

Azerbaijan is very well endowed with mineral deposits. More than one billion tons of crude oil has been produced in the Absheron Peninsula and Azerbaijan sector of the Caspian Sea over last 100 years. Large reserves of oil and gas have been concentrated in producing horizons of the Lower Pliocene. Oil and gas fields have been also discovered in the Miocene, Oligocene, and Eocene horizons of the Shamakhy-Gobustan, Evlakh-Agjabedi, and Ganja regions and in the watershed of Kur and Gabyrry rivers. Nearly 350 mineral deposits of metallic (e.g., gold, silver, lead, copper, zinc, iron, cobalt, molybdenum, etc.) and non-metallic minerals, construction materials, and drilling brines with mineable reserves have been explored in the country (Azizbekov et al. 1976).

This chapter is subdivided into two parts: Sect. 2.1—‘Oil and Gas’ (land and sea) and Sect. 2.2—‘Hard useful minerals’ (land).

2.1 Oil and Gas

2.1.1 Lithological and Facial Characteristics, Porosity, and Permeability of Meso-Cenozoic Deposits

Reliable information on rock qualities in oil- and gas-bearing reservoirs is of high scientific and practical importance. Therefore, many geologists (Gubkin 1934; Aliyev 1949; Avdusin 1952; Abramovich 1955; Aliyev and Daidbekova 1955; Akhmedov 1957; Aliyev and Akhmedov 1958; Alizadeh et al. 1966, 1972, a. o.) dedicated their researches to the study of reservoir rocks in the Meso-Cenozoic deposits of Azerbaijan major oil- and gas-bearing regions. Azerbaijan

Meso-Cenozoic deposits host detrital, carbonate, volcanogenic-sedimentary, volcanogenic, and clayey reservoirs.

Detrital collectors are subdivided into *coarsely clastic* (pseftic) and *fine detrital* (sandy–aleuritic) rocks.

Coarsely clastic rocks (debris sizes of above 1 mm) are of limited distribution and are found as small interlayers of gravelites and conglomerates in the Mesozoic and Paleogene deposits. These rocks consist of the debris of effusive, metamorphic, sedimentary rocks and are consolidated by sandy–aleuritic and carbonate materials. Consolidation type is basal and mixed. Quartz, feldspars, pyroxenes, and grains of other minerals are found in the rock compositions. By their structural signs, they are subdivided into conglomerates (in the Ganja oil- and gas-bearing region—OGBR) and gravelites (the Kur and Gabyrry interfluvium, the Muradkhanly and Lower Kur OGBRs). Their formation is associated with continental facies accumulation in the basin coastal zone.

Fine detrital rocks are represented by sandy–aleuritic formations. They are widely distributed in the near-Caspian-Guba region Mesozoic deposits, in the Yevlakh-Agjabedi trough Cretaceous, Eocene, Pliocene deposits, in the Lower Kur-Gabyrry interfluvium, Upper Eocene and Oligocene deposits, etc. Their thickness varies from several cm to 50 m.

These rocks are extensively distributed in the Lower Pliocene deposits, i.e., the Azerbaijan productive series (PS) and are represented alternating with clay materials.

Reservoirs of carbonate composition are most widely distributed in the Upper Cretaceous (Upper Santonian–Campanian–Maastrichtian age) deposits of Western Azerbaijan, and they are relatively limited in the Kur-Gabyrry

interfluvial (the Lower Eocene), in the Yevlakh-Agjabedi trough, and in the near-Caspian-Guba regions (the Upper Cretaceous).

Reservoirs of volcanogenic-sedimentary composition are distributed rather widely in the Lower Santonian and Middle Eocene deposits of Western Azerbaijan, in the upper part of the Muradkhanly PS (Jarly, Sor-Sor, Muradkhanly) where the presence of commercial accumulations has been established.

Reservoirs of volcanogenic composition are distributed in the Upper Cretaceous effusives (the Turanian–Lower Santonian). Oil- and gas-bearing properties of these reservoirs were determined for the Turonian and Maastrichtian deposits of Muradkhanly area.

Clayey reservoirs are met in the Cretaceous deposits of the Kur-Gabyrry interfluvial, in the Ganja and Muradkhanly OGBRs, and in the near-Kur-Guba region Jurassic deposits. Lithological and petrographic peculiarities of reservoir rocks in the Azerbaijan Meso-Cenozoic deposits, their petrophysical properties, and other rock parameters that influence their porosity and permeability properties are given below according to individual stratigraphic units.

The Absheron and Akchagyl stages. The Absheron stage sandy–aleuritic rocks show oil- and gas occurrence signs at separate areas of Absheron Peninsula, of Gobustan southwestern part, the Lower Kur OGBR, and the Baku archipelago.

Commercial oil- and gas occurrence of the *Akchagyl deposits* is found in the near-Kur region and is associated with granular (sandy–aleuritic) reservoirs, alternating with thick clay members.

2.1.2 Productive Series (PS) and Its Lithofacial Types

Productive series (PS) and red-bed series (RBS), its analog at the South Caspian Basin (SCB), are the most significant commercial oil- and gas-bearing reservoirs of the South Caspian Basin (SCB) and are, thus, examined in more detail.

PS-RBS is a rhythmic alteration of argillo-arenaceous deposits that are 7 km thick at the basin most deeply plunged section. Vigorous orogenic movements of SCB-adjacent folded areas and plunging of its central parts in the Late Pontian–Early Pliocene ages resulted in dramatic drop of the Paleo-Caspian level that, according to some estimates, was from 600 to 1500 m. The Lower Pliocene sedimentation took place in closed basin conditions (in the South Caspian region) that finally separated from the Eastern Paratethys about 5.5 Ma.

PS deposits accumulated here in various geotectonic environments (Aliyev et al. 2005): plunging anticline (the Absheron Peninsula), intermountain trough (the near-Kur lowland), fore troughs (fore-Talysh-Elburs trough, near-Caspian region, Jeirankechmez depression), as well as in platform conditions. These are latter represented by the facies of river canyons and valleys, mainly of the Paleo Volga, that laid its course in the platform region of the so-called Middle Caspian dryland.

Peculiarity of the South Caspian paleogeographic conditions in the Early Pliocene, avalanche sedimentation rate that amounted to 3 mm per year resulted in formation of the powerful complex, unique in its facial image and serving as storage of huge hydrocarbon clusters in the region.

PS has large distribution area within the SCB western margin and encompasses the areas of Absheron Peninsula, Absheron, and Baku archipelagos, Jeirankechmez depression, Alyat ridge, and near-Caspian-Guba region. Several types of PS lithofacial deposits are distinguished: Absheron, Gobustan, Lower Kur, near-Caspian, South Caspian types (Fig. 2.1) (Azizbekov et al. 1972; Akhmedov et al., 1973; Azizbekov et al. 1976; Ismailzadeh et al. 2008).

The Absheron type

This type was selected by V.P. Baturin in 1931 under the name of “disthene–ilmenite province.” It occupies nearly all area of the Absheron Peninsula and Absheron archipelago, as well as the Baku archipelago northern part, and is essentially composed of the sediments that the Paleo Volga has brought from the Russian Platform.

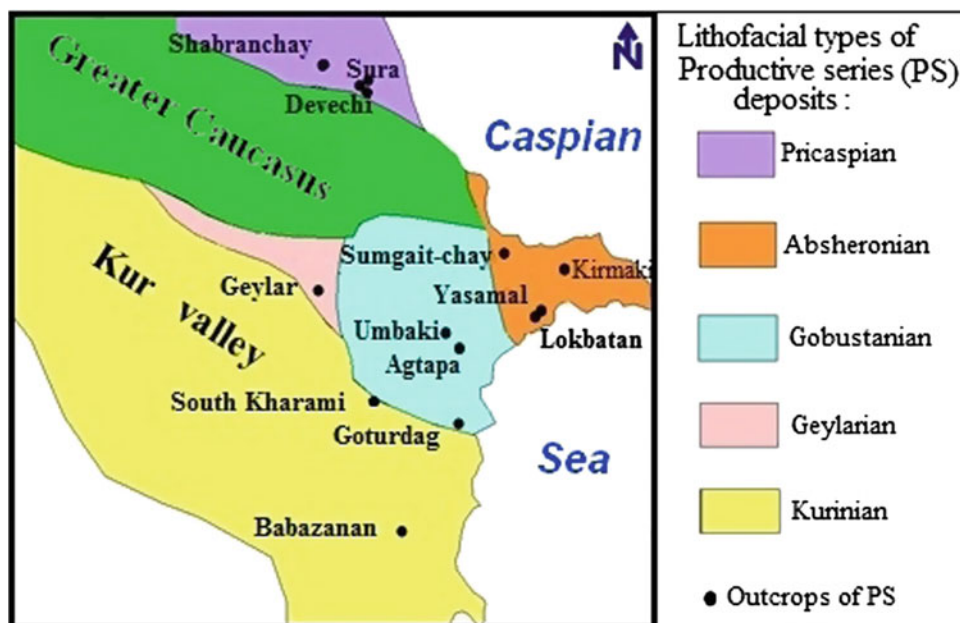
It is proved by the presence of large amount of quartz light fraction that occasionally achieves up to 95 % of its mineralogical composition. Feldspars (up to 20 %) and rock debris (up to 10 %) are also found.

Along with the Russian Platform as the northern distributive province, alternative source areas existed as well but are of subordinate importance that is confirmed by the presence of Paleozoic gravels in the Absheron-type sediments (that were evidently brought from the Middle Caspian dryland), as well as by the Cretaceous and Quaternary fauna from the Greater Caucasus.

Southern distribution boundary of the Absheron-type sediments differed considerably at the separate stages of PS accumulation, depending on the Paleo Volga delta location. The extreme northern boundary passes in the Amiya Cape area, and the western one is in the Perekyushkyul area.

Thickness of units of rhythmical alternating of sands, aleurites, and clays varies widely from several meters to several hundreds and thousands of meters. The PS Absheron

Fig. 2.1 Lithofacial types of PS deposits



facies achieves its greatest thickness of 5000 m in the South Absheron depression.

Increased sandiness of the PS Absheron facies sediments as compared to the other lithofacial types, their peculiar organization in thick terrigenous masses are conditioned by specific genesis of the Absheron-type sediments, and we will deal with it below.

The Absheron lithofacial type of the PS sediments consists of nine oil- and gas-bearing suites (from bottom to top): Kalin, sub-Kirmakin, Kirmakin, supra-Kirmakin sandy, supra-Kirmakin clayey, break, Balakhan, Sabunchi, and Surakhan—which are characterized by successive north-westward thinning out of lower suites.

The PS lower division combines the first five suites.

The Kalin suite (KaS) is exposed at the Chilov (Zhiloi) Island surface and has limited distribution in the Absheron Peninsula southern and southeastern parts. Kalin suite is absent at the substantial part of the Absheron Peninsula. It is composed of clays, thick units of sands, and aleurites. Certain difference between coarse and fine rock fractions is observed in mineralogical composition. The suite peak thickness is 430 m.

The sub-Kirmakin (SK) suite deposits occupy the Absheron Peninsula central part and thin out in its western part. It is basically represented by medium- and large-grained quartz sands. Quartz composition achieves 95 %. Small black angular gravels that are generally poorly sorted are observed in the section lower half sands. Upsection, a decrease in sand fraction grains, is observed. Suite thickness achieves 150 m.

The Kirmakin suite (KS) is distributed along the entire Absheron Peninsula, thinning out in its southwestern part. It

is represented by the alternation of clayey, sandy, aleuritic beds that interchangeably dominate in various section parts. The suite thickness is about 300 m. West of the Absheron Peninsula, in a meridional strip bordering between Absheron and Gobustan, the Kirmakin suite also drops out of the section, and PS begins from the supra-Kirmakin sand suite.

The supra-Kirmakin sandy (SKS) and the supra-Kirmakin clayey (SKC) suites are called so basing on the predominance of sandy or clayey material in them. The SKS suite sands and sandstone are medium- and coarse-grained, and poorly sorted, and they occasionally contain small black gravel. Quartz is predominant in the light fraction up to 85 %, while heavy fraction contains ilmenite, magnetite, disthene, staurolite, stable minerals, and pyrite. Significant admixture of sand material is found in clay composition. Large amount of clay loam and sandy loam is also observed. In the peninsular southwestern part, the SKC section is nearly totally composed of clays. Overall thickness of two suites, the SKS and the SKC, is 250–280 m.

Upper division starts from the *break suite* (BS) 90 % composed by coarse- and medium-grained sands. A conglomerate bed, achieving 4.3 m thickness in the Kirmakin valley, occurs at the bottom. Upsection the break suite, sands become more medium-grained. Quartz prevails in the light fraction, constituting up to 90 %. Magnetite and ilmenite prevail in the heavy fraction. The break suite clays are highly arenaceous and frequently look like clay balls resulting from the river flow activity that outwashes and redeposits the PS clays. The suite thickness is about 100 m.

The Balakhan suite consists of six production sand horizons, from V to X, characterized by alternating predominance of sandy or clayey material. Sand and sandstone

are essentially composed of fine- and medium-grained differences. The suite thickness growth from the Absheron Peninsula toward the Absheron and Baku archipelagos, where it achieves 900 m, is observed.

Similarly to the other PS suites, quartz predominates in the light fraction and then follows the percentage composition of feldspars (up to 35–40 %) and rock debris. Minor content of rock glass and analcime is also typical for the Balakhan suite.

Aleurite porosity varies from 10 to 26 %, and permeability varies from 12 to $94 \times 10^{-15} \text{ m}^2$. In sandstone, it is 7–28 % and $(6\text{--}82) \times 10^{-15} \text{ m}^2$ (respectively, in clay loam, it is 13–16 % and $(4\text{--}30) \times 10^{-15} \text{ m}^2$, and in clays, it is 10–18 %, and the permeability is very poor).

Sorting coefficient is 1.2–2.1, in clay loams, 1.4–2.2, in aleurolites, and 1.2–2.0, in sandstone. Cementation type is essentially contact one and, less frequently, porous and basal (Suleimanova and Atayeva 2002).

The *Sabunchi suite* consists of poorly sorted aleurites, aleurite clays, fine-grained clayey sand, but the suite composition varies in different Absheron Peninsula parts. In the peninsula central part, sand and clay contents are approximately equal and elongated sand units of up to 50–60 m thickness and similar, thick, predominantly clayey interlayers are observed. The presence of large amounts of brown loam and gypsum is noted. In the western part of the peninsula, clay content grows, whereas in the eastern part, three oil-bearing sand layers are isolated.

Like in all other PS suites, quartz predominance is typical. In addition, large amount of rock debris takes place in aleurite and clay compositions. Rock glass is found in small quantities. Heavy fraction contains ore minerals in large quantities. Rock cement is calciferous. The suite thickness is 450 m.

The *Surakhan suite* has the largest thickness in the PS cross section, of up to 1680 m maximally. It is represented by alternation of silty clays, sandy clays, clayey silts, and sands. Upsection clay content grows, where the thickness of sandy interbeds does not exceed 2–10 m. In the suite lower part, thickness of sandy units is 30–35 m.

The Gobustan type

It is also called the “zircon–epidote province” due to the prevalence of these two minerals in the sediments. Two subtypes, the Donguzdyk and the West Gobustan ones, are isolated within the Gobustan type of PS deposits.

The *Donguzdyk series* is developed in Central Gobustan, along the Jeirankechmez depression northeastern part, and bears the name of Donguzdyk camping ground, where the most typical cross section has been described. The zone area is 4–5 km, and its length is 25–30 km. It is subdivided into

two divisions, where the lower one is represented by the alteration of calciferous, arenaceous, argillaceous interbeds with gravel-containing coarse-grained sands, while the upper one displays the alternation of brown loams with conglomerates and gravels. Gravel is of Miocene age. The Donguzdyk series thickness is from 200 to 400 m.

More southward, the Donguzdyk series gradually passes into the *East Gobustan subtype* of sediments with decreasing grain sizes and increasing level of deposit sorting, and more eastward, into the Absheron type. The sediments of this type occupy the Jeirankechmez depression itself and the Alyat-Pirsaat zone, where typical cross sections are being developed. These deposits also participate in the formation of marine structures, located in Gobustan proximity. The sediments are poorly sorted and weakly differentiated. Urely sandy or clayey units are absent, and mixed rock types predominate. Thickness of sandy interbeds sometimes achieves 20 m, and overall thickness is up to 2200–2500 m. It is subdivided into six suites (from top to down).

The *Solakhai suite* is represented by clays with interbeds of aleurite, sands, and sandstone. Its thickness is 500–550 m. The *Duvany suite* deposits, lithologically expressed in sandstone and aleurolites, conformably overlap this suite. Its thickness is 225–275 m.

The *clayey suite* is essentially composed of fine-grained differences, which is evident from the series name. Its thickness is 150–170 m.

The *Miajik suite* is expressed by alternation of sands, sandstone, sandy clays, and aleurolites. Its thickness is 420–430 m.

The *argillo-arenaceous suite* is composed of gray clays with thin interbeds of fine-grained sands and sandstone. Its thickness is 170–180 m.

The *sandy–argillaceous suite*, as it follows from its title, is distinguished by the predominance of more coarse differences in its cross section. Its thickness is 550–700 m.

Mineralogical composition is noted for significant drop in quartz content as compared to the Absheron type and predominance of feldspars and sedimentary rock debris, in the light fraction, and of epidote, zircon, and garnet tourmaline, in the heavy fraction. Such mineral composition is identical to the composition of the Greater Caucasus southern slope sediments, thus testifying to the major role of this distributive province in the formation of the Gobustan-type deposits.

The Lower Kur type

This type of sediments is accumulated in the Lower Kur Depression. The boundary between the Lower Kur and the Gobustan-type deposits passes along the Lengebiz–Alyat range.

Overall thickness of the Lower Kur lithofacial type sediments is 3500–4000 m. Detrital material was basically brought to the basin by the largest river, i.e., the Paleo Kur and by the Paleo Araz that bore the Kur lowland, the Greater and the Lesser Caucasus, and the Talysh erosion products. The cross section is represented by the alternation of aleuritic, clayey, sandy rocks. It is characterized by significant clay alteration in comparison with the Absheron type, low content of quartz, and growth in the amount of feldspars, pyroxene, and hornblende, which witnesses the predominance of erupted rocks in the washout area. Thickness of the sandy units reaches 20 m.

Along the Lengebiz ridge, the northern border of this lithofacial zone, the *Lengebiz* subtype of sediments that represents the combination of the Donguzdyk and the East Gobustan lithofacial types is found. Here, along with predominant fine-grained differences, inequigranular sands and sandstone are met, as well as interstratified beds of conglomerates. Its thickness is about 1000 m.

The near-Caspian type

This type is developed along the Greater Caucasus north-eastern slope. Lithologically, it is represented by aleurite-sandy, gravel and conglomerate formations. Stratigraphically, the deposits are analogous to the Surakhan suite of the Absheron lithofacial type.

Clear-cut distribution zoning is found for two types of sedimentary material: the argillo-arenaceous type in the southeast (the Gyzyburun type) and the gravel type in the northwest (the Guba type).

The argillo-arenaceous *Guzulburun* complex is essentially composed of fine-grained sediments; sands and sandstone are adminicular and are basically represented by fine-grained differences. The Gyzyburun complex largest thickness is 2000 m. In total, gradual thickness reduction of these deposits is noted from the southeast to the northwest, where the Gyzyburun-type transforms into the Guba one. In its mineralogical composition, feldspars (up to 70 %), quartz (up to 32 %), and rock debris (up to 68 %) prevail in the light fraction and brown iron ore (up to 98 %), muskovite (up to 14 %), magnetite, and ilmenite (up to 10 %) prevail in the heavy fraction.

The *Guba* lithofacial type is represented by intercalation of poorly sorted coarse sands, sandstone, gravels, and conglomerates. Light fraction is mainly represented by feldspars and rock debris.

Analysis conducted on some areas of the SCB western margin showed in general the similarity of the PS facial composition, whose sedimentation is related to the encroachment of two large river systems, the Paleo Volga, and the Paleo Kur, to the Paleo-Caspian basin. It resulted in

the formation of a network of laterally connected sandy units that can be traced to the far south up to the Atashkyakh structure. This fact permits to treat the PS as fluid conducting one within the basin. At the same time, PS reservoirs are characterized by inhomogeneity of their structure through the section, which is caused by numerous changes of facial conditions. Quite thick clay masses that can be regionally traced within the VII and V horizons can be considered as regional seals for underlying argillo-aleurite reservoirs of fluvial genesis.

The Miocene sediments

Detrital rocks have wide occurrence in the Miocene deposits and serve as principal oil and gas containers.

Reservoir properties of deposit rocks of the *Chokrak horizon* have been studied at Shirinkum and Muradkhanly areas. Porosity of these areas is 11.4 and 15.4 %, respectively. All investigated rocks were actually impermeable, which is principally associated with their high carbonate content.

The *Sarmatian* stage sandy-aleuritic rocks that have been investigated at Muradkhanly, Eldaroyugi, Kangly, Chabandag, Alajigi, Akhtakhtatepe, Damirtepe-Udabno, Papan-tekyan, etc., areas differ from the above-described Chokrak rocks in their better porosity and permeability properties.

Average porosity, permeability, and carbonate content values for the Sarmatian stage rocks are listed in Table 2.1.

The *Meotian* stage in Azerbaijan is essentially represented by clayey lithofacies and reservoir rocks are absent in its cross section.

Reservoir rocks that deserve attention from the viewpoint of commercial oil- and gas-bearing capacity are absent in the *Pontian* stage deposits.

The Oligocene sediments

Sandy-aleuritic rocks in the Oligocene deposits are widely distributed in Azerbaijan. These deposits bear oil and gas in some of the Republic regions.

Sandy-aleuritic rocks of the *Khadum* horizon in the Ganja region are related to polymictic and tuffaceous differences. Their thickness varies from fractions of cm to 8 m. In the Shamakhy-Gobustan region, only rare interlayers of aleurites in the Khadum horizon section are met. In the Absheron region, the Khadum horizon does not contain sandy-aleuritic formations.

In the *Maykop series* (the Oligocene and Miocene ages), sandy-aleuritic formations are predominantly found at Meshrif-Zeifa, Tengialty, Zagly, Amirkhanly, Saadan, and Siazan-Nardaran areas of the near-Caspian-Guba region. The cross section is represented by alternation of aleurolites,

Table 2.1 Reservoir properties of the Sarmatian stage sandy–aleurite rocks

Area	CaCO ₃ content, %		Porosity, %		Permeability, 10 ⁻¹⁵ m ²	
	Average value	Number of measurements	Average value	Number of measurements	Average value	Number of measurements
Muradkhanly	21.6	2	21.0	2	5.6	1
Eldaroyugi	–	–	13.6	48	–	–
Kangly			10.5	25	–	–
Chobandag			14.5	29	–	–
Alajigi			11.9	14	–	–
Akhtakhtatepe	–	–	12.0	20	–	–
Damirtepe-Udabno	2.6	2	20.9	2	115.3	2
Large Palantekyan	–	–	16.3	16	36.0	6

Table 2.2 Reservoir properties of the Maykop suite rocks, the near-Caspian-Guba region

Subsuits, horizons	Area	Carbonate content, %	Porosity, %	Permeability, 10 ⁻¹⁵ m ²
		Average value (number of tests)		
Upper Maykop	Siazan	6.2(35)	15.0(30)	18.4(4)
	Saadan	4.2(4)	15.8(32)	12.6(3)
	Amirkhanly	5.0(5)	16.3(57)	99.0(4)
Lower Maykop	Siazan	3.5(18)	18.2(8)	32.5(5)
	Amirkhanly	16.0(12)	21.1(10)	18.5(11)
	Zagly	9.6(4)	18.6(8)	16.0(2)
	Tengialty		16.4(7)	32.0(6)

sands, sandstone, and solid clays with breccia interlayers. Thickness of sandstone interlayers varies from 10 to 30 cm. The Lower Maykop sandy–aleuritic rocks are sorted worse than the same rocks in the Upper Maykop and are related to the group of clayey silts. Quartz content is 40–43 %, and feldspar content is 40–55 %.

Table 2.2 lists reservoir properties of sandy–aleuritic rocks of the near-Caspian-Guba oil and gas field (OGF).

In the Shamakhy-Gobustan region, the sandy–aleuritic rocks are distributed non-uniformly. In the northern part region, these rocks either are found like separate interlayers of 0.1–0.2 m thickness or are nearly absent. In the northern part region, they are widely distributed and in some places (Ajiveli, Cheildere, etc.) have significant thickness. Quartz differences with well-rounded grains (Cheildag, Ajiveli, Sundi, etc.) are frequently met among these rocks. Certain parameters of sandy–aleuritic rocks are given in Table 2.3.

In *Ganja region*, sandy–aleuritic rocks are distributed along the entire Maykop suite section, both in the shape of thin millimeter-sized interlayers and as up to 5 m and more thick strata. The thickest strata are found in Dalmamedly, Gazanbulagh, Naftalan, Ajudere, and Gedakboz sections.

Peak values of sand fraction contents are confined to the Maykop suite lower division sections at Kharkhanput,

Karachinar, and Agjakend areas. It is nearly absent at Ajidere, Gazanbulagh, Aliushagi, Dalmamedly, Naftalan, Bor-sunlu, Zeiva, Injachay, and Mirbashir areas and is replaced by the aleuritic fraction. Further southeastward, the aleuritic fraction content does not exceed 55 %.

Average parameter values of sandy–aleuritic rocks are given in Table 2.4.

In *Lenkaran region*, sandy–aleuritic rocks constitute the considerable part of the Maykop suite section. At Kenjibaryu, Lerik, and Shovli areas, these rocks occupy 60–79 % of the section.

The Gabyrry-Ajinour and the Yevlakh-Agjabedi troughs. In the Maykop suite sections of these troughs, detrital rocks are distributed throughout and are major oil and gas reservoirs. Average values of their petrochemical characteristics are listed in Table 2.5.

The Eocene sediments

Terrigenous, carbonate, and volcanic-sedimentary reservoirs are abundant in the Eocene sediments. Reservoirs of sandy–aleuritic composition are developed in the Upper Eocene sections, less frequently, in the Middle and Lower Eocene, in the Yevlakh-Agjabedi trough, in the Lower and Upper

Table 2.3 Reservoir properties of the Oligocene rocks, the Gobustan region

Subsuits, horizons	Area	Carbonate content, %	Porosity, %	Permeability, 10^{-15} m^2
		Average value (number of tests)		
Zuramakend horizon	Umbaki	3.5	1.8(12)	68.0(3)
	Ajiveli	7.5(46)	2.2(17)	32.0(9)
	Cheildag	9.0(27)	4.2(8)	170.0(7)
	Sundi	10.7(4)	1.0(2)	157.0(3)
	Nardaran-Suleiman	4.2(2)	1.5(12)	41.0(11)
	Gijaki-akhtarma	10(12)	2.7(12)	163(11)
	Sheitanud	–	3.4(8)	179(7)
	Kyrkishlak		1.0(5)	13.0(2)
Riki 2	Umbaki	4.7(4)	1.0(3)	46.0(3)
	Ajiveli	2.0(10)	4.2(19)	136.0(28)
	Cheildag	9.5(12)	2.5(9)	101.0(9)
	Sundi	21.0(21)	3.1(21)	214.0(16)
	Nardaran-Suleiman	19.6(2)	3.2(33)	224(23)
Riki 1	Umbaki	5.2(4)	1.7(22)	56.0(28)
	Ajiveli	5.8(7)	4.8(47)	251.0(34)
	Cheildag	25.8(12)	3.7(19)	172.0(13)
	Ilkhichi	2.4(1)		
	Sundi	21.1(21)	2.1(22)	165.0(15)
	Gijaki-akhtarma	30.3(21)	3.1(21)	345.0(14)
Lower Maykop	Umbaki	6.9(6)	2.1(11)	22.0(4)
	Cheildagh	8.0(5)	3.4(24)	72.0(16)

Table 2.4 Certain parameters of the Oligocene sandy–aleuritic rocks in Ganja region

Area	CaCO ₃ , %	Porosity, %	Permeability, 10^{-15} m^2
	Average value (number of specimens)		
Gazanbulagh	7.0(140)	16.6(51)	15.6(37)
	9.8(2)	6.4(2)	0.2(1)
Gedakboz	25.9(22)	15.0(19)	50.8(16)
Sariyaldyg	28.6(15)	15.2(6)	6.0(6)
Naftalan	5.7(515)	17.1(440)	44.0(265)
Mirbashir	44.1(56)	15.7(122)	8.3(49)
Shirvanly	–	5.0(4)	<0.001(6)
ShirinkumShirinkum	0.8(1)	15.5(1)	<0.001(1)
Karachinar	7.2(65)	19.3(91)	108.6(66)
Kharkhaput	30.9(30)	15.8(32)	23.4(34)
Zeiva	15.1(60)	15.1(69)	113.8(68)

Eocene of the Kur–Gabyrry interfluv. Their commercial oil and gas-bearing capacity is determined only for the Upper Eocene.

Generalized results of porosity and permeability determinations are given in Table 2.6.

Table 2.7 lists generalized research results of reservoir properties in carbonate rocks. A numerator gives measurement limits and a denominator, a number of determinations.

The reservoirs of volcanogenic-sedimentary composition (of porous-fractured type) are mainly developed in the

Table 2.5 Certain parameters of the Oligocene reservoir rocks

Area	CaCO ₃ content, %	Porosity, %	Permeability, 10 ⁻¹⁵ m ²
	Average value (number of specimens)		
<i>The Kur–Gabyrry interfluve</i>			
Damirtepe-Udobno	8.2(3)	15.8(3)	1.86(3)
Sazhdag	12.3(11)	15.0(11)	1.77(4)
Gyrakhkeseman	5.6(17)	27.3(17)	353.2(16)
Gaflandere	15.7(11)	22.1(11)	79.9(10)
Borzundag	19.4(3)	4.8(3)	<0.001(3)
Tarsdallyar	0.4(2)	20.3(2)	2.0(2)
<i>The Muradkhanly OGF</i>			
Amirarkh	0.1(1)	16.8(1)	0.03(1)
Zardab	3.7(1)	14.4(1)	2.9(1)
Muradkhanly	20.3(1)	8.0(35)	0.22(7)
Shikhabagi	1.0(1)	18.1(1)	0.3(1)
Mil	17.6(1)	14.2(1)	130(4)

Table 2.6 Porosity and permeability of the Eocene sediments

Region	Stratigraphic frameworks		Porosity, %	Permeability, 10 ⁻¹⁵ m ²
			Measurement limits (number of determinations)	
The Yevlakh-Agjabedi trough	Eocene	Upper	2.8–22.8(38)	<0.001–2.9(32)
		Lower	4.6–15.5(9)	<0.001–0.1(9)
		Middle	2.2–7.4(3)	<0.001–0.8(3)
The Kur–Gabyrry interfluv	Eocene	Upper	2.4–34.8(26)	<0.001–368(15)
		Lower	6.0–23.3(3)	<0.001–0.4 (3)
		Middle	4.0–27.4(20)	<0.001–5.5(20)

Table 2.7 Reservoir properties of the Eocene carbonate rocks

Region	Porosity, %	Permeability, 10 ⁻¹⁵ m ²	Specific density of cracks, m ⁻¹
The Yevlakh-Agjabedi trough	(0.2–17.0)/46	(<0.001–10.4)/40	(<0.001–147.0)/33
The Kur–Gabyrry interfluv	(3.6–16.7)/70	(<0.001–0.01)/12	(<0.001–0.74)/32

Table 2.8 Reservoir properties of the Middle Eocene volcanogenic–sedimentary rocks

Region	Porosity, %	Permeability, 10 ⁻¹⁵ m ²	Specific density of cracks, m ⁻¹
	Measurement limits (number of specimens)		
The Yevlakh-Agjabedi trough	(1.0–22.8)/54	(<0.001–27.8)/50	(<0.001–48.0)/22
The Kur–Gabyrry interfluv	(5.0–26.6)/61	(<0.001–0.3)/18	(<0.001–89.0)/31

Middle Eocene cross sections in the Western Azerbaijan, with confined oil and gas fields. Storage capacities of volcanogenic-sedimentary rocks are associated with pores and fractures, and their filtration properties are essentially related to macro- and microfractures of tectonic and

lithogenetic origin. The pore sizes in these rocks vary from deciles of micrometer to several micrometers.

Table 2.8 lists generalized research results of reservoir properties in the Eocene volcanogenic-sedimentary rocks.

The Paleocene sediments

The Paleocene sediments are distributed in nearly all oil- and gas-bearing fields and are predominantly represented by clay rocks that in most cases constitute above 90 % of the section. Detrital rocks are found rarely as thin intercalations (0.5–10 cm) in the Lower Paleocene deposits of the near-Caspian-Guba OGF. The rocks are polymictic, gray-wacke–feldspar–quartz, poorly sorted ones. Sandy fraction content is 4.0–46.8 %.

In Absheron OGF, the Paleocene sandy–aleuritic rocks constitute only 3 % of the section. Thin intercalations (10–20 cm) are also found in Lenkaran district. They are oligomictic and tuffaceous.

In Shamakhy-Gobustan region, as well as in other OGF, sandy–aleuritic rocks have limited distribution in the Paleocene section.

The Azerbaijan Paleocene sediments as a whole are essentially represented by clayey lithofacies in many regions. And only in certain instances, the interbeds of sandy–aleuritic formations are found that in most cases are packed due to high clay content and, in some cases, due to increased carbonate content and are not thus characterized by high capacity and filtration properties. Therefore, one should not expect commercial-scale accumulation of hydrocarbons in these deposits.

The Cretaceous sediments

Terrigenous, carbonate, volcanogenic-sedimentary, volcanogenic, and clayey reservoirs are distributed in the Cretaceous sediments.

The Lower Cretaceous sediments have been essentially investigated in the near-Caspian-Guba region, partly in Northern Gobustan and in the Muradkhanly OGF. Cross section of these sediments is represented by alternating intercalations of clays and sandy–aleuritic formations. Reservoir properties of these latter are generally good (particularly in the Albian sediments).

The Lower Cretaceous carbonate rocks are characterized by low reservoir properties (Table 2.9).

The Lower Cretaceous sediments of the Muradkhanly OGF are represented by fractured argillites that have undergone the mesocatagenesis stage and might have acted as reservoirs.

The Upper Cretaceous deposits are widely distributed over Azerbaijan territory and bear oil and gas fields in many regions.

In the near-Caspian-Guba region, these sediments are represented by the argillo-arenaceous lithofacies with intercalations of fissured limestone.

Relatively promising perspectives are associated with fissured carbonate rocks in the Shamakhy region southern part as well as with central and southern Gobustan that frequently show oil saturation. Similar fissured carbonate reservoirs take place in sedimentary cross-section of Absheron region and the SCB.

Thus, the presence of conditions favorable for the formation of hydrocarbon clusters, i.e., the presence of reasonably good fissured carbonate reservoirs, overlapped by impermeable seal rocks such as the Paleocene plastic clays gives grounds to assign the Upper Cretaceous sediments of Shamakhy region, central, and southern Gobustan, Absheron region, and the SCB to promising oil- and gas-bearing deposits (Table 2.10).

Table 2.9 Reservoir properties of the Lower Cretaceous carbonate rocks in the near-Caspian-Guba region

Stage	Porosity, %	Permeability, 10^{-15} m^2	Specific density of cracks, m^{-1}
Aptian	0.1–10.7	0.17–2.04	41–114
Barremian	0.5–6.1	0.01–1.49	10–110
Hauterivian	2.8–8.0	0.001–2.27	25–113
Valanginian	0.2–6.0	0.001–0.19	28–120

Table 2.10 Reservoir properties of the Upper Cretaceous carbonate rocks

Region	Rock type	Porosity, %	Permeability, 10^{-15} m^2	Specific density of cracks, m^{-1}
		Measurement limits (number of specimens)		
The Yevlakh-Agjabedi trough	Limestone	(1.5–19)/298	(2.1–42.2)/250	(1.7–233)/300
	Marls	(1.2–21.3)/85	(1.1–13.2)/86	(1.2–230)/97
	Dolomite	(0.2–27.4)/436		
The Kur–Gabyrry interfluv	Limestone	(0.2–27.4)/436	(0.001–12.0)/451	(1.2–230.0)/490
	Marls	(0.6–27.4)/178	(0.001–40.5)/195	(1.5–210.0)/200

Table 2.11 Reservoir properties of the Upper Cretaceous volcanogenic rocks

Field	Porosity, %	Permeability, 10^{-15} m^2	Specific density of cracks, m^{-1}
	Measurement limits (number of specimens)		
Muradkhanly	0.6–28.2 (210)	<0.001–527(185)	1.1–126.0(140)
Duzdag, Mirbashir, Gedakboz, Mil, Zardab, Karajaly, Sor-sor, Jarly	0.6–21.9(41)	<0.001–15.2(30)	1.2–98.0(25)
Mamedtepe, Tovuz-Gazakh	3.5–23.5(31)	<0.001–22.0(32)	1.0–80.0(33)

Hydrocarbon-bearing prospects are also associated with the Santonian-Maastrichtian age carbonate rocks of the Muradkhanly and Ganja OGFs and with pre-Lesser Caucasian Depression. Oil- and gas-bearing capacity is found for the Muradkhanly (Muradkhanly, Zardab) and Ganja OGFs.

The Upper Cretaceous deposits of above 1000 m thickness are widely developed within the pre-Lesser Caucasus Depression and are exposed by the wells of deep-hole prospect at Sovetlyar, Beilagan, Agjabedi, Borsunly, etc. areas. They are represented by fissured carbonate rocks and are characterized by good reservoir properties. Therefore, it is not by chance that significant oil and gas manifestations of commercial importance were discovered in many boreholes of Sovetlyar and Borsunly areas. It serves as the evidence of high prospects for oil- and gas-bearing capacity in the deposits.

