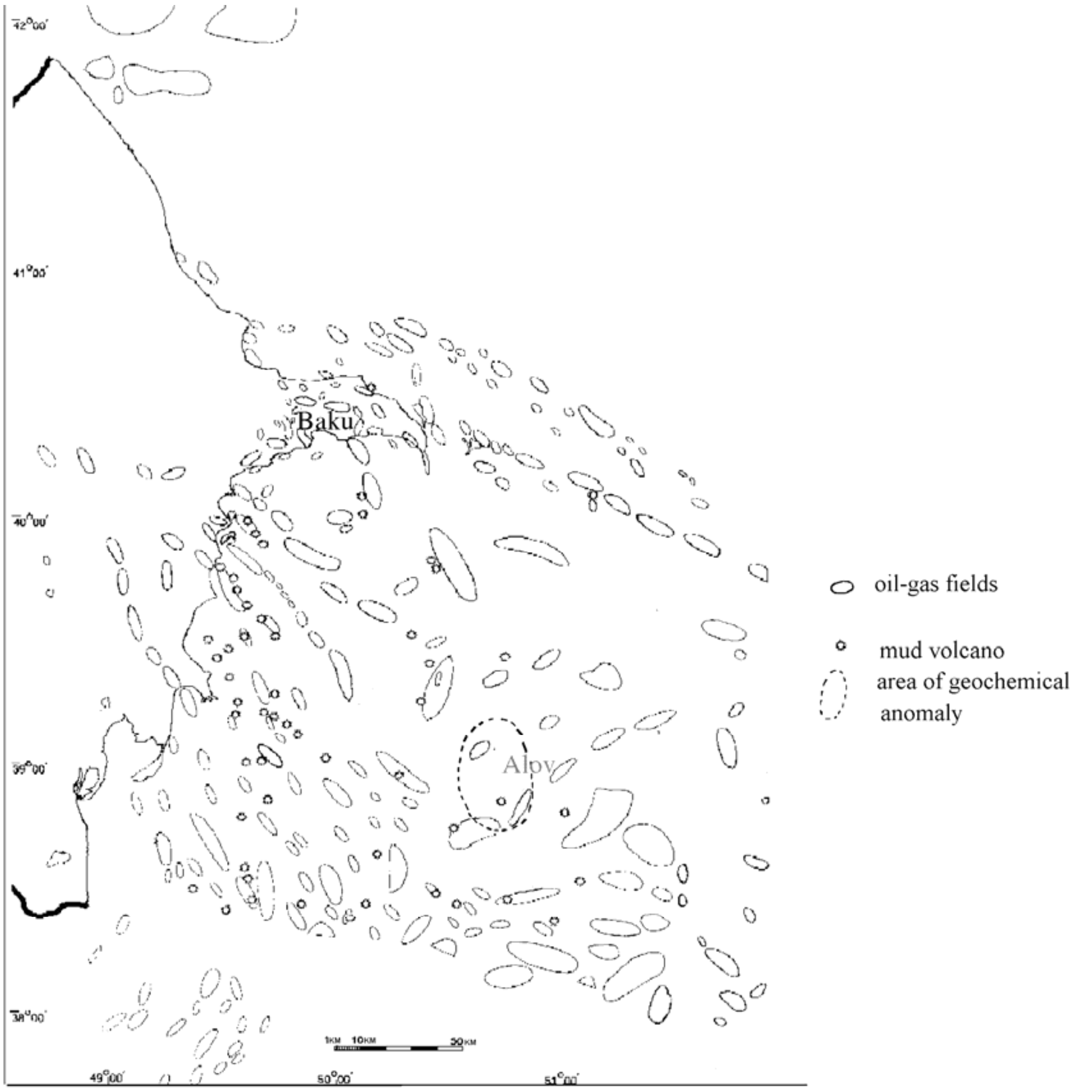


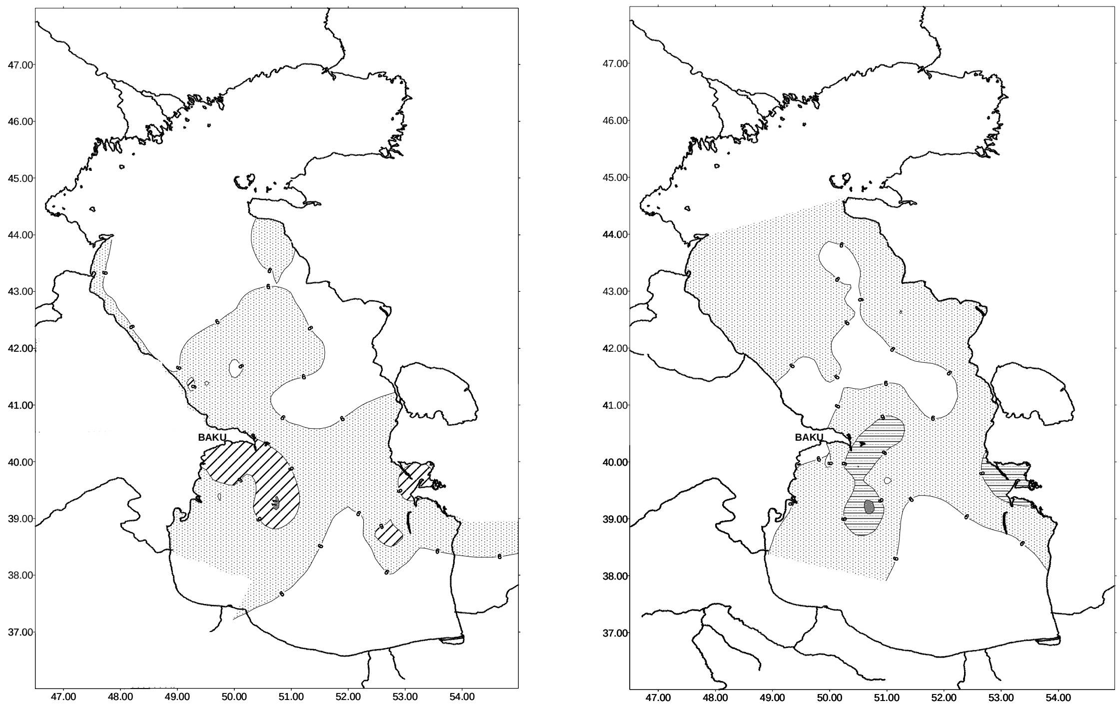
Fig. 7.28. Location of zone of multicomponent anomaly in the central part of the South Caspian

The abnormally high values of the studied indices exist throughout the vertical profile of the deposit and the marine water. A degree of bituminization of the OM grows dramatically in this zone and is 12-13 % at a total syngenetic background of 3 % (**Fig. 7.29**).

The component composition of bitumen changes and the share of oily fraction in it grows up to 45 %. The quantitative prevalence of the oily fraction like that usually occurs when bitumens possess epigenetic character.

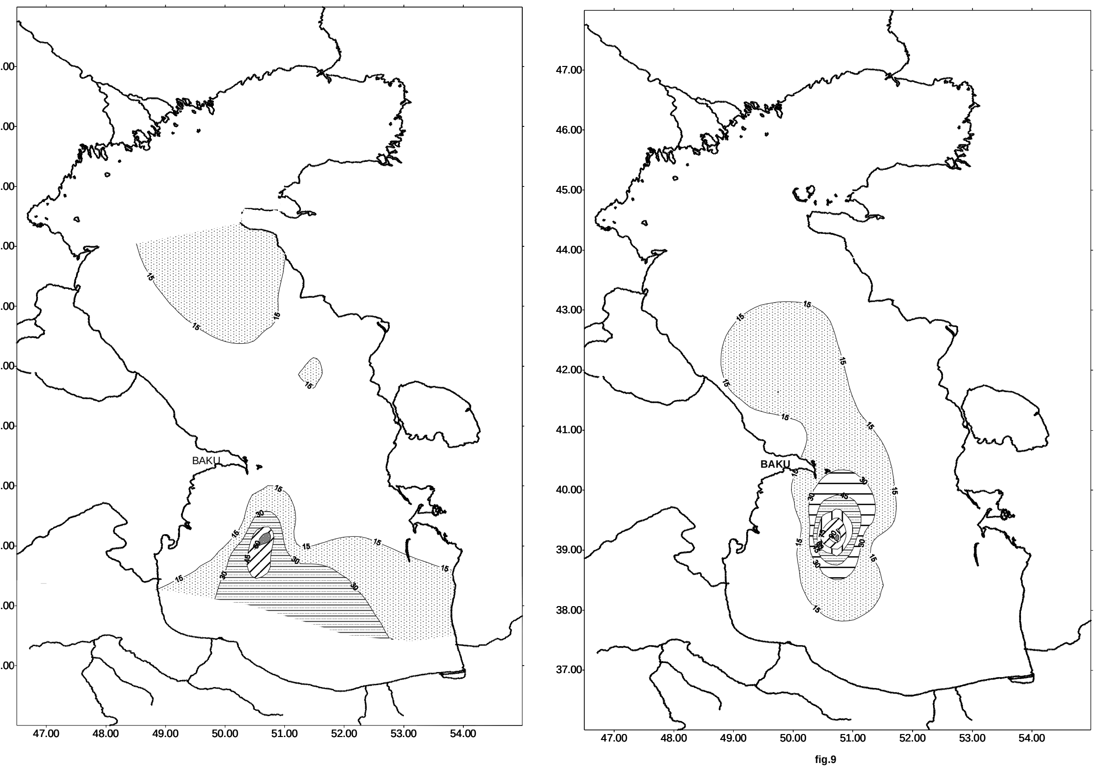
In the oozy solutions in the mentioned zone there exist abnormally high values of some direct indicators demonstrating existence of oil and gas deposits (Zorkin, 1980).This, a ration of ammonium to iodine 4 times exceeds background values in the upper 0.5 m layer of the deposits and 7 times exceeds them in interval from 0.5 m to 1.5 m (**Fig. 7.30**).

The same results were obtained when studying the content of hydrocarbon gases in bottom and surface layers of sea water (**Fig. 7.31**).
Thus, the conducted analysis how that in the central deep-sea part of the South-Caspian depression characterizing by a great thickness of sedimentary cover reaching 22 km, one can observe a multi-component abnormal zone the presence of which proves that the made conclusion dealing with existence of the thick focus of HC generation and fluid flow in that zone. Numerous mud volcanoes located in that zone can be considered as possible channels of fluid flow coming on the surface.



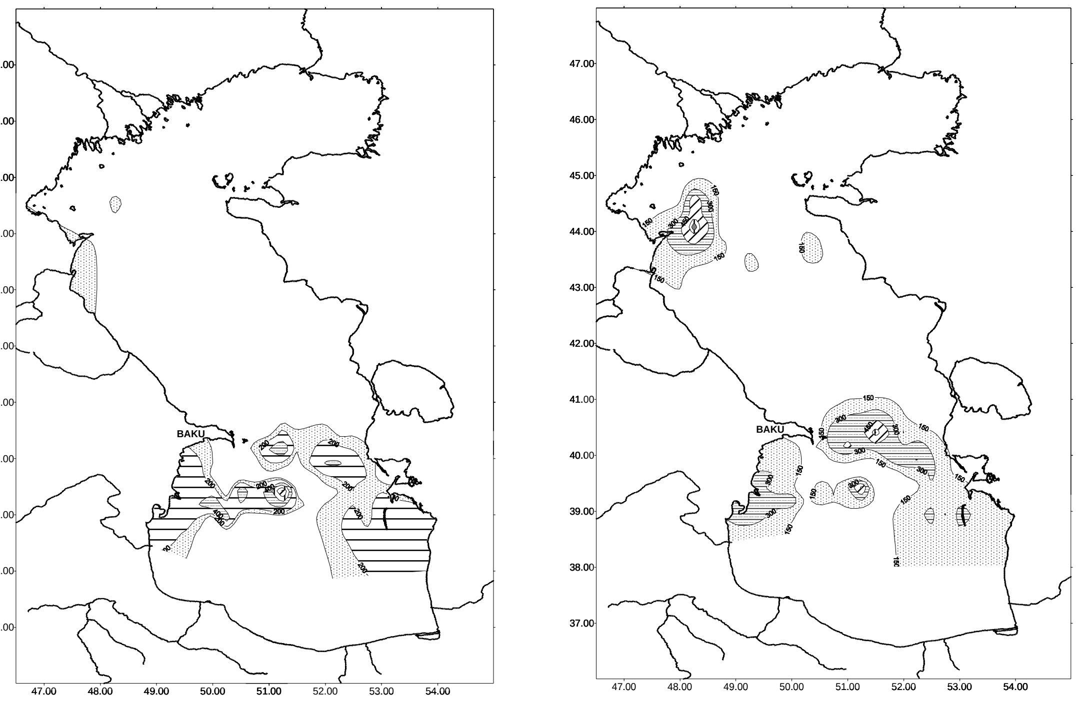
a b

Fig. 7.29. The map of distribution of bitumen coefficient in bottom sediments of the Caspian Sea: a – 0-50cm, b – 50-150cm



a b

Fig. 7.30. Map of distribution of NH4- /J- in bottom sediments of the Caspian Sea: a – 0-50cm, b – 50-150cm



a b

Fig. 7.31. Map of distribution of HC gases in bottom layer of the Caspian Sea water: : a – CH4, b – heavy HC gases

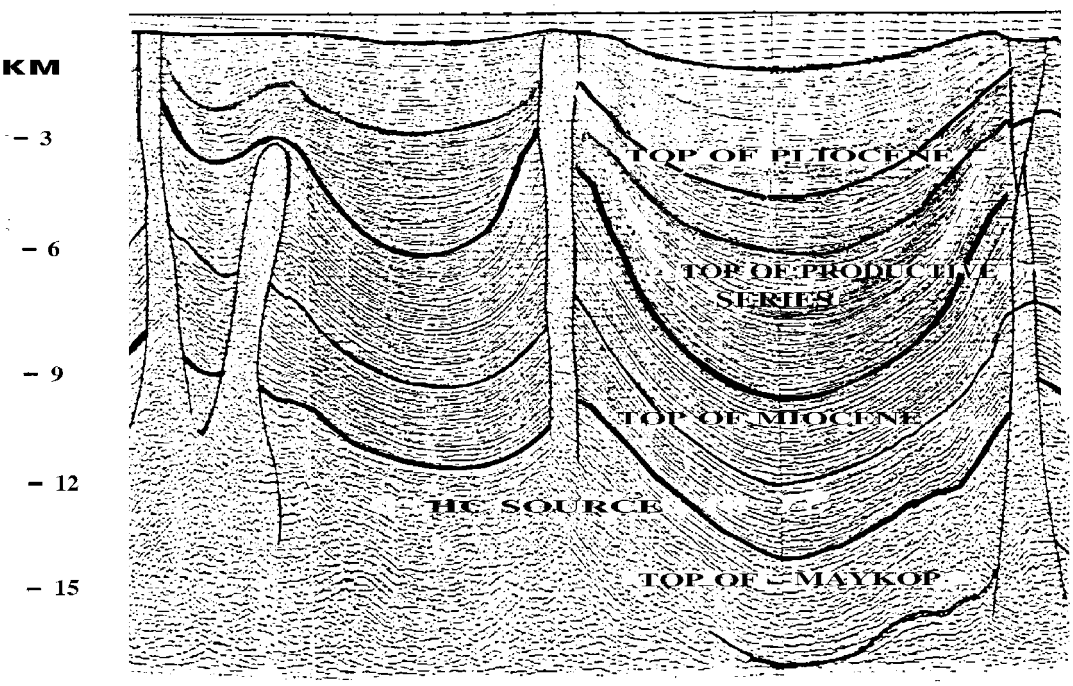


Fig. 7.32. Channels of migration of fluid flow

Determination of the maturity of hydrocarbon gases is based on the calculations of the dependence between the isotope composition of carbon in gases and their catogene maturity (Faber, 1987). On the basis of this dependence and data on vitrinite reflectivity (Ro) in the studied region, one can determine the hypsometric depth of location of the gas source and of the gas from a specific mud volcano. Information about the deep structure of the region where a volcano is located allow us to determine the stratigraphic depth of its root.

To determine the hypsometric and stratigraphic depths of the source of gases from the oil-gas fields and the mud volcanoes we used the relationships between the isotope composition of carbon (ICC) of ethane and its catogene maturity (Ro,%) (Faber, 1987) which is as follows:

$$\delta^{13} C_{(C_2H_6)}(^{0}/_{oo})=22.6 \lg Ro(\%)-32.2. \quad (1)$$

Application of the relationship between the ICC of methane and Ro was not feasible because of a possible isotopic mixing of thermocatalytic and biochemical methane.

Such calculations show that ethane from 8 mud volcanoes (Charagan, Shorbulag, Shikhzagirly, Perekushkul, Kyrlykh-Enikend, Melikchobanly, Airantekan and Bahar), located in different parts of the north-west and north flanks of the South Caspian Basin (**Fig. 7.7**), has R_0 values of 1.3-1.79%. Vitrinite reflectance values in the KSCB have been measured down to depths of 5300 m and extrapolated to the deep-seated horizons. On this basis, the ethane of the studied mud volcanoes in the region is likely to have been generated at depths of 7-8 km. These depths in the north and in the north-west flanks of the depression correspond to Jurassic-Cretaceous strata. In the central, deeper, part of the basin the ethane formation interval is located at depths corresponding to Paleogene-Miocene strata.

The researches of submarine gas hydrates detected in craters of mud volcanoes, have allowed to execute an estimation deep and stratum correspondence of HC gases participating in formation of hydrates in the abyssal parts of Caspian sea, for the solution which ne isotope composition of these gases utilized.

Considering the revealed data of carbon isotopes of ethane in gas-hydrates of the Caspian sea, on the basis of relationship $\delta^{13}C_{C2H6}$ (‰)=22,6 lg R_o (%) - 32,2 shows that maturity degree of ethane varies in range of 1,47-1,94 %, averaging 1,70 and 1,89% accordingly for Azizbekov and Vezirov areas. In accordance 12[th] sec seismic profile ethane of gas hydrate is formed on the depth 10-11km and source rocks for it are Miocene deposits (**Fig. 7.33**).

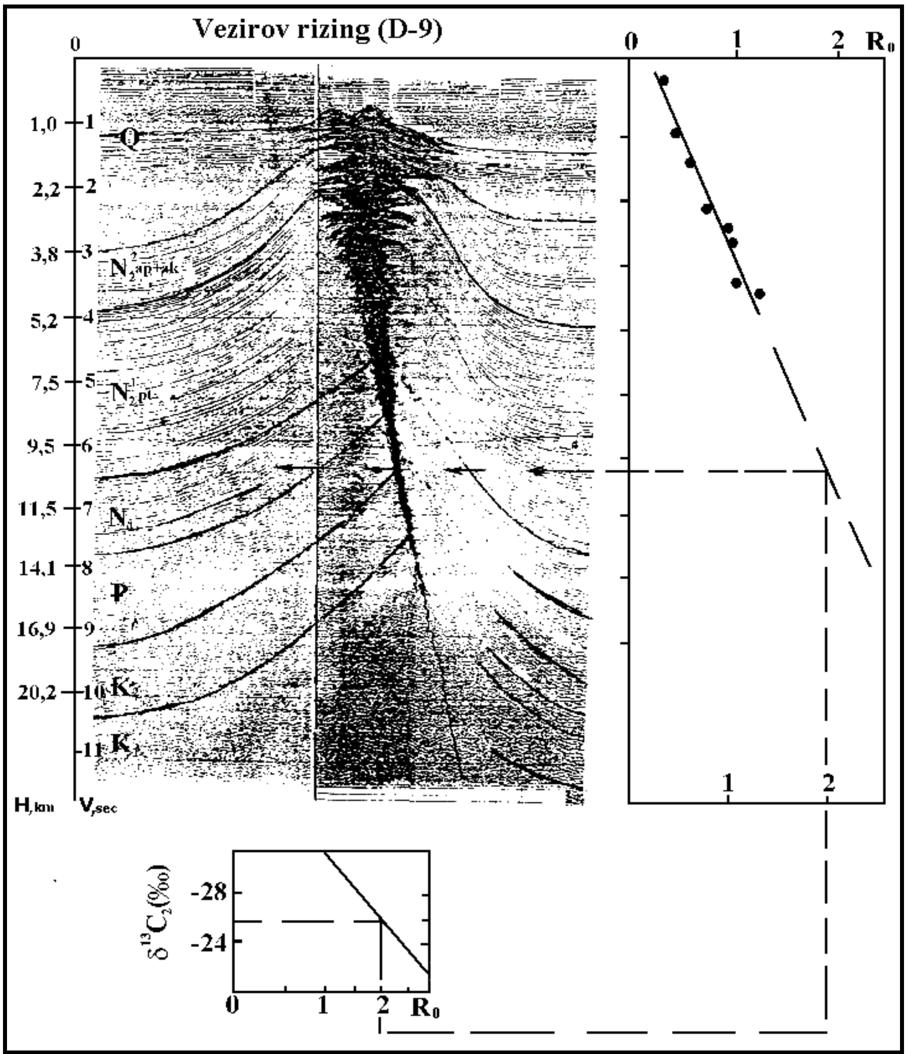


Fig. 7.33. Fragment of 12[th] sec seismic profile demonstrates of depth and stratigraphic source of the gas-hydrate's ethane formation.

The information outlined suggests the existence of several stratigraphically isolated source rocks in Mesozoic, Paleogene-Lower Miocene and Diatom intervals. Thus, the oil and gas formation "kitchens" occur at different depths and different stratigraphic levels. According to the vertical zonation scheme of oil and gas formation (**Fig. 7.20**), all of the oils in the known fields and mud volcanoes correspond to the early stage of the oil window. The gases in the fields and mud volcanoes correspond to the zone of wet gas and methane formation.

VIII. MUD VOLCANISM AS INDICATOR OF THE PHASE AND MECHANICAL UNSTABILITY IN THE RAPIDLY SUBSIDING SEDIMENTARY BASINS

8.1 Mud volcanism and its physical model

Around one third of all mud volcanoes worldwide occur in the eastern Azerbaijan. More than 300 mud volcanoes, on land and under sea water, are known. Their occurrence is rather dense: the number of volcanoes within an area of 16.000 km^2 is as many as 220. Many of these mud volcanoes are particularly large (up to 400 m high). Offshore, ejected muddy breccia forms permanent or temporary islands, and numerous submarine banks over the volcanoes.

Activity of a mud volcano stretches over a long geological interval and may be subdivided into paroxysmal and dormant phases. The active phase of a mud volcano is represented by momentary eruptions after which griffon-dome activity of the dormant phase takes place. Possible period of dormancy between eruptions varies from volcano to volcano. According to the records, the time interval between two eruptions on a volcano may last as long as 4 to 80 years.

Since 1810 in the eastern Azerbaijan almost 200 eruptions have been recorded on some 50 volcanoes. The most active among them is the Lokbatan volcano (see **Fig.. 6.4**) which has erupted 21 times for the last 130 years. Interestingly, it was documented that these eruptions made no impact on volumes of produced oil from oilfield of the same name.