Commercial oil and gas inflows were not found in the Upper Cretaceous sandy-aleuritic formations of the Yevlakh-Agjabedi trough and the Kur-Gabyrry interfluvial despite the fact that they are characterized by porosity and permeability similar to those of carbonate rocks.

In 1971, commercial oil fields were discovered in the Upper Cretaceous volcanogenic rocks of Muradkhanly area. These Turonian-Santonian age reservoirs were occasionally even more productive than normal sedimentary ones, the fact being explained by their rather good reservoir properties (Table 2.11).

The Upper Cretaceous fissured argillites of Jarly, Sor-Sor, and Muradkhanly areas can also serve as reservoirs, as their porosity varies within 1.1–28.0 %, and they have rather high permeability.

According to D.M. Javadov estimates, the Upper Cretaceous argillite from the Ganja OGF (well 18, interval 350–

355 m, Dallyar area) is also characterized by good capacity (18.2 %) and high permeability ($366 \times 10^{-15} \text{ m}^2$).

Of particular interest is the reservoir discovered within 4007–4020 m depths at the cross section of borehole 9, Tarsdallyar area (Upper Cretaceous) (Table 2.12).

Riff formations that are widely distributed in the Mesozoic sediments can also become the potential promising oil- and gas-bearing features.

The Jurassic sediments

The section of investigated Middle Jurassic deposits is represented by the alternation of sandy-aleuritic and clay (argillites and shales) rocks with thin limestone intercalations. Carbonate formations are predominant in the Upper Jurassic age.

The Jurassic sediments are uncovered by deep-hole prospect drilling principally in the near-Caspian-Kur region (at Yalama, Khudat, Khachmaz, Agzyburchala, Talabi, Begimdag, Keshchay areas, and Siyazan monocline) with maximally exposed thickness of about 3000 m at Khachmaz area and in the Jarly-Saatly zone (Ismailzadeh et al. 2008).

Sandy-aleuritic rocks are widely distributed along the entire Jurassic cross section at the Greater Caucasus area. Sandstone are represented by fine-, median-, and (rarely) coarse-grained closely cemented, frequently foliated, and generally well-sorted differences. Aleurites are poorly sorted and latter contain a clayey impurity.

Reservoir rocks of the Jurassic deposits are thoroughly studied in the near-Caspian-Guba OGF. These rocks have totally undergone the metacatagenesis stage, in some places, even apocatagenesis stage, which resulted in their severe packing and consolidation. Despite that, the rocks are met

Table 2.12 Certain parameters of oil-bearing tephroites of Tarsdallyar area (borehole 9)

Interval, m	Carbonate content, %	Porosity, %	Permeability, 10^{-15} m^2	Oil and water saturation, %	
				Oil	Water
4007–4012	2.0	30.0	385.0	33.2	66.8
4012–4020	1.3	29.1	192.0	30.5	10.1

Table 2.13 Average values of some parameters for sandy–aleuritic rocks in the near-Caspian-Guba region [the data were taken from Aliyev and Akhmedov (1958)]

Stage	Granulometric content, % (mm)			Carbonate content, %	Porosity, %		Permeability, 10^{-15} m^2
	>0.1	0.1–0.01	<0.01		General	Effective	
Tithonian	21.3	31.6	47.1	18.8	8.9	–	1.3
Bajocian	27.3	35.4	39.3	15.6	8.3	–	1.3
Aalenian	19.9	44.7	37.4	12.8	6.5	1.1	1.3
Toarcian	32.3	34.6	36.1	4.1	613.8	1.8	6.9

here (Yalama, Khudat, Afurja, Atachay, Keshchay, Tekchay-Begimdagh areas) that possess satisfactory filtration and capacity properties (Table 2.13). So, a gas fountain of 15,300 m³/day gas yield and 70–80 m³/day water yield was discovered at Tekchay area (well 1). Out of the Middle Jurassic deposits, high water inflow (250 m³/day) with oil film was found at Afurja area.

The majority of 1000–1300-m-thick tested features in the Middle Jurassic deposits at Yalama and Khudat areas turned out to be dry that might be related to low porosity and permeability values of sandy–aleuritic formations.

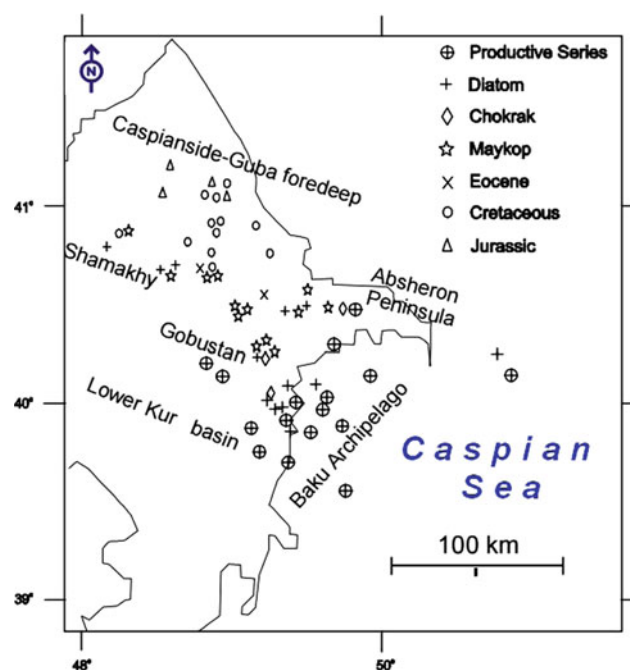
Also, potential oil and gas reservoirs in the Azerbaijan part of the Greater Caucasus are fissured carbonate rocks of the Tithonian stage. These rocks are characterized by fissured porosity of 1 %, specific density of cracks of $96\text{--}300 \times 10^{-1} \text{ m}$, and permeability of $80\text{--}85 \times 10^{-15} \text{ m}^2$. Fissured limestone of this stage that stretches as a range along the Tengi-Beshbarmag anticline and are widely distributed in the Lesser Caucasus northeastern submountain regions (Fizuli, Jebail, etc.) can also be thought as potential hydrocarbon receptacles.

2.1.3 Geochemistry of Organic Matter and Hydrocarbon Fluids and Simulation of Oil and Gas Formation Processes

2.1.3.1 Geochemical Characteristic of Organic Matter in the Meso-Cenozoic Sediments

Study of organic matter (OM) geochemistry and assessment of oil and gas generation potential in the South Caspian basin (SCB) sedimentary rocks are based on pyrolytic analysis data of more than 600 rock samples selected from above 50 areas, including outcrops, mud volcanoes (ejected rocks), and boreholes (Fig. 2.2).

It is vital to take into account that due to weathering processes, OM of outcropped rocks is characterized by relatively lower values of all examined geochemical parameters as compared to the OM of drill-hole cores.

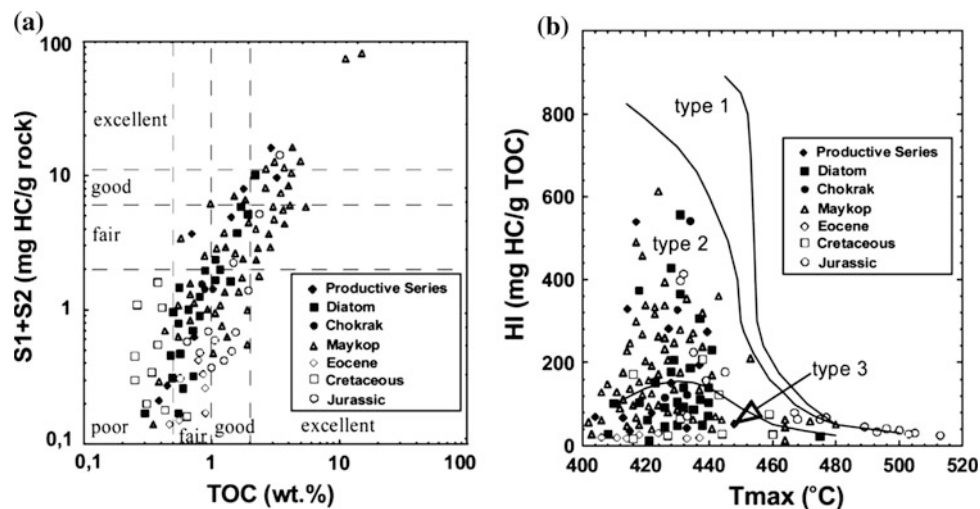
**Fig. 2.2** Distribution of sample collection localities (outcrops, oil fields, and mud volcanoes)

Stratigraphic range of examined deposits embraces the range from the Middle Jurassic to the Lower Pliocene ages. Geochemical investigation of OM in the Lower Pliocene deposits (net oil and gas thickness—PS) was basically conducted using core samples collected from marine oil fields. The research results were set forth in a number of publications (e.g., Korchagina et al. 1988; Guliyev et al. 1991; Bailey et al. 1996; Guliyev and Feyzullaev 1996; Abrams and Narimanov 1997; Inan et al. 1997; Lerche et al. 1997a, b; Tagiyev et al. 1997; Katz et al. 2000; Feyzullayev et al. 2001; Gurgey 2003; Huseynov et al. 2004; Feyzullayev et al. 2008; Ismailzadeh et al. 2008).

The results of pyrolytic studies are graphically represented in Fig. 2.3.

Horizons with favorable HC potential for both qualitative ($S_1 + S_2$) and quantitative factors (hydrogen index—HI) are

Fig. 2.3 Annotate graphs based on pyrolysis parameters: **a** oil and gas source potential of deposits according to Peters et al. (1986) classification; **b** OM qualitative behavior



most commonly encountered in the section Oligocene–Miocene interval.

Below is a brief description of geochemical special features of the Azerbaijan Meso-Cenozoic deposits.

The Jurassic deposits. The sections from the Aalenian to the Callovian age have been studied. Oil and gas source rocks of good quality were found in the Late Bathonian and Early Callovian ages. Paleogeographic data show that basin closing took place at that period, and depositional environment changed due to increase in water salinity. Pr/Ph ratio is 0.39–1.41. Organic matter is mixed and consists of amorphous algae, woody, and higher vegetation, thus corresponding to types 2 and 3. Organic carbon content averages to 0.76, varying within a rather wide range, from 0.05 to 3.41 %. Oil generation potential of the Jurassic deposits is rather low, and HI averages to 87. The Jurassic rocks are predominantly gas producing.

The Cretaceous deposits. The samples from Hauterivian, Albian–Cenomanian, and Maastrichtian stages have been studied. The cretaceous deposits in whole are characterized by low content of C_{org} , which varies from 0.05 to 1.84 % (with average value of 0.22 %). Low value of HI equal to 83 testifies to gas-producing capacity of the sediments under study.

The Paleocene deposits. There are the poorest C_{org} content rocks of the Meso-Cenozoic section. OM content varies within 0.01–0.08, averaging to 0.03 %.

The Eocene deposits are characterized by low C_{org} content and OM quality. OM consists of inertinite and wood residues. OM average value is 0.46 %, and HI does not exceed 29.

The Oligocene–Lower Miocene deposits (the Maykop series). The Maykop series sediments are distinguished by high C_{org} content, achieving 15.1 %, with average content of 1.86 %. HI varies from 11 to 612 with an average value of

146. OM quality and content in the Maykop deposits improve eastward to the Caspian Sea.

The Middle Miocene deposits (the Chokrak horizon) are characterized by C_{org} content within 0.09–2.44 % and by hydrogen index values of 73–541, thus indicating the OM satisfactory quality and potential generation of liquid and gaseous hydrocarbons by these sediments.

The diatom suite is considered as one of the principal oil-generating complexes in the SCB. In the basin northern part, the suite is characterized by median content of C_{org} equaling to 0.63 %, with HI variation from 12 to 427 mg HC/g of rock (average value is 105 mg HC/g of rock). OM content and quantity in the diatom suite deposits concerning liquid HC generation improve with depth and with deposit regional subsidence. It is witnessed by the characteristics of ejected rocks of the Shamakhy-Gobustan zone mud volcanoes and by the Baku archipelago drill-hole cores (Fig. 2.4).

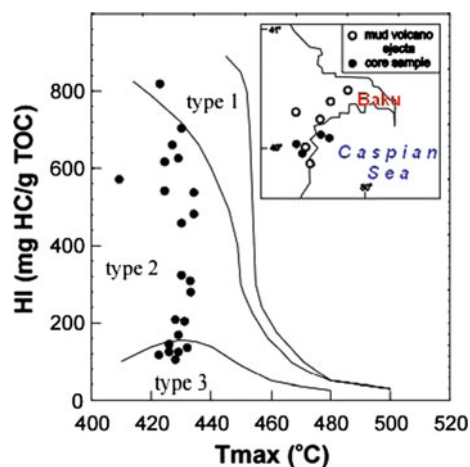


Fig. 2.4 Annotated diagram, indicating improvement of organic matter source quality in the diatom sediments toward the basin deeps

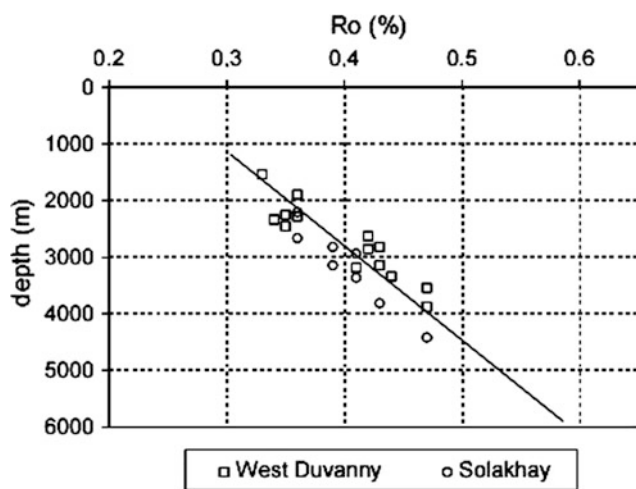


Fig. 2.5 Changes in vitrinite reflectivity with depth in the range of the Miocene deposits exposed at Zapadny Duvanny and Solakhay fields

Kerogen of these formations in most cases corresponds to the 2nd type (see Fig. 2.4). High C_{org} content (0.09–7.8 %, average value of 1.03 %) and HI (107–708, average value of 308 mg HC/g of rock) display good oil generation potential of the diatom suite in the basin deep-sunk part.

The Lower Pliocene deposits (PS). The Lower Pliocene deposits, being generated in the deltaic and shore marine conditions, are characterized by low OM quality, which in most cases belongs to the 3 type and consists of re-sedimented remnants of woody vegetation with insignificant admixture of amorphous and algal OM. C_{opr} content is 0.02–2.71 % (average value of 0.47 %). Hydrogen index varies from 15 to 334 mg HC/g of rock (average value of 147 mg HC/g of rock).

Thermal maturation of the Miocene rock OM was assessed from the data of vitrinite reflectivity (R_o , %). These parameter values in drill-hole cores from Zapadny Duvanny and Solakhay areas (down to 4500 m depth) do not exceed 0.48 % (Fig. 2.5). Similar investigations of the drill-hole cores from the Baku archipelago areas down to 5300 m depth give R_o (%) values, not exceeding 0.6 that testifies to low OM maturation and much deeper occurrence of the “oil window.”

2.1.3.2 Geochemistry of Azerbaijan Oils

Oils of differing properties and compositions occur in Azerbaijan. Qualitative variety of oils manifests itself not only between the oil- and gas-bearing fields (OGF) but also within separate OGFs and deposits, both in various stratigraphic frameworks and in coeval horizons.

Composition of Azerbaijan oils, inherited from the oil source OM, undergoes significant transformations at all stages of their generation and migration.

Oils of the Azerbaijan Meso-Cenozoic sediments are characterized by considerable qualitative changes, reflecting facial-geochemical environments in paleo-basins and compound effect of aggregate factors of migration, catagenic metamorphism, and hypergenesis. It is evident that at shallow depths of occurrence (according to the available estimates, down to about 2 km), oils are essentially exposed to the impact of supergene factors, while at great depths only the thermocatalytic factors prevail.

The effect of supergene factors is most pronounced within the Absheron OGF, where highly cyclic oils, basically of naphthene base, with large content of resinous components, are observed at certain fields in the PS section.

Thermocatalytic transformation process affects first the changes in group hydrocarbon composition of the light fraction, i.e., the fraction that distilled at 200 °C. These processes result in the increase in methane and aromatic HC content—as a consequence of destruction of complex high-boiling molecules, the number of naphthene HCs decreases.

Qualitative variety inherent in Azerbaijan oils is particularly manifested in the PS. The *Absheron OGF* can serve as an example: There, we meet both light and heavy oils, and low and high resinous, with various content of asphaltenes and solid paraffin, with methane and naphthene base, with various degrees of cyclicity and maturation.

This region is characterized by the absence of stringent stratigraphic orientation of changes in oil physical-chemical properties and compositions within the field stratigraphy, specifically “inversion” pattern of density variations, tending to increase with stratigraphic depth. Such “anomalies” are noted by relatively shallow occurrence of petroliferous beds (1000–2500 m) in highly dislocated structures, where supergene processes are acting.

On the other hand, rather definite regularities in oil content changes are observed regionally in the PS like-named horizons, as a function of the basin paleogeographic conditions and hypsometric depth of occurrence.

Heavy tarry oils containing complex high molecular cyclic compounds are found in upraised parts of anticlinal structures, developing in the PS basin shore zones with alternating redox conditions and predominantly humus source organic matter.

Light methane-base oils are abundant in the paleo-basin distant parts, where sapropel-type autochthonous organics was accumulated and stable reducing environment was created. By the subsidence of productive horizons to 3000–5000 m depths, the processes of oil catagenic alterations become primary importance.

Oils of the *Gobustan OGF* deposits are less diversified in their physical-chemical characteristics as compared to the oils of any other field. Their density values permit to classify them as middle and heavy oils (890–910 kg/m³), so that

these values increase with oil occurrence depths. Density value reaches the least-for-the-field value of 870 kg/m^3 only at much deeper fields (4697–4714 m), in the VII horizon oil of the PS, at Kyanizdagh area.

The field oils are tarry and highly resinous, and tar content is 6.5–14.0 %. Nitrogen content fits in 0.11–0.19 % range, sulfur, in 0.11–0.17 %, and so that sulfur content slightly drops with subsidence of coeval beds. In this process, larger quantity of nitrogen and sulfur finds correspondence in larger quantity of silicagel resins, thus permitting to state the existence of genetic bond between sulfur and nitrogen and tarry agents.

Blend composition of oils shows more distinct differences and demonstrates the impact of the depth of occurrence on oil reduction level that is evidenced by oil fraction presence in petroleum compositions, the fraction gradually increasing with depth from 70.6 to 82.4 %, and by the decreased ratio of alcohol–benzene tars to benzene tars.

In the Maykop and Chokrak deposit fields, the oils are heavy, and their density varies from 887 to 957 kg/m^3 .

The *Lower Kur OGF* oils have relatively deep occurrence and are mostly confined to regionally immersed structures; for this reason, they bear the principal feature of catagenic transformation. The oils are predominantly of middle density, occasionally light ones and less frequently heavy ones, and are characterized by methane base of top (petroleum naphtha) and high-boiling fractions. The pools confined to the structure plunged parts or sealed by tectonic dislocation have more favorable conditions for preservation of light hydrocarbons than the upraised blocks, particularly when these latter connect the pool with daylight surface. Degree of transformation in these oils, with relatively homogeneous hydrogeological, lithofacial, and alternative conditions, directly depends on the depth of occurrence.

The influence of stratigraphic depth on catagenic change degree in the *Lower Kur OGF* oils is exhibited only when productive horizons have considerable thickness. Then, hypsometric depth markedly grows with increase in horizon ages. Such regularity is most prominently seen at Kyur-sangya and Garabagly fields, where in the PS I and V–VI horizons depth of occurrence of oils increases by 700–800 m and reservoir temperature increases by 12–15°C.

Blend composition of the *Baku archipelago* oils shows oil fraction within 44.0–76.4 %, while the quantity of benzene and alcohol–benzene tars varies within a small range, as 3.8–4.7 and 3.8–5.1 %, respectively. At Duvanny field, oil content consistently increases with depth, from 59 to 82.9 %.

Predominance of methane HC in the group composition of light and high-boiling fractions is common for all *Baku archipelago* oils. At Sangachal-deniz field, the content of methane HC decreases down dip from 66.8 to 52.7 %, and

the content of naphthene HC and light aromatics rises from 12.2 to 21.5 %, respectively. At Duvanny-deniz field, the content of methane HC rises with hypsometric depth from 48.4 to 64.3 %, while the content of naphthene HC, on the opposite, decreases from 33.6 to 15.9 %. High-boiling oil fractions are characterized by similar values of common cyclicity, varying within 1.7–1.9. The content of aromatic HC in the investigated oils varies from 8.71 to 15.3 %.

Within the *Siazan monocline*, oil- and gas-bearing capacity is confined to the section range from the Upper Cretaceous to the Middle Miocene Chokrak horizon. Here, from Chokrak to Maykop, and deeper in, in the Paleogene and Upper Cretaceous stages, oils become lighter and lose nitrogen and sulfur. In the light fraction, content of alkanes and aromatics increases, and their aliphaticity degree rises.

The oils of the *Siazan monocline* southeastern part, where seal integrity is violated by tectonic dislocations, differ from Zeiva area oils by their higher density, resin content, lesser reduction, and maturation.

Heterochronous oils of the *Yevlakh-Agjabedi trough* fields are characterized both by similar features and by noted differences in properties and contents.

Identity of contents in oils of various stratigraphic level reduces principally to three relatively similar density values within $860\text{--}880 \text{ kg/m}^3$ range, to low sulfur content, increased content of tarry components, predominantly methane composition, and elevated oil paraffinicity (3.12–6.35 %).

With that, the Chokrak deposit oils differ in their properties from the Maykop, Eocene, and Upper Cretaceous oils. They are characterized by comparatively high density (887 kg/m^3), content of sulfur (0.32 %), total resins (44 %), boiling point (135 °C), and methanization. These parameters decrease from the Chokrak horizon petroleum to the Maykop, Eocene, and Cretaceous petroleum, while the content of oil, low molecular aromatics, petroleum ether resins, asphaltenes grows (from 3.4 to 6.8 %). Total light fraction content in the Chokrak oil is considerably less (11.65 %) than in more ancient oils (16.9–22.8 %).

Thus, the reduction and methanization degree, and consequently the catagenic transformation, build up by transfer from the Chokrak to more ancient oils, achieving its peak in the Upper Cretaceous volcanogenic thickness.

Oils of the *Kur-Gabyrry interfluvium* (Tarsdallayar and Gyurundagh areas) differ between them even within each one of the areas under study. As the depth of occurrence increases, density, initial boiling point, oil viscosities, and content of silicagel resins in them decrease. Blend composition shows predominance of petroleum oils and other neutral compounds.

Regional catagenic oil changes within the entire Azerbaijan territory are manifested as general tendency to the

transformation depth increase from the SCB margins to depression zones, specifically from Absheron Peninsula and Gobustan to Baku archipelago and Lower Kur Depression. Facilitation, methanization, and oil decycling are observed in this direction under relevant changes in the maturation index-averaged values.

Typical feature of Azerbaijan oils is permanent predominance of nickel ash over vanadium in their composition, as well as iron over nickel predominance in most fields. Another typical feature is low content of some heavy metal ashes in their composition. Thus, for instance, the sum of $\text{CuO} + \text{NiO} + \text{V}_2\text{O}_5$ oxides does not exceed 3.5 %, whereas in oil ashes of certain world fields, they amount to above 50 % of ash.

Confinement of oil deposits to the reservoirs of broad age range—from the Upper Cretaceous to the Upper Pliocene–Anthropogen—as well as extremely high, one-of-a-kind, thickness of its sedimentary filling, is characterized by the presence of several oil-generating systems. These systems present great difficulties by identification of actual contribution of each of components into the formation of hydrocarbon clusters in the principal oil-bearing facility, i.e., the net oil and gas pay thickness (PS and Lower Pliocene). One group of researches believes that oil in the PS is primary, i.e., it was produced by organic matter of the PS per se (or by its lower division), and then laterally, laterally stepwise, and vertically migrated to the accumulation point from various generation regions located in the South Caspian Mega Depression (SCMD) deeply subsided parts (Weber 1947; Alizadeh et al. 1975, 1985; Bagirzadeh et al. 1987, etc.).

Another group of researchers develops the idea of oil secondariness and its migration to the PS reservoir rocks from the lower lying Paleogene–Miocene and more ancient deposits by fissures and cracks (Gorin 1934, 1958; Mekhtiyev 1956; Mekhtiyev et al. 1971; Abrams and Narimanov 1997, etc.).

Investigation results for stable isotopes of total carbon of oils and for the carbon of their alkane and aromatic fractions are given from 152 samples from 38 oil fields of Absheron, Yevlakh-Agjabedi, Shamakhy-Gobustan, and Lower Kur OGFs, from the Baku and Absheron archipelagos, and from the Kur-Gabyrry interfluvium, taken from oil reservoirs, starting from the Upper Cretaceous to the Upper Absheron inclusively (67 investigated samples are crude oils, and 85 are alkane and aromatic fractions, in separate). The values of carbon isotopic ratios, $\delta^{13}\text{C}$, in Azerbaijan oils vary within the broad range from -28.0 to -24.34 ‰ for overall carbon and from -29.1 to -24.8 ‰ for oil alkane fraction. In this process, Azerbaijan oils are grouped into two classes: (1) isotopic light, with $\delta^{13}\text{C}$ values of -28.0 ‰ to -27.0 ‰ by total carbon, and -29.1 ‰ to -27.0 ‰, by alkane fraction carbon, and (2) isotopic weighted as

-26.5 ‰ to -24.0 ‰ and -26.5 ‰ to -24.5 ‰, respectively, by total carbon and alkane fraction carbon.

The second group oils constitute the overwhelming bulk of Azerbaijan oils. Their share is from 57.6 to 68.6 % of analyzed samples, whereas the isotopic light ones constitute 31.3–42.3 %. The circumstance of major importance is the clearly pronounced regular variation in isotopic ratios in stratigraphic cross section.

So, the most isotopic light oils are typical for the Upper Cretaceous reservoirs (-28.15 ‰; -28.0 ‰) (here and further, the first figure corresponds to $\delta^{13}\text{C}$ in alkane fraction, and the second one corresponds to oil total carbon), which successively replace the oils from the Eocene (-8.32 ‰; -27.86 ‰), Maykop (-28.05 ‰; -27.64 ‰), and Chokrak system reservoirs (-27.95 ‰; -27.5 ‰). Dramatic isotope weighting of oils takes place by transfer to the oils from diatom suite reservoirs (-26.45 ‰; -26.13 ‰). The most isotopic weighted oils are confined to the Lower and Upper Pliocene age reservoirs (-26.35 ‰; -25.75 ‰). Spread in values between the upper and the lower limits of $\delta^{13}\text{C}$ increases simultaneously.

General peculiarities of Azerbaijan oils are high concentrations of normal alkanes $n\text{-C}_{15}$, $n\text{-C}_{17}$, and $n\text{-C}_{19}$ with incomparably low $n\text{-C}_{27}$, $n\text{-C}_{29}$, $n\text{-C}_{31}$, as well as low values of pristane-phytane ratio and sulfur content that in rare cases can reach 1.4 and 0.4 %, respectively, that according to (Sofer 1984; Peters et al. 1986; Chung et al. 2000; Collister and Wavrek 1996) is typical for the oils generated in marine delta conditions.

The importance of this conclusion for the Pliocene reservoir oils should be particularly emphasized because it essentially indicates their epigeneticity to a given age system of deposits, because, according to paleogeographic factors, formation of these latter took place in a closed desalinated basin, where continental organics was vigorously fed along with terrigenous clastic material. This fact had to be reflected in carbon isotopic signature of generated oils. The outlined theory is also confirmed by biomarker parameters of the Pliocene reservoir oils in all OGFs.

It is necessary to stress the observed pronounced differentiation between OGFs based on $\delta^{13}\text{C}$ values of alkane fraction from the Pliocene reservoir oils. Taking into account average weighting values of this parameter, the OGFs are arranged in the following sequence: the Lower Kur field (-26.8 ‰), the Absheron field (-26.29 ‰), the Shamakhy-Gobustan field (-26.1 ‰), the Baku archipelago (-26.04 ‰), and the Absheron archipelago (-25.87 ‰).

Different oil-generating intervals of the Paleogene–Lower Miocene and diatom systems play approximately similar role in the formation of oil deposits at the Absheron Peninsula Pliocene reservoir fields. It is typical for the Pliocene reservoirs of both southeastern Gobustan and Baku archipelago, though certain advantage of diatom complex can be

observed here. About 3/4 of oils of the Lower Kur OGF have been developed in the Paleogene–Lower Miocene sediments, whereas diatom deposits played the leading part in generation of the Absheron archipelago PS and account for 2/3 of oils.

In general, the tendency for oil isotope weighting can be noted in dryland-to-sea direction that can be explained by the involvement of younger deposits in “oil window.” It is quite expected because apparent increase in thickness of young Pliocene–Quaternary deposits in sediments is noted in this direction, and they subside at deep depths.

The mud volcano oils basically have naphthene–aromatic and methane composition; they are highly oxidized and biodegradable. Carbon isotopic signature in saturated oil fraction varies from -28.5 to -25.4 ‰.

2.1.3.3 Maturation Degree of Oils from Heterochronous Reservoirs of the South Caspian Mega Depression

Oil maturation degree is the most essential parameter that, combined with other geological and geochemical indexes, permits to obtain sufficient data concerning depth of oil and gas generation zone, stratigraphic confinement of oil source rocks, migration tendency, and conditions of hydrocarbon fluids and finally to assess the oil- and gas-bearing basin potential. Investigations of oil maturation degree are of extrinsic value for oil- and gas-bearing basins (OGBB), where a number of systems are involved in hydrocarbon generation processes. The vigorously developing South Caspian Mega Depression (SCMD) can serve as an example because several fluid-generating systems are distinguished in its Cenozoic section such as the Eocene, the Oligocene–Lower Miocene (the Maykop), the Middle Miocene (Chokrak horizon), and the Middle–Upper Miocene (diatom) systems (Alizadeh et al. 1975).

Tectonically, the South Caspian area of regional downwarping, being conjugated to the principal geosstructural elements of Caucasus, Kopetdagh, and Elburs of differing geodynamical conditions, happened to be broken into a series of depression structures that were the integrity of intermountain depressions and downwarps differing in their geological and tectonic configuration (Aliyev et al. 2005). Geological and tectonic configuration of the SCMD downwarps finds its reflection on geochemical image of oils condensed therein.

The mega basin most essential feature is high qualitative geochemical diversity of oils from the Pliocene reservoir, where from different in composition oils are produced: both light and heavy, both low sulfur and high resinous, both methane and naphthenic oils, etc.

Another SCMD feature is low maturity level of oils from the Upper Cretaceous, Oligocene–Lower Miocene (Maykop), and Miocene reservoirs of the Shamakhy-Gobustan

OGR, as compared to the oils from the Pliocene age reservoirs of adjacent OGFs. It is known that oil maturity is the function of temperature conditions in the Earth depths and of duration of stay of oil-generating deposits in the oil generation zone. It is directly interrelated with the age of oil-generating thicknesses.

The third, utterly surprising circumstance is the extremely low oil maturity in known oil and gas condensate fields, which does not fit into existing concepts of oil and gas formation vertical zoning, where under the condensates are the products of organic matter highly catagenetic destruction.

High-tech methods (widely used in organic geochemistry) of organic matter and oil research at the level of molecular fossils (biomarkers) permitted to conduct oil–oil, oil–oil source rock correlations, to determine oil stratigraphic age, and, what is most vital, to define catagenetic transformation level for kerogene and maturity level for oil derivatives. To this objective, such parameters as hopane and sterane isomerization degree, sterane aromatization, and relationships between aromatic steranes and steroids, have been used.

Research results for the deposits in all OGFs of the SCMD showed that, basing on sterane isomerization, oil maturity varies from 0.155 to 0.49. The most mature oils are grouped within the Middle Kur Basin OGF, where in 50 % of facilities, oils have maturity value, basing on sterane isomerization, $\text{Req.} = 0.68\text{--}0.73$ %, and in 40 % cases, they are 0.4–0.5 or $\text{Req.} = 0.63\text{--}0.68$ %, i.e., the investigated oils in general show low-level and median kerogene transformation in oil source rocks.

In the Lower Kur, Shamakhy-Gobustan, Absheron troughs, and Baku and Absheron archipelago Pliocene deposits, oil maturity level varies within $\text{Req.} = 0.45\text{--}0.67$ %. The facilities with middle values of this parameter, lying in the $\text{Req.} = 0.53\text{--}0.63$ % range, constitute the main body (81.6 %) of the SCMD Pliocene deposits (the reservoir age is meant here), thus evidencing to OM low transformation level in oil source rocks. The least transformation degree is found in the Absheron Peninsula and the Shamakhy-Gobustan trough oils ($\text{Ro} = 0.43\text{--}0.56$ %). Increased maturity is typical for the Lower Kur Depression (LKD) oils and for the Baku and Absheron archipelago fields ($\text{Req.} = 0.62$ %).

It is important to note sharp isotope weighting of oils southeastward against the general lightweight isotope background of the LKD oils, with isolation of anomalies, having typical diatom mark, in the oils of the most distant southeastward Neftchala field. Particularly notable is that this field features the most mature oils, both within the LKD and in the SCMD central part.

Thus, on the whole, rather low-level maturity has been found for the SCMD oils, not exceeding $\text{Req.} = 0.73$ % (Middle Kur Depression) that significantly raises the prospects for discovering of more mature stage oils.

Table 2.14 Hydrocarbon composition of gases from various stratigraphic frameworks (average values)

Age of enclosing rocks	Methane + ethane	Propane	Butane	Pentane	Propane + high	Carbon dioxide	Methane heavy
Absheron stage	95.28	1.57	0.8	0.37	2.74	0.8	35
Productive strata	90.92	0.64	0.60	0.60	1.84	6.2	49
Chokrak horizon	94.50	1.58	1.25	0.77	3.60	1.6	26
Maykop suite	88.66	3.90	2.65	1.63	8.18	3.1	10
Foraminiferal layers	84.61	5.50	6.22	2.96	14.68	0.7	5

Table 2.15 Change in *n*-butane/isobutane and *n*-pentane/isopentane relationship with stratigraphic depth

Age of enclosing rocks	Number of tests	<i>n</i> -butane isobutane	<i>n</i> -pentane isopentane
Absheron stage	25	0.31	0.20
Productive strata	62	0.67	0.58
Chokrak horizon	9	1.10	0.87
Maykop suite	28	2.01	1.06
Foraminiferal layers	1	3.24	1.58
Cretaceous age	1	4.2	2.0

Isotope weighting of the PS oils with simultaneous increase in their maturity level toward the SCMD deeper area is the consequence of diatome deposit involvement in oil generation zone as they produce the isotope-heavy oils.

2.1.3.4 Geochemistry of Hydrocarbon Gases

Azerbaijan, that through many centuries is being called “the Land of Flames,” together with adjacent Caspian Sea area, is characterized by extensive development of natural surface manifestations of gas.

Many dry gas discharges are being developed at Azerbaijan territory, with 10 burning, above 300 gas manifestations associated with mud volcanoes, about 150 manifestations related to mineral springs, as well as gas manifestations as gas hydrates at the Caspian Sea bottom. Numerous gas manifestations were noted by drilling of exploratory wildcat wells.

Azerbaijan area and the Caspian Sea offshore area are characterized not only by focused gas flows but also by their macro manifestations, related to the Earth regional gas breath.

Azerbaijan natural gases are characterized by diversified chemical composition. Assays of above 500 gas samples showed that natural gas basic constituents are methane, carbon dioxide, and nitrogen. Alternative components such as ethane, propane, butane, and argon are admixtures, with their content not exceeding units of percentage, and such substances as hydrogen sulfide, helium, and neon are contained in micro concentrations.

Methane gases are most widely abundant and are essentially confined to the South Caspian and Kur Depressions, as well as to the Greater Caucasus and the near-Caspian-Guba superimposed trough. Carbon dioxides occupy the Lesser Caucasus area and the Talysh western part. Nitrogen gases are present as small-area zones in the Greater Caucasus, in Talysh, and in the northeast of near-Caspian-Guba superimposed trough.

Hydrocarbon Gases of Oil and Gas Fields

Chemical composition of hydrocarbon gases at the Azerbaijan oil, gas condensate, and gas fields is represented by the following components and their composition limits:

1. hydrocarbon components: methane—from 51.0 to 99.0 %, ethane—from 0.14 to 11.0 %, propane—from 0.04 to 4.4 %, butane—from 0.04 to 3.8 %, and pentane—from 0.04 to 3.3 %.
2. incombustible gases: carbon dioxide—from 0 to 46.0 %, nitrogen—from 0.01 to 9.0 %, argon—from 0.001 to 0.04 %.
3. trace substances: helium—from 0.0002 to 0.03 %; hydrogen sulfide from 0 to 0.5 %.

In some samples, unsaturated hydrocarbons and hydrogen were present. Content of various gaseous components varies in broad range.

We failed to establish a unified trend in methane content changes in the PS section.

Table 2.16 Isotope composition of deposit gases (average values)

Stratigraphy	Number of tests	$\delta^{13}\text{C}_{\text{CH}_4}$ (-) ‰	$\delta\text{DC}_{\text{CH}_4}$, (-) ‰	$\delta^{13}\text{C}_{\text{C}_2\text{H}_6}$, (-) ‰	$\delta^{13}\text{C}_{\text{CO}_2}$	$\delta^{18}\text{O}_{\text{CO}_2}$
PS upper division	22	43.7	202	28.5	+0.6	-4.9
PS lower division	16	43.9	211	27.4	+8.6	-2.3
PS in a whole	38	43.8	206	28.0	+4.5	-3.5
PS-underlying deposits	7	51.7	207	33.9	+2.1	1.7

Regular decrease in methane content with stratigraphic depth was noted from the data of Umbaki, Siazan, and Gazanbulagh fields (Table 2.14).

Interesting results were obtained from the data of normal butane-to-isobutene ratio and normal pentane-to-isopentane ratio for the gases of some Absheron Peninsula, Gobustan SE, and the near-Caspian-Guba region oil fields. The values of these ratios regularly increase from top downward through the Tertiary and Mesozoic deposit section vertically (Table 2.15).

Carbon and Hydrogen Isotope Composition in Azerbaijan Gases

Within the recent decade, the study of isotope composition of elements constituting the investigated facilities has been widely used in geochemical research. Oil and gas geology investigates carbon isotopes of methane and its homologs, carbon dioxide, hydrogen, and oxygen isotopes of carbon dioxide. The works that had been conducted earlier (e.g., Dadashev et al. 1986) studied carbon isotopes of methane. Isotope analysis of 60 samples from 15 Azerbaijan oil fields was conducted at VNIIGeoinformsistem (Moscow).

Later on, Geological Institute, in collaboration with *British Petroleum*, conducted some studies of carbon isotopes not only in methane but also in its homologs as well. Gas specimens were sampled from boreholes into special metal vessels with preserved gas specimen pressure conforming to wellhead pressure. Forty-five specimens of free gas from various PS horizons and suites (38 samples) and from the PS-underlying deposits (7 samples) (Chokrak, Maykop) were taken to containers from 27 oil, gas condensate, and gas fields of Azerbaijan in order to study gas isotope composition. In addition, AMOK Company has studied 9 gas specimens from the Lower Kur OGF deposits.

According to the analysis results, carbon isotope composition of methane ($\delta^{13}\text{C}_{\text{CH}_4}$) varies from -37.2 to -60.3 ‰ (averagely, -45.0 ‰), ethane carbon—from -21.0 to -40.3 ‰ (averagely, -28.9 ‰), propane—from -10.5 to -33.7 ‰ (averagely, -23.7 ‰), isobutane—from -21.5 to -35.8 ‰ (averagely, -27.0 ‰), normal butane—from -14.8 to -30.8 ‰ (averagely, -23.5 ‰), butane—from -18.0 to -32.6 ‰ (averagely, -25.3 ‰), and

hydrogen isotope composition of methane, $\delta\text{DC}_{\text{CH}_4}$, from -101.0 to -277 ‰ (averagely, -207 ‰).

Carbon dioxide accompanies hydrocarbon gases. In sampled gases, carbon dioxide $\delta^{13}\text{C}$ varies from -13.2 to +21.5 ‰, average value being +3.6. Oxygen isotope composition in carbon dioxide also varies in broad range, from +2.5 to -12.5 ‰, averagely, -2.9 ‰. Wider range of changes in carbon dioxide isotopes as compared to carbon isotopes of hydrocarbons adequately corresponds to diversified CO_2 sources, their origins, and fractionation. Results of study of gas isotope composition permit to compare the distribution of gas isotope composition in oil and gas deposits, basing on cross section, depth, and deposit types.

We did not succeed in finding a clear-cut regularity of changing carbon isotopes in HC gases and carbon dioxide, as well as changes of hydrogen isotope in methane and oxygen isotope in carbon dioxide according to the PS individual horizons and suites. Comparison of gas isotope compositions in the PS upper and lower divisions (Table 2.16) shows that they are close to each other by their absolute values. Thus, no changes are found for carbon isotope composition in methane, and only moderate weighting is noted for hydrogen isotopes in methane and carbon isotopes in ethane and propane. More remarkable weighting is found in carbon dioxide isotope composition. $\delta^{13}\text{C}_{\text{CO}_2}$ weighs from +0.5 to +8.6 ‰ on the average, and $\delta^{18}\text{O}_{\text{CO}_2}$ weighs from -5.4 to -1.6 ‰.

A tendency to carbon isotope composition lightening in HC gases, carbon dioxide, as well as hydrogen and oxygen lightening is observed at interval from the PS to underlying deposits.

Comparison of isotope average values in HC gases and carbon dioxide from various types of deposits demonstrates that carbon isotope composition is enriched by heavy isotope in all HC and carbon dioxide components by passing from oil fields to gas fields, that hydrogen isotope composition of methane is lightened, and that oxygen in carbon dioxide does not change. The gases of gas condensate fields occupy an intermediate position. Carbon and hydrogen in methane, both from oil fields and by transfer from gas to gas condensate fields, are enriched by a heavy isotope. Carbon isotope composition in ethane, propane, iso- and normal butane, carbon dioxide, and carbon dioxide oxygen is lightened.

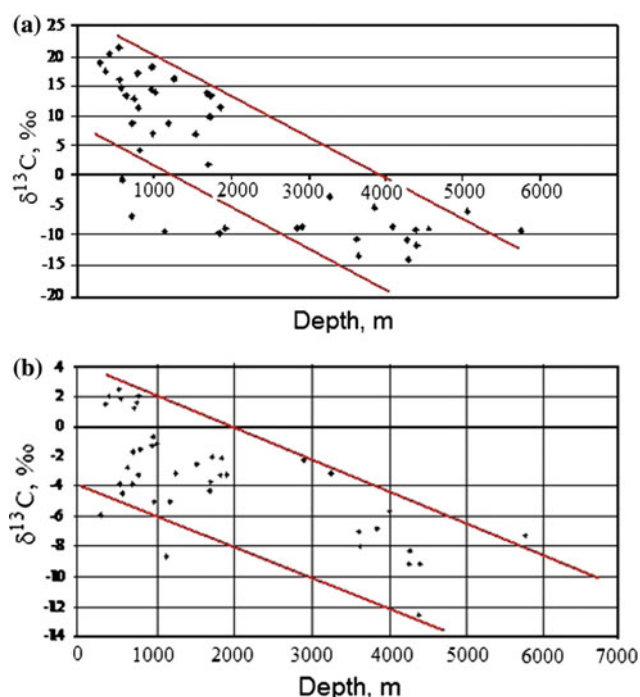


Fig. 2.6 Changes in $\delta^{13}\text{Cco}_2$ (a) and $\delta\text{O}^{18}\text{co}_2$ and (b) values with depth

The investigated samples encompass the depths from 230 to 5754 m; therefore, an attempt was made to trace the changes in gas isotope composition with depth as well. Carbon isotope composition both in methane and in carbon dioxide experiences the tendency to lightening with depth increase (Fig. 2.6).

Carbon isotope composition in the fields' methane shows that two principal zones are found here. The first zone that embraces the fields of the Lower Kur region and the Baku

archipelago southern part is characterized by reduced-weight methane isotope, varying within $-(57.3 \text{ to } 46.2)\%$. The second zone embraces the Absheron Peninsula, the Absheron archipelago, and the Baku archipelago northern part and Gobustan and is distinguished by its heavier carbon isotope of methane within $-(37.2 \div 46.0)\%$.

Two zones are also found in the distribution of hydrogen isotopes of methane. The first one, with $-(277 \text{ to } 194)\%$ values, covers the Absheron Peninsula, the Absheron archipelago, Gobustan, and the Lower Kur region. The second zone, with hydrogen isotope values of $-(194 \text{ to } 101)\%$ in methane, is isolated within the central, southwestern Absheron and within the Baku archipelago.

Two zones are also prominent in areal distribution of carbon isotope composition and other HC gases (ethane, propane, butane), as well as distribution of oxygen and carbon isotopes in carbon dioxide.

On the whole, lightening of carbon isotopes in HC gases and in carbon dioxide and weighting of oxygen isotope in carbon dioxide are observed in downwarping trend of the PS rocks.

According to the dependence graph between $\delta^{13}\text{CCH}_4$ and $\delta^{13}\text{CC}_2\text{H}_6$, the conclusion was made that all mud volcano gases are thermogenic, whereas field gases are represented both by thermogenic and biogenic gases and by their mixture.

Thus, isotope analysis that was conducted permits to point to the diversity of gas genesis and sources in the PS and in underlying deposits. Main scope of the PS gases was generated concertedly with liquid HC generation, i.e., as associated gases. Lesser gas scopes were generated at the expense of OM late transformation stage and oil cracking.

Basin Modeling

Qualitative estimate of oil and gas potential realization was given, and density charts for generated HCs were plotted for

Table 2.17 The scope of oil and gas generation in the South Caspian trough Meso-Cenozoic deposits (from kinetic simulation results)

Stratigraphic framework	Overall quantity			Average-specific quantity (per 1 km ² of basin area)		
	Liquid HC ^a × 10 ⁹ t		Gas ^b × 10 ¹² m ³	Liquid HC × 10 ⁶ t		Gas × 10 ⁹ m ³
	Aggregated generation	Preserved after cracking		Aggregated generation	Preserved after cracking	
Upper Pliocene	58.4	58.4	9.0	0.344	0.344	0.053
Middle Pliocene	159	159	54.3	0.938	0.938	0.32
Miocene–lower Pliocene	534	465	305	3.15	2.74	1.8
Paleogene	1247	732	1240	7.35	4.32	7.34
Mesozoic age	811	233	1170	4.78	1.37	6.88
The whole sedimentary thickness	2815	1670	2780	16.56	9.71	16.39

Notes

^aLiquid HCs that preexist in kerogene structure are included in this quantity

^bGaseous HCs that generated both from kerogene and from the cracking of high molecular HCs

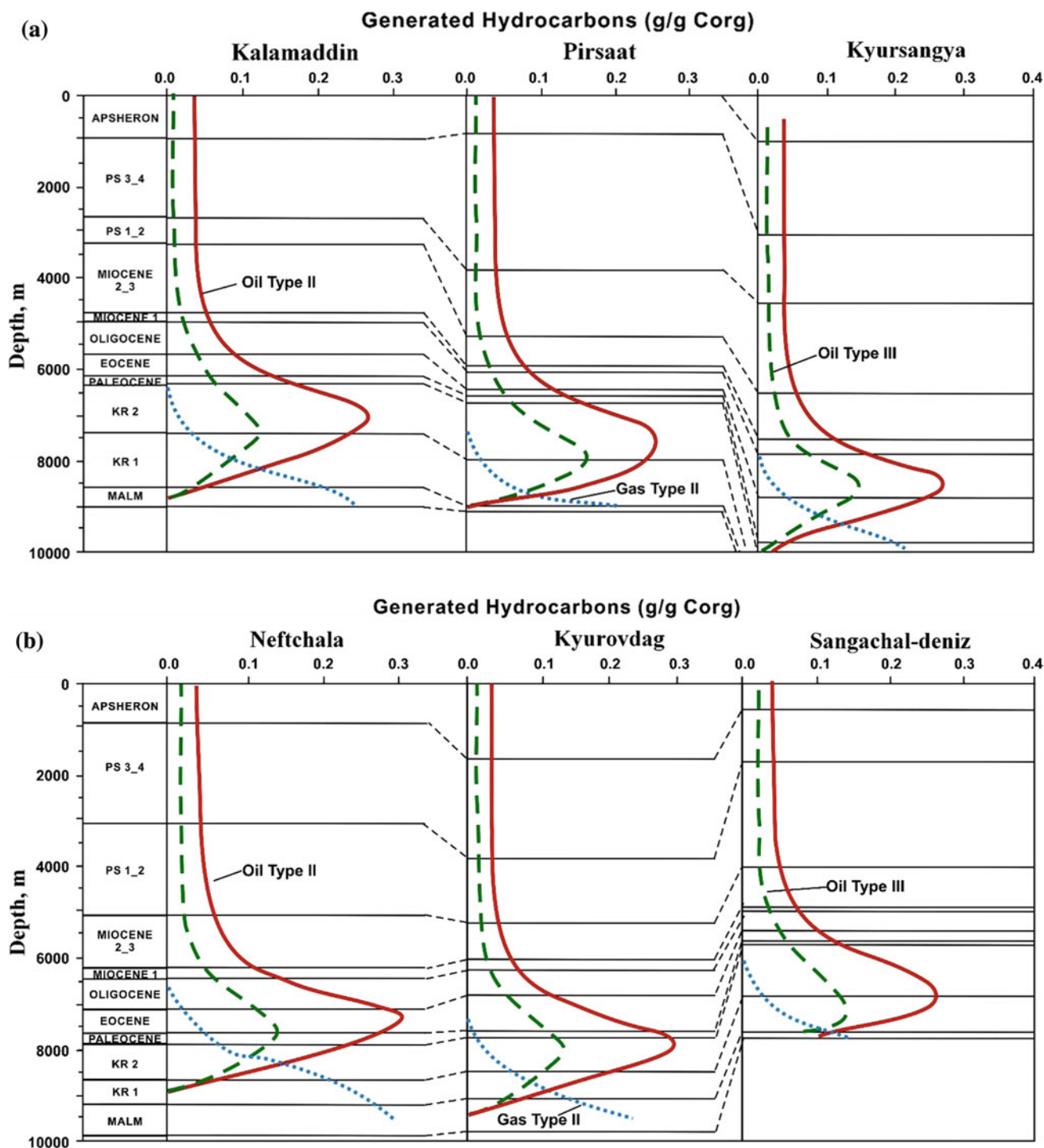


Fig. 2.7 Changes in oil window positions along Kalamaddin-Pirsaat-Kyursangya (a) and Neftchala-Kyurovdag-Sangachal-deniz (b) sections. The depth of oil and gas generation start increases toward the depression depocenter

various South Caspian Basin (SCB) systems using basin modeling (Table 2.17). In addition, the depth intervals in the SCB section with the highest methane concentrations were predicted by plotting the integrated model of gas generation and following migration.

Modeling of oil and gas formation process in the Lower Kur trough sedimentary thickness (Inan et al. 1997) permitted to establish that oil window in the Lower Kur Depression cross section embraces the Paleogene stratigraphic interval. According to this model, oil generation started in the Late

Pliocene and has been continuing at present at 6–12 km depths (Fig. 2.7). The SCB basin modeling was also made, using the SIGMA-2D software, developed at the Engineering Research Center of the Japan National Oil Company. A broad spectrum of geological, geothermal, and geochemical data was used by model plotting.

According to the modeling results, liquid HCs that had been generated in the Oligocene–Miocene deposits and migrated there from in the Late Miocene–Early Pliocene period migrated northward and were accumulated in the Absheron-near-Balkhan threshold structure. Shakhdeniz, Bulla deniz, Bakhar, etc., structures situated in the basin deeper area were not yet generated at that period. Later, by the moment when these structures started to generate, the source deposits were already located at the condensate and gas generation zone. Accordingly, the late generation products, predominantly gaseous HCs, were already arriving there (Fig. 2.8). Implementation of the South Caspian hydrocarbon system key elements (petroleum systems) during the basin geological history is illustrated by special annotated diagram with two areas as an example (Fig. 2.9).

For the organic matter of marine origin (type 2), it corresponded to the initial stage of oil generation. In the diagram built for the specified area, there are two basic phases of hydrocarbon generation—the first one is 6 Ma, and the next one is 2 Ma ago. These two generation impulses were the result of submersion, subsequent rise, and repeated submersion. In Bakhar area, there is only one phase of hydrocarbon generation. Here, according to the vitrinite reflectance equivalent, the Late Oligocene sediments are on the same level of organic matter maturation as it was forecast for Pirsaat area (Fig. 2.10).

Abrams and Narimanov (1997) used BasinMod, the basin modeling package, to assess OM maturity degree and temperature in the SCB Oligocene deposits lying at the depths not exposed by drilling. Thus, OM maximal transformation degree in the Upper Oligocene deposits at Pirsaat area, expressed in the vitrinite reflectivity equivalent, is equal to 0.75 %.

For the marine-origin OM (type 2), it corresponds to the primary oil generation stage. The diagram plotted for the area displays two principal stages of HC generation: The first one was 6 million years ago, and the second one was 2 million years ago. These two generation impulses are the consequence of deposit subsidence, subsequent rising, and repeated subsidence. Only one generation stage was noted at Bakhar area. Here, the Upper Oligocene deposits (according to the vitrinite reflectivity equivalent) are at the same OM maturity level that was predicted for Pirsaat.

According to the data of modeling made by Klosterman et al. (1997), vigorous oil generation in the Yevlakh-Agjabedi trough embraced the depths of 4–6 km and started 3 million years ago. Only minor portion of potential source rocks was plunged to the depths requisite for thermal maturity, and consequently, small volumes of oil were generated in the sedimentary thickness.

For qualitative description of contemporary and paleotemperature conditions and the ensuing oil and gas generation features, modeling on separate areas was conducted in the near-Caspian-Guba region. These models were based on permanent and time-dependent thermal flow calculated from the well temperature data, with due consideration for rock geothermal properties. Plotted thermal models were compared with the data on vitrinite reflectivity (R_o). Thus, it was established that oil and gas formation processes in the near-Caspian-Guba region encompass the stratigraphic interval from the Jurassic up to and including the Early Pliocene.

Figure 2.11 gives as an example of the OM transformation dynamics superimposed on deposit submersion history at Yalama area. According to the calculation results, oil generation in the Lower Jurassic deposits reached its peak already at the boundary between the Jurassic and Cretaceous periods (R_o 0.7–1.0 %). The Cretaceous bottoms enter the oil window zone only in the Miocene period.

Analyzing the results of basin modeling in Azerbaijan, we can conclude that oil formation processes here embrace a broad stratigraphic interval (from the Jurassic up to and including the Early Pliocene) and are characterized by spatial variability.

Judging by modeling results, while oil formation process in the SCB central, most plunged marine part, involves mostly the Miocene deposits, then in the dryland, within the Lower Kur Depression, the Paleogene deposits are predominant.

At the same time, in the near-Caspian Guba marginal trough, where these processes were significantly weakened during the Cenozoic age and had superimposed character, and where Mesozoic rocks have shallow occurrence or are even exposed on the surface (at the Greater Caucasus eastern edge northern outskirts), oil-intensive generation interval is, as a rule, confined to the Cretaceous and Jurassic rocks.

It should be noted in conclusion that peculiar features of HC formation and migration resulting from the modeling are of great importance for the understanding of field formation mechanisms, for the assessment of oil- and gas-bearing prospects, and for planning of oil and gas exploration.

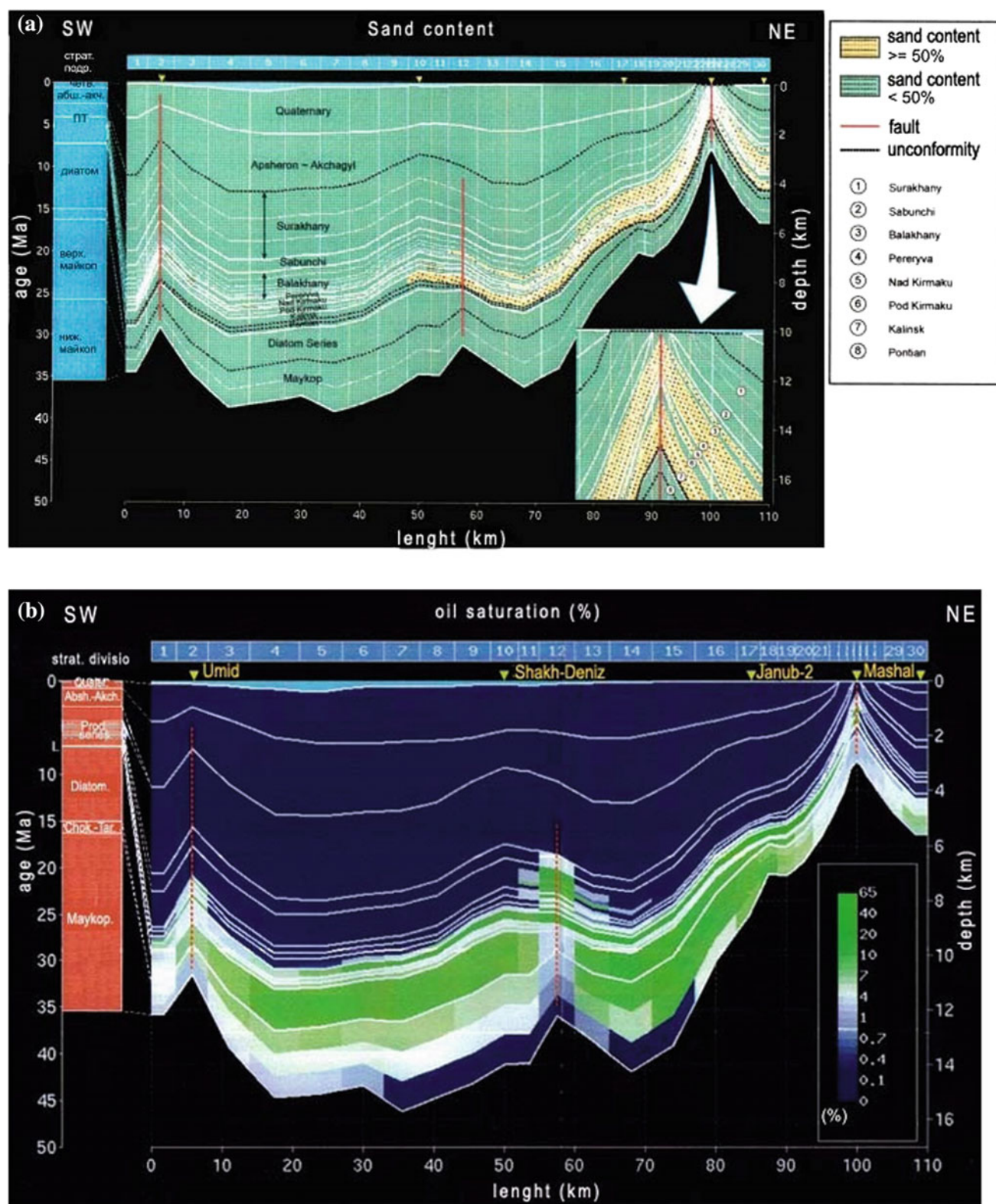


Fig. 2.8 Model of generation, migration, and accumulation of HC, built using the SIGMA-2D software package. In the South Caspian

Basin, the presence, location, and extension of the permeable horizons in the section (a) are the key factors for HC migration and accumulation (b)

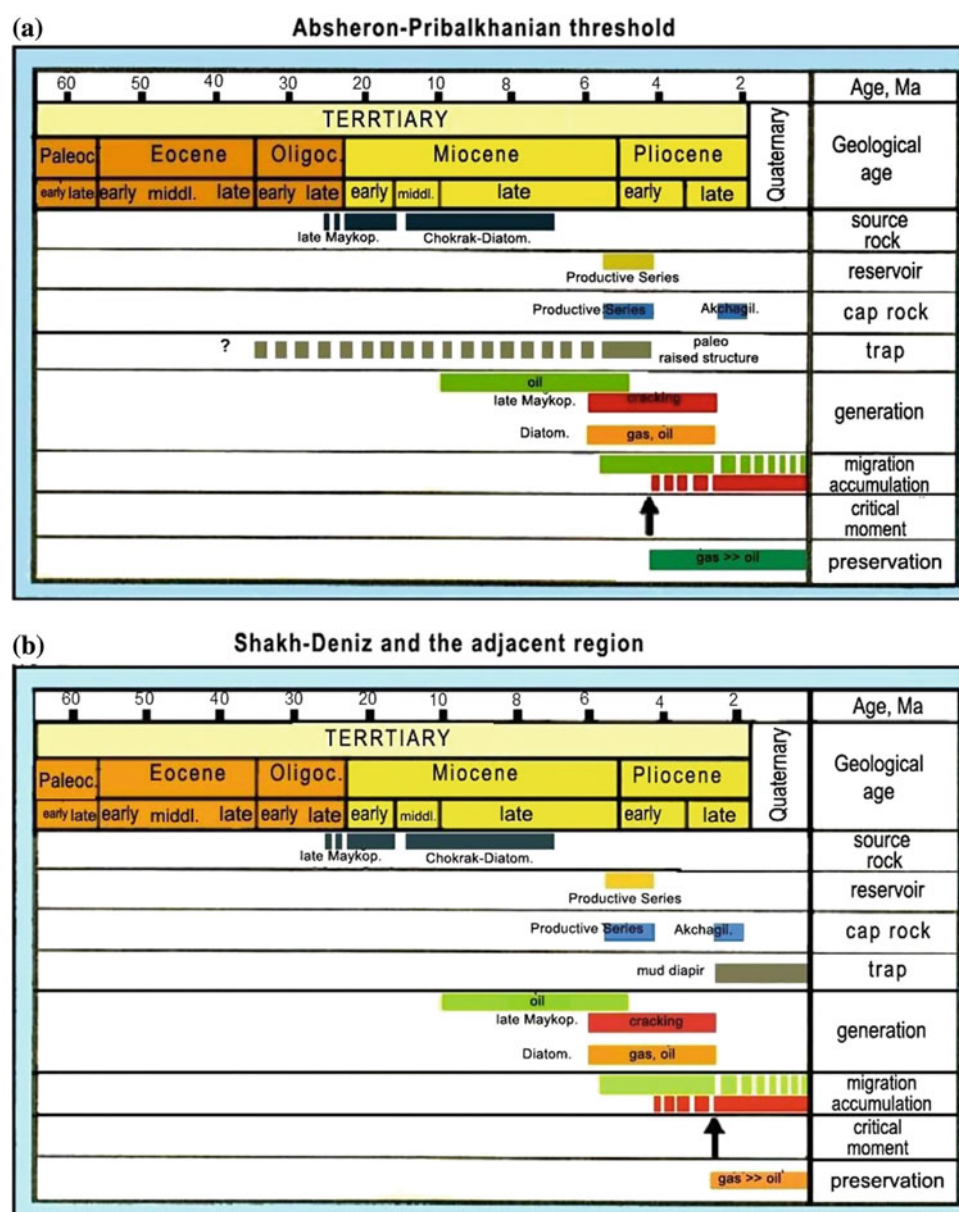


Fig. 2.9 Annotated diagrams of element realization of the South Caspian hydrocarbon system in the course of the basin geological history for **a** Absheron-near-Balkhan threshold and **b** Shakh deniz field

2.1.4 Thermobaric Conditions and Hydrochemical Characteristics of Oil- and Gas-Bearing Complexes

2.1.4.1 Baric Conditions

The SCB is one of the outstanding instances, where extremely favorable conditions for the formation of anomalous high pressures existed due to the peculiarities of development history and contemporary geological structure. Here, avalanche-type (up to 3 km/million years) sedimentation

was observed in the Pliocene–Quaternary period and thick (up to 25 km) sedimentary system was formed, where plastic terrigenous rocks are prevailing. Clay rocks constitute 80–90 % in the SCB Cenozoic section. The SCB is characterized by abnormally low-temperature gradient that varies within 1.5–1.8 °C/100 m in its central, most submersed part. As a result, porous pressures here exceed hydrostatic pressure by 1.5–2.0-fold. Thus, for instance, porous pressure at Zafar-Mashal structure in the SCB deeper area measured at 6475 m depth amounted to 132 MPa, which more than 20-fold exceeds hydrostatic pressure and constitutes about

Fig. 2.10 Rate of hydrocarbon generation (mg oil/g organic matter/Ma) in the Oligocene deposits over the fields: *left panel* Pirsaat and *right panel* Bakhar. Vertically on the *left*, the maturity scale by vitrinite reflectance (% Ro)

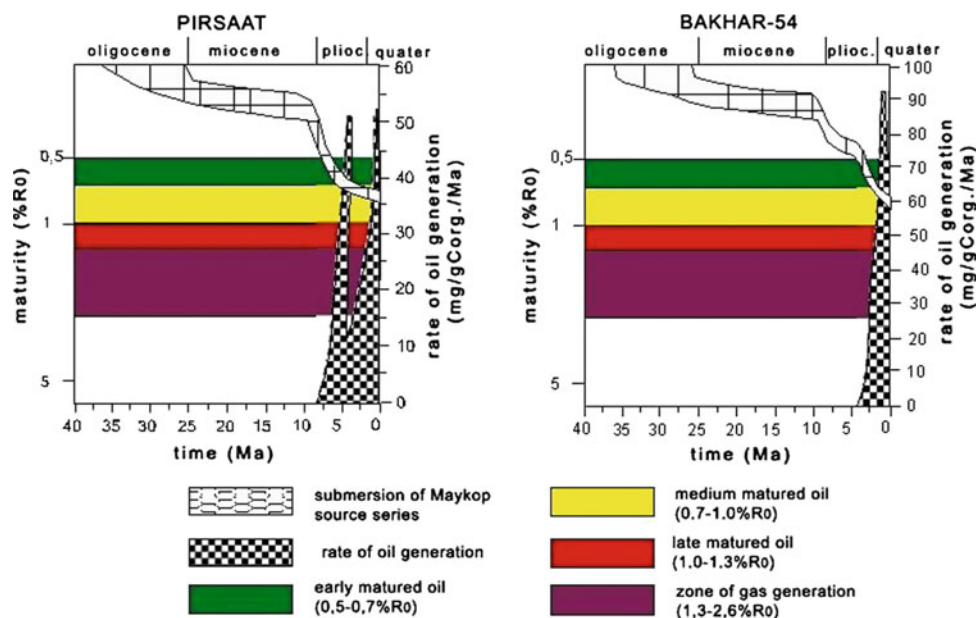
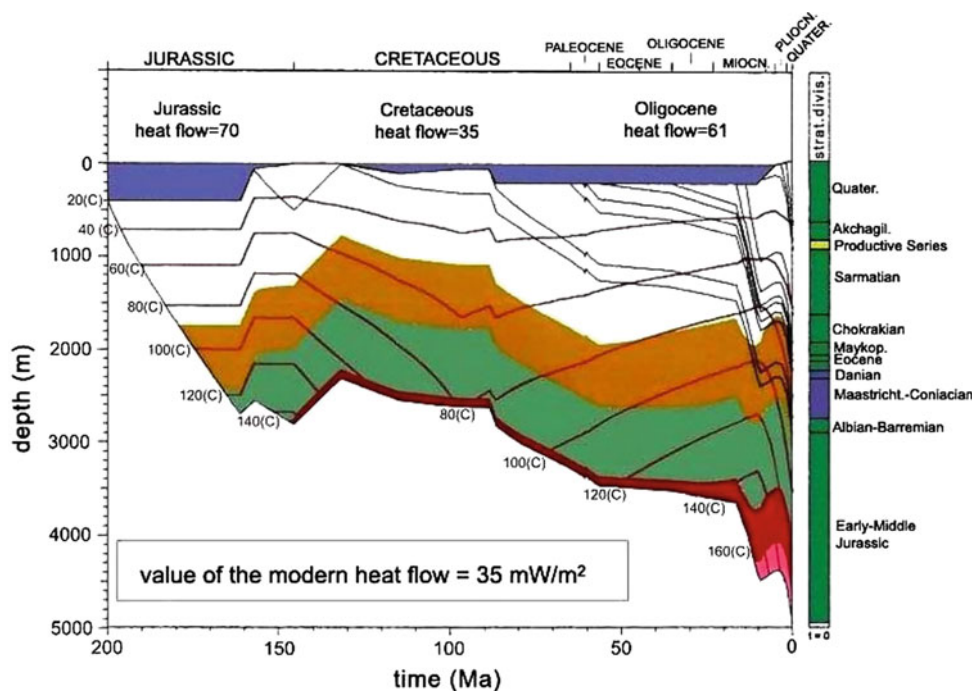
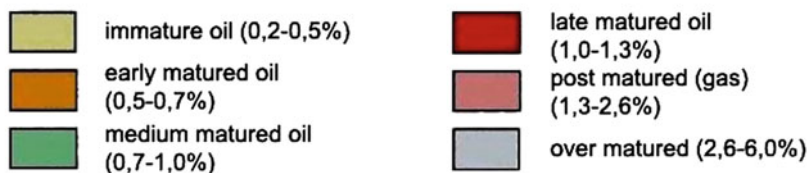


Fig. 2.11 Thermal transformation of organic matter versus submersion of sediments in Yalama area of the near-Caspian-Guba region



STAGES OF THE THERMAL MATURITY OF ORGANIC MATTER
(limits are in % of the vitrinite reflectance)



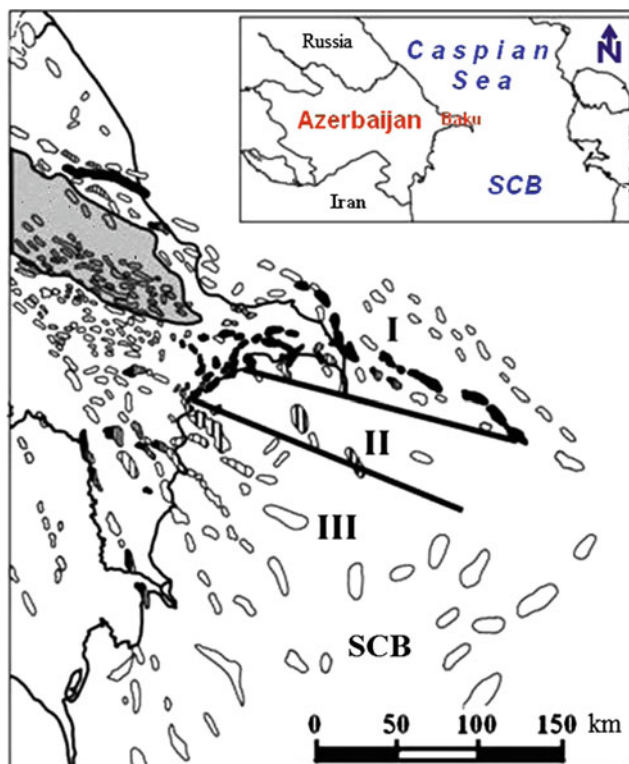


Fig. 2.12 Zoning of formation pressure distributions in the SCB: I Absheron Peninsula and Absheron archipelago; II South Absheron water area; III Baku archipelago

Table 2.18 The SCB: spatial changes in clay mass thicknesses and pressure gradients

Zones	Average values of clay mass thicknesses at various depth intervals, km				Average values of pressure gradients, MPa/km
	1–2	2–3	3–4	4–5	
I—Absheron Peninsula and Absheron archipelago	50	40	30	20	13.5
II—South Absheron water area	750	235	185	150	16.3
III—Baku archipelago	900	725	460	350	18.0

90 % of lithostatic pressure. It is, therefore, not accidental that the SCB structures are as a rule of diapir nature and that mud volcanism is widely developed here.

Analysis of the data on formation pressures and their gradients in the SCB permitted to reveal their inhomogeneous spatial variation. Their intensity grows southward and southwestward in clear-cut correlation with the changes in

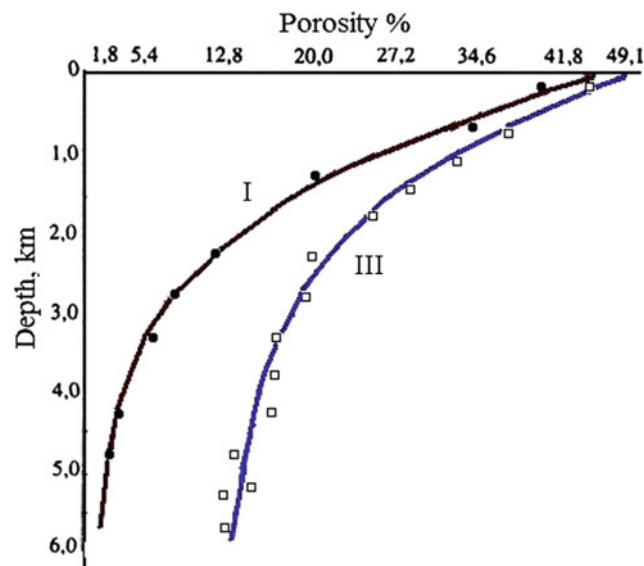


Fig. 2.13 Rock porosity changes with depth in the SCB OGF: Absheron archipelago (zone I in Fig. 2.12) and Baku archipelago (zone III in Fig. 2.12)

rock clay content and in clay mass thicknesses in the same direction (Buryakovsky et al. 1986) (Fig. 2.12; Table 2.18).

The highest geofluid pressures are found within the Baku archipelago (zone III), where pressure gradient average value is 18.0 MPa/km (see Table 2.18). It is reflected in the process of rock compaction. The anomalous high pressures decelerate the process of rock compaction within the Baku archipelago that is vividly seen from the manner of rock porosity changes with depth in the Baku archipelago, as compared to the Absheron archipelago with its relatively moderate geofluid pressures (pressure gradient average value is close to 13.5 MPa/km) (Fig. 2.13).

Investigations of changes in clay porous pressure gradients with depth conducted at Bulla deniz area and calculated from log information and from drilling fluid-specific weight established that independently of drill-hole sites at the structure, upper limit of anomalous pressures is confined to the depth interval of 600–1230 m. Stratigraphically, it embraces the bottoms of Pliocene deposits (ancient Caspian and Absheron), Akchagyl (the Pliocene tops), and, in some boreholes, the PS roof areas (PS, the Lower Pliocene) (Yusufzade et al. 1976; Khalilov and Imanov 1980). In said interval, porous pressure gradients reach 23 MPa/km.

The second jump in changes through the section vertically in the SCB was found below 5 km depths (Khalilov and Imanov 1980; Buryakovsky et al. 1986) (Fig. 2.14). It is the most contrasting zone, where the abnormally high reservoir pressure (AHRP) values become comparable with geostatic pressure.