A mud volcano virtually is a natural "well" for sampling of gases, underground waters, muds and oil-stained ejectas from great depths (8-12 km). Rock fragments ejected during eruption may come from different age strata and have size reaching as large as several meters in diameter (Guliyev and Feizullayev, 1997).

Mud volcanoes are developed worldwide mainly along the active tectonic belts which lie along the boundaries between actively converging tectonic plates. Mud volcanoes are known in Mexico, Trinidad, Venezuela. Colombia, Peru, Ecuador, Albania, Italy, Romania, the Iranian and Pakistan, India, Myanmar, Malaya, Indonesia, New Guinea, Taiwan, China, Japan, New Zealand, Russia (on the Kerch and Taman Peninlulas, and in southern Sakhalin), the western Caucasus, eastern Georgia, SW Turkmenistan. The greatest concentration, and most spectacular development, of mud volcanoes in any one region is the South Caspian Basin (Yakubov A.A, et al.,1970),These areas characterised by the following geological conditions:

1) High rates of sediment accumulation, and a thick (8-22 km) sedimentary succession reflected in the gravitational field (all areas of mud volcanism are associated with zones of extreme negative gravitational anomalies);

2) Depositional sequences composed in the lower part primarily of clastic and carbonate rocks, and the upper part of clastics with a predominance of argillaceous lithologies;

3) The sedimentary fill in the majority of basins associated with mud volcanism is dominated by syn-orogenic depositional sequences;

4) Active tectonic regimes, with disturbance and dislocation of the sedimentary sequence by folds and faults.

Mud volcanoes in Azerbaijan lie on the SE flank of the Great Caucasus and its foothills, in the SE Shirvan region (N side of the Lower Kura Valley) and the Absheron and Baku Archipelagoes of the adjacent south Caspian Sea. The greatest concentration of mud volcanoes in the world is here in eastern Azerbaijan, with up to 220 recognised.

The areas of Azerbaijan where mud volcanoes are developed include the following named oil and gas-bearing regions: Precaspian-Guba, Absheron, Shemakha-Gobustan, Lower Kura, Baku Archipelago and the deep-water South Caspian (**Fig. 8.1**).

The mud volcanoes of Azerbaijan have surface vents within deposits of various stratigraphic ages. In northern Gobustan the vents lie within the Cretaceous or sometimes Palaeogene deposits; in central Gobustan they are in the Palaeogene outcrop area; and in southern Gobustan, the Pre-Kura area, in the Absheron Peninsula and the Absheron and Baku Archipelagoes, they occur in areas of Oligocene to Plicene surface geology.

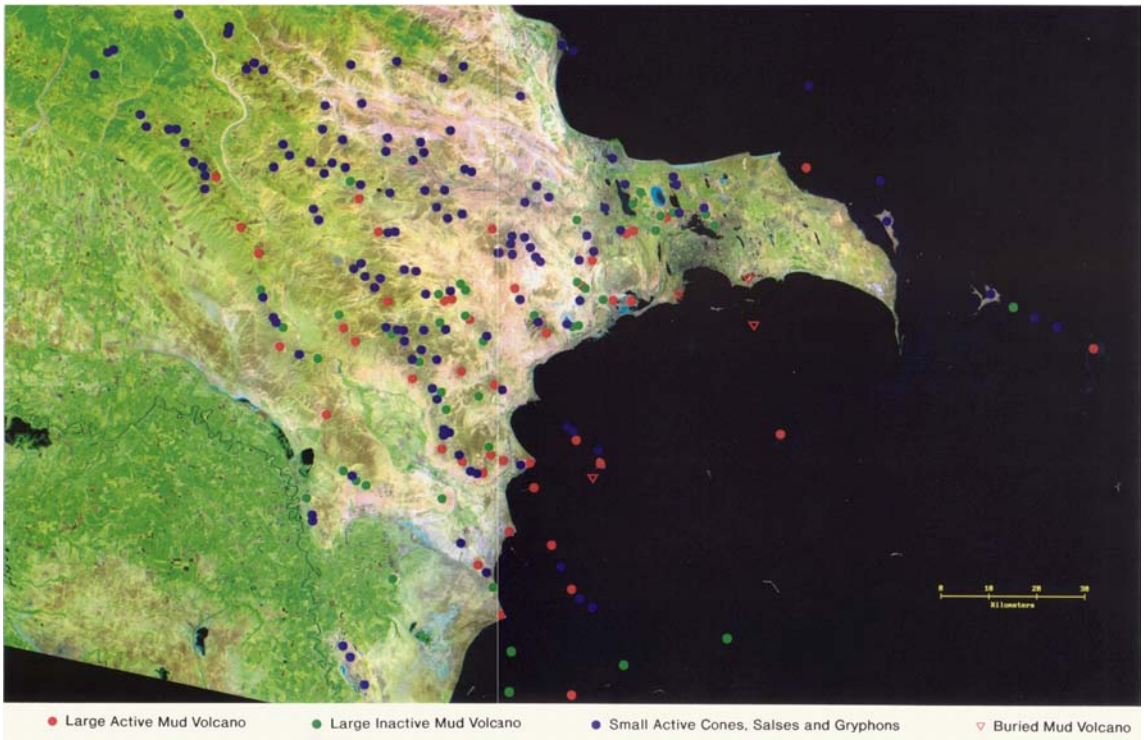


Fig. 8.1. The map of mud volcano location in the South Caspian basin.

In the study of mud volcanoes it is important to determine the specific stratigraphic unit to which they are "rooted". The root of a mud volcano is usually understood to refer to the deepest zone of mud volcano activity, from which the exit channel of the volcano begins. The stratigraphy of the root is usually determined by the microfauna contained in the solid phase of the material erupted, and also by comparative analysis of the lithological and petrographic properties of the breccia and the stratigraphic succession.

The mud volcanoes of eastern Azerbaijan yield clasts with a very wide range of ages from Cretaceous, through Palaeogene to Neogene. Occasionally Jurassic clasts are recovered. However, the great majority of solid material (mud, and breccia clasts) coming out of mud volcanoes in Azerbaijan appears to derive from the Oligo-Miocene sediments, especially from the Maikop Suite. The solid material ejected sometimes includes rock fragments which are younger than those on the surface (eg. Demirchi); these are explained by the presence of thrusts.

Shemakha-Gobustan Region

There are about 107 mud volcanoes in this region. They are widely distributed, and In the SE part include the largest and most active volcanoes of Aierbaijan. The area of mud volcano development corresponds to the Shemakha-Gobustan trough. In its extreme NW part (W of Shamaka) the Palaeogene infill, disturbed by small folds overturned to the south, is partly overrun by a slice of Late Cretaceous rocks of the Baskal'sk nappe. Minor mud volcanism occurs here (Zeiva, Bizlan, Sarysura). There is also an area of tectonic overlap" to the N of Shamaka, where Late Jurassic and Cretaceous sediments are thrust southwards over the Tertiary. Mud volcanoes in this area such as Demirchi rest at surface upon Cretaceous strata but their eruption products include Tertiary material.

To the east of the areas of thrusting, as far as the Maraza trough, tectonic zones are recognised separated by the Zogalavachai superimposed syncline. In the southern part the Palaeogene and Miocene deposits are thrust over Pliocene rocks along the line of the NW-SE trending (Lengebiz- Alyat Thrust). The Palaeogene and Miocene formations here are crumpled, and the crestal zones of folds are cut by reverse faults, thrusts and mud volcanoes (Charkhan, Melikchobanly, Matrasa and other).

In the eastern part of the trough (Gobustan) the age of the deposits and the nature of the fold structures changes along strike. This provides the basis for recognising three tectonostratigraphic zones here: Western, Maraza Zone, clays dominate the section with subordinate sandly-argillaceous sediments Palaeogene and Miocene age. These are unconformablyoverlain by Pontain and Akchagylian deposits which are also cut by unconformities. The PontainAkchagylian succession in this Maraza Zone is slightly disturbed, whereas the Miocene-Palaeogene deposits are characterised by intense folding. Anticlines are strongly squeezed, overturned, tilted to the south and cut by thrusts and locally by mud volcanoes (Shikhzairly, Jirli, Khydyrli, and others).

The Central Gobustan zone composed mainly of Palaeogene - Miocene sediments. In the west and east they are replaced by Pliocene formations infilling the Maraza Trough and Jeirankechmes Depression respectively. Relative to adjacent zones the Central Gobustan zone is the most uplifted tectonic block in the whole structure of the southern slope of the Great Caucasus megaanticlinorium. The Palaeogene and Miocene deposits here reach 4000-4500 m thick and are composed mainly of argillaceous formations. Folds are tightly compressed, locally tilted and even overturned. Quite extensive synclines can be distinguished in the southern part of the zone of anticlines. Major regional longitudinal tectonic faults run along the anticlines. In the Central Gobustan zone, especially in the south, mud volcanism is widely developed and associated with these faults.

Cretaceous and Palaeogene deposits lie within structures occurring in the northern part of the East Gobustan zone. To the south they are replaced by the Pliocene formations of the Jeirankechmes Depression. The thickness of the Pliocene deposits here is 3000-4000 m. Local folds of the most deeply buried East Gobustan zone, the Jeirankechmes Depression, are larger and further apart, plunging eastwards. Mud volcanoes here take on their greatest morphological expression, with Touragay and Boyuk Kyanizadag being the largest two subaerial mud volcanoes on Earth (**Fig. 8.2** and **Fig. 8.3**).

In the SW the Shamakha-Gobustan Trough is contiguous with the SE extension of the Lengebiz-Alyat fold zone, composed of a series of anticlines which are intensely cut by longitudinal and transverse faults. Large mud volcanoes are also developed here (Dashmardan, Durandag, Airantekyan, Koturdag and others).

According to data from CMRW (seismic refraction) profiles the top of the consolidated crust in the deepest parts of the Shamakha-Gobustan trough lie at a depth greater than 15 km. Zones where major active mud volcanoes are developed coincide in plan with the Gushchu-Pirsagat and Tashtinsk gravitational minima.

Fig. 8.2. Touragay mud volcano

Fig. 8.3. Boyuk Kyanizadag mud volcano

Absheron Region

A total of 54 mud volcanoes lie in the western and central parts of the Absheron Peninsula, and to the east in the Absheron Archipelago. The largest and most actively erupting mud volcanoes are concentrated in SW Absheron, the most active of all mud volcanoes being Lokbatan with 22 eruptions recorded since 1828. Las eruption of Locbatan took place on 25 Octobr, 2001 (**Fig. 8.4**). Buried mud volcanoes have also been recognised in the region.

The Caspian Sea basin to the north of the Absheron Peninsula corresponds in plan to the offshore continuation of the Mesozoic folds of the flank of the Great Caucasus. Within the Peninsula, however, especially in the southern half, the Mesozoic plunges sharply and the Palaeogene-Miocene and Pliocene deposits play a substantial role in the structure of uplifts in the area.

The Absheron region corresponds to the periclinal trough of the same name. Local folds here form the West Absheron anticlinorium, the Central Absheron anticlinal zone, and the anticlinoria of the Absheron Archipelago, separated by synclines. In the wider and deeper local trough recognized in the eastern part of the Absheron Peninsula a buried uplift is recognized in which mud volcanism is absent.

Fig. 8.4. Eruption of the Locbatan mud volcano on October 25, 2001 (photo BBC News)

The folds of the Absheron Trough are cut by numerous faults and thrusts. In a number of cases these have a diapiric structure. The greatest concentration of Azerbaijan's petroleum resources lie within the Absheron Trough with many billion barrel oil fields discovered. The great majority of these fields, including Bibeiybat, Binagadi, Balakhany, Neft Dashlari and Gunashli, are associated closely with mud volcanoes,

Lower Kura Region

The Lower Kura region occupies the SE part of the Kura-Araks lowlands, and is represented by a foothill slope (Shirvan steppe) and fiat plain (SE Shirvan and Salyan steppe). Major mud volcanoes are also found here in the form of conical hills (Galmaz, Kyursangia, Agzybir), individual domes (Kalamadyn, Kichik-Pilpila, Neftchala and others), orsalses and gryphons (Khydyrly, Babazanan, Lake Kyrlykh, and others). The total number of mud volcanoes here reaches 33. Galmaz mud volcano is one of biggest in this zone (**Fig. 8.5** and **Fig. 8.6**).

The Lower Kura region corresponds with the basin of the same name. The Lower Kura Basin is a typical synclinorium which includes a thick succession (over 8000 m) of Pliocene and Quaternary deposits. The largest mud volcanoes lie on the steep NE margin of the basin.

The largest structure element of the Lower Kura Basin is the Kharami-Salyan anticlinorium. The Navagi superimposed hemisyncline lies against its NE margin, and the Lower Kura (Mugan-Salyan) synclinorium in the SW.

Fig. 8.5. Galmaz mud volcano

Fig. 8.6. Aero photo of the Galmaz mud volcano

The Kharami-Salyan anticlinorium is composed of two anticiinal zones which divide towards the SE (the Kyurovdag-Neftchala and Kalamadyn-Byandovan zones), separated by the South Shirvan (Kyurgali) syncline which in the NW contains the Kyursangia fold. These anticlinal zones are formed by major en-echelon domes or long brachyanticline (dubly-pluging anticlines), and are composed of Pliocene and Quaternary deposits. All of the folds are cut by major longitudinal faults with throws of 300-500 m and occasionally 1000-1000 m, extending in the axial parts of the anticlinal zones. Mud volcanoes are associated with these faults.

Baku Archipelago Region

Within the Baku Archipelago 8 of the established mud volcanoes form islands (Zenbil, Khara-Zire, Sangi-Mugan, Bula and others), and 13 lie below water, forming rises in the form of banks (**Fig. 8.7**). Some of them erupt periodically to form temporary islands (Chigil-deniz, Yanan Tava, Sabail and others).

The linear anticlinal zones of the Baku Archipelago, with a mainly NW-SE orientation, are cut by major longitudinal faults with throws which locally reach 1200 m, and a series of transverse faults. These faults are associated with mud volcano islands banks. The en-echelon folds of the Baku archipelago (up to 37 in number) occur at a higher level (shallower depth) than the folds of the Lower Kura Basin. They are highly disturbed, with bed dip angles on the limbs varying 10-15º to 40-50º.

Fig. 8.7. Aero photo of the Bulla mud volcano

Deep Water Part of the South Caspian

The total number of mud volcanoes within the South Caspian is not at present known reliably. This is because the specific marine conditions of the area do not enable the true size and number of volcanoes to be distinguished, especially in the deep-water parts of the Caspian Sea.

In recent years it has become apparent from aeromagnetic, acoustic, seismic-survey and bathymetric studies in the South Caspian Basin that the number of marine mud volcanoes is significantly larger than previously thought. Aeromagnetic studies are very important in this respect, since they have assisted in the identification of 24 previously unknown mud volcano centres. New mud volcanoes have been discovered in the deep-water part of the South Caspian on the basis of geoacoustic profiling and seismic survey. Two of them are Nakhchivan mud volcano (**Fig. 8.8**).and Shah deniz volcano (**Fig. 8.9**).

Within the modern structure of this part of the Caspian 3 major zones have been identified;

1) Zone of transverse folding (intersection of the Baku Archipelago and the Absheron-Prebalkhan uplift zone);

2) Zone east-west folding (marginal zone of the Pre-Alborz trough and West Turkmenian Shelf);

3) Pre-Alborz Trough, offshore Iran.

Geophysical data show that the recognized structural elements are linked to each other by major regional faults which cut the entire sedimentary succession. These faults, with varying throws, impart a block-like character to the structure of the South Caspian Basin. Seismic and gravitational survey data demonstrate that the most deeply subsided blocks are the South Absheron and Pre-Alborz troughs, in which the thickness of the sedimentary succession reaches 20-22 km.

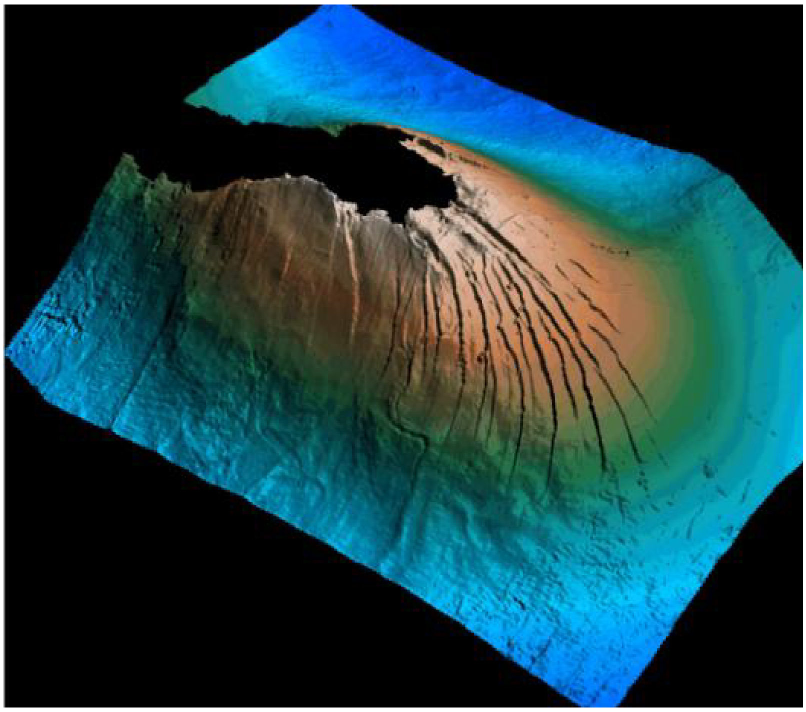


Fig. 8.8. 3D Perspective view of Nakhchivan mud volcano (courteously from J.E.Corthay with permission of Exxon oil company).

In the zone of transverse folding the structures are characterised by their significant elongation (25-50 km). The folds in this zone in comparison with the structures of the Baku archipelago are less disturbed (except for the uplifts in the zone of the submarine Abikha Ridge).

The crests of the folds within the Abikh High anticline zone are raised 3-4 km above the adjacent synclines. Near to its axis this anticlinal zone is cut by a major fault with a throw of up to 1 km, associated with a series of major mud volcanoes.

Within the E-W folded zone brachyanticlinal and dome-like folds have developed, but only expressed at depths greater than 2 km below the sea bed. Buried folds lying close to the axial zone of the Pre-Alborz trough are slightly disturbed. The folds distinguished to the north of these uplifts are more distinctly expressed. Mud volcanoes have been established within these.

Immediately to the north of the folded zone of the Baku Archipelago the Late Pliocene, and part of the Early Pliocene, deposits form an extensive homocline, plunging to the east. Only deposits at the base of the Pliocene are crumpled into folds here.

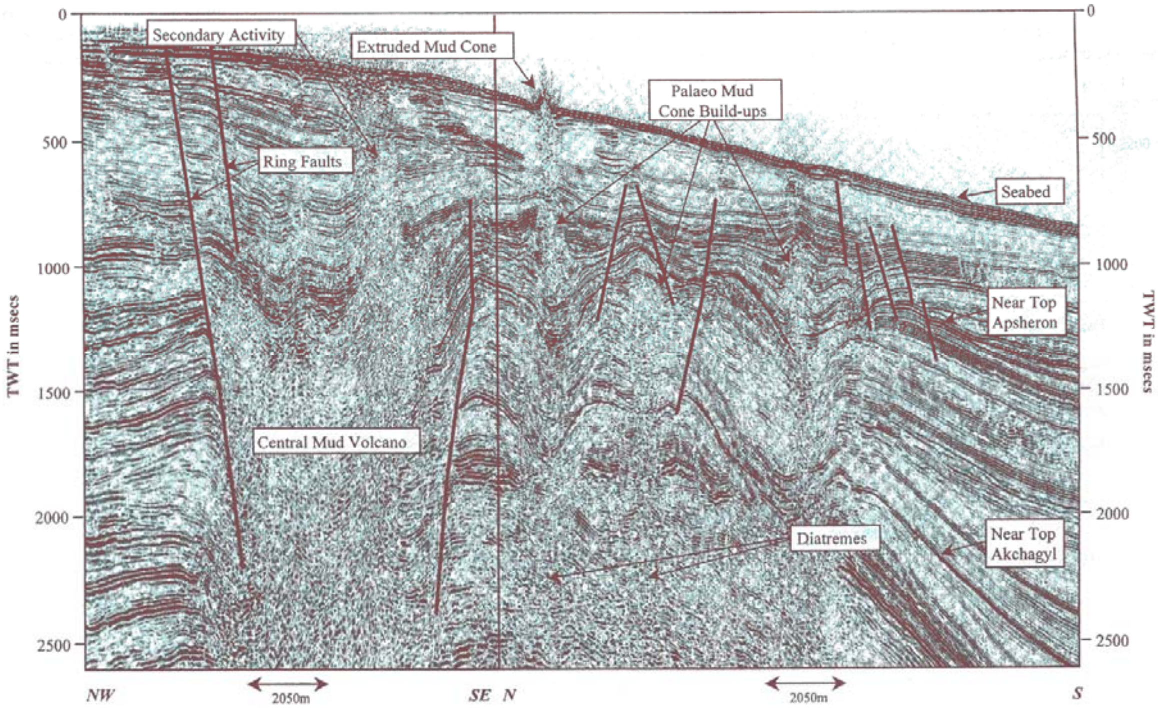


Fig. 8.9. Shah deniz mud volcano image on the TWT section (Fowler S.R. et al., 2000).

Judging from the results of seismic studies along regional profiles in the deep-water part of the South Caspian, the Pliocene succession forms distinct diapiric folds in certain areas. On exploration seismic data many of these appear to be disturbed by mud volcanism.

As geophysical and bathymetric survey data become more closely spaced and more widely available the catalogue and knowledge of mud volcanoes in the South Caspian is sure to increase. Improved knowledge of these mud volcanoes is of great economic and practical importance as a very large proportion of them overlie known oil and gas discoveries or highly prospective structures.

Gravity Model of Mud Volcanoes

Now we mention the results of investigations carried out for the first time on volcanoes in the southwest Absheron region, viz. Lokbatan, Akhtarma-Puta and Gushkhana, all located within one single tectonic zone. The Lokbatan mud volcano was chosen because it is very active not only in comparison to other volcanoes in Azerbaijan but in respect also of all worldwide mud volcanoes. The last eruption occurred on October 25, 2001. The present studies were started immediately after that eruption.

Together with the gravimetric and geodetic studies observations were also conducted. Profiles in different directions were chosen to carry out gravimetric and geodetic measurements on areas of mud volcanoes. One profile, more extended than the others (11 km long), begins near a key gravity-geodetic point at Lokbatan and passes through a line joining the mud volcanoes Lokbatan – Akhtarma-Puta – Gushkhana. The distances between measurement points are never more than 250 m. More than quarter of all known mud volcanoes is concentrated in Azerbaijan within the SE ending of Great Caucasus. Areas around Azerbaijan mud volcanoes are reflected by minima of the Bouguer gravity field (from –120 to –40 mGal) (Kadirov, 2000).