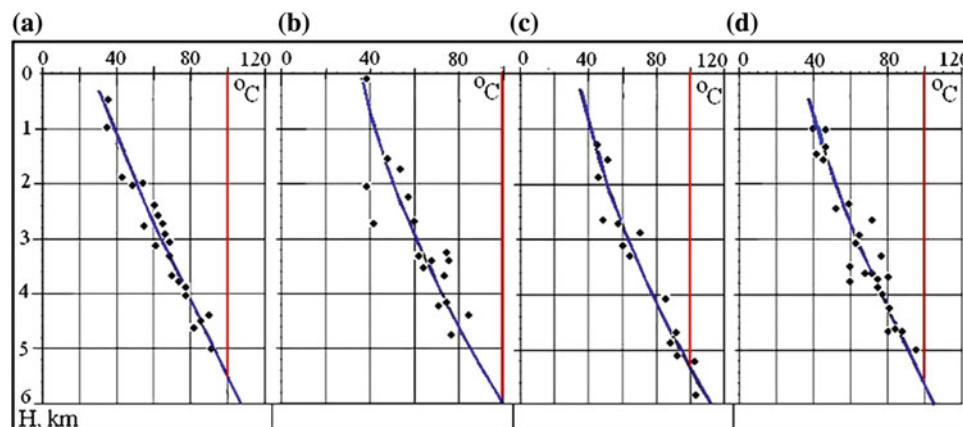


Fig. 2.16 Changes in reservoir temperatures with depth at some SCB marine sites: **a** Aran-deniz; **b** Hamamdagh-deniz; **c** Karasu; **d** Sengi-Mughan

Above 10,000 measurements were taken in more than 150-m-deep nonoperating wells within 100–6000 m depth range in Azerbaijan oil and gas fields (OGF). Geothermal parameters were determined for more than 3000 rock samples from the Azerbaijan and Western Turkmenistan Meso-Cenozoic complexes.

Typical feature of the thermal conditions of the SCB is low warming of the Pliocene–Anthropogenic deposits. Their temperature at 5000 m depth does not exceed 100 °C in marginal zones, which is explained both by high sedimentation rate and by significant depth of occurrence of crystalline foundation (Fig. 2.16).

Decreased thermal behavior of the trough Pliocene and Anthropogenic deposits is to a great degree also determined by lithological composition of the underlying Paleogene–Miocene rocks, a thick 3–5-km clay strata with reduced thermal conductivity.

Conductive and convective components of abyssal thermal flow play important role in the formation of local elevation temperature fields. It is witnessed by 3–7 °C elevated (and more) temperature values at the same hypsometric marks in the area of mud volcano and tectonic dislocations that contribute to the transfer of formation fluids and heat from the Earth crust abyssal zones. Thus, at Balakhan-Sabunchi-Ramany, Lokbatan, Zykh, and Gum Island fields, in the area of mud volcanoes, temperature is 3–5 °C higher than that in alternative parts of the structure. Positive temperature anomaly within the Neft Dashlary, Pirallakhi Island, and other fields is associated with the area of large rupture dislocations that intersect the fold.

Thermal activity of structures that do not contain oil and gas deposits is essentially lower than that of the productive ones. Thermal activity of structures holding gas and gas condensate accumulations (Garadagh, Ziryam Janub, Galmaz, etc.) is much lower than that of the oil-saturated structures.

Generalization and temperature analysis testify to significant differences in geothermal conditions of separate OGFs. Below, a brief description of geothermal conditions in separate Azerbaijan OGFs is given.

The Absheron OGF. Twenty-three structures of 3 anticlinal zones were included into geothermal research. Within the region, the temperature field was found with background values at 3000- and 4000-m sections equal to 74 and 88 °C, respectively. Thermal flow values vary within broad limits, from 20 to 90 mW/m².

The Lower Kur OGF. Ten structures in 2 anticlinal zones have been studied. The plotted map of temperature cross sections for 3000 and 4000 m depths has background temperature of 64.5 and 76.4 °C, respectively. The region is characterized by thermal flow values of about 20–50 mW/m².

The Baku archipelago region. The research included 15 structures of 3 anticlinal zones. Within the archipelago, background temperature value at 3000- and 4000-m-deep sections was equal to 62.6 and 75.4 °C, respectively. Average thermal flow value for the region is 30–50 mW/m².

The Shamakhy-Gobustan OGF relates to the geothermally poorly studied regions. It is characterized by small amount of temperature, thermal conductivity, and, correspondingly, thermal flow measurements. The region larger part is characterized by thermal flow values within 70–90 mW/m² with its southeastward decrease.

The Yevlakh-Agjabedi OGF. Geothermal research included 8 structures that served as the basis for cross-sectional maps of 3000 and 4000 m depths, where background values equaled 75 and 95 °C, respectively. Thermal flow values vary within 20–50 mW/m².

The Ganja OGF. Eight structures were investigated, and their section background values for 3000 and 4000 m depths are 99.5 and 129 °C, respectively.

The Mil-Mughan promising OGF. The research encompassed three structures. In two Orta-Mughan wells, the

investigated depth reached 4910 m, with a depth temperature of 95 °C. At Novogolovka area, at 4910 m depth, temperature was equal to 39.8 °C. At Shorsulu area, at 4500 m depth, temperature was 89 °C.

The Nakhchivan potentially promising OGF. It is one of the poorly investigated regions. The studies were conducted at two prospect wells. At 3500 m depth, temperature was 98 °C. Thermal flow density was about 20 mW/m².

2.1.5 Oil- and Gas-Bearing Capacity of Azerbaijan Sedimentary Sequences

Commercial development of Azerbaijan onshore and offshore areas includes 65 oil and gas fields, where above 405 producing horizons were found, including 45 fields and 320 horizons onshore and 20 fields and 85 horizons offshore. Above 30,000 wells were drilled onshore, and 5000 wells were drilled offshore so that operating well stock preserved about 8200 and 1500 wells, respectively, with average oil yield of 0.9 and 1.4 t/day, respectively.

The largest of onshore developed fields is Balakhan-Sabunchi-Ramany one that is situated in the Absheron Peninsula central part, within the Fatmai-Bakhar tectonic belt. But this field is the mature production field. At present, the largest field is the offshore Gyuneshli-Chirag-Azeri field confined to a large mega structure within the Absheron-near-Balkhan threshold (field map).

The Mesozoic, Paleogene–Miocene, and Pliocene deposit systems are regionally oil- and gas-bearing within Azerbaijan boundaries. Oil- and gas-bearing capacity of these systems varies considerably, both as a function of paleogeographic accumulation conditions in their separate stratigraphic units and as a function of regional tectonic process directions. Study of paleotectonic and paleogeographic factors shows that organic matter accumulation and burial took place in more intensively sinked basin parts at a definite geological period.

The Aalenian and the Bajocian oil- and gas-bearing suites are prominent in the sequence of the near-Caspian-Guba OGF *Middle Jurassic deposits*. Surface indications of oil and gas presence, associated with the Aalenian stage deposits, are noted at Afurja, Ugakh, Atachay, and Keshchay areas. In addition, moderate light oil inflows were obtained by testing sandy–aleurolite interlayers in stratigraphic test wells of Afurja area. At Keshchay area, gas flow to surface was produced by testing a sandy horizon, with initial yield of about 75,000 m³/day and with small condensate volume.

In the *Cretaceous deposits*, first commercial gas flow of up to 67.9 thou. m³/day and oil of 19 m³/day was produced from the Valanginian rocks in well 3, drilled at the crestal position of SE pericline of Tekchay anticline. In said fold

area, the Valanginian deposits were also commercially oil-bearing in wells 20, 21.

In the Siazan monocline region, oil flows of 3–4 to 20–30 t/day were produced from the Upper Cretaceous deposits.

Oil and gas content of the Lower Cretaceous system within the *Shamakhy-Gobustan OGF* is associated with the Barremian, Aptian, and Albian stage deposits. Natural oil and gas indications, such as moderate outflow of thick black oil near Astrakhanka village, as well as intense gas and light oil discharge from the Barremian stage clastic rocks that was observed at Novo-Astrakhanka area, might witness the favorable conditions for oil and gas accumulation in said regions (Akhmedov 1957).

An oil pool is being developed at the Yevlakh-Agjabedi depression northeastern margin, in the Muradkhanly elevation crestal part. It is confined to the weathering crust and is represented by andesites and porphyrites.

There are specific data on oil-bearing content of the *Paleocene* deposits. For instance, at Zagly area, well 665 on the Paleocene deposit Sumgayit suite was put into operation with yield of up to 30 t/day, and well flowed at a primary rate of 70–80 t/day of clean oil. Intense oil and gas shows from the *Eocene* deposits were observed at all Siazan monocline areas. Testing of a number of prospect wells gave oil yield from 8.0 to 40 t/day. During joint operation of the Eocene and Upper Cretaceous deposits, yields of some wells rose by 5–10 t/day (Salayev et al. 1964).

Oil and gas shows were observed by drilling and testing of the Eocene deposits in Ganja region, at Dalmamedly, Gazanbulagh, Gyzylgajali, Naftalan, Sovetlyar, and Beilagan areas. At Dalmamedly area, by testing from the Eocene sequence middle part, light oil with primary yield of up to 5–7 t/day was produced. The III Gazanbulagh oil-bearing horizon is prominent at Gazanbulagh area, in the Eocene deposit upper part. Primary oil yields of individual wells of this horizon were rather high, but they rapidly dropped to 0.2–0.5 t/day. At Ter-Ter area, testing of well 153 gave well flow of up to 0.5 t/day. At Beilagan area, testing of well 22 produced oil with primary yield of up to 18 m³/day, and well 20 produced a short-term oil and water free flow from the Eocene deposits (Alizadeh et al. 1966).

At the Yevlakh-Agjabedi trough northeastern margin, the HC pools are found in the Eocene deposits at Muradkhanly and Jafarly areas. Here, in the Eocene sequence, the Middle Eocene loamy–tuffaceous unit is the major oil-bearing facility.

At Zardab area, use of drill stem tester for well 3 gave 350–400 t/day oil yield from the Eocene deposits. The Middle Eocene deposits are also oil-bearing at Amirakh area, where use of drill stem tester on well 2 yielded commercial oil inflow (up to 20 t/day).

The Oligocene–Miocene subcomplex is widely developed within Azerbaijan oil- and gas-bearing regions and consists

of the deposits of Maykop suite, Chokrak, Kong-Karagan horizons, the Sarmatian, and Meotian stages. The *Maykop suite* deposits are noted for the highest oil-bearing capacity. The suite is commercially oil-bearing within Siazan monocline, western Absheron, southwestern Gobustan, and northeastern part of the Lesser Caucasus piedmont. In all these regions, Maykop deposits are represented by argillo-arenaceous lithofacies, and their oil-bearing capacity is in most cases associated with the Lower Maykop sandy horizons. The Upper Maykop deposits turned out to be oil-bearing at the southwestern Gobustan and western Absheron areas.

The Maykop Suite is the principal oil- and gas-bearing facility of Siazan monocline. Commercial agglomerations are mainly related to the section lower sandy part. Primary yields of some wells amounted to 30–50 t/day. The Upper Maykop sandy horizons rank much below the Lower Maykop ones.

At western Absheron area, the Upper Maykop deposits are oil-bearing at Gezdek, Garaeibat, Damlamaja, Shorbulag, etc., areas where quite thick (5–15 m) layers of sands, sandstone, and aleurolites are found in the sequence.

In southwestern Gobustan, sandy-aleurolite deposits of the Upper Maykop and Chokrak horizons are oil- and gas-bearing at Nardaran-Akhtarma, Umbaki, and Ajuveli areas, and besides said area, the Upper Maykop deposits are also oil- and gas-bearing at Sheitanud, Donguzdyk, Kaf-taran, and Arzani areas, while Chokrak horizon bears oil and gas at Gyrkishlak and Cheildagh areas.

Commercial oil- and gas-bearing capacity is established for the III, IV, and V horizons in the Upper Maykop sequence, at the Umbaki anticline northeastern overthrust margin, where the III horizon, brought into development in 1951, is the most oil-saturated one. The Maykop suite III horizon is gas bearing in one of the northern margin tectonic blocks. Here, prospect well 23 showed gas spouter with primary yield of 500 thou. m³/day with 10-mm choke.

At Eastern Ajiveli area, two prospect wells drilled at the fold northern margin, yielded by testing of the Maykop III horizon commercial oil flows of up to 15 t/day, and testing of the Chokrak horizon sandy layers gave heavy oil inflow of up to 5–7 t/day.

At Cheildagh area, commercial oil content of Maykop suite and Chokrak horizon was supported by drilling of separate wells. Commercial oil content of the Upper Maykop sandy-aleurolite horizons was revealed by drilling at Donguzdyk area, where one of the wells gave light oil inflow of up to 35 t/day.

The Maykop suite and Sarmatian stage deposits are prominent for their regional oil content in the Kur-Gabyrry interfluvial and in the Ganja OGF.

In Ganja OGF, a series of minor commercial oil pools confined to Gazanbulagh, Dalmamedli, Naftalan, Ter-Ter,

and Ajidere areas was found in the Maykop deposit sequence. Powerful oil and gas shows were noted by stripping of the Chokrak horizon at Duzdagh area and of the Sarmatian stage at Duzdagh and Barda areas.

At Naftalan area, prospect drilling revealed a number of oil-bearing horizons in the Maykop deposit sequence. Three horizons (I, the loamy, and II) contain remedial oil of 0.945–0.948 g/cm³ density. Underlying, thicker sandy horizons IV, V, and VI contain commercial oil pools of 0.860–0.900 g/cm³ density, but because of low permeability, relatively high initial well productions (40–60 t/day) within several days dropped down to 3–5 t/day.

Commercial oil flows from the Maykop suite bottom were obtained in well 21 at Zardab area and in well 28 at Shikhsbagi area. Oil yield was 20 and 5 t/day of water in the first well, while the second one yielded 18 t/day of oil.

In the Talysh submountain region northeastern part, at Tumarkhanly area, two prospect well showed by drilling brief oil and gas kicks when the Chokrak horizon and Upper Maykop deposits were exposed.

The Chokrak Horizon is the second oil- and gas-bearing facility of the Oligocene–Miocene subcomplex. This horizon is being developed at Saadan area, where the first well was put into operation with 16 t/day yield. Further, the Chokrak horizon was tested at Amirkhanly area, where in some wells daily oil flow amounted to 10–15 t.

At Umbaki area, a pool of heavy oil that is run by separate wells in the fold western part is associated with the Chokrak deposits (Salayev 1961).

At Muradkhanly field, drill stem tester in well 27, drilled in fold crestal position, produced oil of up to 42 m³/day, and well 18 gave commercial oil flow of up to 110 m³/day produced from the Chokrak deposits.

The Karagan-Konk strata and the Sarmatian deposits within Siazan monocline were not targeted for prospecting works. These deposits were tested concurrently in a number of wells at Saadan, Siazan-Nardaran, and Zeiva areas. In many cases, minor oil flows were produced.

The Sarmatian deposits bear oil at Talabi area. Testing of well 12 at 4461 m depth gave oil flow yield of about 40 m³/day from the Sarmatian deposits.

Surface oil and gas shows occur in the Kur-Gabyrry interfluvial as fluid oil and free gas seeps, kir covers, oil-saturated sandstone and oily spots in rock fractures. Here, at Alachyg anticline northern edge, well 72/1 yielded 1.6 t/day of oil by testing the Middle Sarmatian age.

Deposits of the **Pliocene** oil- and gas-bearing complex are widely distributed in all depression zones of Azerbaijan. However, oil and gas content of this complex varies to a considerable extent as a function of its lithofacial composition.

Within the near-Caspian-Guba region and the Middle Kur Depression, the **Lower Pliocene (PS)** deposits are

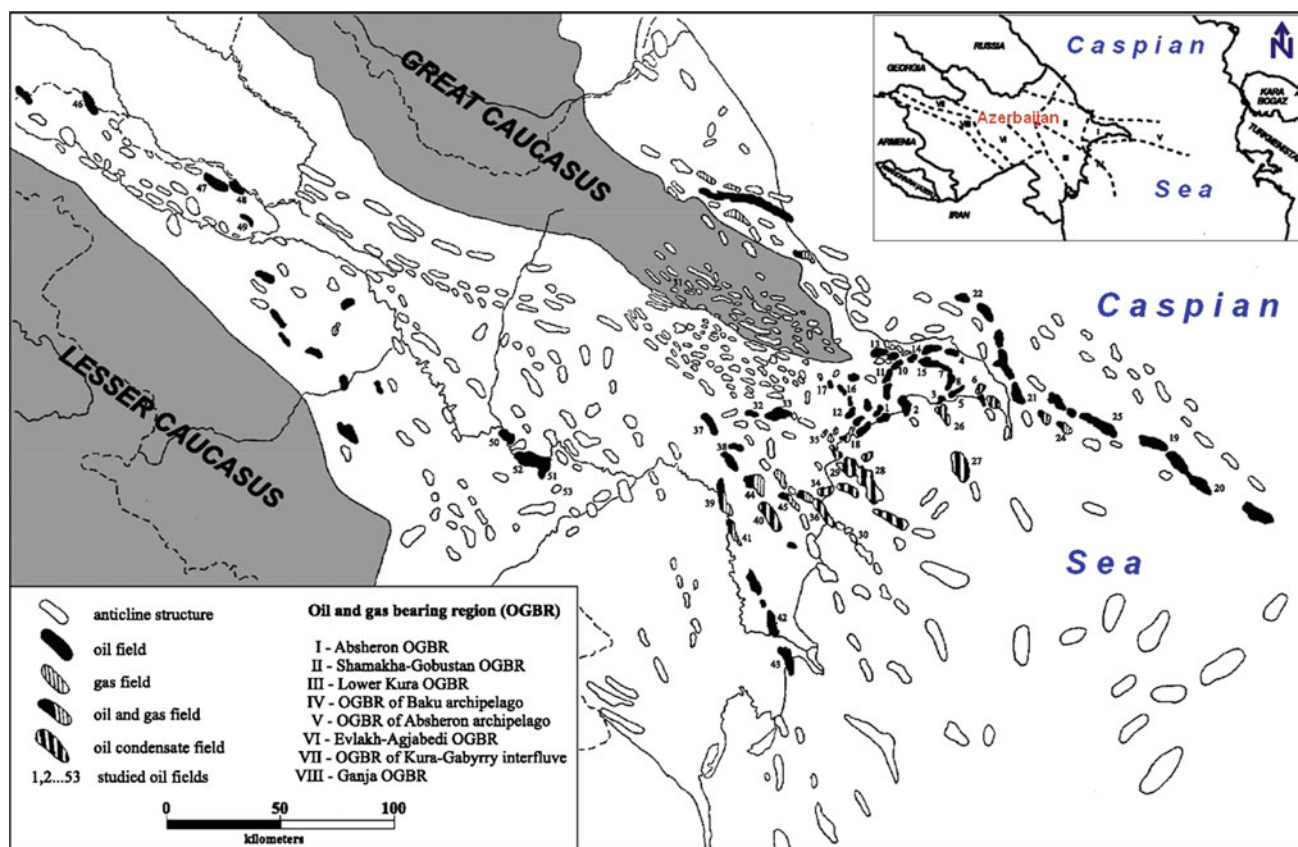


Fig. 2.17 Spacing array of oil and gas fields and potential structures in Azerbaijan

represented by coarse detrital facies and devoid of oil and gas signs. The PS principal oil- and gas-bearing facies are the Absheron and the near-Kur facies that have extensive areal development at the Absheron Peninsula, in Absheron archipelago, and in the Lower Kur Depression.

Within the Absheron oil- and gas-bearing region, oil and gas pools are non-uniformly distributed through the PS section. Maximal oil saturation of the PS section is found in the Absheron Peninsula central part (Balakhan, Surakhan, Bibi-Heybat), where the amount of productive horizons reaches 40 (Azizbekov et al. 1972, 1976; Mamedov et al. 2008).

Stratigraphically, the lower division suites, the Sabunchi suite, and the Balakhan suite upper part are the most oil- and gas-saturated suites of the Absheron Peninsula. The Balakhan suite lower horizons are mostly saturated by oil and gas at the southwestern Absheron fields (Bibi-Heybat, Lokbatan, Puta) and at marine areas (Gum Island, Bakhar, Neft Dashlary).

In the Absheron Peninsula northeastern part, at Shabandagh, and Atashkya fields, where the PS upper part is eroded, the upper division suites do not contain oil and gas pools.

Areal distribution of oil and gas pools is controlled by rock lithological composition and by structural and tectonic conditions. As clay content increases from east to west, dramatic drop in oil saturation of PS sequence takes place. Amount of gas-saturated formations increases with formation regional subsidence from north and northwest to southeast, and oil and gas pools are frequently replaced by predominantly gas condensate pools (Garadag, Zire, Janub-2, Bakhar, Shakh deniz).

Structurally and tectonically, the Absheron region oil and gas pools are confined to anticline highs that are grouped in seven large anticline belts. These anticline belts serve as oil and gas accumulation zones, and above 50 independent highs are found within their boundaries. About 30 anticline highs contain HC deposits that are being developed (Fig. 2.17).

The northern Absheron zone of oil and gas accumulation includes Khazri, Arzu, Dan Ulduzu, Garabagh, and Ashrafi large low-angle folds and a series of southwest-adjacent small anticline folds of Gilavar, Sevinj, Novkhany-deniz, and Gyanjlik. Commercial oil and gas condensate flows are found in the zone SE part at Ashrafi and Garabagh areas. The supra-Kirman sandy (SKS) and sub-Kirman (SK) suites

were productive at both areas. Prospect well 1 at Ashrafi area produced 640 thou. m³/day of gas and 70 m³/day of condensate from SK suite, with 20.6-mm choke. The SKS suite revealed oil and gas pool. Oil yield amounted up to 556 t/day and gas yield, to 27 thou. m³/day.

Two prospect wells, drilled at Garabagh area, gave oil flows from SK and SKS suites as 846 and 700 thou. m³/day, with 16-mm choke, respectively, and gas condensate yield as 24.6 and 83 m³/day, respectively. The third well permitted to produce up to 300 t/day of gas from SKS suite, while the SK suite tops were gas-bearing ones (Jafarov et al. 2003).

The near-Absheron zone of oil and gas accumulation consists of brachyanticlinal folds: Gosha dash, Agburundeniz, Absheron uplift, Darwin uplift, Pirallakhi Island, Gyurgan-deniz, and Janub. Oil and gas pools are found only in four latter folds. Within the Absheron area, commercial gas blowout was produced in well 4 by testing of the PS bottoms. Testing results of wells 11 and 21 in PS northeastern edge established the presence of commercial oil pool.

The Absheron-near-Balkhan zone of oil and gas saturation (the Absheron threshold subzone) represents a large stripe of anticlinal highs, also includes the Azerbaijan sector structures: Chilov Island, Palchyg Pilpilesi, Khali-Neft Dashlary, Oguz, Gyuneshli, Chirag, Azeri, and Kyapaz.

Neft Dashlary field holds a specific place among these oil and gas deposits because here all PS suites are oil- and gas-bearing. Up to 28 independent process facilities are distinguished in the most oil-saturated part of this oil field. Northwestward of Neft Dashlary, within Palchyg Pilpilesi and Chilov Island fields, commercial pools are found only in Kalin, sub-Kirmakin, and Kirmakin suites (Alizadeh et al. 1966).

Large Gyuneshli, Chirag, Azeri, and Kyapaz fields are located southeastward of the Neft Dashlary field.

Gyuneshli field is confined to a brachyanticlinal fold complicated by a series of transversal and longitudinal dislocations and by a buried mud volcano. Here, the principal oil-bearing facilities are the Balakhan suite X horizon and Pereriv ("Fasila") formation (Akperov and Kasymov 2003).

Chirag field and Gyuneshli field are confined to a brachyanticlinal fold complicated by a series of transversal and longitudinal dislocations. At this field, the Balakhan suite VI, VII, VIII, and X horizons, and Pereriv ("Fasila") formation are oil-bearing, whereas the Balakhan suite IV and V horizons in SKS and SK contain gas and condensate pools.

At Azeri field, the Balakhan suite VI and VIII horizons contain gas and condensate pools, while the suite IX and X horizons and Pereriv ("Fasila") formation contain oil pools that are being developed.

Kyapaz field is confined to a brachyanticlinal fold, and oil and gas pools were revealed in the Balakhan suite VI horizon and in Pereriv ("Fasila") formation.

The Buzovny-Zire oil and gas accumulation zone, located in the Absheron Peninsula eastern part, is found within the eastern Absheron depression. This subzone embraces Buzovny-Mashtagi, Kalin, and Ziry fields.

The largest oil and gas accumulation zone is situated in the Absheron Peninsula central part and stretches from the Absheron Peninsula northern seashore, continuing southward to the Caspian Sea. Here, Balakhan-Sabunchi-Ramany, Surakhan, Garachukhur-Zykh, Gum Island, Bakhar, and Shakh deniz fields are arranged. Said oil and gas condensate fields are confined to large anticlinal folds.

Within the Balakhan-Sabunchi-Ramany field, all sandy horizons, despite exposure of the PS suites, were commercially oil-bearing. The PS section revealed 28 oil-bearing horizons here: Ten of them are confined to the lower division suites and 18, to the upper division suites.

Within the Surakhan field, oil- and gas-bearing capacity scope measurably expands and here, overall amount of oil- and gas-bearing facilities becomes 56. Oil-bearing capacity scope narrows at the Garachukhur-Zykh field.

At Gum Island field, commercial oil and gas content starts from the Balakhan suite V horizon and continues to X horizon, inclusively. Pereriv ("Fasila") formation and other suites of the lower division are oil- and gas-bearing as well, to PS inclusively. Nearly all pools of the PS lower division have gas caps.

Binagady-Sulutepe-Shubany zone of oil and gas accumulation is the Absheron Peninsula most elevated tectonic zone. Here, PS deposits are eroded nearly to the Kirman suite, inclusively. Oil and gas pools are essentially confined to the SK and SKS, which thin out at the fold winged sections facing the Baku trough. Up to 9 development facilities are found in SK section within Binagady and Sulutepe fields.

The Bibi-Heybat oil field is confined to a separate brachyanticlinal fold situated southeast of Shubany anticline. Here, commercial oil and gas pools are found in all PS suites.

In Lokbatan-Kergez-Gyzyltepe-Shongar zone, PS is eroded to upper division bottoms. Oil and gas pools are found in latitudinally oriented highs of Lokbatan, Puta, Gushkhana, Shongar, and the northeast—in Kergez-Gyzyltepe and Saryncha-Gyulbakht highs (Alizadeh et al. 1966). The Garadagh high of basically latitudinal course is adjoined to this zone in Kergez-Gyzyltepe high area.

In this oil and gas accumulation area, the largest oil and gas condensate pools are confined to the VII horizon (an analog of the Absheron Peninsula Pereriv ("Fasila") formation) and to the Balakhan suite V and VI horizons. The Gara-Heybat field is situated in the Gyuzdek trough northern marginal part.

The Pliocene oil- and gas-bearing complex is also broadly developed within the Jeirankechmez depression of Shamakhy-Gobustan region that deepens and widens toward

the SCB. Basing on PS deposits, the following sedimentation zones Anart-Shikhigaya-Donguzdyk, Toragay-Kyanizadag-Sangachaldeniz, Khara-Zire Island, the Alyat Range, and Pirsat-Sangi-Mughan-Dashly are prominent within this depression and at its marine extension.

At Anart area, up to nine sandy horizons were selected in the section exposed part, and in three of them, commercial gas production was obtained with 50–75 thou. m³/day yields. At Shikhigaya area, by testing of wells 5, 16 and 18, gas production of 7, 50 and 40 thou. m³/day was obtained, correspondingly. At Kaftaran, Gargabazar, and Donuzduk areas, intense oil shows were noted by drilling of stratigraphic test wells.

Utalgi-Kyanizadag-Sangachal-deniz-Khara-Zire Island zone is the most elevated and extended oil and gas accumulation subzone in Jeirankechmez zone and Baku archipelago. Crest parts of this subzone structure show 800–900 m washout in the PS section upper part. Large oil and gas fields are found here: Kyanizadag, Sangachal-deniz-Duvanny-deniz-Khara-Zire. The PS horizon VII is the most essential oil- and gas-bearing facility. At the Kyanizadag area, oil yields of some wells amounted to 120–130 t per day. Large oil and gas pools with gas cap are under development within Sangachal-deniz, Duvanny-deniz, and Khara-Zire areas. At Khara-Zire area, large gas condensate and oil pools are being developed in the PS horizons V and VII. Separate wells of horizon V yielded 100 t of condensate and 500–800 thou. m³/day of gas, and condensate flow from horizon VII amounted to 400–450 t and to 1.5 million m³/day of gas (Suleimanov and Mekhtiyev 2003).

Commercial oil and gas content of horizon VIII, the analog of the Absheron Peninsula NKP suite, was established for more plunged area of the Duvanny-deniz fold northeastern edge, where gas spouter with condensate was obtained. This horizon contains large gas condensate pools. The pools are noteworthy for their height and high coefficients of trap filling. Well initial daily yields were 100–200 t/day of oil, 500–700 thou. m³/day of gas and up to 100–130 t/day of condensate.

Commercial oil and gas content in horizon V of the Duvanny-deniz fold northeastern edge was exposed by wells 35 and 361, where 300 t/day of oil and 0.5 million m³/day of gas were produced, respectively. The sub-Kirmakin suite in most prospect wells is water-bearing. Positive result of up to 200 thou. m³/day of gas was obtained for well 99.

Within the Bulla deniz fold northeastern edge, prospecting and exploratory drilling revealed the presence of gas condensate pools in the PS V, VII, and VIII horizons. Power gas (above 1.0 million m³ per day) with condensate (up to 350 t/day) spouter was obtained in well 18 by testing of VII horizon. Initial well yields in the V horizon amounted to 200–450 thou. m³/day of gas and 70–200 t/day of

condensate and in the VII horizon, to 1.8 million m³/day of gas with oil and condensate mixture of up to 300 t/day.

Southwest of Kyanizadag, the Duvanny field is located, where the largest gas and condensate reserves are confined to the VII horizon.

The Alyat Range oil and gas accumulation zone is situated between the Shamakhy-Gobustan and the Lower Kur OGFs. The following anticlinal folds are confined to this oil and gas accumulation subzone: Dashmardan, Shokikhan, Durandagh-Baridash, Solakhai, Airantekyan, Goturdagh, Dashgil, and Alyat-deniz. Rather intense oil and gas shows (sometimes of commercial importance) were found by drilling and testing in a number of wells at the PS sandy layers in the Dashgil, Airantekyan, Solakhai, Goturdagh, and Dashmardan structures.

Commercial oil and gas accumulations were found in the central tectonic block and in the Dashgil fold northern edge, where the PS VII horizon produced oil yield of 75–100 t/day, and testing of the V horizon of the same area gave 25–30 t/day of oil and 100 thou. m³/day of gas.

At Alyat-deniz area, commercial oil pools of the PS horizon VII are confined to SE of the fold periclinal part, which is separated by transversal ruptures in crestal position. Here, the horizon VII pool is under development, and yields of separate wells vary from 20 to 320 t/day.

Intense oil and gas shows, often of commercial importance, were found during drilling and testing of nearly all prospect wells of the large Solakhai structure northeastern edge. Here, four sand levels (I, II, III, and IV, according to local Solakhai marking) were distinguished from lower unexposed part of the PS sequence, so that three of them are oil-bearing, and some of this level wells yielded 5–7 t/day of oil. Multiple oil and gas shows in various Alyat range areas are associated with mud volcano gryphons and salsas.

The Lower Kur oil and gas accumulation zone is one of the prime oil- and gas-bearing regions of Azerbaijan. In the Lower Kur oil- and gas-bearing region, the PS deposits and partly the Akchagyl and Absheron stage deposits bear oil and gas. Twenty sand levels are delineated from the PS upper division section at Kyurovdagh area. Here, reference horizon XX of upper division is represented by conglomerates and is the age equivalent of the western Absheron VII horizon (by the Karadagh marking) and of the central and eastern Absheron Pereriv (“Fasila”) formation.

The anticlinal zones are recognized in the Lower Kur Depression and extend further to the Baku archipelago, producing unified oil and gas accumulation zones. Specifically, such zones as Pirsat-Hamamdagh are recognized that continues within the Baku archipelago to Dashly and Sabail structure. Here, the I Pirsat, the II, and III sub-Pirsat suites and the “Fasila” formation are oil- and gas-bearing. Individual wells yield up to 70 m³/day of oil and 250 thou. m³/day of gas.

Southeast of Pirsaat, within the Baku archipelago, prospect and exploratory drilling encompassed the Hamamdagh-deniz, Garasu, Aran-deniz, Dashly, and Sabail anticlinal folds. However, positive result for oil and gas content was obtained only in well 25, drilled in the elevated section of the Garasu fold northeastern edge, where oil free flow to surface from VII horizon amounted to 250 t/day, and gas flow was up to 300 thou. m³/day. The VII horizon in the edge more subsided area was water-bearing.

The Kalamadyn-Mishovdag-Byandovan zone embraces within the Baku archipelago such structures as Yanan-Tava-Atashgyakh and the Kyurovdagh-Neftchala subzone, which continues toward the Kyurdashy and Shirvan anticlinal folds within the sea boundaries.

Commercial oil and gas pools are found in its northwestern part, within the Kalamadyn, Mishovdag, and Galmaz anticlines.

At Mishovdag structure, commercial oil and gas pools were found in the I, II, and III horizons and confined to the fold northwestern part. Commercial oil and gas flows were also obtained from horizon IV (well 37 up to 4 t/day). Well 64 of horizon VII produced up to 3 t/day of oil and well 36 of horizon XII, 2 t/day. The lowest horizon with commercial oil flow (well 62—up to 6 t/day) is horizon VIII of the PS upper division.

At Galmaz field, horizons I, II, and III contain gas pools. Commercial oil and gas content of horizon IV was found for well 15, drilled at the southwestern edge (oil yield is 20 t/day, and gas yield is 20 thou. m³/day). Below horizon V, the PS section is clayey, but in horizons XII, XVII, and XX, separate oil- and gas-bearing sand units appear.

At Khydyrly-Byandovan potential area, the PS section has been studied to the lower division inclusively, but positive results were not obtained. The Absheron stage upper horizons produced commercial gas flows from 40 to 58 thou. m³/day. Southeastern extension of the Kalamadyn-Byandovan anticlinal zone within the Baku archipelago displays oil and gas shows in Byandovan-deniz, Yanan-Tava-Atashgyakh, Kyurdashy, Mughan-deniz, etc., anticlinal folds, within mud volcano boundaries, but commercial oil and gas content of the PS section has not yet been determined.

At Kyursangi oil and gas field, oil and gas pools are confined to 7 sandy levels of the PS section upper part. Commercial oil flow of up to 30 t/day was obtained from well 68, horizon VIII, of the fold northeastern edge.

In the *Kyurovdagh-Neftchala subzone* of oil and gas accumulations, 20 sandy levels are localized in the PS upper division section, predominantly dissociated by clayey divisions. The largest oil pools are confined to sand level I.

Some sandy levels of the Akchagyl and Absheron stages are commercially oil- and gas-bearing in the framework of Kyurovdagh and Garabagly fields.

Southeast of Garabagly field, at the northeastern margin of large and asymmetrical Babazanan high, the PS upper part of up to 750 m thickness is washed out. Multiple natural oil and gas shows are noted in sand layers of the PS exposed part. Oil flow of 3–4 t/day yield was produced by testing of wells 3 and 5, drilled in the fold crest, while well 20 produced gas with initial daily yield of up to 20–30 thou. m³. More powerful gas flows were obtained from sand levels of the Absheron stage middle division.

At Khilli field, the first commercial oil flow of up to 70 t/day yield was obtained from the PS horizon VIII. By testing horizons III, IV, and V, some wells produced from 3 to 10 t/day of oil.

At Neftchala field, oil pools were found in horizons I–VIII of the PS upper division. Unlike Kyurovdagh and Garabagly fields, oil pools are found at both fold edges. Here, oil commercial pools are found in the PS horizons I, II, and III, and in the middle Absheron sand levels that are confined to separated tectonic blocks.

Classification of pools and fields is extremely important for determination of formation conditions, assessment of oil- and gas-bearing capacity in individual regional and districts, and the selection of rational HC exploration, survey, and development methods.

Such well-known geologists like M.V. Abramovich, B.K. Babazade, F.M. Bagirzadeh, A.A. Bakirov, I.O. Brod, I.I. Potapov, M.F. Mirchink, A.A. Trofimuk, N. Yu. Uspenskaya, and others dealt with the classification of oil and gas pools.

They based their pool classifications on a number of morphological, structural, and genetic criteria.

The most acceptable classification for Azerbaijan oil and gas pools based on the analysis and critical assessment of existing classifications and on genetic principle has been developed by Babazadeh (1964, 2005).

HC pools found in the SCB are confined to the traps of two basic types: tectonically screened traps (Fig. 2.18) and stratigraphically/lithologically screened traps (Fig. 2.19). HC fields are as a rule related to the combined type (Fig. 2.20).

A rare type of oil field, confined to the Upper Cretaceous age volcanogenic elevation, buried in the Miocene and Pliocene–Anthropogenic deposits was discovered at Muradkhanly area (Fig. 2.21).

2.1.6 Assessment of Resources for Various Azerbaijan Stratigraphic Complexes

Peculiarities of spatial distribution of ultimate potential resources (UPR) of HC crude in the region are essentially determined by differences in oil and gas generation potential

Fig. 2.18 Pool/field types in SCB: tectonically screened type.
a Gyurdan-deniz, **b** Darrin Kyupasi, **c** Sabunchi

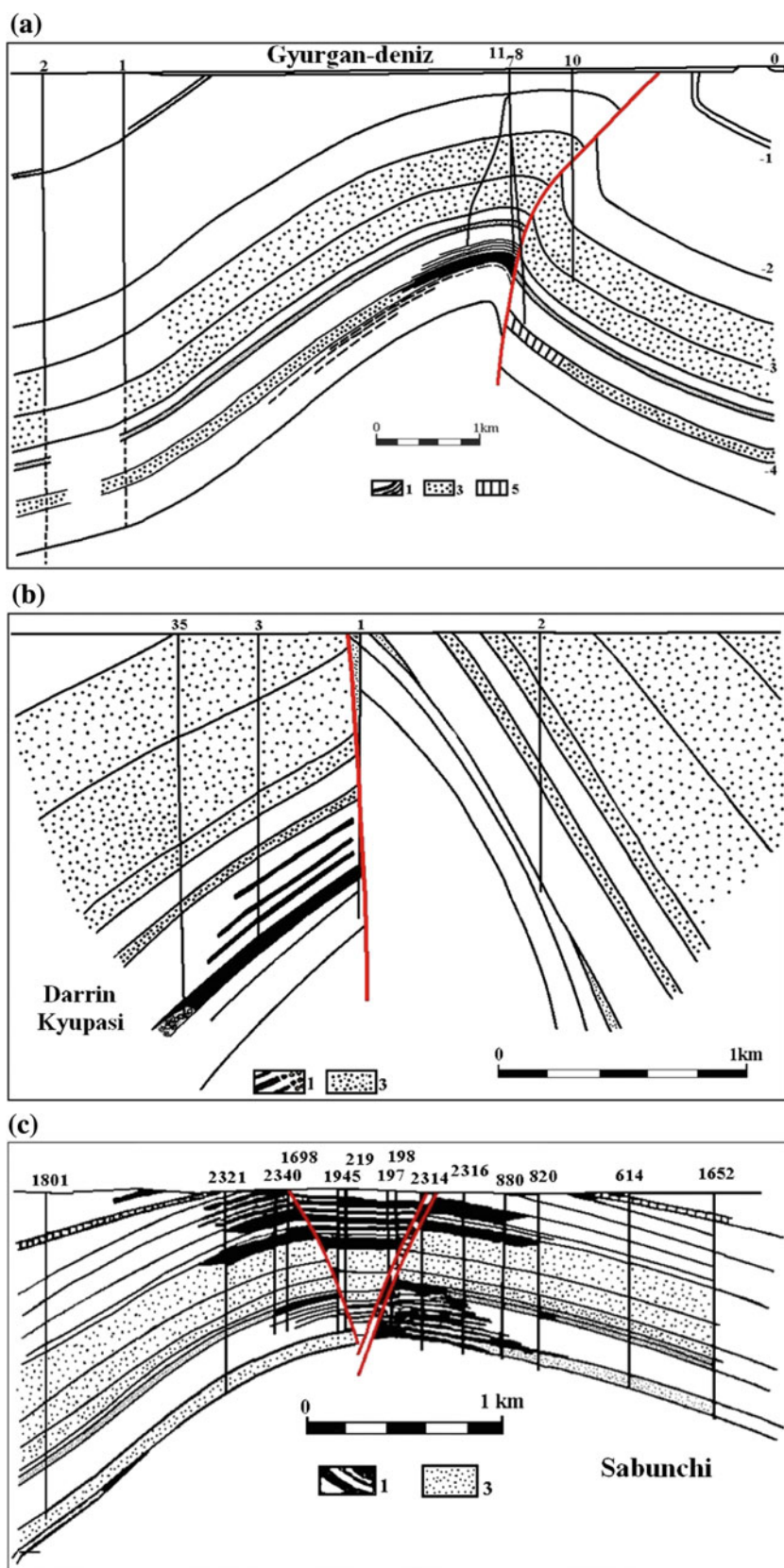
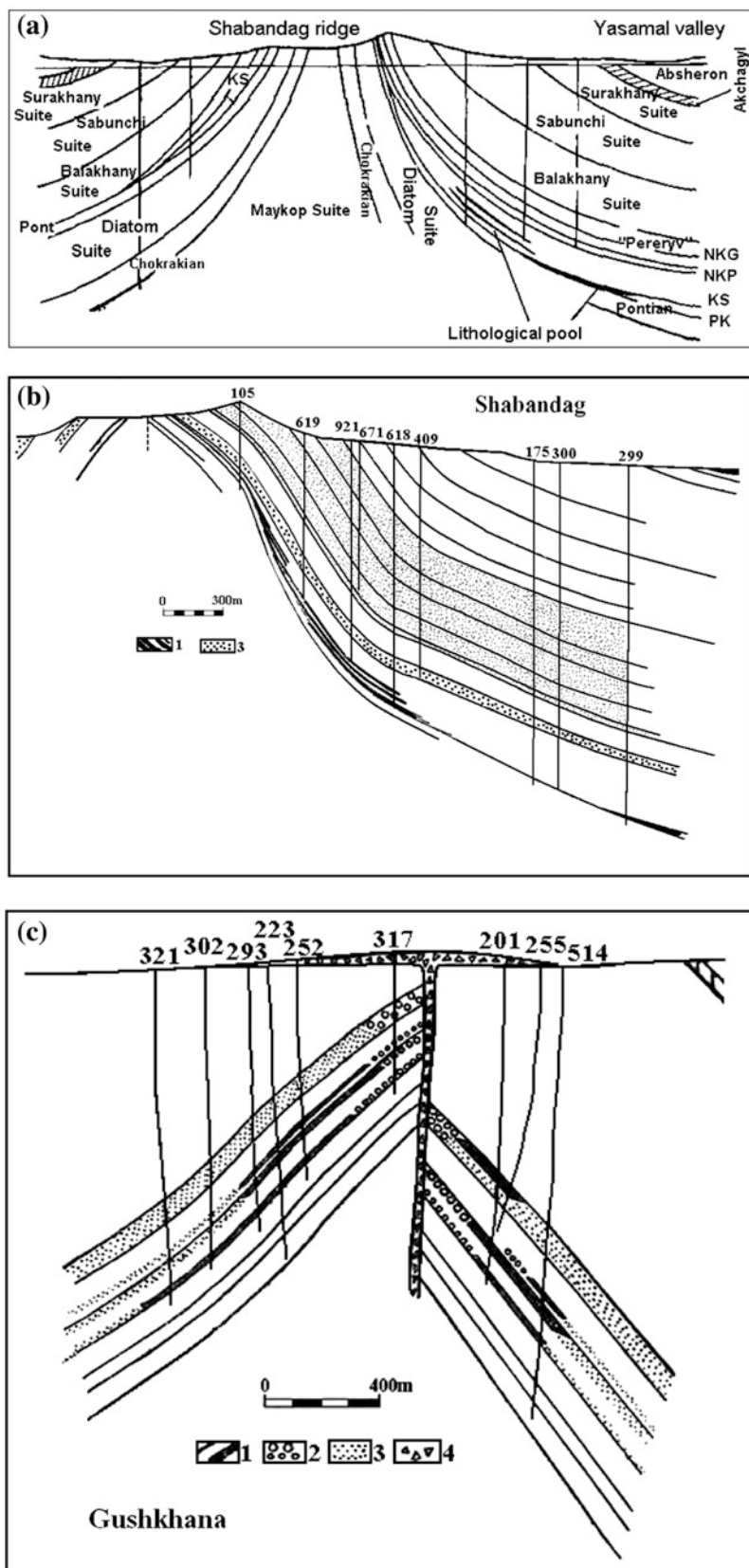


Fig. 2.19 Pool/field types in SCB: stratigraphically/lithologically screened type.
a Yasamal Valley, **b** Shabandagh,
c Gushkhana



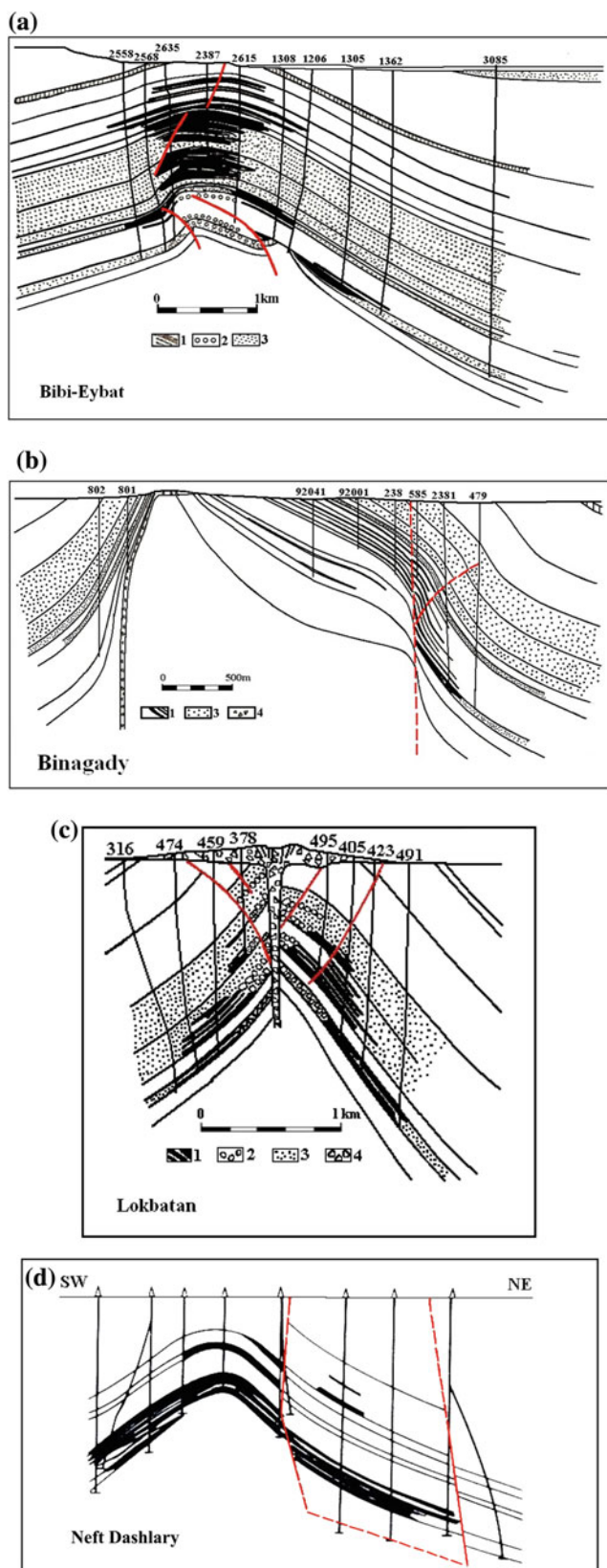


Fig. 2.20 Field types in SCB: combined type. **a** Bibi-Eybat, **b** Binagady, **c** Lokbatan, **d** Neft Dashlary

of the source rocks and in trap/reservoir parameters that control oil and gas accumulation scale.

The applied technique of assessment of oil and gas accumulation scale, or, in other words, assessment of HC resources, is based on the determination of relationship between basin geodynamic type, sedimentation rate, and resource density in sedimentary basins.

Density of HC resources at calculated areas was established, basing on the implementation of reference values for reasonably assured HC resources at a number of fields that are used by calculations with correcting analogy factors, taking into account difference in parameters that control oil and gas content at reference and calculated areas.

Hydrocarbon resources were estimated together with GEON Center (Russia) (D.A. Fedorov, L.E. Levin et al.) from the Jurassic, Cretaceous–Eocene, Oligocene–Miocene, and Pliocene deposits, using both internal (Pliocene, Oligocene–Miocene, Eocene, partly Cretaceous) and external references (Jurassic, partly Cretaceous ones).

The Jurassic deposits

Commercial oil resources were not found in the Jurassic deposits; here, the wells drilled demonstrated only oil and essentially gas shows of various intensity in the near-Caspian-Guba region. By virtue of the South Mangyshlak area with 29.5 thou. t/km² density of reference fuel (RF), these commercial reserves were taken as a reference area.

UPR calculations showed that the HC total reserves in the Azerbaijan sector of the Caspian Sea and on the Azerbaijan dryland consist of 0.41 billion tons of reference fuel (oil + gas + gas condensate). These resources have been estimated for a total potential area of 38.1 thou. km² (Fig. 2.22).

More than 75 % of HC resources in the Caspian region Jurassic system are found in the SCB, while 25 % of them fall on the Middle Caucasus (the near-Caspian-Guba region with adjacent Caspian marine area). The resources of 10 thou. t/km² density occupy the largest area (Fig. 2.22).

The Cretaceous and Eocene deposits

The Cretaceous and Eocene deposits of Azerbaijan contain minor oil pools at the Siazan monocline fields, in the Yevlakh-Agjabedi trough (Muradkhanly, Jafarly), and in the Kur-Gabyrry interfluvium (Tarsdallyar). The Cretaceous–Eocene overall potential area on dryland and in the Caspian Sea of Azerbaijan is 74.5 thou. km², so that 30.3 relate to marine area and 44.2 thou. km² – to the dryland.

To assess the resources, several reference sites were selected in the Middle Kur Depression (2 sites) and in the near-Caspian-Guba region (1 site), with a density of proven

Fig. 2.21 Muradkhanly field. Oil pools are confined to weathering crust of the Upper Cretaceous volcanogenic rocks, and the Middle Eocene deposits are lithologically and tectonically screened at the fold SW edge

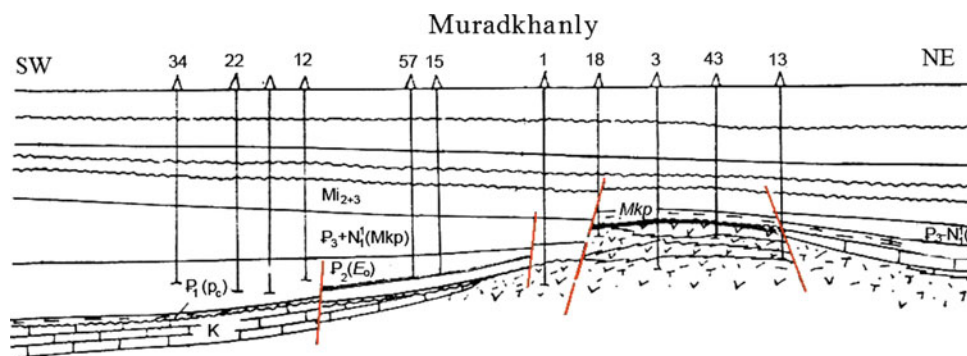
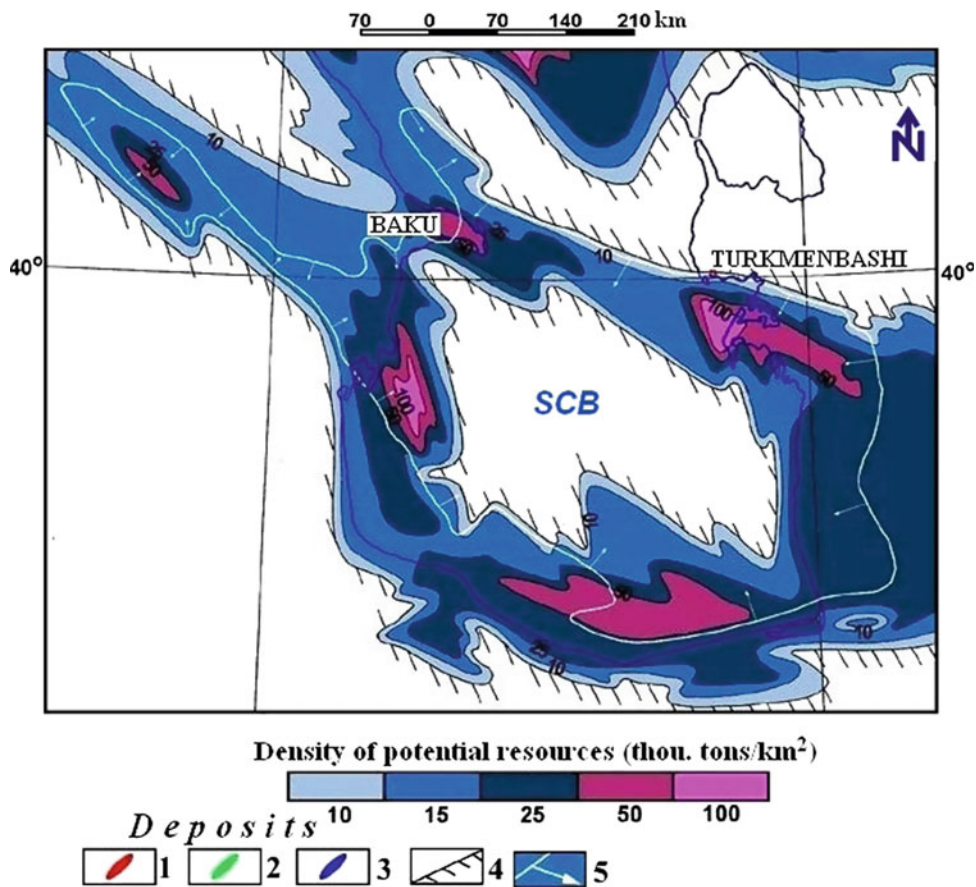


Fig. 2.22 Distribution map of potential hydrocarbon resources in the Jurassic deposits (Guliyev et al. 2003). 1 Oil; 2 gas; 3 oil-gas and gas condensate; 4 regions that are not HC prospecting promising; 5 outline of the region with deposit occurrence roof at below 7 km depth



reserves for sum of hydrocarbons equal to 11–50 thou. t/km².

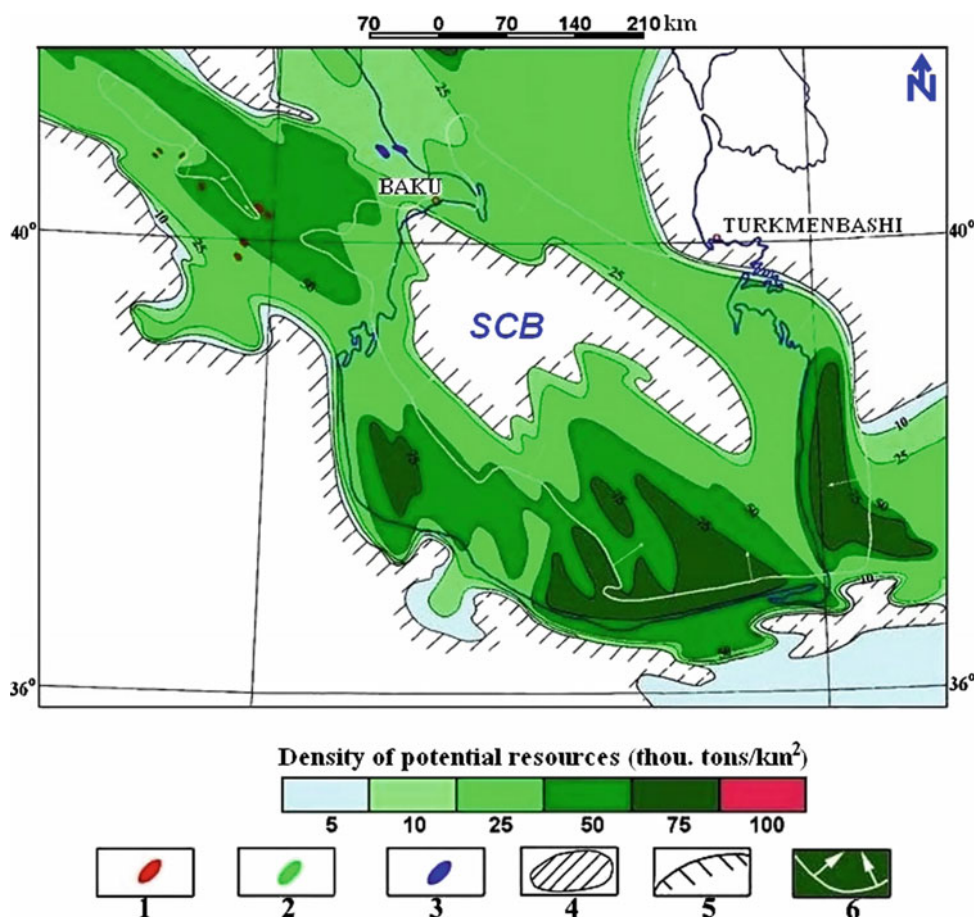
Overall sum of estimated ultimate potential resources for the Azerbaijan Cretaceous–Eocene deposits is 2.15 billion tons of RF, where 1.28 billion tons relate to dryland and 0.87 billion tons of RF - to the marine shelf (Fig. 2.23). The South Caspian resources are estimated as 1.44 billion tons of RF.

The Oligocene–Miocene deposits

Oil and gas content of these Azerbaijan deposits has been proved for a number of regions (near-Caspian-Guba, Shamakhy-Gobustan, Ganja, Muradkhanly, etc.). But oil pools and their reserves are poor, correspondingly.

Estimated sum of Azerbaijan HC is 3.54 billion tons. It is the largest among the resources of the Caspian region

Fig. 2.23 Distribution map of potential hydrocarbon resources in the Cretaceous–Eocene deposits. 1 Oil; 2 gas; 3 oil–gas and gas condensate; 4 internal regions of partial Cretaceous–Eocene sediment denudation; 5 regions that are not HC prospecting promising; 6 outline of the region with deposit occurrence roof at below 7 km depth (Guliyev et al. 2003)



countries (nearly 50 % of the Oligocene–Miocene resources for the region). Most of the HC resources (85 %–3.05 billion tons) resides in the South Caspian Sea, where they are subdivided nearly equally between the offshore and the onshore parts (Fig. 2.24).

All in all, the Oligocene–Miocene resources of Azerbaijan marine zone, equaling 1.99 billion tons, constitute more than 56 % of all resources of this stratigraphic system.

Above half (55 %) of the Azerbaijan Oligocene–Miocene promising onshore and offshore areas is characterized by HC resources density of 20 thou. t/km² (see Fig. 2.24).

The Pliocene deposits

Overwhelming majority of Azerbaijan oil and gas fields is confined to the Pliocene deposits. Meanwhile, potential discovery of new HC accumulations is nowhere near

exhausted, particularly in Azerbaijan offshore part, including the Caspian Sea deep section.

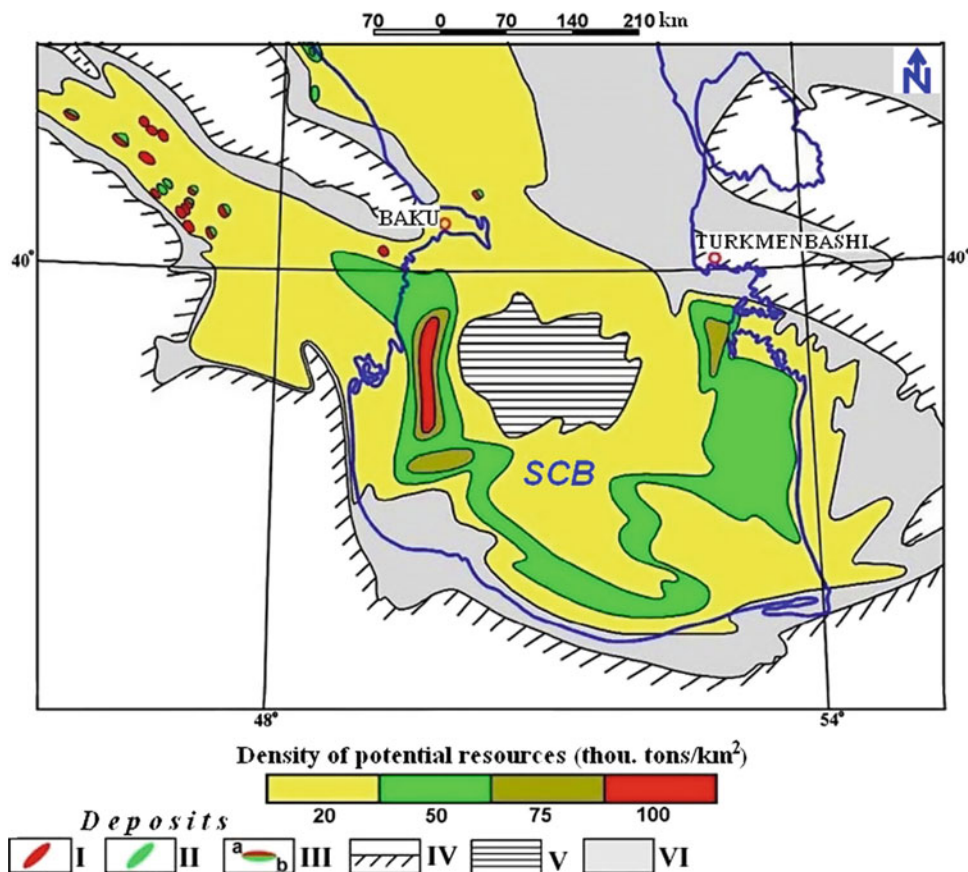
Reference sites have been chosen in Absheron and Lower Kur regions and at the Baku archipelago. Their density of commercial reserves varies from 25 (Jeirankechmez depression) to 910 thou. t/km² (Absheron), averaged value of HC density being 470 thou. t/km².

The Pliocene deposits of the Caspian Sea Azerbaijan section contain nearly 2.5-fold more (15.2 billion tons) of HC than those of the dryland (5.8 billion tons) (Fig. 2.25).

Cumulative review of hydrocarbon UPR distribution in stratigraphic systems of Azerbaijan dryland and Azerbaijan sector of the Caspian Sea is given in Table 2.19.

As seen, basic volume of oil and gas resources is concentrated in the Pliocene complex, i.e., 21 billion tons of RF, or nearly 78 % of the entire sum of hydrocarbons assessed for Azerbaijan as 27 billion tons of RF. In this, two-thirds of

Fig. 2.24 Distribution map of potential hydrocarbon resources in the Oligocene–Miocene deposits. *I* Oil; *II* gas; *III* elevations with established intense flow of: *a* oil, *b* gas; *IV* outline of the Oligocene–Miocene system distribution; *V* system occurrence region at below 9 km depth. Density of potential resources has not been determined; *VI* region of low-thickness sediments, not HC prospecting promising (Guliyev et al. 2003)



these republican resources fall on the Caspian shelf (18.25 billion tons of RF).

2.1.7 Development Outlook of Oil and Gas Extraction in Azerbaijan

Azerbaijan is one of the oldest oil and gas recovery regions in the world, where commercial development of oil fields started already in the second half of the nineteenth century.

At present, 71 oil and gas fields are discovered on dryland and in the adjacent offshore Caspian Sea, and 54 of them are in operation. Azerbaijan depths have, so far, produced about 1 billion, 400 million tons of oil with condensate and about 500 billion m³ of gas. At the same time, according to the Azerbaijan specialists' estimates, only remaining oil in place for operating fields amounts to above 2.4 billion tons, and the issue of oil and gas extraction is extremely pressing and challenging for the Republic (Aliyev and Bagirzadeh 1988; Abasov et al. 1999; Yusufzade 2000). The issue importance is also determined by the fact that oil sector of national economy is one of the principal donors ensuring currency supply to budget, and its development determines Azerbaijan economic well-being in no small measure.

The issue of further development of oil and gas extraction in Azerbaijan (mainly in the SCB) can be conditionally subdivided into two constituents: **engineering and geological**.

Engineering constituent includes advancement of development techniques and systems for both new and newly introduced fields.

For pools under development, the problem consists in advancement of techniques and systems for well development and operation, in application of potential and feasible novel technologies of oil and gas extraction aimed at efficiency enhancement for their redevelopment, as well as in drilling of horizontal and multilateral wells; application of productivity gain techniques in wells and enhanced oil recovery; recovery of operating well stock; and joint operation of productive facilities and some others.

The challenge for newly introduced fields is preparation and implementation of their development projects based on state-of-the-art achievements of oil and gas extraction theory and practice.

Geological constituent of the problem is mainly related to potential enhancement of commercial oil reserves that can be done at the expense of exploration and discovery of new oil fields and additional reservoir exploration of the already

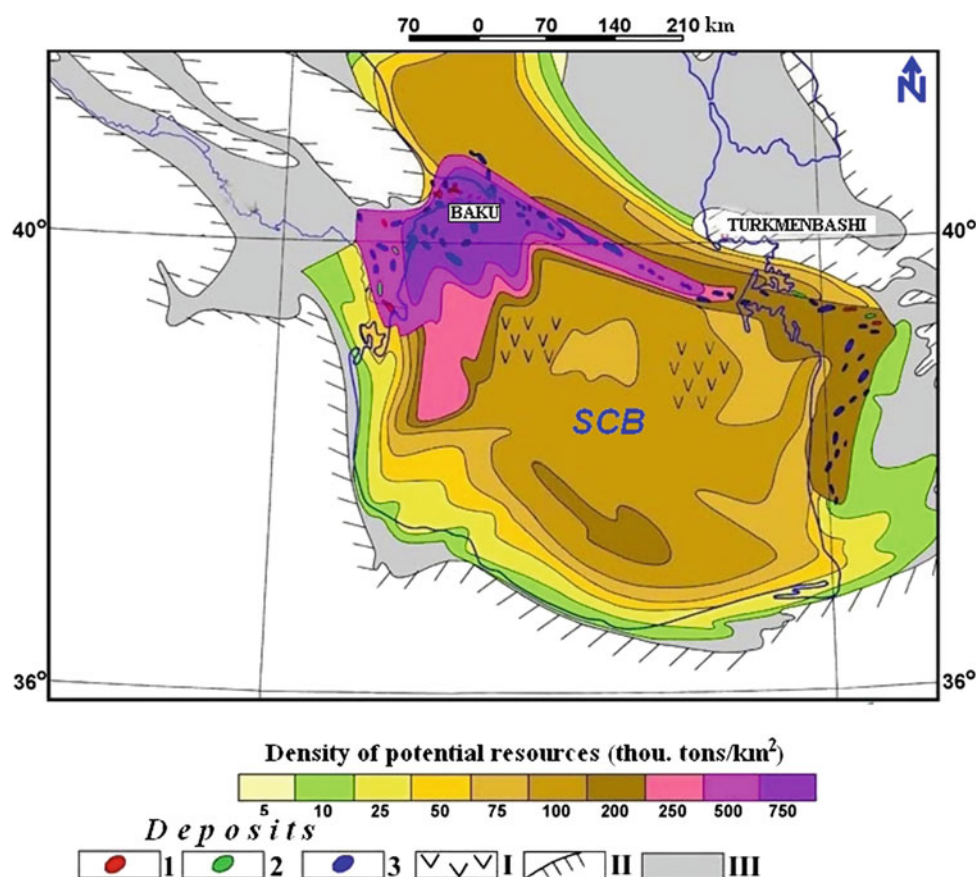


Fig. 2.25 Distribution map of potential hydrocarbon resources in the Pliocene–Quaternary deposits. *I* Oil; *2* gas; *3* oil–gas and gas condensate. *I* Regions of intense gas hydrate generation, hypothetical;

II distribution outlines for the Pliocene–Quaternary deposits; *III* regions of low-thickness sediments, not HC prospecting promising (Guliyev et al. 2003)

Table 2.19 Ultimate potential geological resources (UPR) of Azerbaijan Meso-Cenozoic deposits (in billion tons of RF)

Geological age	Onshore	Offshore	Onshore + offshore
Pliocene	5.8	15.2	21.0
Miocene–Oligocene	1.5	2.0	3.5
Eocene–Cretaceous	1.3	0.9	2.2
Jurassic	0.25	0.15	0.4
Total sum	8.85	18.25	27.1

developed fields, i.e., this constituent is also subdivided into two groups: *long-run developed fields and novel regions, areas, and structures*.

The challenges for long-run developed fields are *detection of missed reservoirs and layers; search for satellite reservoirs; and exploration of new stratigraphic pays*.

Solution of the problem related to *detection of missed reservoirs and layers* is based on analysis and re-interpretation of the bulk of geological and geophysical

materials intended to outline facilities and layers with hydrocarbon saturation that have not been developed in due time, either because of their intricacy or of some engineering reasons. Such cases can be met at Absheron fields.

Another challenge, whose solution will result in oil and gas extraction enhancement at old areas, is *search and exploration of satellite reservoirs*.

By oil and gas migration to the basic trap, they can get into stratigraphically, lithologically, and tectonically screened traps in peripheral sectors. These pools can have no common reservoir limits with principal pool and thus be omitted during prospecting and exploration. Therefore, detection and operation of these reservoirs is a reserve for production gain at old fields (Abasov et al. 1999).

Here, we should also assign the *search for hydrocarbon reservoirs at shallow depths*, including HC gas (essentially methane) accumulations of biochemical genesis in the SCB Quaternary–Upper Pliocene deposits of extreme thickness.

High gas saturation of the SCB surface deposits was noted by drilling of multiple wells and from mud logging data.

Another very important stage in enhancing the resources base of the republic oil and gas complex is search for hydrocarbons *at new stratigraphic pays*.

Azerbaijan oil and gas fields are mainly confined to the terrigenous Lower Pliocene stratigraphic complex, the “productive series” (PS). Despite large thickness of sedimentary filling and presence of good oil and gas parent rocks (source rocks), main hydrocarbon storage is focused in narrow stratigraphic range. Geological explanation of this phenomenon is based on the PS unique parameters: wonderful, stable areal, sandy (predominantly quartz) reservoirs; thick clay cap rocks with good insulating properties; pronounced brachyanticlinal folds with vertical migration channels (fractures, mud volcanoes); and high quality of source rocks (the Miocene–Paleocene); coincidence of fold formation time and migration phases (the Late Pliocene–Quaternary period).

At the same time, *the Paleogene–Miocene deposits* are the high-priority target of prospecting and exploration in the SCB. Their regional oil- and gas-bearing capacity triggers the necessity of development of new techniques for their prospecting and operation.

The Paleogene–Miocene deposits are the principal source rocks in the SCB Cenozoic sequence. At the same time, their regional commercial oil and gas content was defined.

However, despite reservoir discovery and development, potential of the Paleogene–Miocene deposits has been realized not to a full measure, which is essentially connected to limited porosity and permeability modalities and to the intricate structure of natural reservoirs for these sediments. Universal clay content (up to 90 %) of the Paleogene–Miocene deposits shows that generation conditions for large accumulations are very limited here, and for this reason, the bulk of HC is dispersed as small clusters.

Geophysical research and drilling results give grounds to assume that alternative type of reservoirs will serve as oil and gas receptacle in the Paleogene–Miocene deposits. It might be possible that HCs will be localized in the crushing, decompression, and fracturing zones. The traps of salt dome, tectonically screened, stratigraphic, and lithological types are also of interest. Potential production of shale oil might be related to these sediments.

Search for such kind of reservoirs demands much broader scope of modern geophysical and geochemical methods, specifically three-dimensional seismics and its modifications, as well as more detailed data processing and interpretation for these investigation techniques.

The *Mesozoic deposits* are still other search-prospective deposits. Methodical prospecting and exploration efforts for Mesozoic oil search in Azerbaijan were conducted within the recent 50–55 years. During this period, about 300 wells of

overall meterage of nearly 950,000 m have been drilled for studying the Mesozoic deposits. Despite such a large drilling scope of prospecting and exploration wells, commercial oil and gas reservoirs were found only within the Siazan monocline (the near-Caspian-Guba region) and at Muradkhanly and Zardab areas (Middle Kur Depression). One of the reasons of low efficiency of geological prospecting survey is insufficient knowledge of the Mesozoic deposit structure.

Despite low efficiency of conducted research, perspective oil- and gas-bearing capacity and potential capacities of the Azerbaijan Mesozoic deposits are estimated rather high. It is witnessed by prolific oil and gas seeps to the surface and by oil and gas shows discovered by well drilling and testing. The mentioned oil and gas shows are associated both with the Jurassic and with the Cretaceous deposits.

The Mesozoic deposits are promising mainly in the near-Caspian-Guba, in the Shamakhy-Gobustan regions, and in the Middle Kur Depression.

The second group that can be denoted as “*novel areas and structures*” is subdivided into two groups of facilities, *the traditional and the non-traditional* ones.

We perceive structural anticlinal type traps, to which overwhelming majority of Azerbaijan-revealed HC reservoirs is related and which contribute to be the principal oil and gas exploration and prospect targets as *traditional* exploration targets.

The *non-traditional* traps are another group of structures. Among these, we classify the non-structural traps related to lithological thinning out and stratigraphic unconformity zones, the areas of PS regional thinning out, of unconformable overlapping of stratigraphic intervals, where accumulation of commercial-scale HC reserves is possible. *Riff massifs*, whose presence is predicted within the Middle Caspian Depression, are also classified as non-traditional.

The *zone of regional thrusts* is another target of exploration interest. Within the Southeastern Caucasus, a number of large regional nappes (mass overthrusts) are found. Established commercial HC reservoirs are related to some of them. Among them is the Siazan thrust with same-name field situated along it and confined to the underthrust Cenozoic complex and a number of oil- and gas-bearing areas (Amirkhanly, Chinarlar, and others).

Search for the reservoirs of indicated type demands, first of all, novel technologies of seismic survey.

The SCB was for a long time considered as predominantly oil-producing province. However, some objective facts such as OM type in HC-generating complexes, values of oil and gas factors, scope of gas outbursts from mud volcanoes, presence of large gas condensate fields, high quantity of HC gases dissolved in formation water, and, finally, exploration and prospecting results testify to high gas

saturation in the SCB depths and, respectively, to high search potentials for large gas reservoirs at deeper depths.

The PS structure located in the SCB central deeply subsided part is of primary importance in the search for gas condensate reservoirs. Here, geophysical methods permitted to find 15 large structures within borders of which discovery of gas condensate reservoirs with high gas condensate factors and possible oil rims of various sizes is suggested. Gas resources in these structures are assessed as tens of trillions m³.

Implementation of all above-mentioned tasks is directly associated with exploration and prospecting efficiency. Their success is composed of such constituents as the sedimentary basin development concepts, HC genesis and formation of their pools, levels of geophysical research and quality of the result interpretations, and engineering level of well drilling.

The problem of contemporary oil and gas generation and sustainability of hydrocarbon resources is an important and warranting further investigation topic.

Wide applicability of *geochemical and hydrochemical techniques* can promote further search efficiency. It is in geochemical and hydrochemical parameters that the processes of chemical transformation of sedimentary rock substance and associated mass transfer and phase transitions find the most contrasting reflection.