Methods. *Gravity and Geodetic*. Measurements of gravity differences between points were undertaken by four gravimeters under a simple closed loop arrangement. The scale interval of the gravimeters was determined at different temperatures using a control instrument. When processing field measurements, corrections were made for relation of scale interval to temperature, for non-linearity of scale of a micrometer screw, and for lunar-solar attraction. The longitudes and latitudes of the measurement locations were determined with the help of GPS, and altitudes of the points with a level from the firm Carl Zeiss, Jena (the mean quadratic error on a 1 km traverse measured in both directions was 0.2 mm). For calculation of the Bouguer gravity anomaly, the altitude was read from the lowest level (at the Lokbatan reference point), and the inter-layer density taken to be 1.82, 2.0, 2.3 g/cm3. Gravity modeling used a minimization condition on a multi-parameter functional describing the least squares difference between modeled and observed gravity fields and involving parameters of the initial structure model. The initial parameters of the model are modified such that the difference between observed and computed fields does not exceed 1mGal. Along the NE–SW profile gravity modeling was done to investigate the depth structure and tectonic evolution of the mud volcanoes.

Temperature Measurements. Measurements have been made at three sites within the Lokbatan crater at depths of 0.5m, 1.0m and 1.5m into the mud, using a thermistor thermocouple and a balancing Wheatstone Bridge, with resistance calibrated to true temperature in the laboratory to a precision of $\pm$ 0.01 °C using a mercury thermometer. The measurements continue at approximately 30-day intervals at the three crater sites (with exceptions for rainy periods when no traversal of the mud is possible or when flaming outbursts occur when the crater sites are not approachable). Similar temperature measurements, carried out earlier, have shown high temperature gradients in the crater area (Mukhtarov and Adigezalov, 1997).

Results of study. Along the profile Lokbatan – Akhtarma-Puta – Gushkhana, a chart of Bouguer gravity field anomalies is compiled for various values of intermediate stratum density (1.8; 2.0; 2.3 g/cm3). The results obtained show that in zones of mud volcano development (Lokbatan, Akhtarma-Puta, Gushkhana) there are local negative anomalies of -5, -3 and -2 mGal, respectively.

For gravity modeling, the observed gravity values and the geological/geophysical structure section along the NE-SW profile make up the initial reference information. The initial structure model along the profile was obtained using seismic data, well information, geological information, and the density-depth distribution of major rock units of the study area. The initial geologic-geophysical cross-section of the sedimentary cover along the profile is provided by seven contact boundaries: 1) boundary along the lower Akchagil (N_2^2); 2) apparent seismic horizon in the Productive Series (N_2^1); 3) boundary along the upper Kirmaki sandy suite (N_2^1); 4) boundary along the lower part of the Kirmaki suite (N_2^1); 5) boundary separating the upper-middle Miocene and lower Miocene-Oligocene series ($P_3 - N_1^1$); 6) boundary separating Oligocene- and Eocene-Paleocene series ($P_1 + P_2$); 7) boundary of the Mesozoic surface (Mz). The differential density contrasts across the seven contact boundaries (from shallow to deep) are 0.01; 0.04; 0.08; -0.2; 0.25; 0.15; and 0.3 g/cm^3, respectively. The gravity field calculated on the basis of the described model shows that there is a difference between observed and calculated fields in zones of mud volcanoes (**Fig. 8.10**). When computing the gravity model, 10 iterations were first done on the selection of all boundary configurations. Then the selection on density was undertaken. The extra mass in zones of mud volcanoes in the initial model is compensated for by insertion of zones of deconsolidation and additional contact boundaries in these parts of the profile. The deconsolidation stretches to roughly 3 km depth. A contact boundary, representing the volcano neck (with a differential density -0.3 g/cm^3), is raised in these areas to depths of just 5 m below the surface.

The repeated geodetic leveling on the Lokbatan volcano shows that there are currently active geodynamic processes occurring there. During the period of 10.2001 through 10.2002, on the NE part of volcano (of length about 2 km), the contact boundary was as shallow as 60 cm (**Fig. 8.11**).

Thermal information prior to the explosion of 25 October 2001 comes from production wells on the flanks of the Lokbatan mud volcano, indicating a strong focusing of heat flux centered on the Lokbatan volcano (**Fig. 8.12**) over a regional scale of kilometers (Sukharev et. al., 1969).

Three measurement locations within the crater and on the crater floor were marked with iron spikes for ease of relocation. At each location, the thermal resistance probe provides three equivalent temperature measurements at 1.5 m, 1.0 m, 0.5 m into the partially dried mud sediments.

A discussion of the thermal information from these two sections has been given elsewhere (Mukhtarov et al., 2002).

The available thermal data are somewhat ambivalent in terms of either interpretation, suggesting that more detailed thermal measurements and other types of measurements are needed to help resolve the uncertainties (Lerche et al., 2002).A mud volcano provides a channel for heat advection from depth. A discussion of advection from such channels has been given elsewhere (Mukhtarov and Adigezalov, 1997; Mukhtarov, 2002).

Discussion. Paleogene - Miocene deposits spread throughout the subsidence zones of the SCB serve as an example of the interstitial plastic series. The viscosity (η) of such layers varies from 106 Pa s to 1015 Pa s; viscosity of the overlying and underlying formations is 5-6 orders of magnitude smaller. The density (ρ) of clays varies from 2.3 g/cm3 to 2.6 g/cm3. In the zones of regional deconsolidation the clayey series is least dense, up to 0.2 g/cm^3 less differentially. The less viscous Paleogene-Miocene series of the sedimentary complex has the following parameters: thermal expansion coefficient α= 10^{-5} K^{-1}; coefficient of thermal diffusivity χ=5·10^{-7} m^2/s; coefficient of thermal conductivity **k** =2W/(m. K). The thermal conductivity coefficients of sandstones and limestones are 5W/(m. K), respectively. For this reason, the Paleogene-Miocene deposits are heat insulators and, no doubt, they play an important role in the formation of the thermal field in the overlying layers.

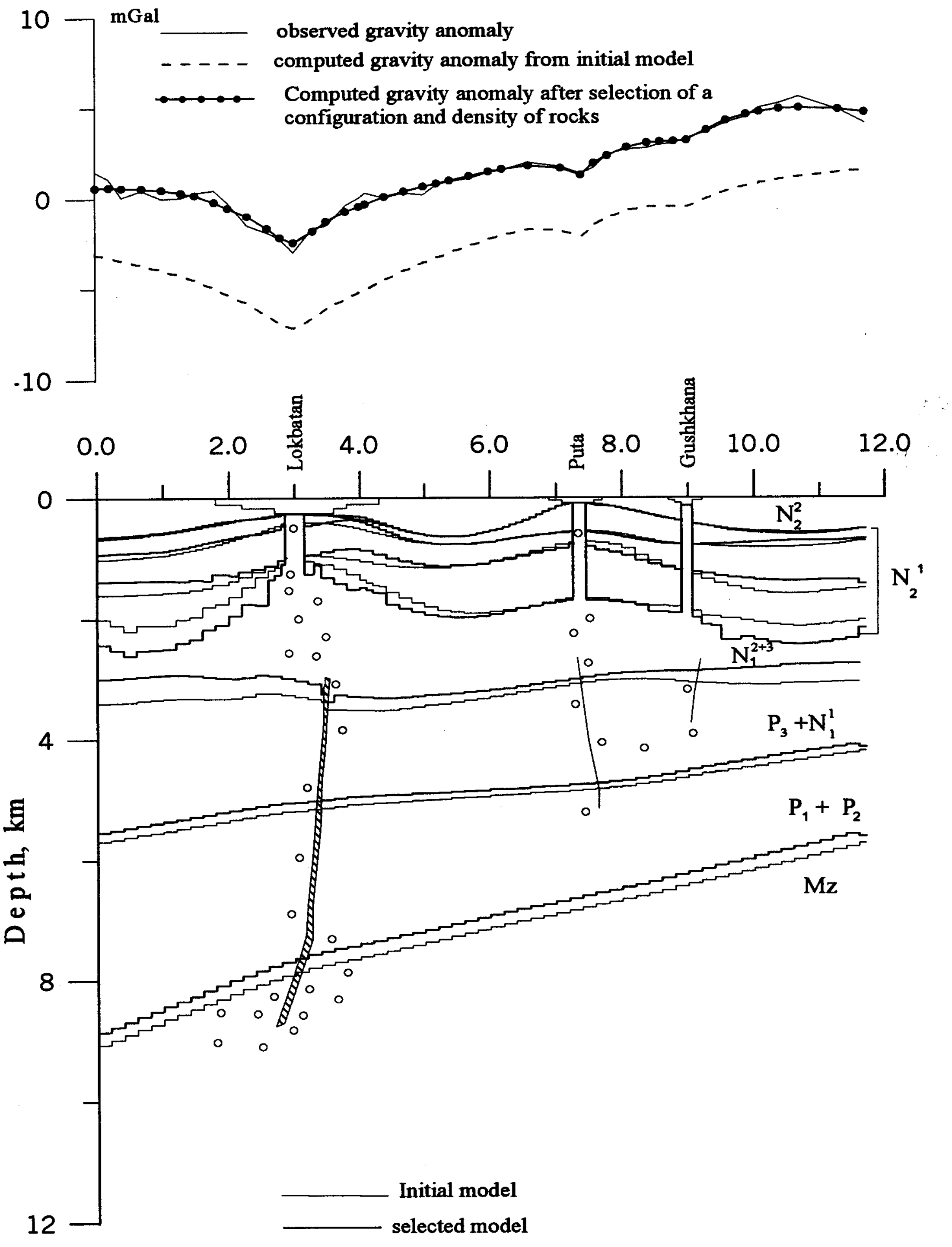


Fig. 8.10. Gravity model of the Lokbatan - Puta-Akhtarma - Gushkhana profile.

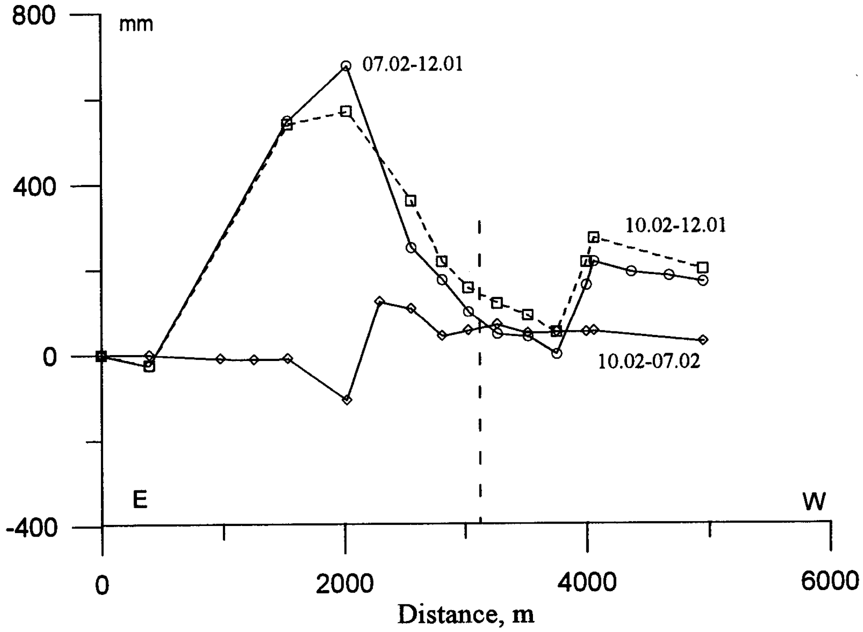


Fig. 8.11. Vertical movement along profile crossing Lokbatan mud volcano.

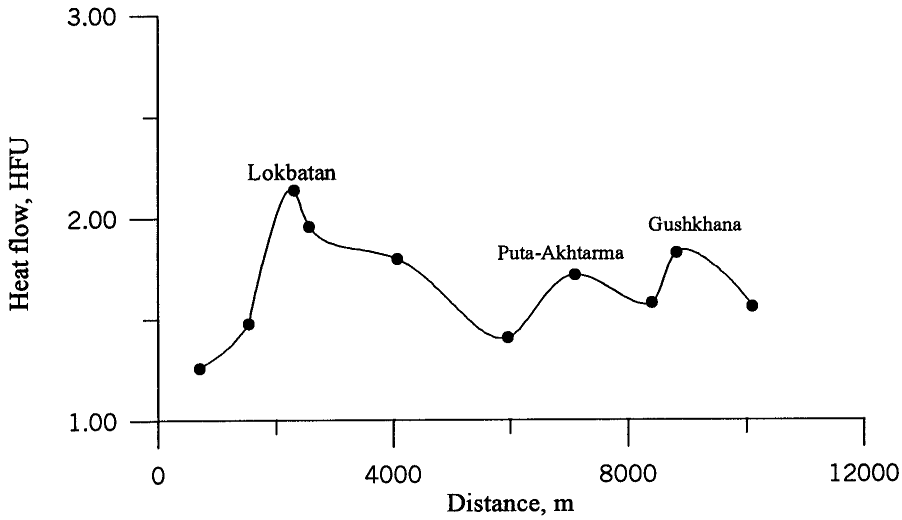


Fig. 8.12. Heat flow distribution along Lokbatan - Puta-Akhtarma - Gushkhana profile.

According to the linear theory of stability, if the Rayleigh number is higher than a critical value $\mathbf{R_c}$, convection movement arises. The critical Rayleigh number for a horizontal layer with no-slip boundaries is $\mathbf{R_c}$ =1300. But the actual Rayleigh number for the Paleocene-Miocene layer with thickness **d** = 5 km is

$$\mathbf{R = \alpha\rho gqd^4/(\chi\eta k) = 3x10^{-2}x10x60x(5x10^3)^4x2.3x10^3/(5x10^{-2}x2x10^{12}) \approx 10^4},$$

which is almost an order of magnitude higher than the critical value for the Paleogene-Miocene layer. For the viscous interstitial layer, the convection time is much less than the age of the Paleogene-Miocene complex. Hence, convection in this layer is stationary. After the establishment of convection, the temperature of the Paleogene-Miocene layer becomes stable as well. If the stresses created by the flow exceed the strength limit of the overlying rocks, then uplift occurs above the ascending flows (Trubitsyn et al., 1998). This Rayleigh-Bernard gravitational instability reflects one of the possible models of hydrocarbon migration in the Paleogene-Miocene series in the SCB (Kadirov and Kadyrov, 1990; Guliev and Kadirov, 2000). Transportation of hydrocarbons upward, together with the enclosing clayey plastic mass of the intermediate layer, under convective processes would appear to be a dominant mechanism of migration and accumulation in the upper parts of the series, with further breakthrough of the overlying permeable series. As the clay is raised, the lithostatic pressure lessens, with the result that hydrocarbon phase transitions will occur and hydrocarbons will be in free phase. It is quite possible that the interstitial layer is the main generator of most of the mud volcanoes in Azerbaijan (Guliev and Kadirov, 2000).

Thus, the results show that there are negative local gravity anomalies (-5, -3 and -2 mGal), respectively, in zones of mud volcanoes. The calculated field based on the model described shows that in zones of mud volcanoes there is a difference between observed and calculated fields. The extra mass in mud volcano zones is compensated for by introduction of decompaction zones and additional contact boundaries. From December, 2001 through June, 2002 the following sequence of events took place. The surface rises in and around the Lokbatan volcano. However, the amplitude of rise varies strongly along the structure. To the east, measured from the neck of the volcano, out to a distance of about 1km, the surface rise is 677 mm. A secondary maximum of 218 mm is observed on the western part to a distance of about 1000 m from the neck. The area of the crater also participates in the general rise, but lags appreciably behind the rise of the regional sites. Geodetic observations from December, 2001 through October 2002 show that, in the period June 2002 - October 2002, to the east away from the crater there is a relative lowering of the surface, while to the west and also in the crater structure, the surface shows a relative rise. Clearly, gas must still be upwelling from the Lokbatan volcano to feed the flame (currently around 0.5-1.0m high) over the last 11 months, so that the thermal regime cannot be one of simple cooling after a single flaming explosion. By mid-December (18 Dec 2001) the mud had cooled sufficiently that it was possible to complete the N-S thermal section. The crater measurements show elevated temperatures of 47°C (0.5m), 53°C (1m), and 58 °C (1.5m) with a systematic cooling within about 100 m of the crater, indicating either thermal cooling of the ejected mud or rain enhanced cooling by infiltration. The background temperature of 35.3°C had then been reached.

8.2 The Modeling of the Mud Volcano and Diapir Formation Mechanism

The South-Caspian Basin (SCB), characterised by a large thickness of sedimenuary formation and considerable negative anomalies of forces of gravity. In SCB's area of water, complex marine geophysical work has for many years been carried out, mainly seismic oil and gas exploration. Additionally, regional studies: gravimetric, aeromagnetic and seismic have been carried out. For the seismic studies were used CMRW (correlation method of refracted wave) and OSS (deep-sea seismic sounding).

Based on the seismic exploration's new data, obtained using the data of earlier processed profiles CMRW and DSS, it is possible to identify the main features of SCB's earth's crust. They are: the sedimentary cover's immense thickness, estimated at 30 km and reduced velocity layers with velocity not higher than 4, 8 - 4, 9 km/sec and the presence of layers with reduced velocity in all the processed profiles. The identification of these layers and their distribution along the system leads to the conclusion of the presence of a large zone of decompaction in the sedimentary cover of SCB.

The presence of the decompressed zone in the sedimentary SCB cover is also proved by the results of the analysis of a considerable amount of collected data about the history of the development, sedimentation and gas accumulation processes. According to the available data, the SCB is characterised by the anomalously high velocity of sediments' sinking (up to 1, 3 km/My), low temperatures (at depths of 5-8 km 100-160^{o}C and super-high-pressures (the average ratio of anomaly is 1, 8). In such conditions the sedimentary sections are formed, it is typical for them in a mechanically stressed state, particularly demonstrated by the lack of compression of arenaceous differences of the section.

The development of such systems is typical for basins of a very intensive downwarping, where loss of pressure of pore water is slower than sedimentation. As a result the pore water undertakes a part of geostatic load, and this causes the growing of a pore pressure gradient in this part of the section and its asymptotic outflow into geostatic pressure.

The investigations (Buriakovski L.A., et al.,1986) show that clays and arenaceous rocks form from 50 to 95% of the section in the central parts of the basin. According to the results of computer modelling the porosity of clays at the depths of 9-10 km could grow up to 10%. The presence of uncompacted clays in the major part of the section of the most submerged SCB areas, possibly, is one of the main resources of anomalously reduced velocity of seismic waves, not exceeding 4,8 km/sec. An additional factor, which, possibly, plays a decisive role in decompaction of argillaceous thicknesses is an intensive hydrocarbon accumulation and the specific changes of argillaceous rocks. The feature of SCB is the preservation of high rate of these processes at a very low depths.

This conclusion is based on the data of mathematical modelling and study of organic substance of super-deep well's core and outbursts of mud volcanoes, isotope composition of methane carbon. Based on the method of total heat impulse a mathematical model was developed of the process of gas- and oil accumulation. A model (**Fig. 8.13**) was used of a total SCB section. The abscissa axis is a scale of absolute age. On the diagram it is shown, that the zone of intensive hydrocarbon generation in Cenozoic sediments is permanent up to a depth of 15 km. The study of methane carbon of oil- and gas condensate deposits show that values $\delta^{13}C$ are in the interval of -35 to -50$^{o}/_{oo}$, which is relevant to methane generation from organic matter stage of mesocatagenesis. The approximate evaluation of the depth of methane generation on the basis of the curves of dependence $\delta^{13}C$ on temperature and reflection ability of vitrinite is 6-13 km (**Fig. 8.13**) .

The above mentioned depth interval of generation of the basic mass of hydrocarbon is proved by the data of reflection ability of colloaltinite, and also by the absence of any changes up to a depth of 6-8 km of the core's hydrocarbon potential, outburst of mud volcanoes, bituminous ratio and so on (Dadashev F.G., et al.,1985).

According to the data of SEM studies, it was estimated that the rocks of ad eep interval studied, dated from the stage of early catagenesis.

The major changes of organic matter and rocks apparently happen underneath drilled depths, possibly, at intervals of 5-13 km.

It is at this depth immense amounts of hydrocarbon are accumulating, combined water transfers into bucyant water. As a result of these processes the argillaceous rocks are becoming more permeable, porous and less solid, than similar rocks, which above or below this interval.

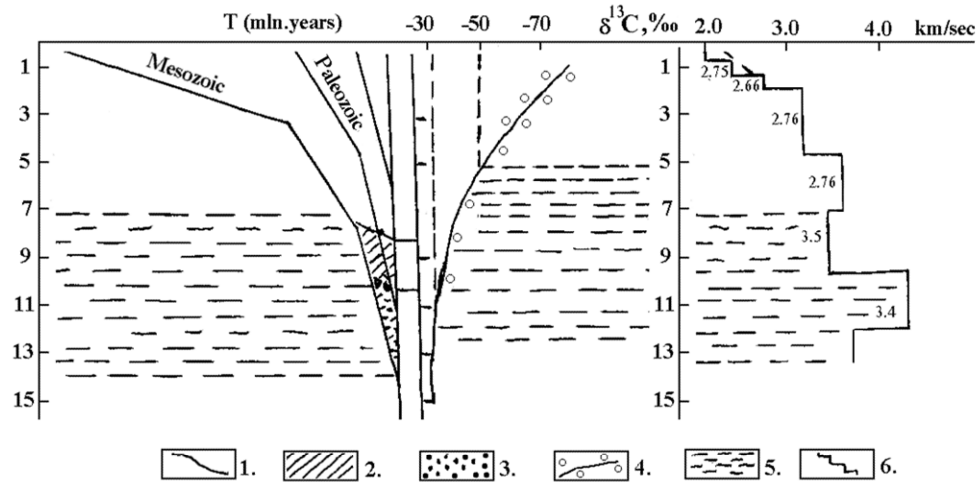


Fig. 8.13. Model of gas and oil formation in dip submerged sediments of SCB.
1 - paleodepths of sediments;2-oil formation zone; 3 - gas formation zone;
4-theoretic curve of dependence of isotope composition of methane carbon on depth and temperature; 5- depths interval of intensive generation of hydrocarbon and inversion of seismic waves' velocities; 6-general high - speed model. PK, MK, AK - stages of catagenesis.

An intensive decompaction is related to the formation of gas bodies and displacement of pore water by gas. When there is full displacement of pore mixtures, the velocity of gases grows abruptly. When this occurs velocity can be reached, when all the substance go into a suspended fluidised state (Ivanov V.V., et al.,1986). The process of decompaction can also be caused by hydraulic fracturing, shattering of rocks etc.

However, it is essential that this process is going on at the stage of mesocatagenesis, which in this case is confined to depths deeper than 5-6 km. It is at this depth, when the tendency to increase with the depth of seismic wave';s velocities has failed, and in a high-speed section there appears reduced velocity intervals, which correspond to decompressed (uncompacted) formations.

For the first time a large regional zone of decompaction (RID) was discovered in the SCB's sedimentary basin at the depth interval of 7-13 km, which coincide with (and, possibly) due to) intensive hydrocarbon generation and catagenetic rock transformation. The presence of such a zone is proved by a general occurrence of: mud volcanism within its limits, carrying away immense amounts of decompressed argillaceous mass (breccia) and gases, by argillaceous diapirism and structural forms, which are typical of zones with development of density inversion (repetition of the same stratigraphic intervals, cover tectonics, isocline-flaky folding etc at an interval). This zone, possibly, has a regional range as well as the close-by areas of Low Kura and West-

Turkrnenia depressions, it is a generator of features of mechanism and generation of geodynamic processes, taking place in the sedimentary basin of a large zone of the earth's crust warping, ranging from the West-Turkrnenia to East-Georgia.