It is important to conclude that choice of prospecting and exploration tendencies should be based not only on geological attractiveness of this or that facility but also on economic feasibility as well.

Economic analysis of the choice of prospecting and exploration tendencies is an important element of the entire geological survey process, and it should be based on the country's economic strategy.

2.2 Hard Economic Minerals

In Azerbaijan occur not only richest hydrocarbon deposits, but also most part of known hard economic minerals (e.g., Azizbekov et al. 1972; Atlas 2000; Ismailzadeh et al. 2005). We will consider here only main types of hard economic minerals (without building, optical, semi-precious, and ornamental stones, chemical raw materials, salt, and some other minerals).

2.2.1 Metallic Minerals

The deposits and occurrences of iron, chromite, and manganese ore are known to exist on the territory of Azerbaijan; however, the only iron ore deposits contain proved mineable reserves (Kashkay 1947; Mustafabeyli et al. 1964; Mustafayev et al. 1989). The titanium occurrences have been found in magnetite-bearing sandstone.

2.2.1.1 Iron

Iron ore formations play a substantial role in the metallogeny of Azerbaijan. Genetically, deposits of iron ore have been subdivided into segregation–magmatic, contact–metasomatic (magnetite skarn mineralization), hydrothermal–metasomatic (hematite mineralization), and sedimentary genetic types. The contact–metasomatic and hydrothermal–metasomatic types are the most prospective types of mineralization.

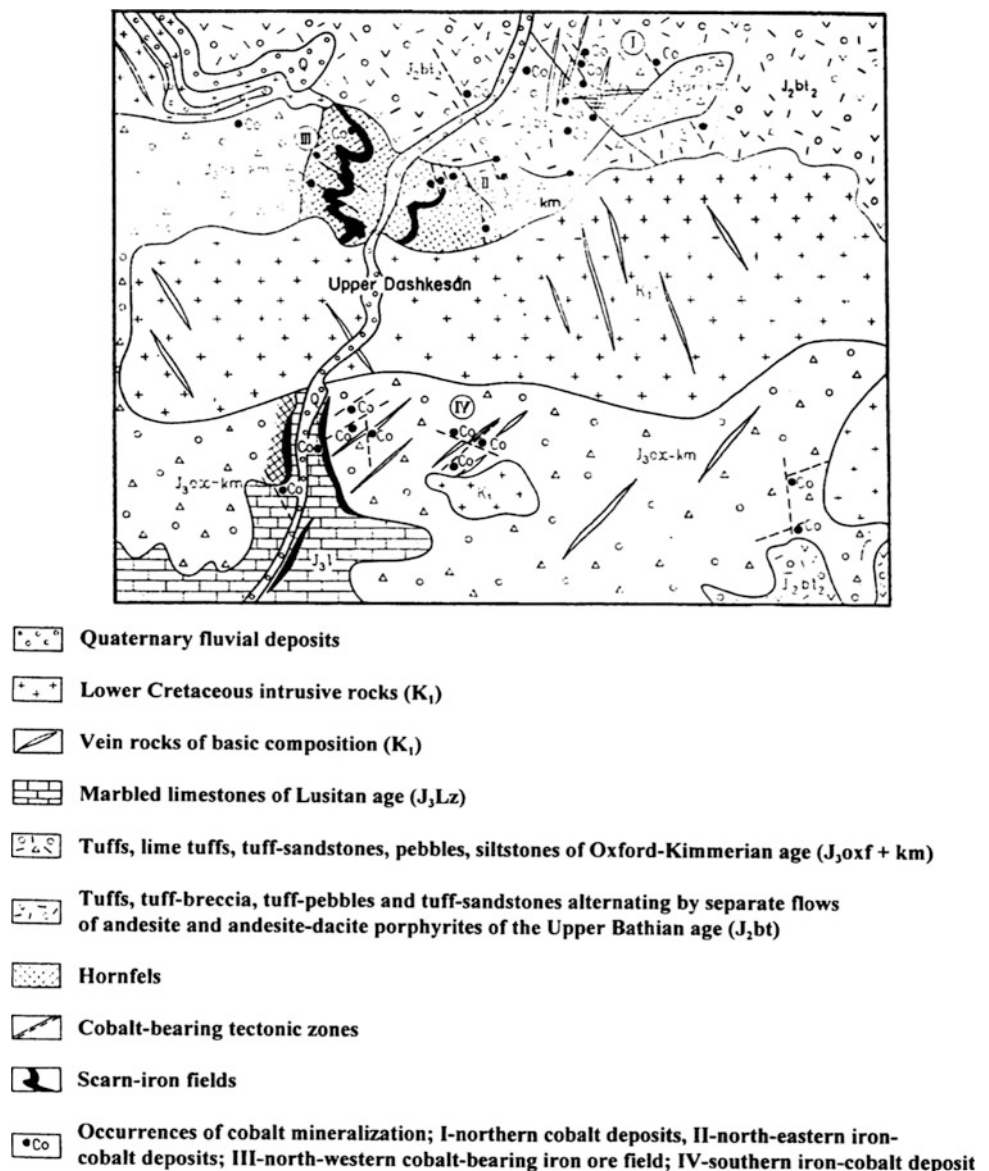
The proved mineable reserves of iron ore are concentrated within the Dashkesan ore region of the Lok-Garabagh (Somkhit-Agdam) metallogenic belt. The Dashkesan group of iron ore deposits is located in the Dashkesan region extending for 40 km to the southwest of Ganja city. The motor highway and railway link the Dashkesan, South Dashkesan, Damir deposits, and series of small deposits and occurrences close to Dardara village and on the slopes of the Ponakh-Chermez Mt. The Dashkesan deposit has been known from times immemorial. However, up to 1917, iron ore has been mined by primitive methods and geological studies were sporadic.

The mineable reserves of the Dashkesan deposit were estimated for the first time in 1933 and recalculated in 1954. The additional mineral exploration of the deposit from 1954 to 1966 has resulted in a discovery of the South Dashkesan iron ore deposit. At the beginning of the 1970s, exploration of the northern area of the Dashkesan deposit was conducted. Mineable reserves of iron ore have been approved by the State Commission on Reserves of Economic Minerals of the former USSR. Total reserves of iron ore of all categories were estimated at 278 million tons. The industrial exploitation of the Dashkesan deposit was initiated in 1954. The Azerbaijanian ore mining and processing enterprise was established. The iron ore deposits of the Dashkesan group have served as the source of raw materials for the metallurgical industry of the Transcaucasus. Iron concentrate was supplied until 1991 to the Rustavi Metallurgical Combine in Georgia. The proved mineable reserves of the Dashkesan group of iron ore deposits accounted for 234 million tons providing 90 years of life cycle of the mine based on annual mining capacity.

2.2.1.2 Magnetite Skarns

The Dashkesan group of iron ore deposits is confined to the Dashkesan syncline, located in the central axial part of the Dashkesan synclinorium, with pronounced intensive volcanic activity in the Bathonian and Kimmeridgian. The transition from the syncline to adjacent anticlines is fixed mainly by bends of beds and outcrops of the Upper Bajocian deposits represented by quartz porphyry and their tuffs with interbeds of tuff–sandstone. The deposits of the Bathonian stage from 450 to 800 m thick are composed of rocks of tuffogenous and tuffogenous–effusive formations.

Fig. 2.26 Geological map of the central area of the Dashkesan ore district



The Upper Jurassic formations are represented by a thick series of volcanogenic and sedimentary rocks of the Callovian and Kimmeridgian stages. Tectonically, the ore region is confined to the jointing zone of the Murovdagh and Shamkir anticlinoriums of the general Caucasian direction and the Shamkir and Pantdagh cross-Caucasian uplifts. Combination of the two folded constructions forms the gentle Dashkesan synclinorium hosting various mineralization.

Two systems of the northwestern and northeastern faults complicated the structure of the ore region and served as the channels of intrusive magmatism. The Jurassic sedimentary formation was intruded by the polyphase and polyfacial Dashkesan intrusive massif confined to the abyssal fault along the axial part of the Dashkesan syncline. The deposits and occurrences of iron ore, cobalt, sulfide-arsenide,

sulfides, alunite, pyrophyllite, kaolinite, and other mineralization of the region are genetically and spatially associated with this intrusive massif. Four phases of intrusion of magmatic rocks were delineated. The first phase is represented by gabbro, gabbro-diorites, syenite-diorites, and other basic magmatic rocks of neck and stock shapes. The most widespread rocks of the second phase outcrop on the area of more than 25 km² and are represented by granodiorites, adamellites, and banatites. Aplites and alaskites of the third phase have a limited distribution. The fourth phase of the intrusion is represented by numerous extended dykes of diabase porphyries and diabase. Cobalt mineralization of the ore region is paragenetically associated with these dykes. The iron ore mineralization is also associated by some geoscientists with these dykes. The intrusion of magmatic

rocks was accompanied by contact–thermal metamorphism of volcanogenic–sedimentary rocks. Metamorphic rocks are represented by hornfels, metasomatites, and marbles.

The rocks of hornfels facies are represented by pyroxene–scapolite, albite–pyroxene–scapolite, pyroxene–plagioclase, amphibole–pyroxene–plagioclase, biotite–pyroxene–plagioclase, and biotite feldspar varieties developed both above and under iron ore deposits. The thickness of hornfels and metasomatites varies from a range of 20–30 to 50 m. They are developed on volcanogenic rocks in contact zones of gabbroids and quartz diorites.

Marbles and marbled limestone have been formed by thermal and contact metamorphism of limestone. According to their chemical and physical properties, they meet the requirements of ornamental stones and flux limestone. The new Dashkesan deposit of white marble is being quarried now, and the Khoshbulag deposit of flux limestones with reserves of more than 57 million tons has been explored near the Dashkesan iron ore deposits.

Magnetite skarn deposits of the Dashkesan group are concentrated in the northern and southern zones of exo-contacts of intrusive massifs. The massifs of latitudinal direction are spatially confined to the abyssal fault passing the axial part of the Dashkesan syncline. The Dashkesan and South Dashkesan deposits of submeridional direction are separated by the Goshgarchay River into the western and eastern parts (Fig. 2.26).

The Damir iron ore deposit is located southeast of the South Dashkesan gabbroid massif of submeridional direction. According to lithofacial analysis, the magnetite skarn mineralization is hosted by the rocks of calcareous series of the top sections of the Oxfordian–Lower Kimmeridgian age. The mineralization is localized in the nearshore lithofacies, where the volume of limestones varies from 0 to 30 %.

The character of localization of magnetite skarn mineralization is variable. In the northwestern area of the Dashkesan deposit, magnetite skarn mineralization overlies the marbled limestones. Its thickness gradually increases reaching 60 m by simultaneous reduction of the thickness of limestones. In the northeastern area, the mineralization occurs between hornfels and keratinized tuffites of the Callovian–Oxfordian series and volcanogenic series of the Kimmeridgian age. Similar types of occurrence were observed within the Damir iron ore deposit.

In general, magnetite skarn mineralization of the Dashkesan group of deposits is represented by 8–10 monoclinal stratified beds concordant by strike and dipping with host rocks. The maximum distance of skarns from the contours of the main intrusive massif is 2.5 km. The length of magnetite skarn deposits varies from 1900 to 4000 m in separate areas. The width of the deposit normally corresponds to the length, and in plan, the deposits have an isometric shape. The thickness of deposits varies from 4 to

40 m reaching a range from 100 to 200 m. Magnetite skarn deposits are characterized by a complicated integral structure due to a wide range of magnetite content from 0 to 90 % and a great variety of skarn types.

The stratified and lens-shaped deposits of economic value of up to 60 m thick extend from 100 to 2000 m. Massive deposits are subdivided into massive magnetite ores containing up to 90 % of magnetite and sulfide–magnetite ores containing up to 20 % of sulfide minerals. The content of iron ore in massive magnetite ores varies from 45 to 60 %. The texture of the ore is: (1) massive, (2) slaggy, and (3) porous. The sulfide minerals of disseminated texture and irregular shapes in the northwestern area of the deposit contain 50 % of chalcopyrite, 40 % of pyrite, 5 % of chalcocite, as well as rare bornite, sphalerite, and arsenopyrite. The sulfide ores of the northeastern part of the deposit contain from 70 to 95 % pyrite, up to 15 % chalcopyrite, 5 to 7 % arsenopyrite, and up to 5 % galenite, rare sphalerite, and bornite.

The massive magnetite ores of the South Dashkesan deposit contain up to 12 % of sulfides being represented by a range of 70–80 % of pyrite, up to 10 % of chalcopyrite, cobaltine, rare pyrrhotite arsenopyrite, glaucodote, bornite, sphalerite, and galenite. Sulfide–magnetite ore contains arsenic, vanadium, titanium, cobalt, zinc, manganese, tin, magnesium, copper, lead, molybdenum, nickel, silver, gallium, cadmium, bismuth, indium, and zirconium.

The deposits of the disseminated type also form beds and lenses and gradually transit into massive magnetite ores. The ores contain from 40 to 70 % magnetite, up to 25 % garnet, 5 up to 30 % calcite, and up to 1 % quartz, epidote, rare hematite, chlorite, dashkesanite, and actinolite. Manganese, gallium, tin, molybdenum, vanadium, titanium, copper, zinc, cobalt, and nickel are assayed in sulfide part of disseminated types of ores. The iron content in this type of ores reaches 30 %.

The contours of mineable iron ores in magnetite skarns are defined by the content of dissolved iron distinguishing massive magnetite ores with iron content of more than 45 %, magnetite skarns from 30 to 45 % of iron content, and ore skarns with iron content from 15 to 25 %. The share of massive magnetite ores of skarn type of total reserves varies from 30 to 50 %, reach magnetite skarns from 10 to 40 %, poor magnetite skarns from 6 to 13 %, and ore skarns from 2 to 4 %. Despite available infrastructure and sufficient mineable reserves of cobalt-bearing iron ore, the Dashkesan group of deposits did not involve to a full commercial exploitation. The open cast mining production has been sharply reduced owing to a low demand after a breakup of the former Soviet Union.

Smaller deposits of magnetite skarns are known to exist on the territory of the Gedabey and Ordubad ore regions. The Novo-Ivanovka occurrence is located within a range of 4–5 km to the northwest from Novo-Ivanovka village of the Gedabey

region. The mineralization is confined to the contact zones of the Lok-Garabagh limestones of the Upper Cretaceous age and volcanogenic–sedimentary rocks of the Eocene intruded by the post-Middle-Eocene granitoids of gabbroid and syenite–diorite phase. Small ore bodies contain fine-grained magnetite with admixture of pyrite. The iron content varies from 9 to 58.2 % and cobalt from 0.015 to 0.02 %. The cobalt mineralization is paragenetically associated with pyrite. The occurrence is of no present economic interest.

2.2.1.3 Hematite Ore

Hematite ore is known to exist in the Dashkesan ore region, being represented by the Alabashli deposit and a number of small occurrences. The deposit is located westward of Gyandja city close to the Alabashli railway station. The deposit is hosted by the Middle Jurassic volcanogenic and the Upper Cretaceous sedimentary formations overlaid by the Quaternary deposits. The Middle Jurassic volcanics are represented by tuff–sandstone, tuff–breccia, and tuff–conglomerates of the Bathonian stage exposed to hydrothermal alterations. The upper section of the Cretaceous system is represented by the formations of the Lower Coniacian, Turonian, and Santonian stages transgressively overlapping volcanogenic rock series of the Bathonian stage. The formations are complicated by a series of tectonic faults of various orientations. The mineralized zone of the Alabashli hematite deposit subsided concordantly with enclosing rocks and has a moderate dipping of 15°–20°. The mineralized zone is broken by faults defining the terrace structure of the deposit. The ore body occurs in the form of stratabound beds.

The ores are represented by massive red hematite and coarse–crystalline hematite of steel-gray color. Ore texture is impregnated and laminated, sometimes banded and breccia-shaped. Main ore minerals are hematite, hausmannite, hydroferrum oxide, pyrite, and chalcopyrite. The associated minerals are quartz, sericite, chlorite, epidote, calcite, alunite, and kaolinite. The chemical assay of samples shows 25 % of Fe_2O_3 , 47 % of SiO_2 , 1 % of TiO_2 , a range of 0.12–0.74 % of sulfur, from 0.4 to 2.0 % of CaO , from 0.04 to 0.08 of Cr_2O_3 , from 0.02 to 0.029 of zinc, 0.019 of copper, and from 0.012 to 0.2 of water-dissolved salts, all indicating the siliceous type of mineralization.

Hematite ores of the Alabashli deposit after enrichment on chemical composition and density can be used as a weighting ingredient of drilling muds. The proved reserves of hematite ore are estimated at 580,000 t. The geological prospecting and geophysical studies carried out in the vicinity of the deposit indicated additional reserve potential in the southeastern flank of the deposit. The stratabound hematite mineralization of up to 60 m thick has been proved to be hosted by rocks of volcanogenic series. Besides the Alabashli

deposit, the Shamkir uplift also hosts typical hydrothermal manifestations of hematite of veinlet type in acid intrusions being characterized by monomineral composition.

The Chardakhli hematite occurrence is located within 2–3 km westward of the Alabashli deposit and confined to a contact zone of the Atabek-Slavyan plagiogranite intrusive massif with quartz porphyrites, where hematite mineralization is represented by stringers and lenses. Ore bodies are small and of a low economic value. A maximum content of ferrum in hematite ore is 60 %.

The Atabek hematite occurrence is confined to the endogenous contact zone of the Atabek intrusive massif of plagiogranites, which were transformed into secondary quartzites. Mineralization is represented by vertically dipping veins and lenses. Similar manifestations of hematite mineralization are developed in various parts of the contact zone of the plagiogranite intrusive massif. This type of hematite mineralization has not been studied in detail.

The titanium–magnetite-bearing mineral sand placers were observed along the coast of the Caspian Sea in the southeastern part of Azerbaijan up to the border with the Islamic Republic of Iran.

Magnetite sandstone

Numerous occurrences of magnetite sandstone are concentrated in the Lok-Garabagh metallogenic belt (Dashkesan, Shamkir, Khanlar ore regions) and stratigraphically confined to the volcanogenic series of the Bathonian age. More than twenty outcrops of magnetite sandstones were traced over a distance of 85 km along the coastal line of the Lower Bathonian paleosea. The occurrences in the form of beds and lens-shaped bodies have a variable thickness from 0.5 to 2 m and are traced over a distance from 10 to more than 1000 m.

The main ore minerals are magnetite, titanium–magnetite, ilmenite, rare hematite–ilmenite, hematite, and martite. Hypergene magnetite, goethite, hydrogoethite, and siderite are rare. Among sulfides, rare grains of pyrite and chalcopyrite are found. The content of magnetite in the form of rolled and angular grains from 0.1 to more than 1 mm varies from 30 to 90 %. According to the content of ore grains, reach (70–80 %) and poor (20–35 %) types of magnetite ore have been distinguished. The grade of titanium–magnetite which is the second ore mineral in titanium-bearing magnetite sandstone varies from 3 to 4 %. The content of ilmenite is from 2 to 3 %. Chlorite is the basic cementing mineral, while quartz, plagioclase, pyroxene, epidote, actinolite, and zircon are found as separate grains. The content of these cementing minerals varies from a range of 1–5 % to 30–50 %, and the quantum of cementing mass varies from a range of 3–12 % to 20–25 %.

The content of Fe_2O_3 in magnetite sandstone varies from 47.8 to 75.7 %, metallic ferrum from 33.4 to 53.0 %, and V_2O_5 from 0.36 to 0.46 %. A method of magnetic separation from magnetite sandstone is applied to obtain enriched iron ore concentrate grading 60 % of Fe_2O_3 and from 0.47 to 0.57 % of V_2O_5 . The flotation method enables the extraction of 55 % of magnetite concentrate from the initial quantity of magnetite ore. The content of TiO_2 in magnetite concentrate varies from 9.6 to 10.68 %. The percentage of extraction of titanium varies from 43 to 64 %. The presence of titanium and vanadium in magnetite sandstone indicates the possibility of using these ores as metallurgical raw materials for high-quality steel. Favorable geological conditions suggest a discovery potential of large deposits of magnetite sandstone in various regions of the northeastern slope of the Lesser Caucasus.

2.2.1.4 Magnetite-Bearing Sands

Titanium placers of magnetite-bearing sands are traced along the coast of the Caspian Sea over a distance of 52 km from Lenkaran to Astara city representing iron ores of sedimentary type. The width of placers varies from 50 to 300 m. Further south, these sands are observed on the Iranian coast of the Caspian Sea. The mineral composition of the sands is represented by magnetite (21.5 %), titanium magnetite (63.2 %), hematite (2 %), chromite (0.5 %), and quartz and feldspar (12.8 %).

2.2.1.5 Chromites

The deposits and occurrences of chromites are confined to the ultrabasic rocks of the ophiolite belt of Azerbaijan. The total extent of the ophiolite belt within the Transcaucasus is about 260 km, from which nearly 160 km falls into Azerbaijan's territory. Tectonically, the ophiolite belt of Azerbaijan is confined to the Goycha-Garabagh tectonic zone of the Lesser Caucasus. Petrologically, ultrabasic rocks of the ophiolite belt are represented by peridotites (harzburgite), dunites, and pyroxenites, all reworked into serpentinites by metamorphism. While all massifs of ultrabasic rocks of the ophiolite belt of Azerbaijan are chromite-bearing, the majority of deposits and occurrences of chromite ores are confined to outcrops of dunites and, more rare, harzburgites. The major chromite mineralization in the Azerbaijanian part of the ophiolite belt was found within the Geydara and Kyazimbini-Gavrilov deposits as well as the Zaydara, Nikolayev, Khotavan, and Ipak groups of occurrences.

The Geydara chromite deposit

The Geydara chromite deposit is one of the known chromite deposits in the Transcaucasus located in the watershed of the Soyutluchay and Istibulag rivers at an altitude of 2290 m

above sea level. The deposit occurs on the contact of strongly serpentinized harzburgites with the massif of gabbro-amphibolites, which is hosted on the northeast by volcanogenic-sedimentary sequence of the Santonian age. The ore bodies of the Geydara deposit are confined to a lens-shaped massif of serpentinized dunites elongated in parallel with an archy contact of peridotites and gabbro-amphibolites. The length of the dunite massif is 350 m with a variable thickness from 0.5 to 15 m. Contacts of dunites with enclosing peridotites are gentle and rare. Chromite ore bodies of economic interest are represented by isolated nests of oval and, rarely, lens-shaped form, being located as a chain along the strike of dunites. Some elongation of ore nests along the strike and dip is observed. Minor chromite ore nests or bodies nearby the massive ore bodies are met in the form of spheroids, veinlets, and fracture fillings. A disseminated type of chromite mineralization is rare.

Five groups of ore bodies were distinguished within the Geydara chromite deposit. The most prominent ore zone on the southeast of the deposit contains around 40 nests of chromite ore. Chemical assay shows a range of 43.1–52.2 % of Cr_2O_3 , 12.5–16.4 % of FeO, 5.77–5.94 % of SiO_2 , 0.17–0.37 % of CaO, 0.01–0.03 % of SO_3 , 0.01–0.02 % of P_2O_5 , and ratio of CrO to FeO from 3.0 to 5.2 %.

Massive chromite ores of deposits and occurrences of Azerbaijan are characterized by the following average composition: from 42 to 54 % of Cr_2O_3 , from 6 to 17 % of FeO, from 6 to 11 % of Al_2O_3 , from 0.13 to 0.16 % of CaO, from 16 to 20 % of MgO, from 0.005 to 0.02 % of P_2O_5 , and from 0.01 to 0.02 % of SO_3 . Vanadium, zinc, cobalt, and nickel are associated ore minerals. Technological properties of massive chromite ore meet the highest requirements of the metallurgical industry and can be used for the production of ferroalloys. Chromite ores of impregnated and nodular types grading from 18 to 39 % of Cr_2O_3 and from 8 to 18 % of FeO can also be used for metallurgical purposes after appropriate enrichment. Field tests have proved that it is possible to obtain concentrates grading more than 50 % of Cr_2O_3 and more than 16 % of FeO. While mining and technological conditions of chromite ore development are generally favorable, additional mineral exploration and mineral economics works are required to determine their development.

The ophiolite belt of Azerbaijan constitutes a part of the large Pontian ophiolite belt extending through northern Turkey, Armenia, and Azerbaijan with known chromite deposits being exploited in Turkey. The proven reserves of the chromite deposits in Turkey vary from a range of 5000–20,000 t to more than 200,000 t. The similarity of the geological environment and tectonic regimes suggests a potential for discovery of new medium-sized chromite deposits in Azerbaijan.

2.2.1.6 Manganese

Only small deposits and occurrences of manganese ore are known to exist in the Lok-Garabagh and Araz tectonic zones of the Lesser Caucasus, on the southern slope of the Greater Caucasus and in the northern Gobustan. All occurrences of the Somkhit-Agdam tectonic zone are hosted by the Upper Cretaceous volcanics being characterized by exhalation–sedimentary and hydrothermal types of mineralization. The most known mineralization in this tectonic zone are the Molladjali deposit and Elvar occurrence in the Agjakend trough and the Dashsalakhli occurrence in the Gazakh trough of the Lesser Caucasus.

The Molladjali deposit is located close to the same village in favorable mining and geographic conditions. The deposit is hosted by volcanogenic and sedimentary rocks of the Upper Cretaceous: andesite–basalts and tuffs of the Coniacian and Lower Santonian stages, clayey–sandy horizon of the Upper Santonian stage, and marly limestone of the Campanian–Maastrichtian stages. Stratiform beds of ferromanganese ore occur in sandy–clayey rocks of the Upper Santonian stage on a contact with limestone of the Campanian stage. Ore bodies are elongated in the northwestern direction conformable with enclosing rocks and are traced as fragmented occurrences. The mineral composition of manganese ores shows a vertical upward zonation from siliceous manganese and ferromanganese varieties to more pure manganese ore in the middle of the mineralized section. The ferromanganese content, however, prevails toward the top-most sections. The deposit is subdivided into the northwestern, central, and southeastern areas.

In the northwestern area, ferromanganese beds are represented by several separated ore bodies from 0.3 to 3.0 m thick and from 45 to 90 m long. The total extent of this mineralized zone is more than 700 m. Chemical assay of ore shows from 0.3 to 16.71 % of MnO, 20.4 to 42 % of FeO, and 1.54 % of P₂O₅. In the southeastern area, the ore-bearing horizon contains two beds thicker from 0.2 to 0.5 m in the lower part and from 0.5 to 1.0 m in the upper part being separated by strongly limonitized sandy clays. Northwestward, the thickness of the upper ore bed increases up to 4 m. The grade of manganese varies within a range from 0.4 to 32 %.

2.2.2 Non-ferrous and Light Metals

2.2.2.1 Lead and Zinc

The lead–zinc deposits of Azerbaijan are characterized by variable genetic and morphological types being hosted by a wide spectrum of the Phanerozoic formations from the Devonian (Gyumushlug deposit) to the Miocene–Pliocene

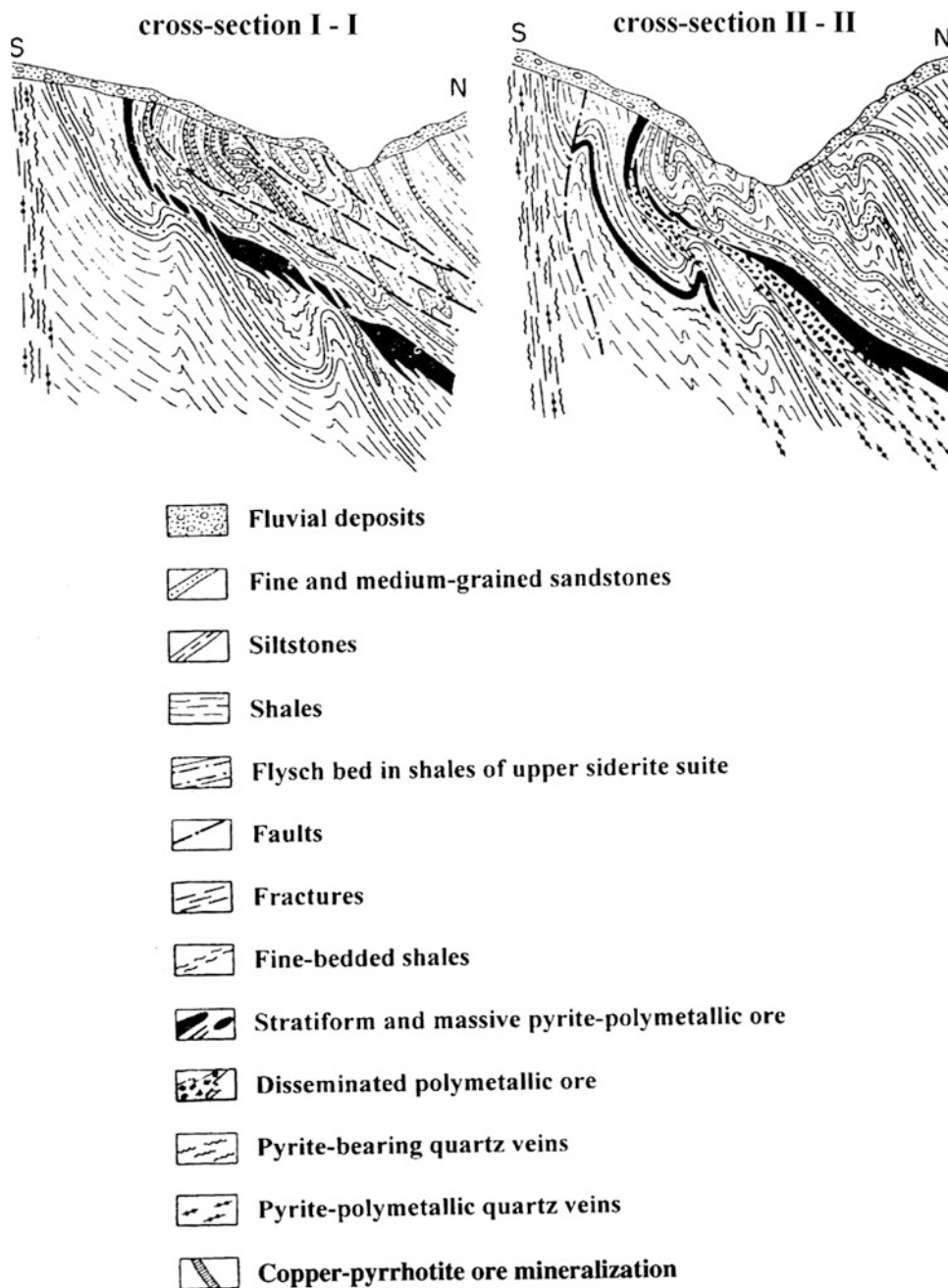
age. Artisanal mining and processing of lead/zinc ores existed in the nineteenth century at the Mekhmana deposit of the Daghliq (Mountainous) Garabagh and the Gyumushlug deposit of the Nakhchivan AR. The geological prospecting and mineral exploration from 1950 to 1954 resulted in the discovery of the Agdara lead–zinc deposit in the Lesser Caucasus, a number of occurrences in Nakhchivan Autonomous Republic (AR) of Azerbaijan and in the Dalidagh intrusive massif in the Kelbadjar region. The discovery of the Filizchay giant deposit on the southern slope of the Greater Caucasus in 1958 triggered intensive exploration work for base metal mineralization in this previously unexplored region and follow-up discovery of the Katsdagh, Katekh, Sagator and some other deposits in Azerbaijan, the Gyzyldara and Gurdul deposits in Dagestan, occurrences of copper–zinc ores within the Azerbaijan territory of the southern slope of the Greater Caucasus, and also in adjacent areas of Dagestan. According to the estimation of some Azerbaijan and Russian geologists, Filizchay deposit by its commercial reserves is within five largest polymetallic deposits in the world. The base metal deposits in the Lesser Caucasus of hydrothermal type are generally of small size. The Agdara base metal deposit has been exploited until depletion and mining operations at the Gyumushlug deposit were ceased owing to political instability in the Mountainous Garabagh.

The metallogenic province of the Greater Caucasus

All known deposits and occurrences of base metals are hosted by the Lower and Middle Jurassic tectonic zones of mountainous folded system of the Greater Caucasus (Kurbanov et al. 1967; Azizbekov et al. 1972; Akberov et al. 1982; Hasanov 1982; Kurbanov 1982; Shirinov 1982; Agayev 1990; Atlas 2000; Ismailzadeh et al. 2008). The geological investigations and tectonic analysis of this tectonic zone distinguished southward the Metlyuta-Akhtichay, Tufan, Katekh-Gyumbulchay, and Zagatala-Kovdagh tectonic subzones. These subzones of a deep thrust-over-thrust nature have served as boundaries of structural–facial zones in the pre-collisional stage and currently represent large tectonic transversal elements of thrusting mature. The Jurassic tectonic zone of the mountainous system of the Greater Caucasus has experienced an intensive magmatism being represented by subvolcanic, hypovolcanic, and hyperabyssal bodies of gabbro and gabbro–diabases, as well as by subvolcanic and hypovolcanic intrusions of dacites, liparites–dacites, liparites, and, more rarely, by andesite–basalts and basalts.

The major structural control of mineralization in this tectonic zone belongs to transversal tectonic elements which divide longitudinal zones into a number of large transversal

Fig. 2.27 Cross sections of the central (I-I) and eastern (II-II) areas of the Filizchay pyrite-polymetallic deposit



terrace uplifts and subsided blocks. On the recent erosional level, the crosscutting blocks are expressed as the north-northeastern or the north-northwestern vertical flexures being complicated by fragmented faults of a thrust-upthrust nature of the same directions.

The Filizchay complex ore deposit

The Filizchay deposit of base metals is hosted by terrigenous deposits of the Upper siderite and Khinalug suites of the Middle Jurassic which are crumpled into a large overturned to the south the sublatitudinal Karabchay anticline. The

morphology of the ore deposit is rather simple being represented by a stratabound lens-like ore body with swells and pinches along the dip and strike of the ore body (Fig. 2.27). The ore body is dipping to the north at 40°–45° and on the top horizons at 60°–70° up to a vertical dipping. Unlike the roof, where the deposit is characterized by sharp and well-pronounced contours, its base has a more complicated structure.

Mineral composition of the ore body is quite monotonous comprising mainly of pyrite followed by sphalerite, galenite, and pyrrhotite. Chalcopyrite, marcasite, arsenopyrite, magnetite, and secondary copper sulfides are found in small

quantities. The cementing minerals are carbonates, quartz, and, to a lesser extent, chlorite and sericite. The ore contains more than twenty rare minerals.

Five types of ore have been distinguished within the Filizchay deposit based on the texture of the ore, namely (a) banded pyrite and pyrite–sphalerite–galenite; (b) massive pyrite; (c) impregnated pyrite and pyrite–sphalerite–galenite; (d) streaky and fracture fillings of pyrite, pyrite–sphalerite–galenite and pyrrhotite, and (e) massive copper–pyrrhotite.

The banded ores occur in a hanging side of the deposit and occupy most of the volume of the ore body. Massive pyrite ores with a minor admixture of chalcopyrite, sphalerite, and galenite are found together with banded ores and form lens-shaped areas in the top and bottom sections of the ore body.

The impregnated and disseminated pyrite–sphalerite–galenite type of ores occurs in the eastern part of the deposit forming the bodies of rather complicated form. This type of ores is characterized by a coarse-grained pyrite segregation of up to 1.0–1.5 cm of cubic and irregular form on the background of cementing material. Textural varieties of impregnated ores are defined by quantitative correlation of pyrite, cementing minerals, and content of polymetallic sulfides. Two extreme textural members are impregnated ores grading from 60 to 70 % of pyrite and ores grading from 20 to 30 % of pyrite.

The veinlets and fracture filling ores are developed in a lying side of the ore body on the eastern flank of the deposit and extend beyond its limits up to 2.0 km. This type of ore is overlain by banded and impregnated ores. Three textural varieties of mineralization are parallel to schistosity, net-like-breccia, and brecciated ores. The thickness of separate stringers and veins varies from 0.5 cm to 0.5 m.

Later massive pyrrhotite ores are developed exclusively in the eastern part of the deposit forming a single vein-shaped body located in a hanging side of massive pyrrhotite and partially among the impregnated and banded ores. Massive textural varieties prevail in the surficial part of the ore body; more abyssal horizons of the ore body are dominated by breccia texture being cemented by fine-grained pyrrhotite.

The deposit has been explored in detail by drilling and mining at four exploration levels. The technological types of ores include the primary ore (97.3 %), mixed (2.2 %), and oxidized ore (0.5 %). Technological properties of ores have been studied in laboratories, and two semi-industrial tests on selected flotation indicate a feasibility of obtaining 67.7 % of copper concentrate, 65.2 % of lead concentrate, and 86.1 % of zinc concentrate. Technology of complex reworking of pyrite concentrate enabled to obtain 90.3 % of lead, 92.0 % of zinc, 84.7 % of gold, 84.6 % of silver, 72.1 % of cobalt, 72.2 % of cadmium, 29.7 % of indium, and 10.4 % of selenium.

The deposit is planned to be exploited by underground mining. The proven reserves of the deposit, the data on which are unavailable, were approved by the State Commission on Reserves of the former Soviet Union in 1983.

The Katsdagh pyrite–polymetallic deposit

The Katsdagh pyrite–polymetallic deposit is located northwest of the above-mentioned Filizchay deposit (Hasanov 1982). All ore zones of the deposit are confined to the Kekhamedan abyssal upthrust–overthrust. The deposit is hosted by the Lower Siderite suite of the Middle Jurassic being represented by alternations of sandstone, sandy–clayey shales, and clayey shales. This sequence overlies the upper clayey series of the Khinalug suite dipping to the north at a variable angle from 20° to 65° (Fig. 2.28). The deposit is tectonically controlled by the Kekhamedan fault which is separated into crushed and schistose zones of various degrees being exposed to hydrothermal metamorphism and sulfide mineralization. These structural units host dykes and sills of basic, intermediate, and acid compositions, which have been formed in two stages. The later stage of intrusive magmatism includes diabases, gabbro–diabases, andesite–porphyrites, andesite–dacites, dacites, and liparite–dacites.