The probability of process in Sedimentary series has been on nature models according to the indicating scheme.

Glass box is successively filled (from top to bottom) by compacted clay (the analogue of hard basement), calcium carbide (yeast paste aluminium carbide), which is imitating the deposits with large potential of HC-formations (hydrocarbon), and layer of sand as the convering series. Intensive generation of HC gases leads to the discompaction of material, mechanical deformation of covered rocks with fractures formation, the ejection of discompacted mass. The process can be described by the following stages (**Fig. 8.14**).

1. Sediment accumulation, which is presented by successive significance of little deformed layers, clays and sands.
2. Intensive formation of gases leads to formation of long fractures of subhorizontal and vertical directions and cavities, filled by gas. The density inversion leads to the mechanical fracture of covering deposits.
3. The emanation of gas and discompacted mass (the stage of mud volcanism) occurs on formed, sharpfalling disturbance. The layers covering discompacted zone are deformed and are forming the bulge bow.
4. Under the leight of upper laying deposits and by reducing vaporization intensity the shrinkage occurs, insignificant cracks closing, the reducing of system capacity.

In accordance with theoretical and nature models the complete cycle of mud volcanism includes follow.

1) The buried deposits within the sedimentary succession develop into a mechanically heterogeneous condition, particularly within underconsolidated argillaceous rocks (Magara K.,1982).

Such systems are particularly typical of basins with very rapid subsidence, in which the expulsion of pore waters from the lower horizons of the succession does not keep pace with the rate of sediment accumulation (Magara K.,1982; Buryakovsky L.A., et al.,1982) as a result the pore water it self bears some of the lithostatic load, which leads to an increase in the pore-pressure gradient in this part of the section, which asymptotically approaches the lithostatic value (**Fig. 8.15**). The increase in temperature with depth also contributes to the pore pressure if it is not accompanied by a corresponding leakage of pore water from the system, or by a transition of it to the solid phase.

2) The establishment of an "unrelaxed" state in a necessary but not a sufficient factor in the development of an MV. The decisive factor in its development is the formation of hydrocarbons, and particularly methane, within the sedimentary succession due to the burial of organic matter. A characteristic of alpine geosynclinal basins, and particularly of the South Caspian Basin, is that process is occurring with great intensity at considerable depths, reaching 8-10 km (Dadashev G.G., Guliyev I.S.,1984). The formation of methane may be characterised by its local abundance. This can be described by the amount of methane entering a unit volume of pore fluid over a unit time from the surrounding rocks, If it is expressed in normal cubic centimetres (T = 293 K; P = 0.1 MPa), then the dimensions of this quantity will be inverse time (s^{-1}).

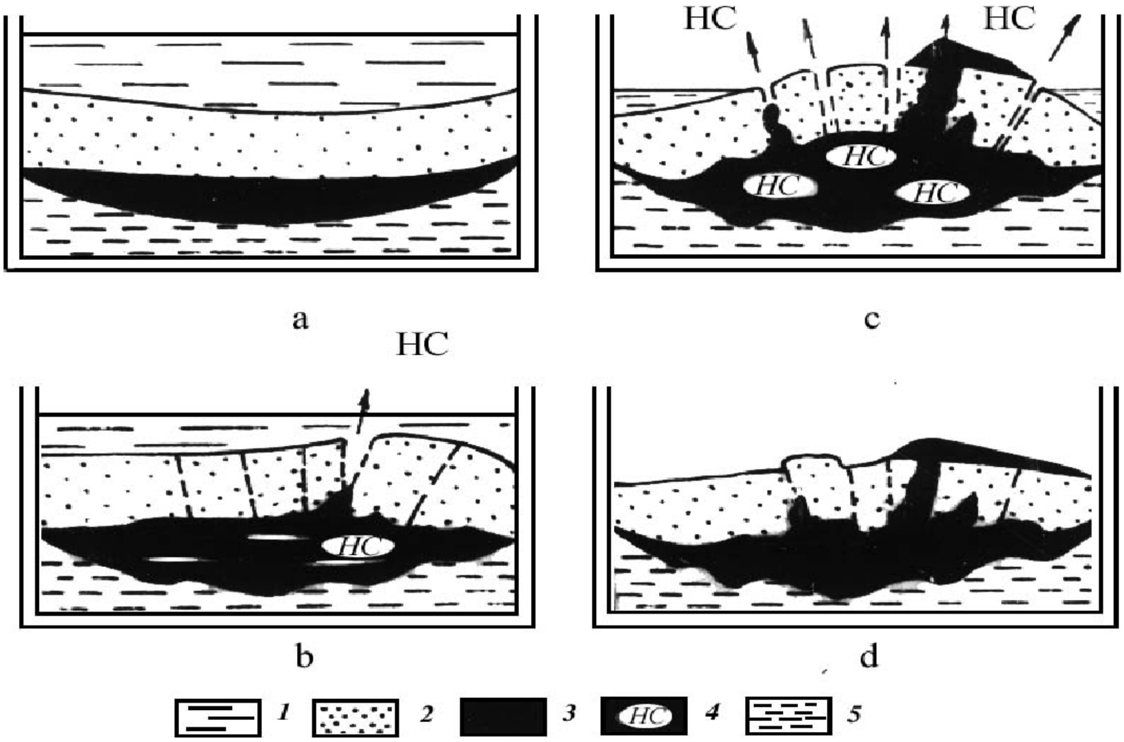


Fig. 8.14. The stages of mud volcanism appearance on nature models
1 - water, 2 - sand, 3 - calcium carbide, 4-cavities filled by HC, 5 - clay.

The oxidation of methane in the near-surface oxidising zone depends on the existence of a flow of molecules of methane within the pore fluids from the area of its formation to the earths surface. lithe formation of methane in some part of the sedimentary succession is not balanced by a corresponding out flow into the zone of oxidation, then it will accumulate within the pore fluid. Through time it is concentrated-until it reaches a critical saturation (solubility), beyond which it passes the threshold of supercritical methane saturation. At this point the methane begins to separate into the gas phase. The actual phase transition creates a pulse of excess pressure, the amplitude of which, however, does not exceed the following size:

$$\Delta P \sim (\delta\text{-}1) \cdot C_{cr} \cdot C_A \qquad (1)$$

where: ΔP is the pulse of excess pressure in the region of phase separation; $\delta = C_{scr} / \mathbf{C}_{cr}$ the excess responsible for the phase transition; C_{scr} is the threshold supercritical concentration; C_{cr} is the critical concentration (solubility); and P_A is atmospheric pressure.

With δ in the interval 1-2 and $C_{cr} \sim$ 2—3 ncm^3/cm^3 the amplitude does not exceed 0.6 MPa; i.e., at great depths it is less than 1% of the primary pressure. But if after the formation of a zone of polyphase saturation the relationship noted above is preserved, then the pressure in this part of the porespace will grow. This condition can be described by the following inequality:

$$Fh > DgradC \qquad (2)$$

where: F is the richness of the sources of methane; h is the thickness of the generating zone within the sedimentary succession; D is the molecular permeability of the pore space. and C is the concentration of methane in solution.

The magnitude:

$$F_{exc}=F - \frac{\mathrm{DgradC}}{\mathrm{h}} \qquad (3)$$

and is that part of the source which is expended in adding to the new phase. During the phase transition, microscopic bubbles of gas from nuclei around which the excess methane is in conditions where water is unable to escape from the pores, such concentration leads to an increase in pressure. To a rough approximation, applicable to short time intervals, the increase in excess pressure (ΔP) can be represented by the relationship:

$$\Delta P_C = \Delta P + P_A F_{exc} t \qquad (4)$$

where P_A is atmospheric pressure and t is time.

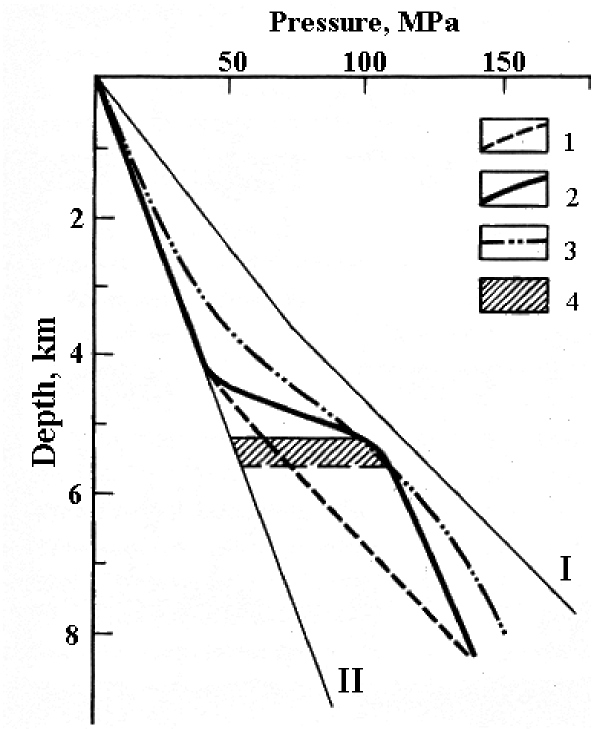


Fig. 8.15. Probable distribution of pore pressure and compensating stress with depth in sedimentary successions of alpine geosynclinal basins.

1) Pore pressure developing in an unrelaxed' system; 2) depth curve of pore pressure; 3) depth curve of compensating stress in pores; 4) seat of mud volcano.

I) Normal lithostatic pressure.

II) Normal hydrostatic pressure.

3. The system will remain mechanically stable while the stresses arising within it and the pore pressure are in equilibrium. It is natural to suppose that the minimum resistance to loading will be within the pore-water continuum. It is therefore reasonable to attempt to evaluate its scale, based on an analysis of the structure of pore networks, and the rheological properties îf solutions within such channels. In typical pore networks with cross sections in the range 10^{-6} – 10^{-2} cm, the pore fluids do not act as Newtonian fluids. Despite the somewhat conflicting empirical data, it can be considered as established that films of water 10^{-5} – 10^{-6} cm thick possess elastic properties, and layers up to 10^{-2} cm thick can be described by the characteristics of visco-plastic bodies, in particular the initial shear streng (Dadashev F.G. et.,1985). Considering the presence of a phase seption in the pores, the compensating forces within the fluids in the pore network can be represented approximately by a relationship of the form:

$$P_p = \frac{2(\sigma + \int_0^1 \beta\tau dx}{r} + P(r) \qquad (5)$$

where P_p is the stress within a pore channel of *r*, δ is the surface tension, γ is initial shear shear stress. $\Pi(r)$ is the capillary pressure of the aqueous film within the pore channel; β is the coefficient of tortuosity; and l is the length of the pore channel.

The parameters σ and γ, together with the capillary pressure *Ï(r)* decrease with temperature (Bondarenko N.F., Nerpin S.V.,1967).

The pore channels of the rock are characterised by a continuously changing diameter, and there is a tendency for the porosity and the size of the pores to decrease with depth, and the pore morphology is inhomogeneous, being related to lithofacies. Buryakovskii et al. (1982) have shown that in fields in the marinc part of the South Caspian basin, the porosity and pore-size distribution within argillaceous facies vary with depth. A large proportion of the pore channels at a depth of 1400 m have dimensions of 2-3 $\times 10^{-4}$ cm^2, with a maximum radius of 10^{-3} cm. Lower in the section the proportion of channels with dimensions of $n \times 10^{-5}$ cm and less increases. At a depth of 5100 m theyr form 50% of the total number. The maximum cross-section in this interval is only 7×10^{-4} cm^2.

By plotting these data on a graph, a curve of the distribution of P_p for the most probable pore radii at each at depth can be constructed. Comparing this curve with the relationship between pore pressure and depth shows that zones may arise where the pore pressure exceeds the compensating stress, i.e.:

$$P_{\Sigma} \geq P_p \qquad (6)$$

where P_{Σ} is derived from the pore-pressure curve,

Areas of the sedimentary succession in which relationship (6) is valid are potential “seats” of mud volcanoes.

4. Where condition (6) is fulfilled the pore fluids must be expelled along those of the channels where the pore pressure exceeds the compensating forces. The leakge of pore fluid from zones of polyphase provides the conditions for the growth of gas bubbles. Due to this process the pressure in these zones will be maintained at a constant level. The formation of hydrocarbons at this stage leads to an increase in the volume of bubbles.

The growth of bubbles leads to their merging into distinct aggregates, which in facies with sufficiently large pores may become mobile. They will accumulate at the tops of pores with low-radius pore throats, forming continuous bodies of gas. In certain areas the pore waters, or polyphase mixture of small bubbles and pore water, will begin to be replaced by a continuous gas phase. As the channels are infilled with gas, its resistance to flow falls, and the pressure difference along the length of the channels increases. This results in irregular increases in velocity of gas along the channels. The evaluation of the probable velocty given the values temperature and pressure presents quite a complex problem. In systems of communicating pore networks the flow velocity of gas can reach tens of centimetres per second or more.

If the overlying zone contains an area where there is quite a dense network of permeable channels, then once a certain critical gas-flow velocity has been attained, all of the material in this zone may reach a pseudo-liquefied, suspended state. The minimum estimate of this velocity for low-diameter particles (10^{-3} - 10^{-1} cm) may be found from the approximate relationship:

$$V_{min} \sim \frac{d^2(\rho_s - \rho_g)g}{1650\mu} \qquad (7)$$

where: *d* is the diameter of the particles; ρ_s is their density; ρ_g is the gas density at the base the pseudo-liquefied layer; μ is the gas viscosity at the same level; and g is the acceleration due to gravity. The value of V_{min} for particles of various diameters in the modelled conditions ($\rho_s \sim 2g/cm^3$; $\rho_g \sim 0.3$ g/cm^3; $\mu = 4x10^{-5}$Pa.s) are:

d=10^{-3}cm;	V_{min}=2.5x10^{-3}cm/s
d=10^{-2}cm;	V_{min}=0.25cm/s
d=10^{-1}cm;	V_{min}=25cm/s
d=1cm;	V_{min}=25cm/s

If the gas flow reaches the so-called “hover velocity”, defined by the relationship:

$$V_1 = \sqrt{\frac{4gd(\rho_s - \rho_g)}{3\rho_g \lambda}} \qquad (8)$$

then the particles will begin to leave the dispersed layer. With further velocity increases the whole of the dispersed layer will begin to move. In equation (8), λ is a coefficient of resistance which depends on the flow regime. For particles with diameters d>10^{-2} cm, λ can be considered to aqual 0.43. The corresponding values of the hover velocity are:

d=10^{-1}cm;	V_{min}=41^3cm/s
d=1cm;	V_{min}=130cm/s

Comparing these estimates with preceding ones shows that the velocity necessary for the creation of a pseudo-liquefied layer may be reached and exceeded. In the presence of an excess the whole bed will move and will act almost as a quasi-viscous fluid. The material will be expelled from the area of pseudo-liquefaction like a projectile or a piston by the movement of gas, and corresponds to a genuine mud-volcano eruption.

As the zone is cleared of dispersed material, gas will begin to flow along an open channel with a large diameter, in the conditions modelled the movement will be supersonic. An approximate estimate of the gas velocity can be obtained using a formula for adiabatic flow (Loitsyanskii L.G.,1973):

$$V = \sqrt{\frac{2k}{k+1} \cdot \frac{P_0}{\rho_0}} \tag{9}$$

where: P_0 and ρ_0 are the pressure and density of gas at depth; and k is the adiabatic index.

In the modelled conditions this value is typically 620 m/s. The flow channel will generally contain areas where it tapers and widens. If the gas is suddenly compressed as it passes through a narrow zone, and its temperature reaches 537° C (the ignition temperature for a methane-air mixture), then the gas will ignite. In order for this to happen it is sufficient that the velocity of the gas is not much more than twice the local speed of sound. The calculation provided above shows that such a flow velocity is more than likely.

The stability of the flow channel is determined by the high-velocity pressure of the flow. As it falls below a certain level of gas output it will again be infilled with dispersed material. This moment may be regarded as the completion of that particular cycle of eruption of the mud volcano. At this point the pressure at the seat of the volcano drops to a level which may lie somewhere between the maximum values of the initial pore pressure and hydrostatic pressure, in general the lower limit of this pressure is greater than hydrostatic. The time taken for the pressure to rise back to its initial value may be regarded as an estimate of the time until the next eruption. The increase in pressure is due both to the mechanical inill of the volcano, and to the continuing production of methane within the succession. The period between eruptions is therefore determined by a combination of two factors: the time over which the volcano is mechanically understressed, and the time for a sufficient volume of methane to build up within it.

We estimate for order of magnitude of that part of the methane source which contributes to the attainment of a critical level of methane saturation in the pore fluids using the relationship:

$$F_{comp} \sim \frac{C_{cr} D}{h^2} \tag{10}$$

where C_{cr} is the critical concentration of methane in the solution; F_{comp} is the amount of the source contributing methane; and D is the molecular permeability.

The corresponding concentrations of methane in the sedimentary basin are typically within the range 1-3 n.cm^3 of water. With the thickness of the sedimentary succession estimated as between several and ten kilometres, and with a molecular permeability of the pore fluid at $10^{-5} cm^2/s$,the value wanted works out as:

$$F_{comp} \sim \frac{(1-3)\cdot 10^{-5}}{(10^{10}-10^{12})} \sim 10^{-15} - 10^{-17}\ S^{-1}$$

There fore the excess abundance must in any case be higher than this estimate, i.e. $10^{-16} < F_{exc}$. An estimate can be attempted of the order of magnitude of the upper limit of the range of possible values of excess abundance on the basis of the rate of organic matter maturation. If this process can be described by a first-order reaction, with a constant rate of reaction λ then the following relationship must exist between the source abundance and the weight-concentration of organic matter:

$$F = \frac{22414}{16} \cdot \frac{\rho}{m} \lambda\gamma \quad (11)$$

where: ρ is the rock density, m is its porosity; and γ is the weight concentration of organic matter.

The concentration γ at any moment must be related to the initial value γ, by the simple relationship:

$$\gamma = \gamma_0 \frac{\rho}{\rho_0} \frac{m_0}{m} e^{-\lambda t} \quad (12)$$

Assuming that γ/λ_0= 0.01-0.1; ρ/ρ_0~10; t~107 years (=3.15x10^{14} s) we find that λ~ $10^{14}s^{-1}$ and F~10^{-13} – $10^{-12}S^{-1}$ on the assumption that γ~ 0.1-1 weight %.

The occurrence of methane-forming abundances in the range 10^{-16} – 10^{-12} scems to be characteristic of alpine basins infiiled with thick successions of sedimentary rocks.

This level of mehane formation guarantees a continuous phase transition in the pore fluid continuum, and the generation within them of corresponding stresses. These stresses may be resolved either in the form of mud volcanoes, as shown above, or as less catastrophic phenomena such as the formation of piercement structures (mud diapirs), i.e. hydrocarbon formation at the scale estimated is the driving force behind specific tectonic processes within the sedimentary succession. Moreover, in these types of system which occur in a near-critical state, the trigger mechanisms for these processes may be relatively minor occurrences such as the ebb and flow of waves, seismic fluctuations, etc.

However, these stresses may be relieved by the simple redistribution of pore fluids, without any significant changes to the surrounding medium. In this case, continuous bodies of gas are formed and become established within the pore space. Hydrocarbon formation at the scale described is typical of the stage of development of a basin which may be described as “youthful”. It corresponds to a period when accumulations of oil and gas form and grow. The genetic relationship noted above between MV’s and the processes of gas and oil formation can be explained in terms of the model presented here.

The level of methane formation, with typical values of $10^{-16}s^{-1}$ provides the pore waters with the critical saturation, and also the thermodynamic stability for accumulations of gas and oil, found in continuum with the underground waters.

However, this is not sufficient for the formation of true gas phases. Therefore the stage of development of a basin where hydrocarbon development occurs at this level may be designated “mature”.

And finally, if the richness of methane sources in the basin falls below the level discussed, i.e. $F<10^{-16}$ s^{-1} then the concentration of methane within the pore fluids is reduced, methane from the gas body passes into solution, and the accumulation is involved in the processes of dissolution and dispersal. This stage of existence of the accumulation is the geochemical “old-age” of the basin.

The model proposed does not explain all aspects of mud volcanoes, and does not pretend to be an all-encompassing explanation for these phenomena. However, with regard to the problems at the beginning of this paper, the model has provided answrs which do not contradict one another.

The model developed contributes both to the scientific aspects of the theory of the formation of oil and gas fields, and to the practical prognosis of oil and gas within different basinal successions. Therefore the further testing of this model, and work to refine it and increase its precision, are fully justified.

In a more recent publication, Brown (1990) expresses very similar, but also introduces the additional arguments of buoyancy driven diapirism coupled with the additional power during eruption of the decompressing / expanding gas.

His belief that gas has a most important role is emphasised by his observation that "methane has been observed in association with all recorder subaerial mud volcanoes", and that "the volume of gas released at the surface during gas-rich eruptions may be enormous in relation to the mud component". He refers to eruptions in Azerbaijan to support this observation.

Brown's basic hypothesis is similar to Ivanov and Guliev and may be summarised briefly as follows:

In situations where rapid sedimentation is occuring mud may be driven to the surface by bouyancy forces due to bulk density contrasts between mud and overlying sediments cover. Such density contrasts may be simply the result of compaction disequilibrium, but more importantly may be related to gas expansion when fluids are transported to shallower depths with lower pressure and temperature conditions. He argues that methane is a compressible and variably soluble phase in pore fluids which may form a significant source of fluid volume during the decompression of a rising mud mass. The 'variably soluble" remark relates to the non-linear relationship between solubility and temperature and fluid pressure. Above about 4 km pressure and temperature conditions are such that methane solubility 13 small. Fluid migrating to these depths will suffer a major expansion in volume due to methane exsolution and expansion (**Fig.8.14**).

Essentially his arguments are similar to those previously outlined with the exception that instead of arguing for conditions of high methane saturation to allow free gas flow, Brown argues that as sediments are "unloaded" there is a natural expansion of methane and a substantial increase in mud porosity causing a decrease in mud density. This density reduction causes the muds to become extremely buoyant and as they migrate to the surface a zone of accelerated expansion occurs above about 4 km and certainly above 1-2km causing the catastrophic / powerful emission of mud, gas and fluids at the surface. Methane expansion he concludes is a significant (mud volcano) driving mechanism.

It is concluded from this study that the incorporation of hydrocarbon gas, in particular methane in association with high fluid pressures caused by compaction disequilibrium, is the main driving mechanism in mud volcano formation in Azerbaijan. The presence of methane causes a significant reduction in sediment density leading to the buoyant rise of mud diapirs which upon passing through lower temperature and pressure regimes suffer a major expansion of free gas causing an acceleration of the rate of migration to the surface.

IX. THE BASIN MODELING

Geologic-geophysical and geochemical material, accumulated for the last years, allowed modeling the generation, migration and formation of hydrocarbon accumulations; these material had been done by some researchers (M.Tagiyev et al, 1997; R.Nadirov et al, 1997; Inan S. et al, 1995; M.Abrams, 1996; M.Abrams et al, 1997; I.Lerche et al, 1997a, 1997b;).

Inan S. et al (1995) had made a basin modeling of the Lower Kura basin. A computer-aided basin modeling study has been carried out to outline the spatial variation of the oil window and thus help in further identification of possible source rocks for the reservoired oil in the Lower Kura Depression. Modeling results suggest that the potential hydrocarbon source horizons of the Oligocene-Lower Miocene (Maykop) Formation and the Pliocene Red Colour Series are, even at depocenter areas, immature to marginally mature with respect to oil generation, and thus, are very unlikely to have been source rocks for the reservoired oils. However, the Lower Eocene rocks, presumed to have been source for the Lower Kura oils (Inan et al, 1997) have been confirmed to be mature with respect to oil generation at all representative field locations. Oil generation from the Lower Eocene source rocks commenced at the end of Pliocene and continues at present at depths between 6000 and 10000 m (**Fig. 9.1**). Only at the locality of the Kursengi field, this source rock has reached and passed the stage of peak oil generation and some of the generated oil has already been cracked to gas for the last one million years.

An unusually deep (>6000 m) oil window in the depocenter areas has been caused by the depressed isotherms due to extremely high sedimentation rates (up to 1500 m/Ma) for the last 2 million years. The main phase of oil generation is taking place at depths greater than what most of the wells in the study area have reached.

The next attempt to model geo-, thermal and hydrocarbon generation history north-west South Caspian Basin was made by M.Tagiyev et al. (1997) at the same year. The model consists of three parts: a geohistory model; a thermal history model; and a hydrocarbon generation model. Input data for the model are commonly used depth values of geological parameters: lithofacies, formation thicknesses, stratal ages, porosity, permeability, pore pressure, temperature, total organic carbon content, type of organic matter, vitrinite reflectance and other maturity indicators. In order to bracket oil generation in terms of timing and depth location, two extreme thermal histories were modeled: paleoheat flow values at one half and twice the present-day values with a linear variation through time to present day measured values. The most intensive oil generation occurs during the last 5.2 My, when the "oil window" is confined to depths between 5-7.5 km in the northwest, 7-10 km in the west (onshore part of the study area), and 8-11 km in the central and southwestern parts of the area (**Fig. 9.2**). Below the "oil window" cracking occurs of oil into gas. Avalanche sedimentation, which took place in the middle Pliocene through Quaternary, results in overpressure build-up across al of the study area. Maximum values of excess fluid pressure of 300-400 atm at 6-10 km are noted in the central and southeastern parts of the area, where the sedimentation rate is the highest. Isobaric contours of excess pressure are then at shallow depths compared to the previous history of the area. Because there is a laterally decreasing trend of excess pressure, oriented from the central and western parts of the area to the northeast and, in addition, the sand/shale ratio is increasing in the same direction, inferences can be drawn on the most probable hydrocarbon migration directions.

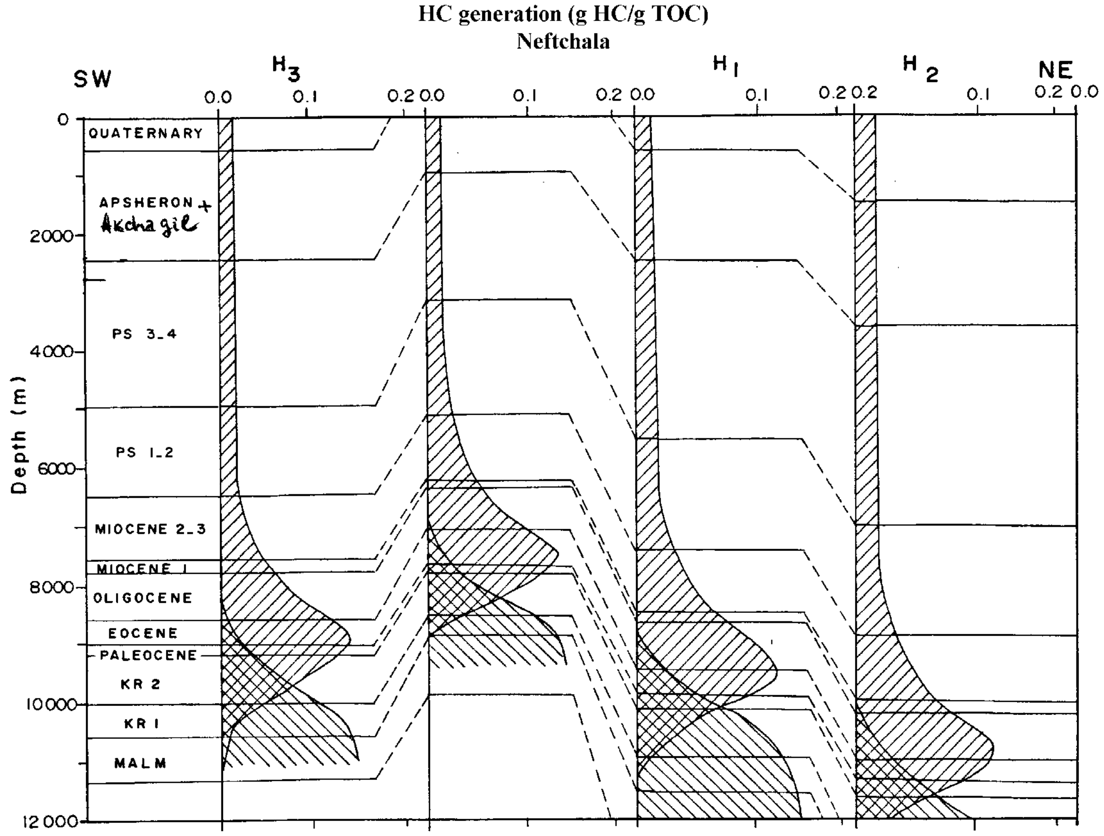


Fig. 9.1 Spatial variation in oil and gas windows along a cross section from Neftchala field to selected three hypothetical wells (H1, H2, H3). Depths to the oil and gas windows are shifted down at the depocenters due to depressed isotherms caused by high burial rates.

The same authors had modeled flexural plate subsidence and structural development of the super-deep part of the South Caspian Basin (R.Nadirov, 1996). On a 270 km long seismic line across the west central and central parts of the South Caspian Basin an inverse flexural plate method is used to recover original unloaded plate parameters. The shift in depositional behaviour with time, from west to more northerly across the line of section, is tied to the orogenic rise of the Caucasus mountains to the north of the section, and to the continued subduction of the Tlysh-Vandam plate fragment northward today. The transpressional nature of the basin, and the resolution of the in-line compressive stress into components perpendicular to the Greater Caucasus (~70%) and also perpendicular to the West Caspian deep-laid fault (25-30%), are both in accord with the 25-30 km of present day sedimentary cover, including the variations of thicknesses of seismic stratigraphic units along the section from Azerbaijan in the west to nearly the Turkmenian border in the east.

M.Abrams at al. (1997) used the Plate River Associates basin modeling program Basin Mod to estimate current subsurface maturation and temperatures in areas where well penetrations are not sufficient to characterize the deep Upper Oligocene (lower Maikopian) source rocks.

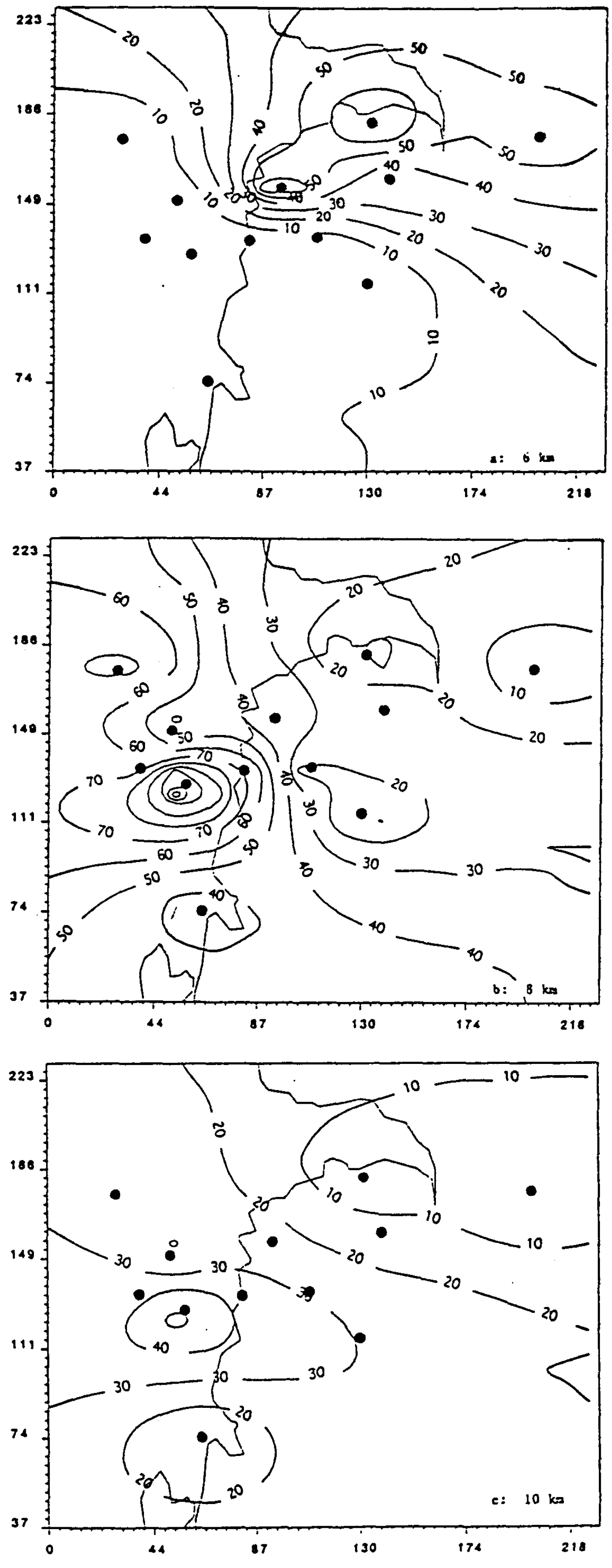


Fig. 9.2 Contour maps of cumulative oil generation at present-day at different depths: (a) 6 km; (b) 8 km; (c) 10 km. Contours are in mg/g TOC

The maximum present level of organic maturation for the proposed Upper Oligocene source rock at the Pirsagat location is 0.75 VRE (**Fig. 9.3a**). This corresponds to early, pre-peak oil generation or a Type II marine source rock. The Pirsagat modeling site shows two major pulses of hydrocarbon generation, one at 6 my, and the other at 2 my. These two pulses result from burial, uplift and subsequent reburial.

The maximum present level of organic maturation for the proposed Upper Oligocene source rock at the Bakhar location is also 0.75 VRE (**Fig. 9.3b**). This again corresponds to early, pre-peak oil generation for a Type II marine source rock. The Bakhar modeling site shows only a single pulse of hydrocarbon generation.

I.Lerche et al (1997) used the 6-second N-S seismic cross-section to the evaluate the dynamical and thermal evolution of the offshore region and hydrocarbon accumulation prospects.

On the dynamical side, the rapid deposition of sediments since Pontian time (~5 MYBP) implies a massive overpressure build-up, prevalent across the whole basin, but with highest overpressure on the eastern side of the basin, corresponding to the deepest sedimentary pile. The corresponding retention of porosity at depth, and the development of fractured formation, are both of importance in controlling pathways for fluid retention and fluid migration.

On the thermal side, the South Caspian Basin is extremely cool, placing hydrocarbon generation windows in the 8-14 km depth range. However, the northern part, near the Absheron-Balkan uplift, has high values of heat flow, implying a higher temperature gradient and, therefore, earlier and shallow hydrocarbon generation than to the west, but also implying a more rapid conversion of retained oil to gas.

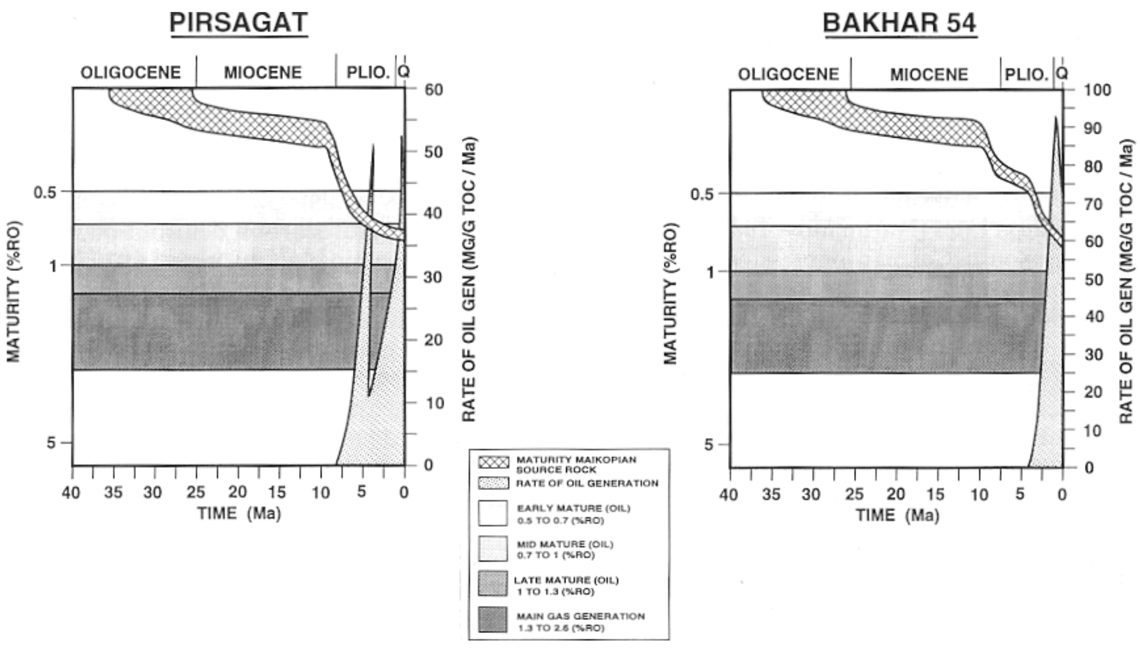


Fig. 9.3. Rate of hydrocarbon generation: (a) Pirsagat and (b) Bakhar.

On the hydrocarbon side, the generation is dominated by the last few million years of sedimentation, which causes both temperature shifts as well as alterations of migration pathways. The calculations reported here would indicate that the largely unconsolidated upper 10 km of sediments provide excellent pathways for hydrocarbons, generated at depth, to migrate to shallower formations, driven by buoyancy, excess pressure, and also carried in water solution (particularly gas). Faults also play a role in the transportation and retention of oil and gas accumulations. The multiple shallow sands of the Pliocene Productive Series, trapped between relatively impermeable shales, then provide almost ideal reservoirs for accumulating gas and oil, as shown in the model calculations.

B.S. Mudford et al (1997) carried out the study of the evolution of pressure, temperature and thermal maturity along a northeast to southwest cross-section from onshore to offshore in the northwestern part of the South Caspian Basin.

The results of modeling suggest that for the permeable units (e.g. the Nadkirmaki sand, the Pereryv and the Sabunchi Formations) to remain overpressured there must be faults or facies changes between structures which compartmentalize the offshore part of the basin.

In the deeper parts of the basin (southeast of Bakhar structure) each formation has an approximately constant level of maturity, independent of the depth of burial. For example, the Kirmaki Formation has a predicted vitrinite reflectance of about 0.65%Ro at Bakhar field and a value of 0.74%Ro at the southeastern end of the line, even though there is a difference in burial depths of nearly 4 km between these two positions. This behaviour of VR with depth is the result of the rapid deposition of cool sedi ment in the offshore parts of the South Caspian Basin. Under a wide range of scenarious concerning the timing of faulting, the oldest parts of the Productive Series begin to generate hydrocarbons in late Pliocene and early Pleistocene time.

Very interest results obtained by I.Lerche (Lerche et al., 1997) for modeling diapir formation. Modeling was applied to Abikh diapir. Data processed with GEOPET II program. The base of the diapir was taken to be rooted in Cretaceous deposits. As evaluated to the end of Maikopian time, there was no evidence of diapir evolution and the sedimentary layers were horizontal and non-deformed. The starting point of diapiric development was sometime in the Miocene and, by the beginning of Productive Series time (Early Pliocene), a diapir existed of approximately 8-9 km height. At this time the top of the mud diapir was at a sub-mudline depth of 2-3 km. The further growth of the diapir was accompanied by huge rates of sedimentation; by the end of Middle Pliocene and Late Pliocene, in spite of high rates of diapiric uprise (to the beginning of the Quaternary, the diapiric pillar height reached 16-18 km), the top of the intrusion remained at a sub-mudline depth of 2-3 km, and, at present-day, is almost at the sediment surface (sea bottom). By the beginning of Middle Pliocene, the diapiric intrusion penetrated all Cretaceous, Paleogene and Lower Miocene (Maikopian) sediments. By the end of Pliocene time, the top of the diapir was in the upper part of the very thick Productive Series and, at present-day, penetrates all the sedimentary cover from Cretaceous to Quaternary. Tthe rise of the diapir and result of this model is shown on **Fig. 9.4**.

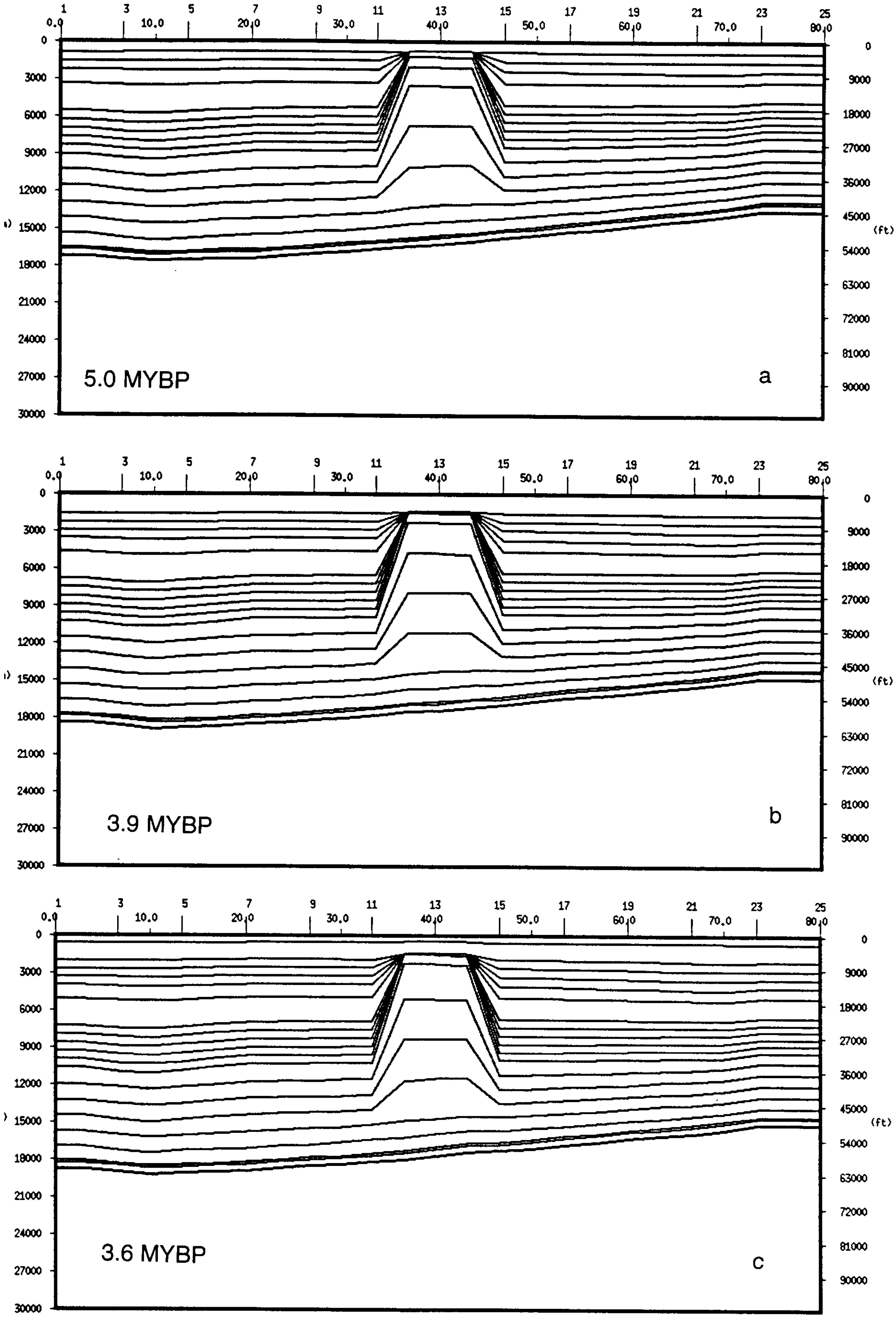


Fig. 9.4 Development of the Abikh diapir at:
5.00 MYBP; b) 3.9 MYBP; c) 3.6 MYBP;