Based on intensity of mineralization, the deposit has been subdivided into several mineralized zones. The most prominent zones I and IV have been traced in sublatitudinal direction parallel to each other over a distance of more than 2000 m. Comparatively, shallow ore zones of up to 60 m deep are represented by a series of subparallel ore-bearing fractures up to 50 m long. These fracture filling zones form echelon-like mineralized zones from 50 to 300 m long and occurring from each other at a distance from 30 to 50 m. The detailed mineral exploration within the most prospective zone I has revealed mineralized beds, lenses, and veinlets with an average thickness from 2.5 to 5 m and a maximum thickness from 10 to 16 m in their swellings. The ore bodies are composed of banded and massive ores of sulfide–polymetallic and copper–pyrrhotite composition, which are found in equal ratios. The stringer-impregnated type of mineralization of same composition prevails in other parts of the deposit. The major role in localizing mineralization belongs to the above-mentioned dykes and sills, which were exposed to an intensive hydrothermal–metasomatic alteration preceding the mineralization. These dykes and sills are considered to be the screens for large ore deposits. The presence of numerous shallow veins composed of all known mineral associations in all types of dykes indicates their preceding formation in relation to major mineralization time.

Massive, banded, and stringer-impregnated types of ores are the prevailing textural types of mineralization in the

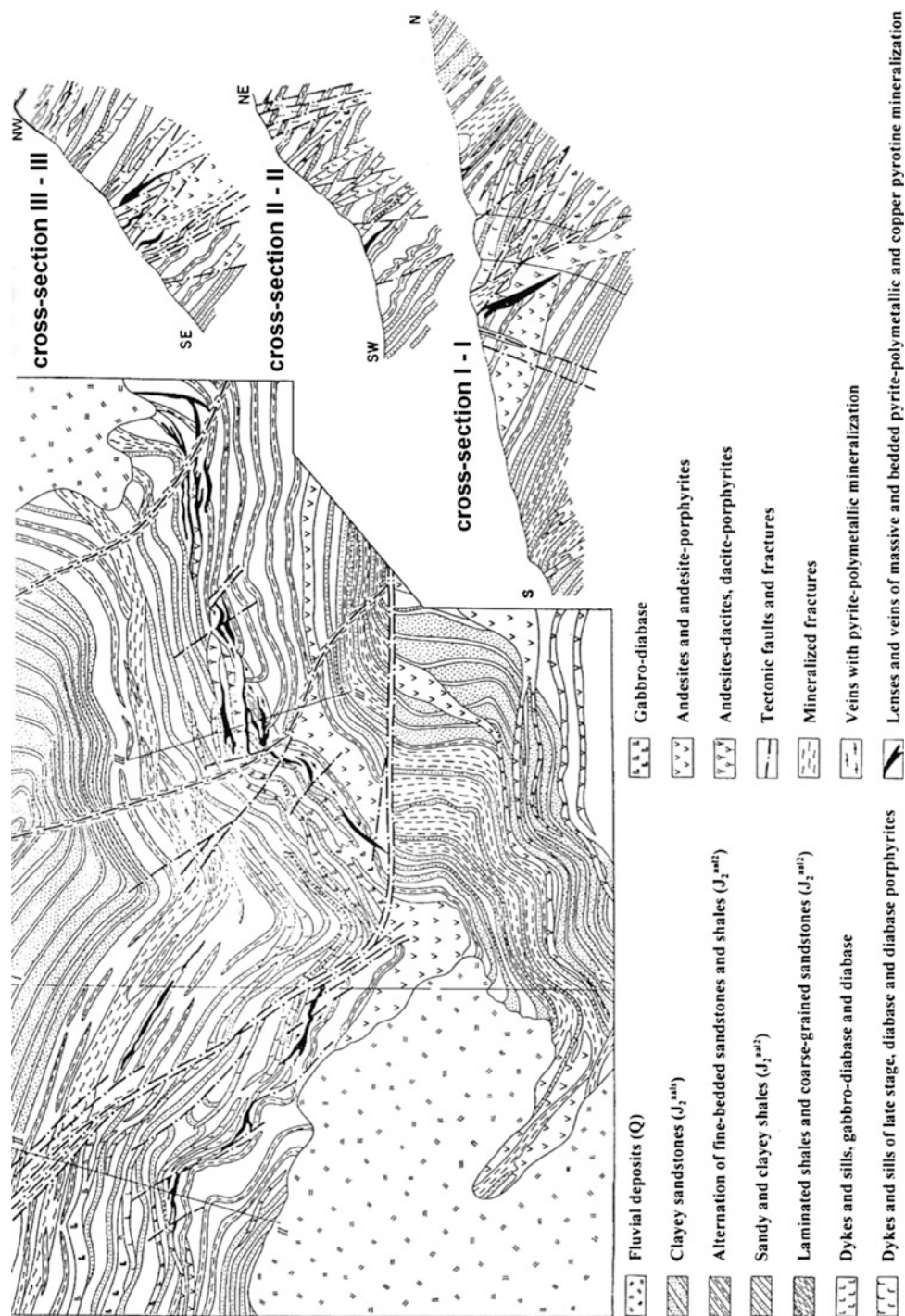


Fig. 2.28 Geological map and cross sections of the Katsdag pyrite-polymetallic deposit

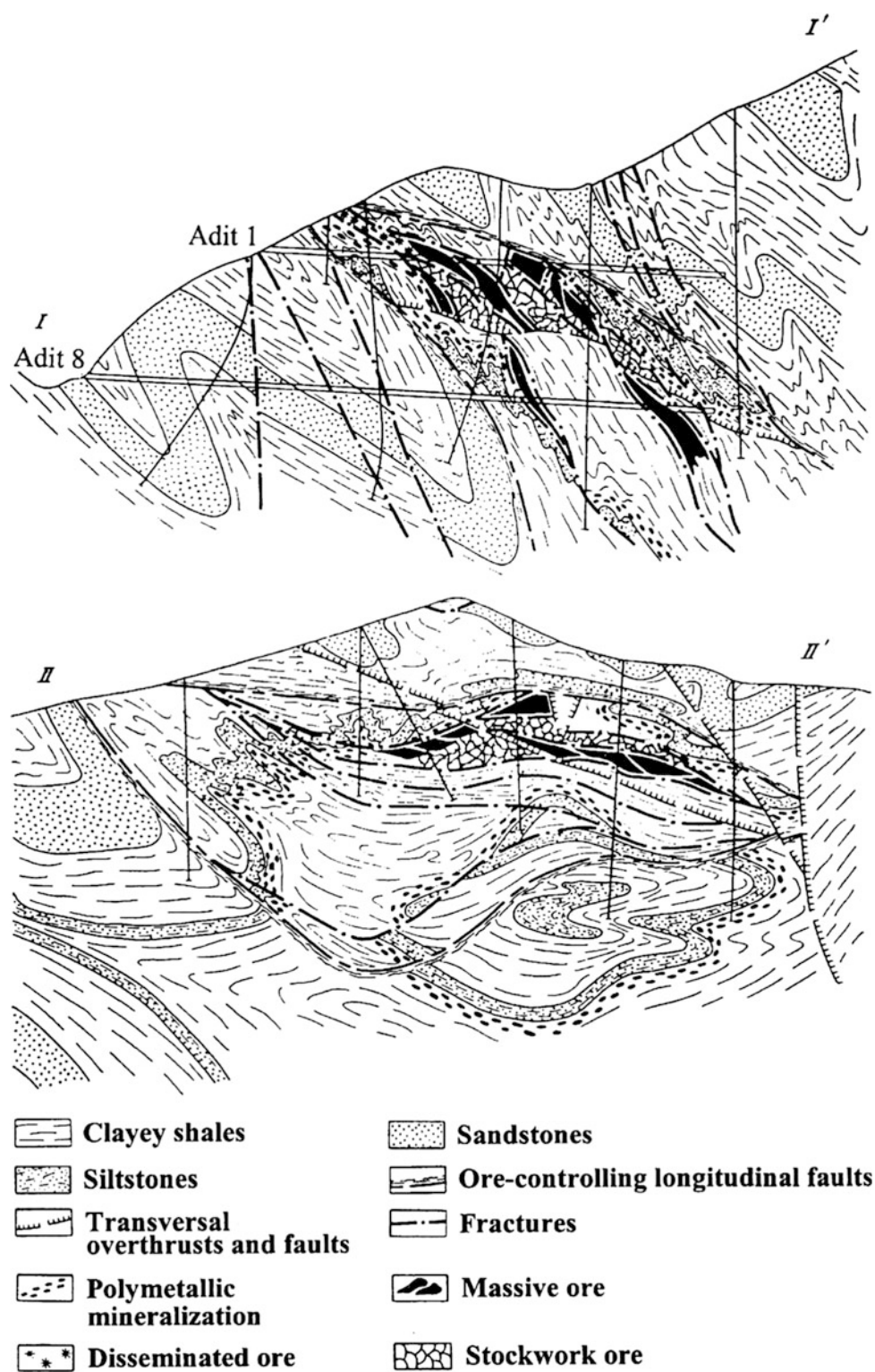


Fig. 2.29 Transversal (*I-I'*) and longitudinal (*II-II'*) cross sections of the Katekh polymetallic deposit

Katsdag deposit. The banded type of mineralization includes mineral associations of copper–pyrrhotite and sulfide–polymetallic composition. Hydrothermal alterations of host rocks at the Katsdag deposit which are accompanying or preceding mineralization are different from those in the Filizchay deposit. Unlike the Filizchay deposit, the hydrothermal alterations here are pronounced with the same intensity in hanging and lying sides of ore bodies. Differing from the Filizchay deposit, where the major hydrothermal alteration is carbonization, quartzitization, chloritization, and sericitization create a metasomatic column of facies of secondary quartzites around the ore bodies of the Katsdag deposit.

Five ore bodies in the form of mineralized beds and lenses have been explored by drilling and mining within the Katsdag deposit. Ore bodies have been traced and contoured on five horizons at a depth from 1800 to 2100 m level. The major ore-forming minerals are pyrrhotite, sphalerite, galenite, chalcopyrite, pyrite and rare arsenopyrite and cobaltite. Major metals are zinc, lead, copper, sulfur, silver, and associated cadmium and gold.

The Katekh polymetallic deposit

The Katekh deposit occurs in the Katekh-Gyumbulchay ore-bearing tectonic zone south of the Katsdag deposit (Kurbanov 1982). Numerous clayed siderite and pyrite concretions from 1 cm up to 1.5 m size are hosted by flyschoid sandy–clayey formation of the Aalenian suite being subdivided into two large rhythms with regressive and transgressive structures.

Katekh anticline being located between transversal and longitudinal faults (Fig. 2.29). Three genetic types of sulfide mineralization are (a) diagenetic, (b) sulfide–polymetallic, and (c) polymetallic mineralization of vein type. The most prospective are the latest two types. By texture, the mineralization is subdivided into massive, impregnated, vein, and rudaceous ores. All these types of ores are spatially associated with each other and localized in the same ore zones being controlled by faults limiting the tectonic wedge. This tectonic wedge hosts three ore-bearing zones.

The major morphological type of sulfide deposits of the Katekh deposit are lens-shaped bodies complicated by longitudinal and crosscutting ore-controlling faults. Pyrite, galenite, sphalerite, chalcopyrite, arsenopyrite, secondary copper sulfides, marcasite, and pyrrhotite are the basic ore-forming minerals. Lead, zinc, silver, copper, gold, and cadmium are the major metals of commercial value.

Technological properties including enrichment of ores of the Katekh deposit have been studied on seven samples in laboratory conditions. Application of a scheme of collective–selective floatation enabled to obtain tradeable commodity concentrates with extraction of lead up to 85.5 %,

85.8 % of zinc, 33.2 % of copper, 76.2 % of gold, and 65.5 % of silver. The ore reserves of the Katekh deposit have been approved by the State Commission on Reserves of the former Soviet Union. The deposit was planned to be exploited by underground mining.

The Sagator polymetallic deposit

The Sagator deposit is located within a distance from 10 to 12 km northward from the Filizchay deposit. The deposit is hosted by terrigenous formations of the Pliensbachian and Toarcian suites of the Middle Jurassic. The deposit is confined to the development of aleuro-clayey series represented by intercalation of fine-bedded aleurolite–sandstone, clayey shales, and aleurolites.

Two natural ore types are massive copper–zinc and vein-type copper–pyrrhotite mineralization. Sphalerite, chalcopyrite, and pyrrhotite are the basic ore-forming minerals. Lead, zinc, silver, cobalt, and cadmium are the major metals of commercial value. Separate technological tests of three samples have been conducted on vein and massive ores as well as on admixture of these types of ore in a ratio 1:1. An appropriate technological scheme and ore enrichment regime enabling to extract up to 86.8 % of copper and 68.1 % of zinc have been developed and recommended.

The metallogenic province of the Lesser Caucasus

Polymetallic deposits and occurrences of the Lesser Caucasus are known to exist within the Lok-Garabagh, Ordubad-Zangazur, and Sharur-Djulfu metallogenic belts (Aliyev 1976; Azizbekov et al. 1976; Kerimov 1964; Kerimov et al. 1986; Ismailzadeh et al. 2008).

The Lok-Garabagh metallogenic belt

This metallogenic belt hosts one hydrothermal polymetallic deposit and numerous occurrences of vein type containing lead, zinc, and barite mineralization. The sporadic lead–zinc mineralization is mainly pronounced in small occurrences consisting of single veins or a series of small quartz and quartz–carbonaceous veins.

The Mekhmana base metal field

The Mekhmana copper–lead field contains reserves of commercial significance in the Lok-Garabagh metallogenic belt. The deposit is located near Mekhmana village of the Garabagh region. The artisanal mining of this deposit is recorded since the end of the nineteenth century.

The deposit occurs in a complex of volcanogenic–sedimentary rocks of the Middle Jurassic – Upper Cretaceous

and is hosted by the Middle Jurassic sedimentary rocks. The main structural unit of the deposit is a large anticlinal fold of the north–northwestern direction. The structure of the deposit and mineralization is controlled by a deep-seated tectonic fault being a channel of multiple magmatic activity during the Middle–Late Jurassic time. The magmatic series is represented by gabbro–diabase magma and subvolcanic intrusions of quartz porphyries of the Upper Bajocian, small intrusions of diorite–porphyries of the Late Jurassic, and finally quartz ore veins of the Mekhmana field. The youngest intrusive rocks are the Late Jurassic dykes of diorite–porphyrites in the eastern part of the deposit being localized in fragments of more late tectonic downthrusts. Around thirty ore-bearing quartz veins of the Mekhmana field are concentrated in a narrow strip of sublatitudinal direction corresponding to a bending area of anticlinal fold and localized in fracture fillings. The veins' volume is usually filled up by calcites, quartz, and ore-forming minerals intermixed with enclosed hydrothermally altered rocks. Ore minerals are mainly represented by galenite and sphalerite, which are closely associated with quartz and carbonates. Chalcopyrite, pyrite, marcasite, chalcosine, bornite, and secondary copper sulfides have a lesser distribution. Galenite and sphalerite in quartz veins and veinlets are met in the form of strips from 5 to 10 cm thick, large and small nests, stringers, and impregnations. The most typical banded texture of ores is followed by breccia, colloform, looped, and impregnated textures. As a rule, structure of ore accumulations is coarse-grained. Based on the content of lead and zinc, the ores have been divided into predominantly lead ores, predominantly zinc ores, and mixed lead–zinc ores. Associated metals are cadmium, silver, selenium, and tellurium.

The Ordubad–Zangazur metallogenic belt

This belt is a typical representative of the Late Alpine stage of development of the Lesser Caucasus, wherein various ore formations, typical to the pre-, syn-, and post-collisional stages, are present. All large polymetallic deposits are associated with a late stage of belt's development and concentrated within the western margin of the Megri-Ordubad granitoid massif. The deposits are typical examples of sulfide formation genetically linked with volcanites being the constituent part of a single volcanoplutonic complex. Small deposits and occurrences of sulfide–polymetallic type within the Ordubad ore region are spatially and genetically associated with the areas of hydrothermal–metasomatic alterations in enclosing volcanogenic rocks of the Lower Eocene which form a single basalt–andesite–liparite–dacite formation. The most intensive concentration of sulfide–polymetallic ores is linked with sulfate–fumarole

fields of the central type being the products of post-magmatic activity of acid volcanites in subsequently differentiated basalt–andesite–liparite–dacite formations.

In spite of a common presence of sulfide mineralization in volcanites of acid composition, a distribution pattern of massive sulfide deposits is irregular. Large deposits of pyrites and pyrite–polymetallic ores are confined to local uplifts being expressed by closely converged volcanic structures of various types. The most typical are volcanic dome extrusions which are synchronous with volcanism of subvolcanic bodies. The tectonic and magmatic control of sulfide mineralization within this metallogenic belt has been studied in detail within the Agdara sulfide–polymetallic deposit in the northwestern part of the belt.

The Agdara sulfide–polymetallic deposit

The deposit is confined to the northern part of the core of the Agdara archy uplift which is composed of typical volcanic brachyanticlines appeared on the site of extrusive structures and volcanic domes. The core of the fold is composed of rocks of eroded pipes and prepipe facies. Wings and the eastern periclinal hinge of the old consist of more younger basic volcanites. Sulfide–polymetallic mineralization is concentrated within the core of the southern periclinal hinge of brachyanticline. The mineralization is controlled by a wide subvertical zone of intensive tectonic reworking. The core of ore-enclosing brachyanticline is intruded by subvolcanic bodies of liparite–dacite exposed to intensive hydrothermal–metasomatic alteration of secondary quartzites and propylites.

Mineral exploration in the southern part of the brachyanticline has revealed massive sulfide mineralization underlined by secondary quartzites and overlapped by sedimentary–volcanogenic sequence. Two morphogenetic types of sulfide–polymetallic mineralization are stratabound massive and streaky-impregnated ores which occupy various structural positions, though spatially are closely associated with each other.

The stratabound bed of massive sulfides varies in thickness from 0.2 to 4.5 m and has been traced from the surface to a 65 m depth, where it reaches a range of 120–130 m length. Bend of the ore body on dip and extent repeat those of overlapping and enclosing sedimentary–volcanic rocks. Along the strike, the ore body has sharp contacts with underlying secondary quartzites. The roof structure of the deposit is more complicated. The morphology of streaky ores developed in a base of bed-shaped ore deposit is rather complicated.

Sulfide stringers from 1 mm to 1.5–2.5 cm form a complicated stockwork inside of areas of mineral concentrations where they coat fragments of mono-quartzites and sericite–quartzose rocks.

Major ore-forming minerals are pyrite (80 %), sphalerite (3–4 %), galenite (3 %), and chalcopyrite. The volume of bed-shaped deposit is composed of sphalerite (70–75 %), pyrite (5 %), chalcopyrite (10 %), and galenite (20–30 %). A certain vertical zonation in localization of sulfides is expressed by a prevalence of ferrum, copper, and lead sulfides in the lower part of the ore body and a domination of zinc and lead sulfides in the massive ores of the deposit upward. Secondary minerals are tennantite, tetraedrite, stromeyerite, bornite, molybdenite, chalcosine, cerussite, and covellite. The cementing minerals are quartz, sericite, alunite, barite, calcite, and chlorite. The formation of stringer-impregnated ores has occurred in two stages, where the initial stringers of quartz–pyrite–chalcopyrite and molybdenite composition have been crosscut by stringers of quartz–calcite and sphalerite–galenite composition. The deposit has been worked out and closed due to its depletion.

The Sharur-Djulfu metallogenic belt

The polymetallic mineralization within this metallogenic belt is known to exist in the Gyumushlug and Darridag-Paradash regions. The Gyumushlug ore region is situated in the area of the Paleozoic terrigenous–carbonaceous complex development and hosts the known Gyumushlug lead–zinc deposit and the Danzik and Sadarak small occurrences.

The Gyumushlug polymetallic deposit

The deposit was discovered at the end of the nineteenth century and has been exploited by the “Alagez” Joint Stock Company during a period from 1908 to 1916. The deposit is confined to the southwestern limb and core of the Gyumushlug anticline made up by limestone, clayey shales, marly limestone, and sandstone of the Givetian and Frasnian stages of the Devonian age. The Gyumushlug anticline has a complex tectonic structure due to intersection of lateral and transversal tectonic faults forming a clear block or mosaic structure.

The mineralization is strictly confined to limestone of the Givetian stage being localized in pre-ore meridional brecciated zones and also in interlayer space of limestone favorable for ore deposition. Structural and lithological factors have defined the existence of two morphological types of mineralization, namely steeply dipping crosscutting ore zones and stratabound mineralized beds.

Altogether, twenty four steeply dipping ore zones with a variable thickness from 0.4 to 6 m have been found in the deposit and only eight zones have been proved to be of an industrial importance. Clayey shales played a screening role in the formation of ore bodies enabling the localization of mineralization in the topmost sections of the limestone

sequence. Industrial concentrations of lead and zinc have been found only in the lower horizons. The mineralization spreads toward from the fractures of a range of 25–30 m with a thickness of stratified mineralized lenses from 1 to 11.0 m. Veins, nests, and lens-shaped veins being accompanied by the areal of impregnated ores are distinguished in both morphological types of ores. The main initial ore minerals are galena and sphalerite; secondary minerals are pyrite, chalcopyrite, and secondary copper sulfides; rare minerals are boulangerite, boutnonite, and argenite; associated minerals are smithsonite, cerussite, limonite, covellite, chalcosine, anglesite and malachite; vein minerals are quartz, barite, calcite, rarely ankerite, dolomite, and gypsum.

The mineralization has concentrated in three stages being separated by the periods of tectonic movements. These stages are the main sulfide ore-forming stage, the galena–barite stage, and the galena–carbonate stage. According to texture peculiarities, massive, gneissose, brecciated, streaky, and impregnation ores have been distinguished, while massive ores have localized in ore zones and adjacent areas of stratabound mineralization streaky and impregnated ores have been met in the peripheral parts of ore bodies. The cemented, subgraphical, emulsioned, and replacement types of ore structures are distinguished. According to the chemical composition, three industrial types of ores, namely the prevailing lead type and lead–zinc types, have been identified. The polymetallic ores of the Gyumushlug deposit are typical hydrothermal formations being concentrated under conditions of shallow depths and low temperatures.

The deposit has been explored by underground mining in combination with drilling. The reserves have been estimated. The deposit has been exploited since 1955, and up to now, the reserves of the I, II, and El ore areas have been nearly worked out. The ore-processing capacity of the Gyumushlug processing plant used to be at around 50 t per day. The detailed geological prospecting and mineral exploration have identified further prospects of sulfide mineralization in the southeastern flank of the IV ore zone of the deposit. The reserves here have been estimated and the underground mining is visible from a single shaft. At present, the exploitation works have been suspended due to technical reasons. The remaining reserves as of January 1, 1991, were 133,000 tons of ore or 5800 lead metal.

2.2.2.2 Cobalt

Cobalt mineralization is closely associated with magmatic activity and has been found in many tectonic zones of Azerbaijan (Azizbekov et al. 1972; Atlas 2000; Ismailzadeh et al. 2005, 2008). The cobalt deposit of the Dashkesan ore region is paragenetically associated with the Dashkesan polyphase granitoid massif of the Upper Jurassic age. The deposit has been studied in details by mineral exploration

and has been partially worked out in the Lok-Garabagh zone. Cobalt mineralization has also been observed in sulfide ores of the Goshgardagh and Chanakhchi occurrences (Bajocian-Bathonian), hematite ore of the Novo-Ivanovka occurrence (Eocene), and others. In the Goycha-Garabagh tectonic zone, the prospects of cobalt mineralization are associated with hyperbasites and magnesite schists of the Late Cretaceous. In the Araz tectonic zone, cobalt mineralization is associated with skarns of the contact area of the Megri-Ordubad pluton of granitoids of the Early Eocene–Late Pliocene age. On the southern slope of the Main Caucasian ridge, cobalt mineralization has been found within the southern limb of the western part of the Tufan anticlinorium. Cobalt mineralization here occurs as isomorphic admixture

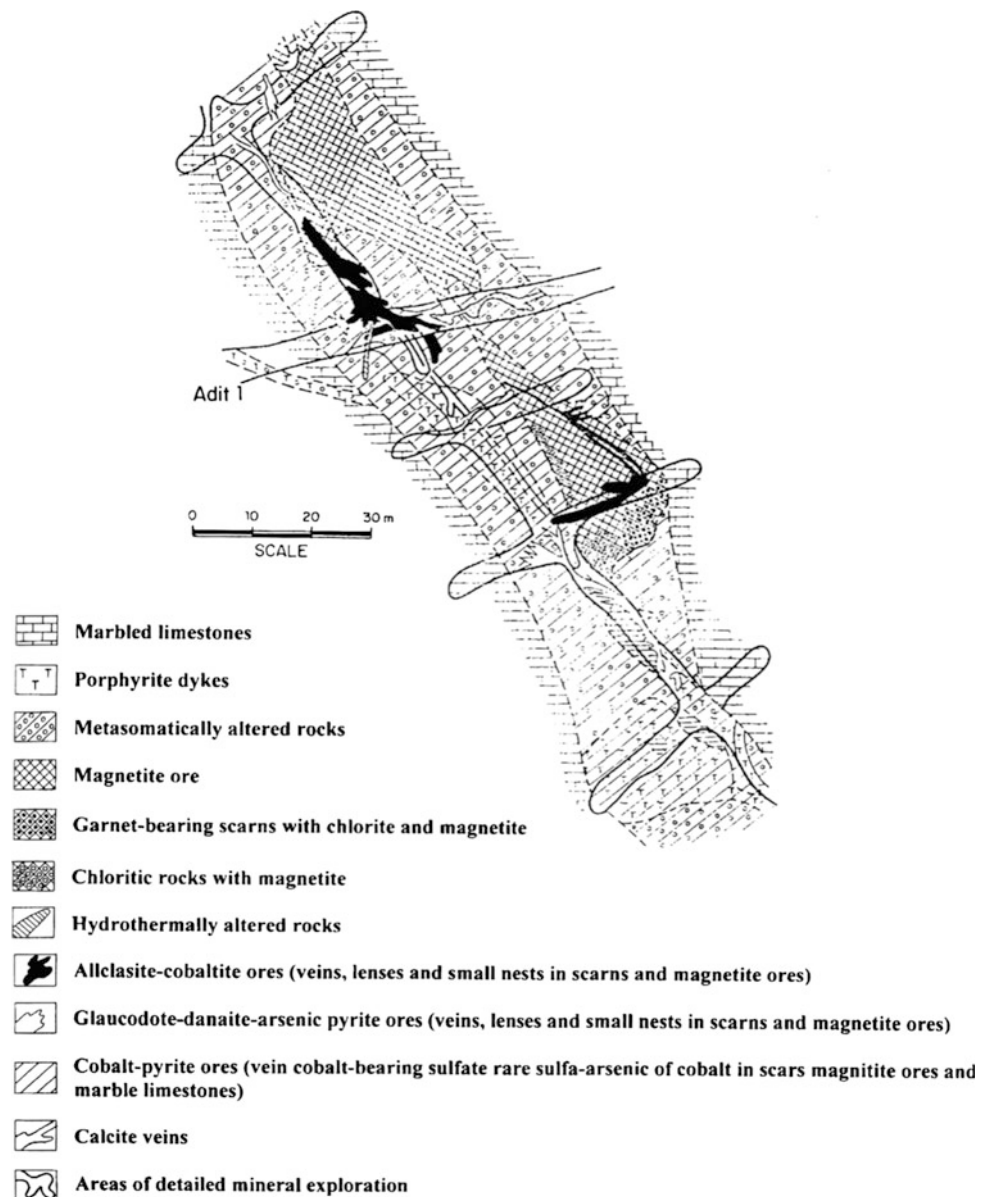
to pyrite–copper–polymetallic ores of the deposits of the southern slope of the Greater Caucasus.

The Dashkesan ore region of the Lok-Garabagh metallogenic belt

The Dashkesan ore region is hosted by the Middle and Upper Jurassic sedimentary, volcanogenic–sedimentary, and volcanic rocks. These rocks are intruded by the Dashkesan polyphase granitoid massif, the exocontacts of which host metamorphic and contact–metasomatic rocks, hornblendes marbles, as well as barren and mineralized skarns.

Numerous dykes of mainly diabase diorite and plagioclase porphyrites have been found in the Jurassic

Fig. 2.30 Geological map of the SE area of the South Dashkesan iron–cobalt deposit



sedimentary rocks containing the intrusive massif. The presence of dykes inside of the granitoid massif is very rare. The main tectonic element is the Dashkesan anticline of the west–northwestern direction and associated numerous tectonic dislocations of variable age. Cobalt mineralization is also known to occur in the form of cobalt sulphoarsenide in the Dashkesan iron deposit of ore and in hydrothermal ore bodies beyond the skarns zones in the north deposit. Cobalt mineralization has been also found in a dispersed form in magnetite and as isomorphic admixture in pyrite.

By structural–geomorphological features and mineral associations, the following types of cobalt deposits and occurrences have been identified: (a) steeply dipping zones with sulphoarsenic cobalt mineralization (the north deposit of the Dashkesan ore region); (b) lenses and nests of sulphoarsenic cobalt concentration in magnetite skarns (the northeastern iron ore deposit); (c) steeply dipping zones bearing lenses and nests sulphoarsenic cobalt mineralization (Amamchay area); and (d) lenses and nests of cobalt–pyrite and sulphoarsenic cobalt mineralization in magnetite skarns (the South Dashkesan (Fig. 2.30) and Damir deposits).

The Amamchay cobalt deposit

The Amamchay cobalt deposit is located to the southwest from the South Dashkesan deposit. The character of ore mineralization has common features with that within the “north” and “northeastern” deposits. The deposit is hosted by marbled limestone of the Tusitanian suite of the Upper Oxfordian–Lower Kimmeridgian age up to 250 m thick.

Magnetite skarns series occurs in the upper section of limestone being cut by numerous dykes of porphyrites of the northwestern and, rarely, northeastern directions. In some places, brecciated and fractured matrix of dykes is substantially replaced by magnetite exposed to chloritization, epidotization, carbonatization, and pyritization, with associated cobalt mineralization. Some zones contain only cobalt mineralization along dykes without magnetite skarn mineralization. The most intensive cobalt mineralization up to 30 m thick has been found to occur in tectonically crushed and reworked areas of the deposit being a result of intensive tectonic activity and crosscutting dykes. Cobalt grade varies from 0.004 to 0.95 %. Cobaltite is met in a disseminated form, as fissure fillings and separate crystalline aggregates. Other ore minerals are pyrite, chalcopyrite, safflorite, hematite, and molybdenite.

The Goycha-Hakeri metallogenic belt

Cobalt mineralization within this metallogenic belt has been identified in all types of magnesite schists of ultrabasic rock development in the Kelbadjar region, where the cobalt

content varies from 0.001 to 1 %. It has been found that an increase of cobalt content in ultrabasic rocks is associated with an increase of magnesite. The maximum cobalt concentrations have been observed in olivine and less in enstatite. The increased cobalt content has been also observed in serpentinites in comparison with source peridotites.

The Ordubad-Zangazur metallogenic belt

Cobalt mineralization of the Kilit-Ketan occurrence in the Ordubad ore region has been found in exocontact of the Megri-Ordubad granitoid massif. The cobalt occurrence is hosted by the Upper Cretaceous sandy–argillitic series of the Lower Turonian, marly–argillitic series of the Lower and the Upper Coniacian, limestone of the Upper Coniacian, tuffogenous series of the Lower Santonian, limestone of the Upper Santonian, and marly–argillitic series of the Campanian age. Metasomatic rocks such as marbles, hornfels skarns, and epidotes were formed as a result of intensive magmatism in a strip from 200 to 1000 m long.

Cobalt-bearing sulfide mineralization is confined to the external margin of the Upper Cretaceous rocks surrounding the Megri-Ordubad intrusive massif, where mineralization has been traced over a distance of 2.5 km. Copper–cobalt mineralization is associated genetically with the post-magmatic activity of the Megri-Ordubad pluton. Epidote–garnet skarns of the most promising Ketam zone contain lenses, nests, and impregnations of sulfides. Mineral exploration by underground horizontal adits has been terminated due to security instability on the territory of the Nakhchivan AR.

2.2.2.3 Molybdenum

The deposits and occurrences of molybdenum ores in the Lesser Caucasus are concentrated within the Ordubad and Dalidagh ore regions (Azizbekov et al. 1972; Kerimov and Kerimov 1974; Babazadeh et al. 1990; Ismailzadeh et al. 2008). The majority of ore deposits of the copper–molybdenum formation are concentrated within the Megri-Ordubad intrusive complex confined to a large geosynclinal uplift and representing the median massif in the definite stages of the geologic evolution. Molybdenum mineralization is mainly developed in intersection of longitudinal and northwestern faults with cross-faults of the northeastern direction. The large Misdag, Alchalig, and Diakhchay copper–molybdenum deposits of industrial type are mainly characterized by stockwork type of mineralization with the leading copper component.

Deposits with industrial molybdenum mineralization with a dominant molybdenum component of vein type are represented by either quartz veins and fissure fillings or veinlets

and stockworks with impregnated mineralization. The thickness of veins and veinlets varies from 0.1 to 1.0 m reaching a thickness of up to 2 m in swelling. The molybdenum content varies from 0.2 to 1.1 %. Associated ore minerals are copper (0.02–1.73 %), rhenium (0.04 % in molybdenite), selenium (0.06 %), and tellurium (0.02 %). The molybdenum deposits, unlike the copper–molybdenum deposits of the region, have limited reserves from 100 to a range of 1500–2000 tons of molybdenum metal.

The Paragachay deposit

The Paragachay molybdenum deposit is located in the central part of the Ordubad ore region and hosted by gabbro–diorites, diorites, and dykes of lamprophyres and diorite–porphyries. The mineralization is tectonically controlled by sublatitudinal (NW—280°–310°) and submeridional (NE—20°–60°) faults. The mineralization in the form of veins and veinlets is concentrated in sublatitudinal faults. Ore-bearing gabbro–diorites and diorites have been subjected to intensive hydrothermal–metasomatic alteration. The formation of ore mineralization at the deposit has occurred in the following five stages: (a) quartz–molybdenite early stage productive for molybdenum; (b) quartz–molybdenite–chalcopyrite stage productive for molybdenum and copper; (c) quartz–pyrite–chalcopyrite stage productive for copper; (d) quartz–galena–sphalerite stage; and (e) latest carbonate stage. Four quartz–molybdenite veins of industrial importance, namely Glavnaya, Novaya, Pyataya, and Srednya, have been exploited within the Paragachay deposit.

Unlike the Glavnaya (Bash or Major) vein, where the dyke-related mineralization demonstrates its continuity, the mineralization in the last three veins discontinues along their strike. The prospects of the Paragachay molybdenum deposit are associated with the lower horizons of the Yeni and Besh veins which can be opened by mine or adit from 2 to 2.5 km long. At present, due to unfavorable economic–technical conditions, the exploitation works have been suspended. The remaining mineable reserves of molybdenum as of January 1, 1999, are about 54,000 tons of molybdenum ore or 256 tons of molybdenum metal.

The Urumis molybdenum deposit

There are known to exist ten quartz–molybdenum veins distributed in the endocontact zone of the Megri–Ordubad pluton. The deposit occurs in gabbro–diorites, granodiorites, and quartz syenite–diorites with cutting dykes of granodiorite–porphyrites, diorite–porphyrites, lamprophyre, aplite, and pegmatites. Tuffs and tuffites of the Eocene in the southeastern part of the deposit have been changed into secondary quartzites in the contact zone with the intrusion.

The veins strike to the west–northwest at 270–290° and dip to the southwest at the angle from 50° to 70°. The average thickness is 0.4 m. The molybdenum content is from 0.001 to 0.1 % and that of copper from 0.06 to 0.7 %. The veins consist of milky-white quartz containing impregnations of pyrite, chalcopyrite, and molybdenite. Secondary hydrothermal alterations are expressed by silicification and sericitization. The veins have a banded texture and lens-shaped structure.

The northwestern part of the deposit contains mainly copper vein mineralization, which has been explored by short underground adits. The tense concentration of copper-bearing quartz veins within a narrow strip of 400 m wide and a shallow erosion depth suggests good development prospects. Mineral exploration also expects a possible increase of thickness and content of molybdenum in the southeastern flank of the deposit where mineralization has not been effected by erosion.

The Gekgyundur deposit

The deposit is hosted by intrusive rocks of the Megri–Ordubad pluton represented by rocks of the early adamellite intrusive phase and late quartz syenite–diorites and porphyry granosyenites being crosscut by dykes of diorites and granite–porphyries. The tectonic structure of the deposit is defined by the major Ordubad fault which divides two intrusive phases and the Vardanichay fault of meridional direction with adjacent zones of hydrothermal alteration.

The thickness of these zones with molybdenum mineralization varies from 0.5 to 1.2 m where molybdenum content is from 0.01 to 2.5 %. The zones are composed of loose chloritized and epidotized rocks. The molybdenum mineralization, except zone No. 1, is being controlled by the Vardanichay fault. The mineralization at zone No. 1 was traced up to 360 m deep on four horizons every 60 m by adits and by underground drilling wells. In some intervals of two horizons, this zone contains the industrial accumulations of molybdenum. The average thickness is 1.1 m, and the average grade of molybdenum is 0.44 %. Reserves are so far limited, while the identified further exploration is required to judge its economic prospects. The stockwork type of molybdenum–copper mineralization was suggested at a depth in the area of the Vardanichay fault, where the molybdenum content in individual samples from quartz stringers varies from 0.01 to 2.5 % and that of copper from 0.2 to 2.5 %.