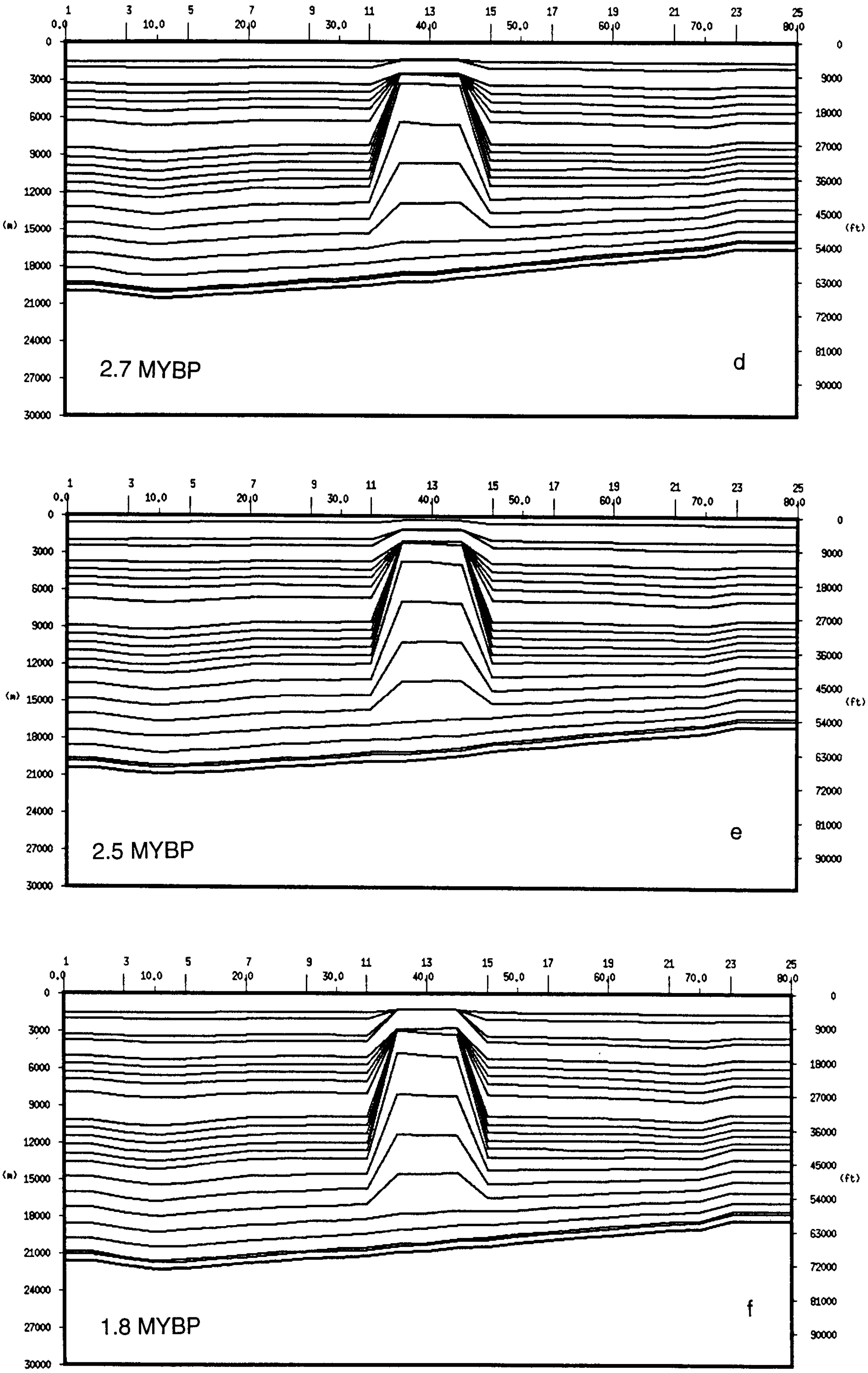


Fig. 9.4 d) 2.7 MYBP; e) 2.5 MYBP; f) 1.8 MYBP;

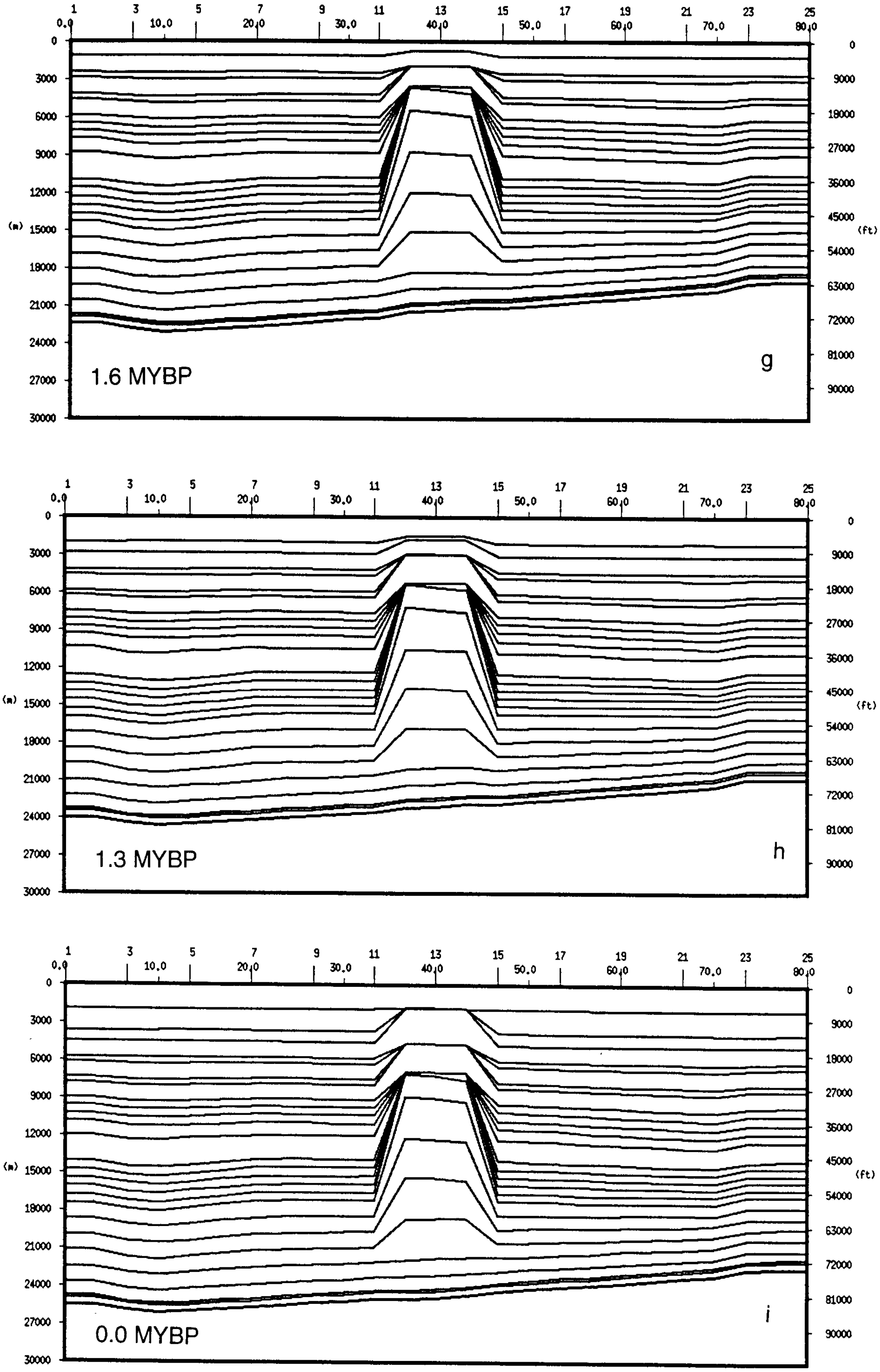


Fig. 9.4 g) 1.6 MYBP; h) 1.3 MYBP; i) present-day.

SUMMARY

The available geologic-geophysical data confirm the plate-tectonic conception of presence of the marginal-marine basin with typical crystalline crust of oceanic type, flanks morphostructure and sedimentary complex in the South Caspian region. The present deep-sea basin of the South Caspian is the relict of the Mesozoic-Paleogene uncompensated depression. By the orogenic stage it had experienced three main cycles (stages) of the geodynamic development, namely: 1) riftogenic, with origination of deep trough of the Great Caucasian marginal sea; 2) mature, with stages of marginal sea widening and isolation; 3) island arc, with stages of volcanic arcs development, compression and subduction processes. Starting with the Oligocene and especially Neogene-Pleistocene the marine basin had been gone through the fourth stage. This stage is characterized its transformation into unique intracontinental basin. The same stage is characterized by forming of very non-equilibrium oil-gas bearing basin with specific hydrocarbon system with the following parameters:

-Non unidirectional folding zones formed at different tectonic stages;

-High density of non unidirectional fractured zones and abyssal faults;

-High velocity of vertical and horizontal movements;

Paleomagnetic and GPS data point to continued displacement of the Arabian plate and its north periphery northeastward with velocity 10-12 mm/year. Vertical movements on the anticlinal structures are +1,2 - +4,5 mm/year, in some areas they reach +90 mm/year. At the same time there can be observed the sinking with velocity -25 - -50 mm/year. Thus, the relative velocity of the vertical movements can reach 140 mm/year.

-Very high velocities of subsidence and sedimentation (up to 3,5 km/my) for a very short period of geological time (Pliocene-Quaternary);

-Formation of a sedimentary cover of a huge thickness (according to the latest data it is up to 30 km);

-Mainly clayey composition of rocks in the Cenozoic section;

-Abnormally high porous (close to geostatic) and formation pressures;

-Abnormally low temperature gradients (1,5-1,80C/100 m) and thermal flows (25-50 mW/m2);

-Large scale variation of the hydrocarbons maturity: low maturity of oils - R_0 does not exceed 0,75%, and high maturity of HC gases – R_0 more than 2,0%;

-Extended zone of hydrocarbon generation. In the central part of the basin from the obtained models one can predict the presence of large zone of HC formation reaching to 8-10 km and extending to the basement –20km;

-Several source-rocks of different starticraphic age. Isotopic-geochemical studies show, that hydrocarbons had been generated by Mesozoic, Paleogene and Miocene complexes.

-Inversions of hydrogeochemical parameters, which are reflections of active fluid dynamics;

-Mosaic character of spread of HC fluids, high velocities and impulse character of vertical

fluid migration.

-Wide spread of diapirism and mud volcanism. Basic part of mud volcanoes in the world are concentrated in the South Caspian region supplying about $1x10^9$ m^3 of hydrocarbon gases a year, which proves the high hydrocarbon generation in sedimentary cover;

- High saturation of deep subsided horizons with fluids;

-High seismisity and superposition of small-focus earthquakes with mud volcanic sources in the interval 10-20 km;

-Mosaic and multistory of hydrocarbon deposits. The majority of reservoirs and hydrocarbons reserves (about 90%) are concentrated in thick (7 km) Lower Pliocene Productive Series (PS) consisting of rhythmically bedded fluvial-deltaic sediments deposited in the isolated South Caspian basin by several large river systems. From the conducted research it is clear a key role of high-frequency closed Caspian sea level fluctuations in Early Pliocene in depositional environment changes, facial shifts and architecture of multistory reservoirs.

From all above mentioned it is clear, that elaboration of new untraditional model of petroleum systems of non-equilibrium basin from the example of SCB is an important task. A traditional paradigm of HC exploration in the SCB is oriented to the study of the structure and properties of the sedimentary cover in static. New approaches propose to direct at the whole arsenal of up-to-date methods to the study of the structure and properties of rocks and fluids in dynamics. The main task is the differentiation of the sedimentary basin according to the level of phase and mechanical stability (Guliyev I. and Ivanov V., 2001). The solution of the problem includes:

-division of the ground waters into zones of convective and diffusion exchange and reconstruction of the velocity field of the convective zones;

-contouring of zones of HC formation and assessment of the abundance of their sources;

-identification of sub-zones (zones of recent and paleo-accumulation), where the velocity of production is exceeding (or was exceeding) the velocity of the withdrawal;

-differentiation of the zones according to the distribution of accumulation velocity, ratio of metastability and surplus pressure.

Technologic chain, promoting implementation of the above-mentioned points includes the following regional exploration tasks:

-3D and 4D seismic servey;

-mapping of high-gradient zones by means of the study of the spatial variability of the different components concentration fields (first of all helium and tritium) aimed at the reconstruction of the underground water-exchange;

-the study of HC fields for the localization of their zones of production, migration and accumulation.

- good understanding of sedimentary model of Lower Pliocene Series in the different parts of the basin as well as precise mapping of different facial zones formed by different sediments suppliers are vital important in searching of nonanticline hydrocarbon traps.

Tasks of the local exploration are as follows:

-mapping of paleo and recent “excitement” sources, their capacity and productivity.

As it was mentioned above the phase transitions in HC systems occur in zones of the extreme saturation of formation waters by HC. In seismic profiles such zones are identified in the form of inversion of velocities of seismic waves, which are interpreted as the under-compaction-decompaction zones. Mapping such zones, the study of their nature, assessment of thermodynamic parameters, physical properties of rocks and geochemical peculiarities of fluids is urgent task. Such areas are potential zones where the phase transitions are quite possible. The process of the phase transitions (“excitement” of system) occurs periodically. Coordinates of the zones of excitement may be mapped more precisely by methods of seismic monitoring, as far as act of the “excitement" is accompanied by a dramatic change of pressure and temperature, density, permeability, viscosity of rocks and fluids and appropriate mechanic effects.

-mapping of sources of mud volcanoes eruption and small-focus earthquakes, which logically may be connected with process of the "excitement" of the sedimentary rocks. In this case, it is possible to fix not only coordinates of the "excitement" source and to determine its volume, facial peculiarities, stratigraphic localization, quality of source rocks, their possible productivity.

-mapping of migration channels. It is supposed, that the widest migration of HC occurs during the "excitement" of the system, when permeability of the environment (especially in the migration channels) increases considerably as a result of the decompaction of the matter. The migration channels may be of a different morphology. Impulse subvertical discharge of energy accompanied by the intrusion of the matter (clay saturated with gas, oil and water) under a high pressure into the upper layers of the sedimentary series creates a complex system of the destructive zones. As a rule it resembles a crown of a high tree and it may be characterized as "migration tree" Typical configuration and consistency of such zones is identified by seismic methods and their projection on the surface occurs in the form of natural oil and gas seepage and geochemical anomalies.

-mapping of HC bodies. Theoretically HC bodies may be fixed in any sedimentary basin, where is carried out conditions of mechanical stability of the gaseous bodies in the porous space, i.e. not obligatorily in traditional traps.

Non-traditional traps of a complex configuration (hydrodynamic, in particular) were determined in all oil and gas basins. From this point of view, of a special interest are giant subvertical bodies-diapirs and mud volcanoes, which are zones of HC drainage from the surrounding sedimentary rocks (Lerch I. et al., 1997). Methods of mapping of such bodies and evaluation of their HC saturation have not been developed yet, though there are interesting ways of interpretation of the geophysical data for such cases. It is know also instances of the determination of HC accumulations, mapping as zones of inversion of the seismic waves velocities or zones of the porous pressure anomalies.

"Excitement" centers, migration channels and zones of HC stabilization in bodies of different configuration are united in the individual HC systems, autonomous in their evolution. The study of such individual HC systems is very difficult.

- elaboration of good models of reservoirs geometry in different fields. Non – structural traps may be connected not only with subvertical bodies, but with lithological traps of Lower Pliocene formed as a result of rapid environmental changes under influence of small scale sea level fluctuations.

The most common regularities of the change of dynamic parameters of the environment depending on the intensity of HC migration may be studied basing on the example of the investigation of mud volcanoes, which are associated spatially and genetically, through their complex monitoring. The obtained regularities may be applied during the modeling of paleo HC system.

The above-mentioned ideas may serve as a base for the improvement of technology of HC field's exploration. This technology may supplement the traditional one with a new information about centers of mud volcanoes eruptions, about hypocenters of earthquakes in the sedimentary cover, natural gas-water seepage seeps in wells, elasticity and concentration of HC in the ground waters and about chemical and isotope composition of ground waters and gases, first of all helium and hydrogen. These indices usually are not used sufficiently in the assessment of oil and gas potential. The upgraded technology of search for HC will allow increasing the efficiency of exploration works in a complex basin like SCB.

ACKNOWLEDGEMENTS

At different stages of performing the studies, results of which formed the basis for the book, the authors closely cooperated with Drs. M. Abrams, R.Archer, N.Bailey, P.Barnard, I.Lerche, M.Simmons, S. Kroonenberg, D.Wavrek, and N.Yalchin, all of which are gratefully acknowledged.

REFERENCES

Abaceliya, 1937. To a problem Kyurdamir gravitational, bridge of Transcaucasia, Azerbaijan oil industry, N9, seconds 6-10 (in Russian).

Abdullayev R.N., Mustafayev G.V., 1984. Magmatism and metallogeny of Azerbaijan in the light of new data. Papers "Essays on Azerbaijan geology", Baku.

Abdullaev T., Falt L.-M., Akhundov A., van Graas G.W.. Kvamme T., Flolo L.H., Mehmandarov K., Narimanov A.A., Olsen T.S., Seljeskog G., Skontorp O.,.Sultanzade T, Tank N.and Valieva E., 1998. A reservoir model for the main Pliocene reservoirs of the Bahar Field in the Caspian Sea, Azerbaijan. Petroleum Geoscience, Vol.4, pp. 259-270.

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: Marine and Petroleum Geology, v.14, p. 451-468.

Adamia, Sh.A., 1984. Pre-Alpine basement of the Caucasus - composition, structure and formation. In: Tectonics and metallogeny of the Caucasus. Tbilisi, 3-104, (in Russian).

Adamia, Sh.A., Zakariadze, G.S. and Lordkipanidze, M.B., 1977. Evolution of an active continental margin by the example of the Alpine history of the Caucasus. Geotektonika, No.4, 88-102, (in Russian)

Agabekov, M.G., 1968. The Kura Depression. Azerneshr, Baku, 257p.

Agabekov, M.G., Azizbekov, Sh.A., Akhmedbeyli, F.S., Gajiev, T.G., Grigoryants, B.V., Mamedov, A.V. and Shikalibeyli, E.Sh., 1972. Tectonic scheme of Azerbaijan, 1:1,000,000. Geological State Committee, Geology Institute Azerbaijan Academy of Sciences. In: Azizbekov Sh.A. (Ed.), Geology of the USSR, Azerbaijan. Vol. XLVII. Nedra, Moscow (in Russian).

Agamirzoyev, R.A. and Gul, E.K., 1971. On abyssal structure of Azerbaijan on macroseismic data. In: Meeting materials of the commission for study of seismically hazardous zones by the methods of exploration geophysics. Moscow, 53-58, (in Russian)

Akhmedov G.A., 1961. Geology and oil-gas content of Gobustan. Baku (in Russian)

Aksyonovich, G.I., Aronov, L.E., Galperin, E., Kosminskaya, I.P. and Gegelgants, A.A., 1962. Deep seismic sounding in central part of the Caspian Sea. Publishing House of USSR Academy of Sciences. Moscow, 146 p. (in Russian).

Aliyev G and Aliyeva E. 2000. Conditions of Hydrocarbon Formation in Sedimentary Series of Azerbaijan. Proceedings of EAGE 62sd Conference, Glazgo.

Aliyev N.A. 1998. Hydrocarbon potential of the South Caspian. Azerbaijan oil industry, No7, p.2-7, (in Russian).

Aliyev S.A. and Aliyev A.S., 1995. Heat flow in depression of Azerbaijan. In Trresstrial heat flow and geothermal energy of Asia. Editors Mohan L. Gupra and Makoto Yamano. Oxford & IBH Publishing Co. PVT. Ltd. New Delhi.

Aliyev A.A., Guliyev I.S. and Panachi B. 2000. Mud volcanoes hazards. Baku. “Nafta-Press” 56 p.

Aliyev Ch., Feyzullayev A., Zolotovitskaya T. 2001. Peculiarities of radioactive fields of mud volcanoes of Azerbaijan. Geophysics news in Azerbaijan, N 3, p.25-32.

Aliyeva E. 2001. The newest stage of the Caspian Sea evolution: bio- and sequence stratigraphy. Proceedings of Azerbaijan Academy of Sciences. Sciences of Earth. N1, p. 88-97.

Aliyeva E. 2002. Depositional environment of hydrocarbon-bearing Lower Pliocene Productive Series in Southwest Caspian basin. Proceedings of 16th Sedimentological Congress, South Africa, p.9-12.

Aliyeva E. 2003. Model of HC generation and accumulation applied to prospects of Caspian deep water part. Extended abstract book of 65th Conference of Eropean Association of petroleum geologists and engineers. Stavanger.

Aliyeva E. 2003. Prediction of zones of hydrocarbon generation and accumulation in the South Caspian deep water part. J. “geology of oil and gas”. N4,. Moscow.

Aliyeva E. 2003Integration of different stratigraphic methods applied to closed basins (from the example of the Pliocene- Quaternary Caspian Sea). Abstract book of XVI INQUA Congress. Nevada, USA.

Aliyev G, Aliyeva E. 2003. Hydrocarbon potencial of recent and Cretaceous carbonate deposits of the Caspian Sea. Extended abstract book of 65th Conference of Eropean Association of petroleum geologists and engineers. Stavanger.

Ali-zade A.A., Ahmedov H.A., Aliyev H.-M.A., Pavlova V.A. and Khatskevich N.I., 1975. Assessment of oil generative properties of the Meso-Cenozoic deposits in Azerbaijan, Elm, Baku, p. 140. (in Russian).

Ali-zadeh, A.A., Ahmedov, H.A., Ahmedov, A.M., Aliyev, A.K. & Zeynalov, M.M. 1966. Geology of oil and gas fields in Azerbaijan. Nedra, Moscow (in Russian).

Ali-Zadeh, Ak.A., 1997. Stratigraphy of the Mesozoic and Cenozoic deposits. In: Lerche, I. and Ali-Zadeh, Ak.A., (Eds.): South Caspian Basin: stratigraphy, geochemistry, and risk analysis. Nafta-Press, Baku, p.6-93.

Ashirov G., Dubrovski V.G., Odekov O.A., 1976. Geothermic conditions in the Pri-Balkhanian depression. Proceedings: Geothermy. Moscow, "Nauka", part 1, p.59-64 (in Russian)

Azizbekov, Sh.A, Agabekov, M.G., Grigoryants, B.V., Shikalibeyli, E.Sh. and Mamedov, A.V., 1972. The history of the geological evolution, In: Azizbekov Sh.A. (Ed.), Geology of the USSR, Azerbaijan Vol. XLVII. Nedra, Moscow, pp.441-503 (in Russian).

Baba-Zadeh, B.G., 1960. Classification of oil and gas accumulations in Azerbaijan. Azerb. Oil & Sci. Lit. Publ., Baku, 134p. (in Russian).

Bagir-Zadeh, F.M., Kerimov, K.M. and Salayev, S.H., 1987. Abyssal structure and oil and gas content of the South Caspian Megadepression. Azerneshr, Baku, 304 p. (in Russian).

Bagir-Zadeh, F.M., Narimanov, A.A. and Babayev, F.R., 1988. Geological and geochemical features of the fields in the Caspian Sea. Nedra, Moscow, 208 p. (in Russian).

Bailey, N.J.L., Guliyev, I.S., & Feyzullayev A.A. 1996. Source rocks in the South Caspian. in: AAPG/ASPG research symposium "Oil and gas petroleum systems in rapidly-subsiding basins". Book of abstracts, Baku, Azerbaijan.

Balavadze B.C. 1975. To construction of model of earth crust of Caucasus and adjacent of water areas, Information AS USSR, Physics of the Earth, N2, p. 75-83. (in Russian)

Bazhenov M.L., Burtman V.S., Tsyganova I.V., To reconstruction of the Mesozoic Tethys on the Caucasus.

Bevis M., et al., 1997. Blending old and new approaches to regional GPS deodesy. EOS. Trans. Am. Geophys. Union. 78, 61, 64-66.

Bhaskara Rao, D. and Ramesh Babu, N., 1991. A fortran-77 computer program for three-dimensional analysis of gravity anomalies with variable density contrast. Computer and Geosciences 17, 655-667.

Bhaskara Rao, D., 1986. Modelling of sedimentary basins from gravity anomalies with variable density contrast. Geophys. Jour. Roy. Astr. Soc. V.84, No.1, 207-212.

Bhattacharyya, B.K., 1966. Continuos spectrum of the total magnetic anomaly due to a rectangular prismatic body. Geophysics 31, 97-121.

Blakely R.J. 1995. Potential theory in gravity and magnetic applications, New York, Cambridge University Press, 441p.

Blakely R.J., Simpson R.W. 1986. Approximataing edges of source bodies from magnetic or gravity anomalies, Geophysics, v.51, N6, p.1494-1498

Bogdanov N.A., 1988. Tectonics of the deep-water depressions of the marginal seas. Moscow, "Nedra" (in Russian)

Boillot G., 1983. Geologic des Marges Continentales. Moscow

Bondarenko, N.F. and Nerpin, LV., 1967. The shear strength of liquid and its calculation from the study of surface occurrences, in: Studies in he surface forces, Nauka, Moscow. (in Russian)

Bracewell, R.N., 1983. Discrete Hartley transform: J. Opt. Sec. Am. 73, 1832-1835.

Bracewell, R.N., 1986. The Fourier Transform and Its Applications: McGraw Hill Book Co.

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., 72, 416-424.

Brown,K.M. 1990, The Nature and Hydrogeologic Significance of Mud Diapirs and Diatherms for Accretionary Systems, journal of Geophysical Research v.95.

Bulakh E.G., Markova M.N., 1992. The solution of return problems of a gravimetry by a trial and error method, Geophysical log-book, N4, p.9-19

Bulakh E.G., Markova M.N., Timoshenco V.A., 1984. A software of the automated system of interpretation of gravity anomalies, Kiev., Naucovo Dumca, 1984, 112 p.

Burjakovski L.A., Guliev LS., Dzhevanshir R.D., 1986. Forecast of gas bearing of deep depth in Cenozoic sediment-rock basins: Thesis of rep. V All-Union seminar “Oil and gas formation at deep depths”. M.

Buryakovskii, L.A., Jafarov, I.S., and Dzhevanshir, R.D., 1982. The prognosis of the physical properties of oil and gas reservoirs and seals, Nedra, Moscow. (in Russian)

Chung H.U., Rooney M.A., Toon M.B. and Claypool G.E. 1992. Carbon isotope composition of marine oils. The American Association of Petroleum Geologists Bulletin, v.76, No.7, p.1000-1007.

Dadashev F,G., Guliev I.S., Dadashev A.A., 1985. Geologic-geochemical preconditions of gas deposits in SCB:, Resume of reports of the ÕI International Conference “Petrol-geochem” Poland Visla.

Dadashev, A.A., Feizullayev, A.A. and Guliyev, I.S., 1986. On vertical zonality of oil and gas generation deduced from carbon isotopic composition of methane from Azerbaijan mud volcanoes. Oil and gas geology and geophysics : Express Information Series, Moscow, 6, 24-28. (in Russian)

Dadashev, F. G., 1964. Chemical composition of gases in oil, gas-condensate, and gas fields in the southeast Caucasus and its variation regularities. In: Essays on geology of Azerbaijan. Azerb. Acad. of Sci. Publ., Baku, 58-65. (in Russian)

Dadashev F.G. and I.S.Guliyev. 1981. Bildungs gesetzmabigkeiten der Gase in der Stratisphare der Sud-Kaspi-Senke und der angrenzenden Gebirgssysteme: Zeitschrift fur angewandte Geologie. Bd.27, Heft 3, p.145-148.

Dadashev, F.G. and Guliev, I.S., 1984. The gas content in Mesozoic and Cenozoic deposits and the prospects for finding new fields in the South Caspian Basin, in Outline of the Geology of Azerbaidzhan, Elm, Baku. (in Russian)

Dadashev, F.G., 1963. Hydrocarbon gases of Azerbaijan mud volcanoes (in Russian). Azerneshr, Baku, 66 p. (in Russian)

Deryagin, B.V. and Churaev, NV.,1984. Wetting Films, Nauka, Moscow. (in Russian)

Diaconescu C.C., Kieckhefer R.M., Knapp J.H., 2001. Geophisical evidence for gas hydrates in the deep water of the South Caspian basin Azerbaijan. Marine and Petroleum Geology, No 18, p. 209-221.

Diaconescu C.C., Knapp J.H. and Conner J., 2000. Crustal scale imaging of the Absheron Ridge (South Caspian Sea) re-built by deep seismic reflection profiling. AAPG's Inaugural Regional International Conference, Istanbul, Turkey.

Dotduyev S.I., 1986. About the cover structure of the Greater Caucasus. Geotectonics, №5. (in Russian)

Dzabayev A.A., 1970. Application of data of high-precious aeromagnetic mapping aimed to study of deep structure of the south part of the Caspian Sea and western Turkmenia. Turk. GU, p.42 (in Russian)

Edwards D.J., Lyatsky H.V., Brown R.J., 196. Interpretation of gravity and magnetic data using the horizontal-gradient vector method in the Western Canada Basin. First Break, v.14, No 6, p. 231-246.

Faber E. Z., 1987. Isotopengeochemie gasformiger Kohlenwasserstoffe: Erdole, Erdgas and Kohle. 1987, 103, p. 210-218. (in German)

Fairbrige R.W., 1961. Eustatic changes in sea level. Physics and Earth, 4.

Feyzullayev A.A. 1999. The hydrocarbon pools search prospective in the seismoactive regions. 2nd Balkan Geophysical Congress and Exhibition. Istanbul, Turkey. July 5-9.

Feyzullayev A.A., Aliyeva Es. A. 2000. Mud volcanoes and geochemistry of fluid and rock ejecta, the South Caspian Basin. EAGE 63 Conference and Exhibition, Glasgow, The Scotland. 29 May-2 June.. Extended Abstracts Book. P-11.

Feyzullayev A.A., Tagiyev M.F. 2001. The deep-water part of the South Caspian Basin- anticipation of gas-dominated hydrocarbon recourses. (with M.). EAGE 63 Conference and Exhibition, Amsterdam, The Netherlands. 11-15 June. Extended Abstracts Book. P 541.

Feyzullayev A.A., Movsumova U. 2001. About origin of isotopicaly heavy CO2 in gases of Azerbaijan mud volcanoes. Azerb. Geologist. # 6, p. 96-105. (in Russian).

Feyzullayev, A.Khalilov, E.Aliyeva. 2002.About the mud volcano's roots on isotope-mineralogical data, example of the Bahar mud volcano, Azerbaijan. Abstracts Book of International Conference on "Petroleum geology and hydrocarbon potential of the Caspian & Black Seas Region" Baku, Azerbaijan 24-26 September.

Feyzullayev A.A. 2003. Geological conditions and peculiarities of mud volcanoes formation. Abstracts of AAPG Annual Meeting. Salt Lake City, Utah. May 11-14. A 53.

Feyzullayev A.A.and Huseynov D.A. 2002. Peculiarities of oil-gas formation within Baku archipelago. Azerbaijan Oil Industry, Baku, N4, pp.1-5

Fowler S.R., Mildenhall J., Zalova S., Riley G., Elsley G., Desplanques A., Guliyev F. 2000. Mud volcanoes and structural development on Shah Deniz. Petroleum Sciences and Engineering, No 28, p.189-206.

Gajiyev R.M., E.M.Makarov, A.T.Nabiyev and F.A.Kadirov. 1984. Study of the non-tidal variations of acceleration of free fall on Absheron geodynamic range. In: Repeated gravitational supervision. Problems of theory and results. Edit. Y.D.Bulanzhe. M. P. 55-59. (in Russia).

Gajiyev A.N., Ragimkhanov F.G., 1986. Tectonics and oil-gas content of the Turkmenian shelf of the Caspian Sea according to complex geologic-geophysical data. VNIIE-Gazprom, Information reviews. Series: Geology and exploration of offshore oil and gas fields. Moscow, p.36 (in Russian)

Gajiyev R.M., Kadirov F.A., Makarov E., Nabiev A.T.1984. Study of Non-Tidal variations of acceleration of free fall on the Apsheron geodynamic range. In: Yu.D.

Boulanger (Editor) Repeated gravimetric observation. Proceedings of the Meeting of the Commission for the Study of Non-Tidal Gravity Changes.. Nedra, Moscow, p.53-60. (in Russian).

Gajiyev, R.M., 1965a. Abyssal geologic structure of Azerbaijan. Azerneshr, Baku, 199p. (in Russian)

Gajiyev, R.M., 1965b. Deep geological structure of Azerbaijan. Azerneshr, Baku. 205p. (in Russian).

Gajiyev A.N., Popkov V.I., 1988. Structure of the sedimentary cover of the Middle Caspian. Geotectonics, November December (in Russian)

Gamkrelidze, I.P., Dumbadze, G.D., Kekeliya, M.A., et al., 1981. Ophiolites of the Dzirul Massif and the problems of Paleotethys in the Caucasus (in Russian). Geotektonika, No.5, p.23-33.

Gasanov I.S., Ismailov K.A., 1966. Recent structure of the South Caspian depression and its relations with deep tectonics. Proceedings: Exploration geophysics on the Caspian Sea. Leningrad, p.101-119 (in Russian)

Gavrilov V.P., 1998. Geodynamic model of oil-gas generation in the lithosphere and its consequences. Oil and Gas Geology, No6.

Geology of the USSR, 1972. Azerbaijan SSR. Geological Description. Ed. Azizbekov, Sh.R. Vol.47, Nedra, Moscow, 520 p. (in Russian)

Ginzburg, G.D., Guseinov, R.A., Dadashev, A.A., et al., 1993. Gas hydrates of the southern Caspian. International Geology Review, 34, No.8, 765-782.

Golonka J. 2000. Geodynamic evolution of the South Caspian Basin. AAPG's Inaugural Regional International Conference, Istanbul, Turkey

Gorin Yu.N., 1969. Deep structure of Turkmenian according to geophysical data. Moscow, Publishing House "Nedra". (in Russian)

Grachevsky M.M., 1989. Potentially oil-gas bearing reefs of the World Ocean. Proceedings "Problems of oil-gas content of the World Ocean", Moscow, "Nauka". (in Russian)

Gravimetric map USSR, 1990. Scale 1:2500000, M., Ministry of Geology.

Gubkin I.M., 1934. Tectonics of the South-East part of the Caucasus relating to oil and gas presence in this areas. M.: Mine-geologic-oil publishing house, 51 p.

Gugunava G.E., 1985. Concerning the interrelation of some geophysical fields and deep structure of the Caucasus. Moscow, "Nauka", p.70-79

Guliyev I.S. 1999a. The internal factors in the self-development geological bodies. Materials of the Third International conference " New ideas in geology and geochemistry of oil and gas ". Moscow, MSU. P. 77-78 (in Russia).

Guliyev I.S. 1999b. “Exited” sedimentary complexes and their role in the dynamic processes and formation of petroleum deposits. Proceeding of the International Meeting -Seminar " Newest tectonics and its influence on formation and distribution of petroleum and gas deposits" Baku. P. 53-60 (in Russia).

Guliev I.S., Feisullayev A.A. and Tagiyev M.F. 1997. Isotopic-geochemical characteristics of hydrocarbons in the South Caspian Basin. Energy, Exploration and Exploitation, 15, No. 4/5, p. 311-368.

Guliyev I.S and Ivanov V.V., 2001. New paradigm for hydrocarbons exploration in South Caspian basin. In.: New ideas in geology and geochemistry of oil and gas. Abstract-book of the 5th Intern. Conf. Moscow State University. Part 1. Moscow, p.113-115.

Guliyev I.S. and F.A.Kadirov. 2000. About one mechanism of intrastratal migration of hydrocarbons. Doklady RAN, v. 373, № 4, p. 506-509 (in Russia).

Guliev I.S. and Feizullayev A.A. 1996a. Geochemistry of hydrocarbon seepages in Azerbaijan. In: Hydrocarbon migration and its near-surface expression: AAPG Memoir, 66, p. 63-70.

Guliyev, I.S. and Feizullayev, A.A., 1996b. Zonality of hydrocarbon generation and oil and gas resources in the South Caspian Basin (in Russian). Az.Neft.Tasar./ Az.Neft.Khoz., No.4, 6-8.

Guliyev, I.S. and Feizullayev, A.A., 1997. All about mud volcanoes. Nafta Press, Baku, 52p.

Guliyev, I.S., Feizullayev, A.A. & Huseynov, D.A. 2000. Maturity level of oils contained in different age reservoirs in the South Caspian mega-Basin. Geologiya nefti i gaza, No.3, 41-50 (in Russian).

Guliyev, I.S., Feyzullayev, A.A. & Huseynov, D.A. 2001a. Isotope geochemistry of oils from fields and mud volcanoes in the South Caspian Basin, Azerbaijan. Petroleum Geoscience, 2001, v.7, No2, p.201-209.

Guliyev, I.S., Feyzullayev, A.A. & Huseynov, D.A. 2001b. Isotopic composition of carbon of the hydrocarbon fluids in the South Caspian megadepression. Geochemistry, No 3, Moscow, p. (I Russian)

Guliyev I.S., Feyzullayev A.A., Tagiyev M.F., 2001. Source potential of the Mesozoic-Cenozoic rocks in the South Caspian Basin and their role in forming the oil accumulations in the Lower Pliocene reservoirs. Petroleum Geoscience, vol. 7, No4, pp. 409-417

Guliyev I., M. Tagiyev, A. Feyzullayev. 2001. Hydrocarbon potential of maikop deposits in Azerbaijan. Litologiya i Poleznye Iskopaemye. N 3, p.324-329

Guliyev, I.S., Frantsu, Y., Muller, R., Feyzullayev, A.A. & Mamedova, S.A. 1991. Geologic-geochemical features of oil and gas formation in the Alpine intermontane basins. Geokhimiya, No.1, 148-156 (in Russian).

Guliyev I.S., Huseynov D.A. and Aliyeva E.G. 2001. Mud volcanoes in the South Caspian basin-deep sourses and dynamics of development .Abstracts book ESF workshop Natural Hydrocarbon Seeps, Global Tectonics and Greenhouse gas Emission. Delft, Holland. P.

Guliyev, I.S., Klyatsko, N.F., Mamedova, S.A., Suleimanova, S.F. and Feizullayev, A.A., 1989. Some questions of rock physical properties forecast at deep subsurface of the South Caspian Basin. Az.Neft.Khoz. / Az.Neft.Tasar., No.6, 1-6. (in Russian)

Guliyev I.S., Huseynov D.A. and Feyzullayev A.A. Geochemical features and sources of fluids of mud volcanoes of the South Caspian basin according of carbon, hydrogen and oxygen new isotopic data. Accepted to publication in J. Geochemistry in 2002. Moscow.

Guliev, I S., and Kadirov F A., 2000. A mechanism of intrastratal migration of hydrocarbons. Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Section, 373, No. 6, August-September, 941-944.

Guliyev I.S., Kadirov F.A., R.E.Reilinger, R.I.Gasanov, and A.R.Mamedov. 2002. Active Tectonics in Azerbaijan Based on Geodetic, Gravimetric, and Seismic Data Transactions (Doklady) of the Russian Academy of Sciences/Earth Science Section, Vol. 383, No2, p.174-177

Guliyev I.S., Feyzullaev A.A., Kadirov F.A. 2002. Petroleum System in Dis-Equilibrium Basins (in case of South Caspian Basin) Publishing house “Nafta Press”. Baku, 27p.

Guliyev I.S. 2003. South Caspian basin - excitement and movement of sedimentary masses : mechanism and geologic consequences. Abstracts of AAPG Annual

Meeting on CD-ROM. Salt Lake City, Utah. May 11-14.

Guliyev I.S., N.I.Pavlenkova and M.M.Rajabov. 1988. Regional decompaction zone in sedimentary cover of South Caspian Basin. Izvestiya Academii Nauk SSSR. Litologiya i poleznye iskopaemye. No 5, p.130-136 (in Russia).

Hager B.H., King R.W., Murray M.H. Measurement of crustal deformation using the Global Positioning System. Annu. Rev. Earth Planet. Sci.,19, 351-382, 1991

Hartley, R.V.L., 1942. A more symmetrical Fourier analysis applied to transmission problems. Proc. IRE, v. 30, No. 2, 144-150.

Hearn E.H., Burgmann R., Reilenger R.E., 2000. Dynamics of Izmit earthquake postseismuc deformation and loading of the Duzce earthquake hypocenter. Bull.Seismol.Sos.Am, submitted.

Herring, T.A., GLOBK: Global Kalman Filter VLBI and GPS Analysis Program. Version 4.1, Cambridge: Mass. Inst. Technol., 1998.

Hinds D., Simmons M., Allen M., Aliyeva E., 2000. Fluvial architecture variability within the Pereriva and Balakhany Suites of the Productive Series, Azerbaijan: Implications for reservoir quality. AAPG Inaugural Regional International Conference. Istanbul. Turkey (in press AAPG bulletin).

Huseynov D.A., 2000. Origin of oils in the western part of the Kura-South Caspian oil-gas bearing basin. In: Extended Abstracts Book, 62th EAGE Conference and Technical Exhibition, Glasgow, UK.

Huseynov, D.A., Guliyev, I.S., & Feyzullayev, A.A. 2000. Isotope-geochemical prognosis of the stratigraphic origin of the oil seepages sources in the South Caspian Basin. Materials of International symposium on “Oil and gas Business of the Greater Caspian Area - Present and Future Exploration and Production Operations”, July 9-12, Istanbul, Turkey.

Huseynov D.A. 2002. Paragenesis of metals and oil-generating series in the South Caspian sedimentary basin. Proceedings of 16th Sedimentological Congress, South Africa, pp.23-27.

Huseynov D.A. 2002. South Caspian basin: geochemistry and fluid flows of submarine folded zones. Proceedings of 7th International Conference on “Gas in Marine Sediments”. Octobr 7-12, Baku.

Huseynov D.A. 2003. Integrated geochemical analysis of oils – Application to reservoir infill on Caspian shelf Extended abstract book of 65th Conference of Eropean Association of petroleum geologists and engineers. Stavanger, Norway.

Huseynov D.A. 2003. Pliocene-Quaternary methane emission from South Caspian mud volcanoes. Abstract book of XVI INQUA Congress. Reno, Nevada.

Huseynov D.A. 2003. New data on oil source-rocks in Pliocene sediments of the South Caspian petroleum system. Extended abstract book of 1th North Africa/ Mediterranen Petroleum and Geosciences Conference of Eropean Association of petroleum geologists and engineers. Tunis, 2003.

Inan S., Yalcin N., Guliev I., Kuliev K. and Feisullayev A. 1997. Deep petroleum occurences in the Lower Kura Depression, South Caspian Basin, Azerbaijan: an organic geochemical and basin modeling study. Marine and Petroleum geology, v.14. No.7/8, p. 731-762.

Inan, S., Yalchin, M. N., Guliyev, I.S. and Feizullayev, A.A., 1995. Organic geochemical characterization of some oils from the Lower Kura Depression, South Caspian Basin, Azerbaijan. In: Organic geochemistry: developments and applications to energy, climate, environment and human history. Selected papers from 17th international meeting on organic geochemistry, ed. Grimalt, J.O., and Dorronsoro, C., San Sebastian, Spain, 456-459.

Ivanov V.V., E.F. Antonenko and S.N.Obukhova. 1991. The fields of gas content and surplus pressures in sedimentary series. Sovetskaya Geologiya. No1, p.11-20 (in Russia).

Ivanov V.V., Guliev I.S., 1986. Experience of physical-chemical modelling of mud volcanism / Bull. MOIP. Geology branch. V.61. Issue 1. p.72-79.

Ivanov V.V. and I.S.Guliyev. 1988. Physical-chemical model of mud volcano. In "Oil-gas bearing problems of Caucasus" M. Nauka. P. 92-100 (in Russia).

Ivanov V.V. and I.S.Guliyev. 2001. Mass-exchange, hydrocarbon formation and phase conversion in sedimentary basins. Baku. Nafta-press. 106 p.

Jackson J., 2000. Partitioning of strike-slip and convergent motion between Eurasia and Arabia in eastern Turkey. J.Geophys. Res., 105, 5695-5719.

Jackson J.A., Priestly K., Allen M.B., Berberian M., 2001. Active tectonics of the South Caspian Basin. Central Asia Project Report 7.

Javadova R., Muradov Ch., Feyzullayev A. 2001. About Nature and stratum occurrences of gas-hydrates hydrocarbon gases in the Caspian Sea.. EAGE 63 Conference and Exhibition, Amsterdam, The Netherlands. 11-15 June. Extended Abstracts Book. P 561.

Kadirov F.A. 1997. About thermal factor of oil and gas migration. Doklady Academii Nauk Azerbaijana. Elm. V. LIII, №1, p.76-79 (in Russia).

Kadirov F.A., 2000. Application of the Hartley Transform for Interpretation of Gravity Anomalies in the Shamakhy-Gobustan and Absheron Oil and Gas Bearing Regions, Azerbaijan. Journal of Applied Geophysics, v.45, p.49-61.

Kadirov F.A., 2000. Filtering of Gravity Date Using the Hartley Transform: A Case Study of the Kura Intermontane Trough. Izvestiya, Physics of the Solid Earth, v. 36, N 10, 2000. p. 866-871. (in Russian)

Kadirov F.A., 1998. Geologic interpretation of full horizontal gradients of a gravitational field of Azerbaijan, Reports AS of Azerbaijan, V. LIV, N5-6, p. 129-134 (in Russian)

Kadirov F.A., 1999. Gravity anomalies and depth structure model for the South of the Caspian sea (within Azerbaijan), Geophysics News in Azerbaijan, vol 3, p.22-25.

Kadirov F.A., 2000. Gravity field and models of deep structure of Azerbaijan. Baku, Publishers, Nafta-Press, 112 p. (in Russian)

Kadirov F.A., 1998. Horizontal gradients of Bouguer Gravity anomaly of Azerbaijan, Geophysics News in Azerbaijan, No 1, p. 19-20

Kadirov F.A., Askerhanova N.G., 1998. Gravity model of the Hekery rive - Fizuli - Carly - Maraza (Azerbaijan) profile. In: Extended Abstracts Book, 60th EAGE Conference and Technical Exhibition, Leipzig, Germany, 10-33.

Kadirov F.A. and A.G.Kadyrov. 1990. About an opportunity thermal convection in sedimentary layers of Azerbaijan. Izvestiya Academii Nauk Azerbaijana. Seriya Nauk o Zemle. Elm. № 1, p.97-100 (in Russia).

Kadirov F.A., Nabiev A.T., 1991. To the tidal gravity variations nature on the Absheron geodynamic polygon. Revue Academy of sciences of Azerbaijan. Earth sciences .Publishing House "ELM". Baku, No 5-6, 1991, p.135-139. (in Russian).

Kadirov F.A., Guliev I., Kadyrov A., Feyzullaev A.A., Mukhtarov A. 2002. Model of mud volcano by the geophysical, geodetic and geochemical data 7-th International Conference. On Gas in Marine Sediments. Extended abstract book, Baku. October 7-12, p.105-107.

Kadirov F.A., Guliev I.S., Gasanov R.I., Mamedov A.R. 2002. The study of present geodynamic situation of the Azerbaijan territory with applying GPS, Seismic and

Gravimetric Data. International Conference "Assessment of Seismic Hazard and Risk in the Oil-Gas Bearing Areas" (100-anniversary of Shamakha earthquake), Abstracts, October 28-30, Baku.

Kadirov F.A.,Lerche I., Guliev I.S., Kadyrov A.H., Mukhtarov A.Sh., Feyzullayev A.A. 2003. Gravity model of mud volcanoes, AAPG AAPG Annual Meeting of the AAPG: Energy -Our Monumental Task; May 11-14, Salt Lake City, Utah. D/Username: 79116. Password: 205790, Abstracts on CD-ROM.

Karig D.S., 1974. Evolution of arc systems in the Western Pacific. Reviews of Earth and Planetary Sciences, No2, p.51-75.

Katz, B., Richards, D., Long, D., & Lawrence, W. 2000. A new look at the components of the petroleum system of the South Caspian Basin. Journal of Petroleum Science and Engineering, 28, 161-182.

Kazmin V.G., 1989. Collisions and riftogenesis in the history of Tethys ocean. Geotectonics, №5. (in Russian).

Kerimov K.M., Gajiyev F.M. and Gasanov I.S., 1999. Azerbaijan oil industry. 1999, No7, p.1-11. (in Russian).

Kerimov K.M., R.R.Rakhmanov and M.B. Kheirov. 2001. Oil-gas bearing of South Caspian depression. Baku. Adilogly. 441 p. (in Russia)

Kerimov V.Y., Khalilov E.A. and Mekhtiev N.Y. 1991. Paleogeographic conditions of formation of the South Caspian depression during the Pliocene in relation to its oil-gas potential: Petroleum Geology, v.26, No.3/4, p.119-122.

Khain V.E., 1984. Regional Geotectonics. Moscow, "Nedra". (in Russian)

Khain V.E., Lomize M.G., 1995. Geotectonics on the bases of geodynamics. Moscow (in Russian)

Khain, V.E. and Shardanov, A.N., 1952. Geological history and structure of the Kura Depression. Elm, Baku, 346 p. (in Russian)

Khalilov E.N., 1983. Role of horizontal movements of the lithosphere in formation of fault-block structures of the Caspian. Express information. General and regional geology. Iss.10, Moscow. (in Russian)

Kheirov M. B., 1979. Impact of burial depth on transformation of clay minerals in sediments. Izv. Akad. Nauk SSSR. Ser. Geol., No 8, p. 144-157. (in Russian)

King, R.W. and Bock, Y., Documentation for the GAMIT Analysis Software. Release 9.7, Cambridge: Mass. Inst. Technol., 1998.

Kityk V.I. 1979. Disharmonic folds of the sedimentary series. Kiyev. Naukova Dumka. 128 p. (in Russia).

Kleshev K.A., 1986. Geodynamics of the oil-gas bearing basins. VNIIONG, Series "Oil-gas geology and geophysics", Iss. 12, p.25 (in Russian)

Knapp J.H., Diaconescu C.C., Conner J.A., 2000. Deep seismic exploration of the South Caspian Basin: Lithosphere-scale imaging of the World's deeplest basin. AAPG's Inaugural Regional International Conference, Istanbul, Turkey.

Knapp J.H., C.C. Diaconescu, J.A. 2000. Crustal-scale imaging of the Absheron Ridge (South Caspian Sea) revealed by deep seismic reflection profiling. AAPG's Inaugural Regional International Conference, Istanbul, Turkey.

Knipper, A.L., 1975. Oceanic crust in the structure of the Alpine folded area. Moscow, Nauka, 206 p. (in Russian)

Korchagina, YU.I., Guliyev, I.S., and Zeinalova, K.S., 1988. Hydrocarbon source potential of deeply buried Mesozoic and Cenozoic deposits of the South Caspian Basin. In: Problems in the oil and gas content of the Caucasus. Nauka, Moscow, 35-41. (in Russian)

Kornev V.A., Lutsuk E.M., Sungurov A.M., 1962. Basin features of the Caspian Sea tectonics according to data of geophysical studies. "Soviet Geology", No12 (in Russian)

Kroonenberg S. B., Badyukova E.N., Storms J.E.A., Ignatov E.I., Kasimov N.S., 2000. A full sea-level cycle in 65 years: barrier dynamics along Caspian shores, Sedimentary Geology, 134, Elsevier.

Kucheruk E.V., Ushanov S.A., 1985. Plate tectonics and oil-gas content. Results of Science and Techniques. Series: Earth Physics, Moscow, VINITI (in Russian)

Kulhanek, O., 1976. Introduction to digital filtering in geophysics. Elsevier Scientific Publishing Company Amsterdam, 169 p.

Kulikov V.I., 1961. Deep structure of the East Caucasus and Caspian depression according to data of geophysical studies. Proceedings: State and prospects of development of the exploration geophysics. Gostoptehizdat, Moscow (in Russian)

Kunin, D. and Levenshpil',O., 1976. Industrial pseudo-liquefaction, Khimiya, Moscow.

Kunin N.Ya., 1989. Structure of the continents and oceans lithosphere. Moscow, "Nedra" (in Russian)

Kuzmin V.G., 1989. Collisions and riftogenesis in the history of Tethys ocean. Geotectonics, No5. (in Russian)

.Le Pichon X., P.Henry and S.Lallemant.1989.Water flow in the Barbados accretionary complex.J.Geophys.Res.,95, 8945-8967.

Lebedev L.I. et al., 1987. Caspian Sea. Geology and oil-gas content. Moscow, "Nedra", p.295

Lerche I., Bagirov E., Nadirov R., Tagiyev M., Guliyev I. Evolution of the South Caspian Basin: Geologic Risks and Probable Hazards Baku, "Nafta Press", 1997a, p. 581.

Lerche I., Ali-Zade Ak., Guliev I., Bagirov E., Nadirov R., Tagiyev M. and Feyzullayev A.1997b. South Caspian Basin: Stratigraphy, Geochemistry and Risk Analysis. Nafta-Press, Baku, p.430.

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

Loitsyanskii, L.G., 1973. Mechanics of Liquid and Gas. Nauka, Moscow…, p. (in Russian)

Lomize M.G., 1987. Alpine geosyncline of the Caucasus in the global aspect. Geotectonics, №2. (in Russian)

Magara, K., 1982. The Compaction of Rocks and the Migration of Fluids, Nedra, Moscow. (in Russian)

Mamedov A.V., 1977. History of geological development and paleogeography of the Middle Kura depression in connection with oil-gas content. Baku, Publishing House "Elm".

Mamedov, A.V., 1973. Geological structure of the Middle Kura Depression (in Russian). Elm, Baku, 192p.

Mamedov P.Z., 1985. Revealing of reefogenic formations with the help of seismostratigraphic studies. Oil and Gas Geology, No7 (in Russian)

Mamedov P.Z., 1988. Structure of the north-Absheron trough on the base of seismostratigraphic analyses. Oil and Gas, No12 (in Russian)

Mamedov P.Z., 1989. Clinoforms of the Middle Pliocene on the Turkmenian structural terrace. Proceedings: AZINEFTEHIM, Baku, p.97-102 (in Russian)

Mamedov P.Z., 1991. Paleo-deltaic complexes in the north of the South Caspian depression. Petroleum Geology, v. 225, No9-10, September-October

Mamedov P.Z., 1994. Revealing of prospective oil and gas deposits in the South Caspian megabasin by seismic stratigraphy. Proceedings of 10th Petroleum Congres of Turkey.

Mamedov P.Z., Babayev D.Kh., 1995. South Caspian Megatrough Seismostratigraphy. AAPG International Confrence, Nice, France.

Mamedov P.Z., Stelting C., Kieckefor R., 1997. Tectonic history of the Southern Caspian Sea. Bulletin AAPG, v.81/8 August.

Mamedov P.Z., 1998. Seismostratigraphic sedimentary models of South Caspian Megatrough. Abstracts of 60th EAGE Conference, Leipzig, Germany

Mamedov P.Z. 1999. South Caspian Megatrouch seismostratigraphy. Abstracts of 61th EAGE Conference, Helsinki, Finland

Maucione D., V.Serebryakov, P.Valasek, Y.Wang and S.Smithson. 1994. A sonic LOG study of abnormally pressured zones in the Powder River Basins of Wyoming. AAPG Memoir 61, 333-348.

McClusky, S., Balassanian, S., Barka, A., et al., J. Geophys. Res., 2000, vol. 105, no. 3, pp. 5695–5719.

Milanovski E.E., 1987. Riftogenesis in the Earth history (riftogenesis in the mobile belts), Moscow, "Nedra" (in Russian)

Mironov V.S., 1980. A course gravimetry. M., Nedra, 544 p. (in Russian)

Mohan, N.L., and Anand Babu, L., 1994. A note on 2D Hartley Transform. Geophysics 59, 1150-1155.

Moshashvili, A.B., 1982. Evolution of the Earth's crust within the Kura Depression and its relation with the Paratethys problem. In: Problems of the Caucasus geodynamics. Moscow, Nauka, 64-71. (in Russian)

Mukhtarov, A. Sh., and Adigezalov, N. Z., 1997, Thermal regime of mud volcanoes in eastern Azerbaijan, Proceedings of Geology Institute 26, 221-228 (in Russian).

Mukhtarov, A. Sh., Kadirov, F. A., Guliyev, I. S., and Lerche, I., 2002, Temperature Evolution in the Lokbatan Mud Volcano Crater (Azerbaijan) After the Eruption of 25 October 2001, Marine and Petroleum Geol. (submitted).

Nadirov, R.S., Bagirov, E.B., Tagiyev, M.F. and Lerche, I., 1997. Flexural plate subsidence, sedimentation rates, and structural development of the super-deep South Caspian Basin. Marine and Petroleum Geology, 14, No.4, 383-400.

Nevskiy M.V., A.V. Nikolayev and(in Russia). P.A. Troizkiy. 1985. Development of 3D and 4D seismic search. Proceeding of XXX Intern. Geoph. Symposium. M. P. 38-45 (in Russia).

New Strategy Aids Deep Gas Hunt. 1999, May. AAPG Explorer

Nikitin A.A., 1986. Fundamental theory of processing of the geophysical information, M., Nedra, 342p.

Odekov O.A., 1971. Orogenic structures of the Caspian-Kopetdag region. Publishing House "Ilm", Ashkhabad.

Okhawa S. and Yokojama I. 1976. Sistematical change of gravitational field in west part of Hokkaido Isle. J.Geod.Soc.Jap. Vol.22, p.63-73.

Omokawa, M. 1985. Source rock - oil correlation using stable carbon isotopes. The case of Niigata basin. Journal of Japanese Association of Petroleum Technology, 50, 9-16.

Oral, B., Global Positioning System (GPS) Measurements in Turkey (1988–1992): Kinematics of the Africa–Arabia–Eurasia Plate Collision Zone, Ph.D. Thesis, Cambridge: Mass. Inst. Technol, 1994.

Pavlenkova N.I., Egorova E.P., Staroctenco V.I. Kozlenco V.G., 1991a. Three-dimensional density model of rock sphere of Europe. I, Isv.. AS USSR. Physics of the Earth, N4, p.p. 3-13. (in Russian)

Pavlenkova N.I., Egorova E.P., Staroctenco V.I. Kozlenco V.G. , 1991b Three-dimensional density model of rock sphere of Europe. II, Isv.. AS USSR. Physics of the Earth, N4, p.14-23. (in Russian)

Pavlenkova N.I., 1979 Wave field and the earth-crust models. Kiev: Nauk. Dumka. 216p. (in Russian)

Pavlenkova N.I., 1996. Development of ideas about seismic models of the Earth crust. Geophysics, No4, Moscow, p.11-19 (in Russian)

Perradon A., 1985. Histore des grandes decouvertes petrolieres. Paris

Peters K.E., 1986. Guidelines for evaluating petroleum source rock using programmed pyrolysis. American Association of Petroleum Geologists Bulletin, 70, 318-329.

Peters K.E. and Moldowan J.M. 1993. The Biomarker Guide: Interpreting molecular fossils in petroleum and ancient sediments. Prentice Hall, Englewood Cliffs, New Jersey, p.363.

Philip H., 1989. Cisternas A., Gvishiani A., Gorshkov A. The Caucasus: an actual example of the initial stages of continental collision. Tectonophysics, 161, 1-21

Polyakova I.D., Borukayev G.Ch., 1999. Geochemical peculiarities of oil deformation and formation at large depths. Oil and Gas Geology 3-4, p.34-39. (in Russian)

Polanskiy O.P. 1988. Formation of diapir structures on the base of modeling of the Relay-Benar instability. Geologiya nefti i gaza. No1, p.83-89 (in Russia).

Putkaradze, A.L., 1958. The Baku Archipelago: geological structure and prospects of oil and gas content. Azerneshr, Baku, 336p. (in Russian)

Rajabov, M.M., 1978. Study of the structure of the Earth's crust consolidated complex of the Azerbaijan using deep seismic sounding and refracted wave correlation method data. In: The structure of the earth crust and upper mantle in the central and east Europe. Naukova Dumka, Kiev, pp. 205-211 (in Russian).

Rajabov M.M., 1977. Modelling of high-speed model of the earth-crust using an example of Kurinsk depression // New of ÀÑ of the USSR., N 7. p. 42-55. (in Russian)

Rajabov M.M. Wavy fields and deep structure of the Caucasus according to seismic data. In book: Geophysical fields and structure of the Earth crust of the TransCaucasus. Moscow, "Nauka", p.5-32 (in Russian)

Rao, B.N., Rama, K.P. and Markandeyulu, A., 1995. Mapros-A computer program for basement mapping and filtering of gravity and magnetic data using a Hartley transform. Computer and Geosiences 22, 197-218.

Reilenger R.E., et al., 2000. Coseismic and postseismic fault slip for the 17 August, M=7.5, Izmit, Turkey Earthquake. Science, 289,1519-1524.

Reilenger R.E., Toksoz N., McClusky S., Barka A. 1999 Izmit Earthquake was no surprise. GSA Today. 10,1-6.

Reynolds A.D., Simmons M.D., Bowman M.B.J., Henton J., Brayshaw A.C., Ali-Zade A.A., Guliev I.S., Suleymanova S.F., Ataeva E.Z., Mamedova D.N. and Koshkarly R.O. 1998. Implications of outcrop geology for reservoirs in the Neogene Productive Series: Absheron Peninsula, Azerbaijan. American Association of Petroleum Geologists Bulletin, v. 82, p. 25-49.

Reynolds A.D., Simmons, M.D., Bowman, M.B.J. et al., 1998. Implications of outcrop geology for reservoirs in the Neogene Productive Series: Absheron Peninsula, Azerbaijan. AAPG Bull., 82, 25-49.

Rezanov I.A., 1974. Earth crust. Moscow, "Nedra" (in Russian)

Rubinshtein, M.M., 1960. On age of the crystalline substratum of the Caucasus. Reports of the Acad. Sci. Georgian SSR. v.24, No.2, p.182-187. (in Russian)

Saatcilar, R., Ergintav, S. and Canitez, N., 1990. The use of the Hartley transform in geophysical applications. Geophysics 55, 1488-1495.

Seiya Uyeda, 1971. The new view of the Earth. San Francisco

Shapiro V.A. 1982. Study of temporal dynamics of the Monchazhian regional magnetic anomaly. Izvestiya Academii Nauk SSSR. Fizika Zemli. №8, p.65-77 (in Russia).

Shapirovski N.I, Rajabov M., 1966. About seismic exploration on the sea // Seismic method of exploration. M.: Nauka, p.53-63. (in Russian)

Shein V.S., Kleshev K.A., 1989. Conditions of oil-gas accumulation on platforms and in the folded areas (from views of lithosphere plates tectonics). Oil and Gas Geology, Moscow, No3 (in Russian)

Shengelaya G.Sh., 1984. Gravity model of the Caucasus crust, M., Nauka, 1984, 128p. (in Russian)

Shepard F.P., 1956. Late Pleistocene a Recent history of the Central Texas coast., Geology, 64.

Shevchenko, V.I., Guseva, T.V., Lukk, A.A., et al., Fiz. Zemli, 1999, no. 9, pp. 3–18.

Shreider A.A., Kazmin V.G., Lygin V.S., 1997. Magnetic anomalies and the problem of the Black Sea depression. Geotectonics, №1.

Shikhalibeili, E.Sh., 1980. Principal features of the crustal structure of the South Caspian Basin and the conditions of its formation. Tectonophysics, 69, 113-121. (in Russian)

Shikhalibeyli E. Sh., Askerkhanova N.G., Kadirov F.A., 1990. Gravitational modeling along a profile GSZ N3 Poylu-Masally, Isv. AS of Azerbaijan, Series of sciences about the Earth, 1990, N2, p.107-110 (in Russian)

Shikhalibeyli E.Sh. et al., 1984. To problem on the structure and formation of the South Caspian depressions. Papers "Essays on Azerbaijan geology", Baku. p… (in Russian)

Shikhalibeyli, E.Sh., 1996. Some problematic problems of a geological feature and tectonics of Azerbaijan. B., ELM, 1996, 216 p. (in Russian)

Shikhalibeyli, E.Sh., 1972. Location of Azerbaijan in general structure of the Caucasus and surrounding folded region. In: Azizbekov Sh.A. (Ed.), Geology of the USSR, Azerbaijan. Vol. XLVII. Nedra, Moscow, pp.286-290 (in Russian).

Simakov S.M., Anikiyev K.A., Artamonova T.P., 1986. Prediction and estimation of oil gas content at a large depths. L., Nedra, 1986, p.248. (in Russian)

Smith D.E., Kolenkiewics R., Robbins J.W., Dunn P.J., Torrence M.N., 1994. Horizontal crustal motion in the central and eastern Mediterranean inferred from Satellite Laser Ranging measurements, Geophys. Res, Lett. 21,1979-1982.

Spector, A. and Grant, F.S., 1970. Statistical models for interpreting aeromagnetic data. Geophysics 35, 293-302.

Strakhov V.N., 1990a About steady methods of the solution of linear problems of geophysics. I. Statements and main design ideas. Isv. AS USSR. Physics of the Earth, N7, p.3-27 (in Russian)

Strakhov V.N., 2000. Geophysical «dialect» of tongue of mathematics, M., OIFZ, 60p. (in Russian)

Strakhov V.N., 1990b. About steady methods of the solution of linear problems of geophysics. II. The main algorithms. Isv.. AS USSR. Physics of the Earth, 1990, N8.p.37-64

Sukharev, G. M., Taranukha, Yu. K, and Vlasova, S. P., 1969, Heat flow from Azerbaijan. – Soviet Geology, 8, 146-153. (in Russian).

Sundararajan, N., 1995. 2-D Hartley transforms. Geophysics 60, 262-267.

Tagiyev, 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. Marine and Petroleum Geology, 14, No.4, 363-382.

Thurston J.B., Brown R.J., 1994. Automated source-edge location with a new variable pass-band horizontal-gradient operator, Geophysics, 1994, v.59, N 4, p.546-554.

Triep E.G., et al., 1995. Active thrust front of the Greater Caucasus: The April 29, 1991 Racha. Georgia Earthquake sequence and its tectonics. J. Geophys. Res., 100, 4011-4034.

Trubitsyn V.P., Kadirov F.A. and A.G.Kadyrov. 1998. Influence of thermal convection into viscous intermediate layer on the temperature distribution of the multilayer sedimentary complex. Izvestiya Academii Nauk Azerbaijana. Seriya Nauk o Zemle. Elm. №1, p.64-69 (in Russia).

Tsimmelzon I.O., 1961. A method of series allocation of local anomalies, News oil and gas engineering, series "Geology", Gostoptechizdat, v. 4, p 27-30. (in Russian)

Tsimmelzon I.O., 1965a. A plutonic crustal architecture and tectonics of Azerbaijan under the data of geophysical studies, Soviet Geology, ¹4, seconds 103-111. (in Russian)

Tsimmelzon, I.O., 1959. To geological interpretation of the Talysh-Vandam gravity maximum. Geologiya nefti i gaza, No.3, 56-65. (in Russian)

Tsimmelzon, I.O., 1965b. Geological interpretation of the local gravity anomalies of the Absheron peninsula and the Near-Caspian region. Exploration and Mining Geophysics., No. 38, 13-24 (in Russian).

Tugolesov D.A. et al., 1985. Tectonics of the Mesozoic-Cenozoic deposits of the Black Sea depression. Moscow, "Nedra". (in Russian)

Valyayev, N.M., Grinchenko, YU.I., Yerokhin, V.E. et al., 1985. Isotope characteristics of gases from mud volcanoes. Litologiya i poleznye iskopayemye, No.1, 72-87. (in Russian)

Volarovich, M.P.,Bayuk, E.I., Salekhli, T.M., Guseynov, F.G., 1966. Compressional wave velosities in sedimentary rocks of Azerbaijan under confining pressures to 4000 kg/cm^2. Transactions of Institute of the Earth's Physics. 37(204), Nauka, Moscow, pp.130-139 (in Russian).

Wangen M.1993. Vertical migration of hydrocarbons modeled with fractional flow theory. Geophys. J. Int. № 115, p.109-131.

Wavrek, D.A., Collister, J.W., Curtiss, D.K., Quick, J.C., Guliyev, I.S. & Feyzullayev, A.A. 1996. Novel application of geochemical inversion to derive generation/expulsion kinetic parameters for the South Caspian petroleum system (Azerbaijan). In: AAPG/ASPG research symposium "Oil and gas petroleum systems in rapidly-subsiding basins". Book of abstracts, Baku, Azerbaijan.

Yakobson A.N., 1997. Basic features of structure of the South Caspian lithosphere according to data on the seismic Rayleigh wave. Reports (Doklady) of Academy of Sciences, vol.353, p.111-113. (in Russian)

Yakubov AA., Alizade A.A., Zeinalov M., 1970. Atlas of mud volcanoes of Azerbaijan.

Yakubov, AA., Ali-zade. A.A., Rakhmanov, R.R. et al., 1974. Catalogue of known eruptions of mud volcanoes in Azerbaijan (1810-1974). Academy of Sciences, AzSSR, Baku. (in Russian)

Zakariadze, G.S., Knipper, A.M. and Lordkipanidze, M.B., 1982. A tentative correlation of the Mesozoic volcanism of the Lesser Caucasus ophiolite belt with the framing zones (geodynamic aspects). In: Problems of the Caucasus geodynamics. Moscow, Nauka, 117-121. (in Russian)

Zaseev V.G., Abramovich I.I., 1993. Jurassic-Cretaceous petrochemical zonality of Somkheto-Kafan island-arc system. Geotectonics, №2. (in Russian)

Zhabrev, D.V., & Mehtiyev, Sh.F. 1959. On bitumen content of the Tertiary complex in South-East Azerbaijan. USSR Academy of Sciences Publishers, Moscow (in Russian).

Zonenshine L.P., Kuzmin M.I., Natanov L.M., 1990. Tectonics of the lithosphere plates of the USSR territory. Book 2, Moscow, "Nedra", p.400 (in Russian)

Zorkin L.M., Lopatin N.V., 1980. Geochemical methods of search of oil and gas deposits. “Nedra”. Moscow, 1980, 300p. (in Russian)

C O N T E N T

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HYDROCARBON SYSTEMS OF THE SOUTH CASPIAN BASIN

BAKU – 2003

Publishing house director**: H.Kh.Abiyev**
Computer design: **Q.Kheyrullaogly**

Signed for printing: 08.07.2003. Edition size 70x100 1/16.
Printer's sheet 12,875. Order № 37. Edition 500. Agreed price.

Publishing house of Geology Institute of Azerbaijan National Academy of Sciences
Baku, H.Javid av. 29A, Tel.: (99412) 393972