The Dalidagh ore region

Molybdenum mineralization of this region is closely associated with the post-magmatic activity of the Dalidagh

intrusive massif. The early copper–molybdenum and most later polymetallic ore formations have been distinguished within the deposit. Structural position and localization of these ore formations are defined by a series of dykes which separated the enclosing rocks into two blocks.

The typical Teymuruchandagh molybdenum deposit of the Dalidagh ore region is confined to the northwestern exocontact of the Dalidagh granitoid intrusive massif composed of porphyry granosyenites, quartz syenite–diorites, and syenite–diorites. The regional west–northwest trending fault of a thrust nature with amplitude of 400 m was traced by the Istisu mineral springs and confined to the axis of the Dalidagh anticlinorium. The deposit is subdivided into the northwestern and southeastern blocks by a meridional fault. The most part of a subsided block is covered by thick flows of the Quaternary andesite–basaltic lava. Quartz molybdenum veins are confined to ruptures of shearing and fissures along the fault within the uplifted northwestern block.

Altogether, 41 quartz veins and zones of hydrothermally altered rocks have been identified within the deposit. The veins strike northeast with a variable limb from 30° to 85° and dip to the southeast and sometimes to the northwest at angles from 50° to 90°. Ore veins are mainly controlled by pre-ore dykes of diorite porphyrite composition. The thickness of veins and zones varies from 0.1 to 1.8 m. Molybdenum content varies from 0.01 to 0.2 %, copper from 0.01 to 0.3 %, lead from 0.001 to 1.83 %, and zinc from 0.01 to 0.74 %.

Veins of a lens form are separated in some places by stepped faults with amplitude of displacement from a range of 0.5–2.0 m up to 10 m. Veins are composed mainly of quartz; the main ore-forming minerals are pyrite, molybdenite, galenite, and sphalerite. Mineralization is represented by nests and stringers in quartz mass. Veins have brecciated and banded texture owing to imposition of late quartz–polymetallic and quartz–carbonate stage on quartz–molybdenite stage of mineralization. The secondary minerals are chalcocopyrite, secondary copper sulfides, bornite, covellite, chalcocite, anglesite, cerussite, malachite, azurite, and limonite. Mining, technological, hydrogeological, and the relief conditions of the deposit are favorable enabling to develop the deposit by horizontal underground mining.

2.2.2.4 Alunites

Alunite resources are known to exist in the Zaglik deposit and the Seifali and Dugli occurrences (Azizbekov et al. 1972; Ismailzadeh et al. 2008).

The Zaglik deposit

The Zaglik alunite deposit is confined to the northeastern side of the Dashkesan syncline composed of volcanogenic

and sedimentary formations of the Middle and Upper Jurassic being intruded by the polyphase Upper Jurassic granitoid massif. The deposit is known since the Middle Ages, when alum has been produced from alunites. The host volcanosedimentary sequence upward includes the Upper Bajocian porphyrites, agglomeratic lava, yellow tuff–sandstone, tuff–conglomerate, and tuff–sandstone which are overlain by a thin bed of argillites and sandstone. The cross section is followed by carbonate rocks of the Oxfordian and Lizitonian suites being covered by yellow tuffites and extrusive–effusive diabase porphyrites. The topmost volcanogenic section is subdivided into lower tuffogenic, lower effusive, upper tuffogenic, and upper effusive series with a total thickness of 600 m. The lower tuffogenic series of 250 m thick was subjected to intensive metasomatic reformations during the intrusive magmatism.

The composition of metasomatized rocks is changing over a distance from the intrusive massif reflecting the changes of a temperature regime. The metasomatic rocks are associated with the intrusion host magnetite skarns mineralization. Westward, these rocks transfer to silicified rocks and then into the alunites series with some propylitization in the transition zone. Based on this zonation, the deposit has been subdivided into (a) northwestern alunite–iron ore area; (b) Alunitdagh alunite–siliceous area; (c) Kirvadagh alunite–propylite area; (d) Zaglik alunite area; and (e) Western Zaglik kaolinite–alunite area.

The alunite series of rocks has a gentle (10°–15°) dip to the southwest. Thrusts up to 30 m uplifted the southern blocks in relation to the northern ones. Based on degree of alunite, morphology, composition, and admixtures of ores, eight textural and structural types of mineralization have been distinguished in the alunite series of rocks. Besides alunite, the primary minerals of alunite rocks are kaolinite, propylite, quartz, hematite, and limonite. The secondary minerals are chalcedony, opal, monothermite, zunyite, pyrite, diaspore, halloysite, corundum, fluorite, magnetite, ilmenite, sericite, chlorite, and barite.

The thickness of the upper alunite section varies from 4 to 39 m with an average thickness of 19 m. It has a limited distribution and pinches out within a short distance. The lower alunite section of the deposit has a wide distribution. Main minerals of industrial significance are alunite and quartz (95 % of the volume) and clayey minerals (5 %) represented by kaolinite, dickite, and halloysite. Less important weakly alunitized rocks are represented mainly by quartz, clayey minerals, volcanic glass, and hematite. Hydromicas, chlorite, calcite, and pyrite are observed in some places. Due to economic and technical reasons, the exploitation of the Zaglik alunite deposit is currently suspended. The remaining reserves were estimated as about 160,000,000 tons.

The Seifali alunite occurrence

This occurrence is located in the Shamkir region and confined to hydrothermally altered rocks of the Middle Jurassic (Bathonian) of the Alabashli iron ore deposit. Similar to the above Zaglic deposit, the alunite mineralization is likely to be hosted by the Upper Jurassic rock series. Major genetic types of mineralization are (a) titanium–magnetite sandstone; (b) intensively hematitized volcanogenic rocks; and (c) alunitized and kaolinized volcanogenic rocks. The cross section of this occurrence demonstrates a vertical zonation with distinguished downward in layers of (a) alunite–quartz with little content of dickite and kaolinite; (b) alunite–dickite–kaolinite–quartz; (c) argillite–sericite; and (d) propyllites. Gradual transitions are observed between these zones. The alunite content varies in a wide range from 9.52 to 57.0 %.

2.2.2.5 Bauxites

On the territory of Azerbaijan, bauxites have been initially found in the Sadarak region of the Nakhchivan AR in the Arpachay River basin. The mineral exploration within this river basin has identified the existence of the Geransgalasi, Gabakhyl, Myunkhbalal-oglu, Gabakdagh, Sadarak, Danzik, and Kyarki bauxite occurrences. The occurrences are hosted by terrigenous–carbonate formations of the Devonian and Carboniferous systems and carbonate formations of the Permian and Triassic systems. Magmatism is weakly pronounced and represented by dykes and layered injections of diabase and gabbro–diabase. Bauxites and bauxite-bearing rocks are confined to the lower section of the Permian formation occurring on various rock formations of the Lower Carboniferous. The bauxite-bearing section is overlapped and underlies everywhere by carbonate rocks and outcrops on the surface in a form of two strips.

The specific feature of bauxites and bauxitic clays is their red and reddish brick color, clearly distinguished on a background of dark gray and black limestone. Bauxite-bearing rocks of gray and light-gray color are also met. The main morphologic type are layers with lens-shaped bodies. Leguminous, oolitic, and polytomorphic structures are typical. Conglomerate and brecciated varieties are met in some places. The bauxite-bearing layer has been traced over a distance from 1.5 to 2 km with a thickness from 2 to 13 m.

The Geran-galasi occurrence

The occurrence has been found on the left bank of Arpachay River, south of Ashagi Yaidji village in the periclinal part of the anticlinal fold. Two outcrops of bauxites are represented by red, reddish brown, gray, and greenish gray varieties in the upper part of bauxite-bearing section. The bauxite-bearing lateritic profile is represented by clayey,

loose, and conglomerated rocks with typical leguminous, leguminous–oolitic, and pelitomorphic structures. The thickness of the profile varies from 2 to 8 m depending on a volume of loose sediments. The distribution of bauxites in the bauxite-bearing section is uneven. The lower part of the section is dominated by red bauxitic clays which tend to increase gradually upward reaching the even ratio with legumes in the middle part of the section. In the upper part, legumes dominate over cementing material. Bauxites with a silica module over 2.1, allites, and sialites are the major rocks in the section. The content of Al_2O_3 varies from 30 to 57 %. Mineralogically, bauxites of the Nakhchivan region are of metamorphosed type where the large part of goethite transformed into hematite, gibbsite discontinued to exist as trihydrate of aluminum and boehmite–diasporic association with corundum admixture had originated in bauxites. This occurrence is of mineralogical interest only.

2.2.2.6 Copper

Copper mineralization is the most widespread type of mineralization in the metallogenic provinces of the Azerbaijanian part of the Greater and Lesser Caucasus (Azizbekov et al. 1972; Atlas 2000; Ismailzadeh et al. 2005, 2008). Copper deposits are involved in all stages of metallogenic development of Azerbaijan and are characterized by a wide range of formational types. The most productive types of copper mineralization are pyrite and porphyry copper types. Copper deposits on the southern slope of the Greater Caucasus are of massive pyrite type. Copper deposits within the Lesser Caucasus are typical to all tectonic zones of Azerbaijan except the Goycha-Garabagh zone with its ophiolite belt where pyrite and porphyry copper formation types are dominant.

The metallogenic province of the Greater Caucasus

Copper deposits within the metallogenic province of the Greater Caucasus are concentrated mainly in the Zagatala-Balakan ore region. The proven reserves and resources of copper ore are associated with massive pyrite and copper–lead–zinc–pyrite types represented by stratiform deposits in sandy–shaley formation of Jurassic age (Kurbanov et al. 1967; Agayev 1982; Akberov et al. 1982; Azizbekov et al. 1972; Kurbanov 1982).

The Zagatala-Balakan ore region proved to host the large Filizchay and medium Katsdagh and Katekh deposits of pyrite–polymetallic ores of the copper–lead–zinc–pyrite type. Mineable reserves of the Sagator, Jikhikh and Karabchay deposits of copper–zinc ores of the copper–zinc–pyrite type have also been estimated. More detailed data on these deposits are given in the Lead and Zinc section. The industrial development of these copper deposits will be

feasible only by integrated utilization of large reserves of pyrite–polymetallic deposits. The extensive mineral exploration program for copper–pyrite mineralization within the southern slope of the Greater Caucasus has been launched following the discovery of the Mazimchay deposit.

The Mazimchay copper-pyrite deposit

The Mazimchay copper–pyrite deposit is located 20 km from Balakan city of Azerbaijan near the confluence of Balakhanchay and Mazimchay rivers at the altitude from 1500 to 2200 m. The deposit occupies an area from 6 to 7 km in a highly mountainous area with relief uplifts from 200 to 1200 m. The Mazimchay deposit is located within a distance of 500–600 m to the south from the Katsdag pyrite–polymetallic deposit. The combined proved reserves of these two deposits can serve as the additional raw material base of the Filizchay mining and processing enterprise in the future.

Tectonically, the Mazimchay deposit is located at the intersection of the Tufan and Sarbash tectonic zones of the Greater Caucasus being separated by the Kekhamedan deep-seated fault of overthrust nature of 1.5 km wide. Numerous crosscutting sills and dykes of diabase porphyrites, liparite–dacites, and gabbro–diabase hosting copper–pyrite and pyrite–polymetallic ores have been found within the deposit. The deposit is confined to the southern overturned limb of the Katsdag anticline composed of sandy–shaley formations of the Katsdag series of the Pliensbachian and Toarcian suites of the Lower Jurassic. Coarse-laminated rocks of this series are saturated by magmatic formations such as lava–basalts, spilites, and diabases and have been subdivided into three seams.

The lower seam is represented mainly by dark-gray clayey shales with separate beds of laminated sandstone. In the top of the seam, there are pockets of thin flysch. The middle seam consists of clayey shales enriched by accumulations of concretions, syngenetic with sedimentation, and globular segregations of pyrite and pyrrhotite of economic interest. The upper seam is characterized by rhythmic intercalation of sandstones, aleurolites, and clayey shales with an increased thickness of sandstones upward of the section. The total thickness of the section varies from 1950 to 2200 m.

The structure of the deposit is tectonically complex. Rocks of the Katsdag series are crumpled in longitudinal linear folds and cross-flexures intensively complicated by cleavage along axial plane, zones of plastic flow, and tectonic faults. Faults of sublatitudinal and northwestern extension are united into two systems. The sublatitudinal faults are generally conformable with a lamination of overthrusts being concentrated in a strip of 500 m wide in parallel to a large

Kekhamedan fault, passing to the south of the deposit. Upthrusts–overthrusts with a large thickness enclose dykes and sills of diabase and ore-bearing zones including that of the Mazimchay deposit. The thick ore-bearing zone of the Mazimchay deposit is confined to a zone of hydrothermally altered and crumpled rocks with a stringer-impregnated mineralization of pyrrhotite–chalcopyrite composition. This mineralized zone of sublatitudinal direction has been traced over a distance of 5 km with distinct swells and pinches along its strike and dip. The thickness of two separate ore bodies of vein type with saturated stringer and fissure filling mineralization varies from 0.6 to 14 m.

Lens-shaped bodies of massive ore have also been observed within this zone. As a rule, massive pyrrhotite–chalcopyrite ores transform into stringer and fissure filling/impregnated ores of the same composition along the strike of this zone. Morphologically, ore bodies have tape and lens form with slightly pronounced contacts and metasomatic processes within enclosing rocks. The grade of copper in ore-bearing dykes is higher than that in ores of sandy–shaley formations.

Pyrrhotite in association with chalcopyrite has been observed as stringers and small lens-shaped bodies and pyrite in a disseminated form. The share of quartz, calcite, ankerite, biotite, and other rock-forming minerals in the fissure-impregnated types of ores is at a range of 80–85 %. The grade of major mineral component, copper, varies from 0.55 to 13.3 % with an average grade of 2.33 %. Associated minerals are cobalt, bismuth, gold, silver, and sulfur. Technological feasibility study on flotation enrichment of a 500 kg sample has proved recovery of 97.6 % of copper in 27.2 % copper concentrate and pyrrhotite–pyrite product with 37 % of sulfur content and 38.1 % of sulfur extraction. The associated metals of copper concentrates are 50.2 % of gold, 59.1 % of silver, 73.5 % of bismuth, and 63 % of cobalt. The combined share of noble metals (gold, silver) and bismuth in copper concentrate substantially increases the value of this product.

The detailed mineral exploration has been conducted by a combination of underground mining openings and adits, drilling, and underground geophysics. The inferred reserves of copper ore and copper metal have been estimated. By reserve/resource categorization scheme, the deposit is rated as a medium-class copper deposit. The deposit is planned for development by underground mining upon availability of investment.

The metallogenic province of the Lesser Caucasus

The metallogenic province of the Lesser Caucasus hosts the copper deposits of massive copper–pyrite and porphyry copper types as well as polymetallic deposits with a major

copper component of various genetic types (Kerimov 1964; Azizbekov et al. 1972; Kerimov and Kerimov 1974; Aliyev 1976; Kerimov et al. 1986; Babazadeh et al. 1990; Kerimov et al. 1996).

The Lesser Caucasus is generally characterized by a complex polymetallic and polycyclic metallogeny being defined by various patterns of spatial distribution of various metals including copper, lead, zinc, molybdenum, mercury, antimony, and gold. The Lesser Caucasus is known as one of the ancient areas of copper ore development. At present, numerous places of ancient production and reworking of copper ores at the Alaverdi, Shamlig, Miskhana, Gedabek, Zangazur, and Shanardara ores are known to exist within the Azerbaijanian part of the Lesser Caucasus.

In the proximity to the Azerbaijanian part of the Lesser Caucasus, development of the Gafan and Alaverdi copper-pyrite, Gafan and Agarak copper-molybdenum deposits in Armenia and the Madneul copper deposit in Georgia is being continued. The large-scale geological mapping and mineral exploration programs within the Azerbaijanian part of the Lesser Caucasus have proved high prospects for copper and copper-bearing polymetallic mineralization. Based on the results of these works, the following prospective metallogenic zones have been delineated:

- The Lok-Garabagh metallogenic belt includes the Gazakh, Gedabek, Dashkesan, Murovdagh, Mekhmana, and Garabagh ore regions hosting the Gedabek, Garadagh, Khar-Khar, Goshgarchay, Gyzybulagh, Damirli, Khachinchay, and Zardaryn deposits of massive copper-pyrite, porphyry copper, and complex polymetallic ores.
- The Goycha-Hakera metallogenic belt includes the Kelbadjar and Lachyn ore regions.
- The Kelbadjar-Gochaz metallogenic belt with its Dalidagh ore region.
- The Gafan metallogenic belt.
- The Ordubad-Zangazur metallogenic belt with the Ordubad ore region hosting the Diakhchay, Shalala, Geygel, Paragachay and other deposits of porphyry copper and copper-molybdenum ore.

Brief overview of major types of copper deposits in the above-mentioned ore regions of Azerbaijan is provided below.

The Gedabek ore region

The Gedabek copper-pyrite deposit with associated gold is located to the northwest of Gedabek district center in the exocontact zone of the Gedabek granitoid massif of the Jurassic-Early Cretaceous age and gabbroids of the Late Jurassic age.

The deposit is hosted by volcanogenic formations of the Lower Bajocian, the Upper Bajocian series of quartzose plagioporphyrries, effusive pyroclastic formations of the Bathonian stage, strongly schistosed tuffogenous-sedimentary deposits of the Callovian-Oxfordian stage, and carbonate deposits of the Lusitanian stage. As a result of magmatic activity, the carbonates of the Lusitanian stage have been transformed into vesuvian-garnet-wollastonite and mixed skarns. The process was accompanied by the formation of quartz diorites and numerous dykes of plagioclase, diorite, and diabase porphyrites and, rarely, of aplite and kersantite. Tectonically, the deposit is confined to the anticlinal fold of the northwestern direction complicated by parallel faults and fractures. The complex tectonic position of the deposit has favored concentration and localization of various mineralization. The mineralization was mostly found in secondary quartzites of mono-quartzites of mono-quartz, quartz-sericite and quartz-kaolinite facies, and, partially, hornfels around a local volcanoplutonic structure. These ore-bearing secondary quartzites of sedimentary and sub-volcanic nature are overlaid by a series of epidotized, keratinized, and chloritized formations and their pyroclasts, frequently with impregnated sulfide mineralization represented mainly by pyrite and, rarely, chalcopyrite.

Morphological types of ore bodies are stocks and lenses of high-grade massive pyrite ores and large stockworks of stringer-impregnated fissure filling ores of poor grade. Stocks and lenses of massive ores are represented by covellite-bornite-chalcosine-chalcopyrite-pyrite association of minerals, sometimes with galenite and sphalerite. Stringer-impregnated ores of large stockworks contain chalcopyrite-chalcosine-quartz-pyrite association, in some places, with barite, covellite, bornite, and native copper. Major metals of copper-pyrite ores are copper, gold, and silver, and associated minerals are lead, zinc, molybdenum, cobalt, and others. Six individual stocks with a length from first tens to several hundred m and a width up to several tens of m are known within the deposit. These stocks have been exploited by the Siemens Company before 1917. The stringer-impregnated type of mineralization with relatively poorer grades of metals in stockworks usually frames stocks of high-grade ores. Limonite, sulfur, melakonite, manganese oxides, malachite, azurite, chrycolite, gypsum, melanterite, and epsilite are found in the oxidation zone of ore bodies. A zone of cementation is rather distinctive containing covellite, rare chalcosine, and native copper with native silver and cuprite in some places. Substantial remaining reserves of gold, copper, and silver have been evaluated in mine dams and tailings of ancient and old mining workings of the deposit.

The scale of stringer-impregnated type of mineralization with presence noble metals, favorable, geographic,

economic, and mining-technical conditions define high prospects of the Gedabek deposit for mining investment.

The Novo-Gorelovka deposit

The Novo-Gorelovka deposit of copper–zinc ores is known since the end of the nineteenth century in the Gedabek region. The deposit is hosted by the Upper Bajocian quartz plagioporphyrries as well as volcanoclastic and volcanic formations of the Bathonian stage of the Middle Jurassic with a total thickness up to 600 m. This volcanogenic formation is intruded by the Novo-Gorelovka Late Jurassic granitoid massif composed mainly of quartz diorites. In the exocontact zone of this massif, rocks of the Bathonian suite are intensively silicified, sericitized, epidotized, and ferruginated. Tectonically, the deposit is confined to the anticlinal fold of the second order, dislocated by the Novo-Gorelovka fault of a dome structure. The fault is likely to play an essential role in localization of mineralization.

The ore body of a stock shape contains mainly sphalerite and chalcopryite. Marcasite, pyrrhotite, galenite, chalcocite, and hydroferrum oxide are the secondary minerals. Quartz and barite are major cementing minerals. The texture of ore is massive. Chalcopryite forms nests and stringers. The deposit is genetically associated with post-magmatic activity of the Novo-Gorelovka intrusive massif. The deposit requires additional mineral exploration to judge its economic prospects.

The Battibulagh copper–mercury deposit

The Battibulagh copper–mercury deposit is known to occur in the Gedabek ore region since 1850. Mineral exploitation has been conducted by Siemens Company during 1910–1911 and 1916–1917. The deposit occurs in volcanogenic formations of the Lower Bajocian suite with a thickness more than 300 m being intruded by the pre-Bathonian Atabek-Slavyan plagiogranites. Intensive hydrothermal alteration of volcanogenic formations is represented by sericitized, silicified, kaolinized, and epidotized rocks. Rocks of vein type are represented by dykes of diabase porphyries and, rarely, of diabase. Tectonically, the deposit is confined to the northern limb of anticlinal fold of latitudinal direction. The Gedabek ore-controlling fault of submeridional direction plays an essential role in the structure of the deposit and localization of mineralization.

The impregnated type of ores is mainly of quartz–pyrite composition and that nest-vein type of enargite–barite composition. Impregnated ores are widespread though the intensity of mineralization is gradually decreasing with a depth. Major ore minerals are chalcopryite and enargite. The nest-vein type of mineralization forms irregular nests, lenses,

and veins among quartz–sericite rocks. The main ore minerals are enargite, and pyrite, chalcopryite, galenite, sphalerite, and barite are found rarely. Main cementing minerals are sericite, rarely quartz, and kaolinite. Enargite–barite ores are characterized by a limited development on a depth yielding to impregnated pyrite ores. The deposit requires further exploration to identify its economic prospects.

The Garadagh porphyry copper deposit

The Garadagh porphyry copper deposit is located in the Gedabek ore region, 600 m to the west–southwest of Chanlibel village and 30 km from the adjacent Shamkir railway station. The deposit is confined to the eastern part of the large Atabek-Slavyan massif of plagiogranites which serves as an intrusive frame of porphyry copper system. The area of the deposit is characterized by a complex geological structure and is composed of andesites, andesite–porphyrites, liparite–dacite porphyries, and their rudaceous facies of the Upper Bajocian age. These volcanic rocks are intruded by the Atabek-Slavyan massif of plagiogranites, small stocks of quartz–diorite porphyries, and subvolcanic bodies of liparite–dacite porphyries and are crosscut by a series of dykes of diabase and quartz–diorite porphyrites. Tectonically, the area of the deposit is confined to the knot of intersection of the Maarif-Khar-Khar-Chanlibel fault of submeridional extent with faults and fractures of the north-eastern and the northwestern orientation, which defined its stockwork inner structure.

The thickness of the cementation zone varies within 20–80 m reaching 130 m in some places. The zone of secondary pyrite enrichment is of economic interest. The grade of copper and molybdenum varies from 0.4 to 1.0 % and from 0.001 to 0.1 %, respectively. Small nests and stringers of turquoise of practical interest have been observed at the boundary of the zone of leaching and the zone of cementation. The zone of primary ores is represented by secondary quartzites, partially silicified diorites–porphyrites, plagiogranites with impregnated thin stringers and small nests of pyrite, rare chalcopryite, and more rare—molybdenite.

The major metals of economic interest are copper and molybdenum, with associated gold and silver. Exploration drilling has contoured the ore body with a variable barite copper grade from 0.3 to 0.45 %. The thickness of the productive section varies from 200 to 250 m with an average content of copper from 0.64 to 0.68 % and that of molybdenum from 0.005 to 0.006 %. By reserve/resource categorization scheme, the deposit is regarded as a medium by its reserves and as a large deposit by its projected resources. Feasibility studies on floatation scheme of ore enrichment indicate the extraction of combined copper–molybdenum concentrate with a recovery of copper at 88 % and

molybdenum at 50 % with associated gold and silver. Laboratory tests on heap-leaching of ores of the Garadagh deposit indicate a good recovery of copper with low grades.

The deposit is planned for development by open-pit mining. Favorable geographic and economic conditions place the deposit into a category of highly prospective targets for investment of exploitation works. The Gedabek ore region also hosts the Maarif, Beyuk-Kalachy, Maschit, and other small occurrences of porphyry copper.

The Murovdagh ore region

The Murovdagh ore region hosts a number of copper and molybdenum, lead, zinc, and other mineral deposits and includes the Goshgarchay and Gyzyt-Arkach ore fields. The Goshgarchay ore field includes the Goshgarchay deposit, Goshgardagh occurrence of porphyry copper, and the Chanakhchi and Zivlyan occurrences of copper-pyrite ores. The Gyzyt-Arkach ore field hosts the Gyzyt-Arkach, Kechaldag, Djamilli, Elbekdash, and other occurrence of porphyry copper.

The Goshgarchay ore field

The Goshgarchay ore field is located in the central part of the northwestern flank of the Murovdagh anticlinorium made up of the Lower Bajocian andesite-basalt subformation and differentiated basalt-andesite-rhyolitic formation. The Goshgarchay porphyry copper deposit of this ore field is a typical example of porphyry copper mineralization of the whole Murovdagh ore region.

The Goshgarchay deposit

The Goshgarchay porphyry copper deposit is located within a distance of 10–12 km to the southwest from Khoshbulag village of the Dashkesan region. The deposit is mainly composed of the Bajocian volcanogenic formations being intruded by rocks of the Goshgarchay granitoid massif. Rocks of volcanogenic series are represented by effusive plagioclase-pyroxene, plagioclase, and diabase basalts, andesite-basalts, andesites, and their pyroclasts. Intrusive rocks include gabbro, gabbro-diorites, diorites, quartzose diorites, and porphyry granodiorites. Steeply dipping multiple dykes of diorite, quartz-diorite, and gabbro-diabase porphyrites are cutting the above intrusive and volcanic rocks.

The intermediate zone consists of quartz-sericite-chloritic facies of secondary quartzites, occupying an area of 1200 m in length by a range of 400–600 m in a width. Porphyry copper mineralization of vein-impregnated type is distinctly superimposed on this facies of secondary quartzites. The third external zone is represented by propylitic

facies of secondary quartzites hosting streaky-impregnated stockwork ores and quartz and carbonate veins with disseminated pyrite, chalcopyrite, and molybdenum mineralization.

The stockwork body of the central part of the deposit occupies an area of 0.4 km² in the apical and peripheral parts of the intrusive massif of porphyry structure hosting ten enriched areas of copper mineralization with a copper grade above 0.3 %. The largest area is of 0.12 km² in size. These mineralization zones are hosted and intercalated by barren and slightly mineralized rocks with copper grading up to 0.2 %. These enriched areas on the surface are likely being combined at a depth into a unified ore body of a stockwork type with a complex morphology.

The grade of copper varies from 0.2 to 2.5 % with an average grade of 0.4 % with associated molybdenum, gold, silver, and cobalt. The grade of gold in some intervals is more than 1.0 ppm and that of silver is from 2.5 to 40 ppm, which are well correlated with a copper content for porphyry type deposits.

Along with a stockwork type of mineralization in the southern and southeastern parts of the deposit, the vein type of copper mineralization indicates some prospects of buried porphyry mineralization. The rare “Mantas” type of mineralization typical for numerous porphyry copper deposits of Peru and Chile is represented by chalcosine in association with quartz, calcite, and epidote which fill cavities has been observed in the deposit. The vertical profile of mineralization varies from 600 to 700 m. This deposit of economic interest is a target for investment and development.

The Garabagh ore region

The Garabagh ore region includes the Gyzybulagh, Mekhmana, Gyulyatag, Damirli, Khachynchay, Agdara, and Gazanchay porphyry copper and the Khazinadagh copper-pyrite deposit and occurrences. The ore region is located in the southeastern part of the Lok-Garabagh tectonic zone and confined to a knot of intersection of the Agdam anticlinorium and the Dalidagh-Mekhmana uplift. The Garabagh ore region is characterized by a spatial linkage of various genetic and morphological types of sulfide mineralization. The ore region is hosted by the Middle–Upper Cretaceous sedimentary and volcanogenic-sedimentary rocks dislocated by faults of the northwestern, northeastern, and sublatitudinal directions and by intrusive massifs. The Damirli, Gyulatağ, Khachinchay, and Agdara deposits and occurrences of porphyry copper are confined to exo- and endocontact zones of the Djanyatag intrusive massif of gabbro-diorite-granodiorite formation which intruded the Jurassic volcanites and, in some places, is unconformably overlain by more recent Cretaceous formations.

The Damirli porphyry copper deposit

The Damirli porphyry copper deposit is located within two km southeast of the Damirli village of the Ashderin district. The deposit is confined to the endo–exocontact zone of the Djanyatag intrusive massif. The mineralization is hosted by silicified and pyritized rocks of the granitoid massif and volcanic rocks of intermediate composition. These rocks are intruded by subvolcanic bodies of andesite–dacite and liparite–dacite porphyries being transformed into secondary quartzites. The structure of the deposit is complex being crossed by a series of closed faults of the northwest–submeridional and northeast–sublatitudinal directions with crosscutting dykes of granodiorite–porphyries, liparite–dacites, andesite–dacites, and diorites.

The deposit is represented by stockwork bodies of fissure filling–impregnated type with pyrite–molybdenite–chalcocopyrite association, sometimes with chalcocine, bornite, and covellite. The area of development of copper mineralization is around a range of 5–6 km² being from 1.8 to 2.2 km wide and more than 3 km long. The deposit also includes six quartz–vein zones with gold sulfide mineralization traced over a distance from 4.5 to 8 km. The grade of gold is up to 5 ppm and that of silver is up to 91 ppm. The grade of copper in fissure filling and disseminated types of ore varies from 0.1 to 0.8 %, molybdenum from 0.001 to 0.2 %, gold from 0.1 to 0.2 ppm, and silver from 4 to 6 ppm.

Mineral exploration by drilling and geophysics has proved the extension of fissure filling and disseminated types of copper and molybdenum mineralization to a depth over 300 m. Given the large reserves of copper ore despite its relatively low grades, the deposit constitutes a target for open-pit mining in the future.

The Khachinchay porphyry copper deposit

The Khachinchay deposit of porphyry copper is located within 9 km northwest of Agdam city in the south–southeastern contact zone of the Djanyatag granitoid massif. The deposit is confined to the archy part of the local Eddikhirman brachyanticline of the Garabag uplift composed of intermediate and acid volcanics of the Middle and Upper Jurassic being intruded by stocks of granitoids. The mineralization is hosted by quartz diorites and diorites of the southern endocontact zone of the Djanyatag granitoid massif and, partly, by the Early and Middle Bathonian andesite–dacites and liparite–dacite porphyries.

The deposit is represented by a stockwork body of low-graded copper–molybdenum ores with associated gold and silver of higher grades confined to an area of conjunction of faults of the northwestern and northeastern directions. Numerous dykes of andesites, diorite–porphyrites, liparite–

dacite porphyries and liparite, as well as hydrothermally altered rocks have been found within the deposit's area.

The total area of distribution of fissure filling and disseminated types of sulfide of mineralization is around 0.8–1.0 km² and that of the mineralized stockwork is 800–1000 m by 300–400 m. Copper grade varies from 0.1 to 0.6 %, molybdenum from 0.003 to 0.02 %, gold 2.2 ppm, and that of silver up to 30–40 ppm. The deposit did not undergo a detailed mineral exploration; however, given the intensity and character of sulfide mineralization, prospects of enclosing volcanic rocks for future discoveries of porphyry copper mineralization are very high. The other porphyry copper occurrences in the Garabagh ore region are very similar to the Damirli deposit. Given a widespread distribution of porphyry copper mineralization in exo- and endocontact zones of the Djanyatag intrusive massif, favorable tectonic and geologic environment, as well as positive results of geological, geophysical, and geochemical exploration, the Garabagh ore region represents one of the highly prospective targets for discovery of new porphyry copper mineralization of large scale.

The Ordubad ore region

The Ordubad ore region constitutes a part of the Mekhmana–Zangazur tectonic subzone hosting a number of known porphyry copper and molybdenum deposits. The region is sharply distinguished from other zones of the Lesser Caucasus and includes the known copper–molybdenum belt part of which is observed on the territory of the Nakhchivan AR of Azerbaijan.

Porphyry copper deposits of the Ordubad ore region were localized within the western part of the Megri–Ordubad granitoid massif, where the Paragachay, Diakhchay, Misdag, Goygel, Geydagh, Gekgyundur, Shalalag, and other deposits were found. The detailed mineral exploration and estimation of reserves has been completed only within the Paragachay deposit. The reserves and prospects of the rest of the deposits are unknown. At present, the exploitation of the Paragachay copper–molybdenum deposit has been suspended due to economic problems.

The Diakhchay deposit

The Diakhchay porphyry copper deposit is located in the central part of the Diakhchay ore field in the upper streams of the Ordubadchay River. The deposit is enclosed in monzonites, granodiorites, quartz diorites, granosyenites, quartz syenite–diorites, and granodiorites–porphyries being intruded by crosscutting dykes of granite–porphyries and diorite–porphyries. The mineralization is tectonically controlled by the Ordubad deep-seated fault being accompanied

by a zone of metasomatic rocks from 1.2 to 1.5 km wide. The major stockwork zone represents a system of fractures, fissure fillings, and impregnation of molybdenite, chalcopyrite, and pyrite in quartz syenite–diorites in a contact area in the south with hydrothermally altered gabbro–diorites and adamellites.

The stockwork zone is elongated along dykes of granodiorite porphyry or along a contact of intrusive rocks of various phases over a distance of up to 2 km. The thickness of the zone tends to increase in the areas of dykes jointing. Relatively intensive hydrothermal–metasomatic changes in the form of local feldspathization, biotitization, silicification, and sericitization are observed in tectonically reworked parts of the zone along contacts with dykes. The major ore minerals are copper and molybdenum of fissure filling and disseminated types. On the surface, the zone has been traced over a distance of 600 m. A width of the mineralized zone is 140 m with the most intensive mineralization from 40 to 100 m.

Mineral exploration of the deposit by drilling and adits indicates a copper grade on the surface from 0.66 to 1.3 % up to 2.0 % and that of molybdenum from 0.001 to 0.003 %. The grades of copper and molybdenum tend to decrease with a depth with 0.7 % of copper and 0.0022 % of molybdenum. The mineralization has been traced up to a depth from 350 to 400 m.

The Sarkidagh and Fakhlidara occurrences of copper–molybdenum ores were found in the northwestern and southeastern parts of the Diakhchay ore field, respectively. The occurrences are represented by stockwork zones with a variable copper grade from 0.4 to 2.44 % and a molybdenum grade from 0.01 to 0.02 %. The proximity of these occurrences to the Diakhchay deposit increases the economic prospects of the Diakhchay copper–molybdenum ore field for future development.

The Misdagh deposit

The Misdagh deposit is located in the Ordubad region on the southwestern slope of the Zangazur ridge in the upper streams of the Vanandchay River. The deposit is confined to the endocontact of the Megri-Ordubad granitoid massif and is basically composed of quartz, monzonites, monzonite diorites, diorite syenites, diorites, and gabbro–diorites. Major structural elements are tectonic faults and associated fractures of submeridional and northwestern directions. The mineralization tends to be associated with separate fractures, dykes, and zones of jointing of the northeastern direction. The deposit is represented by a series of numerous closed steeply dipping ore zones including 18 prospective zones concentrated within an area of 0.3 km². The distance between zones varies from a range of 15–20 to 100–150 m.

On the surface, the mineralized zones have been traced from 300 to 700 m with a variable thickness from 0.5 to 10 m. Most part of the zones strikes in the northeastern direction and dip at 60°–85° northwest. On the recent erosion level, these zones were traced to a depth of more than 350 m. Ore bodies are represented by veins and stockworks characterized by frequent swells and pinches of veins. The thickness of lenticular ore bodies in swells is increasing up to 40 m and is reducing up to 0.5 m in pinches.

Distribution of major metals in the ore bodies is irregular. The grade of copper varies within a wide range from 0.2 to 7.2 % with an average grade from 1.3 to 2.5 %. Associated metals of economic importance are molybdenum, cobalt, and gold in some veins. Major ore minerals are magnetite, chalcopyrite, sphalerite, galenite, pyrrhotite, and cubanite and those of the oxidation zone are malachite, azurite, bornite, chalcocite, limonite, goethite, and hydroferrum oxide. A high content of copper in veins and fissure zones is accompanied by accumulation of disseminated copper mineralization in host rocks with a copper grade from 0.1 to 0.4 % that substantially increases the economic prospects of the deposit. Due to complex mining and geological conditions, the deposit has not been studied at a depth.

The Geygel deposit

The Geygel deposit is located within 8 km northeast of the Nyurgyut village in the watershed of the Zangazur ridge. The deposit is subdivided into the northern, central, and southern areas. Mineralization of stockwork type is confined to rocks of the granodiorite–porphyry phase of the Megri-Ordubad intrusive massif being intruded by dykes of granodiorite porphyries. The deposit is tectonically controlled by a system of faults and fractures of submeridional (20° NE) and northwestern (270°–290° NW) direction being healed by dykes of diorite porphyrites and granite–porphyries, respectively. More intensive mineralization has been observed within the central part of the deposit containing five ore-bearing zones of sublatitudinal direction and several hundred meters long. Almost all stages of mineralization typical for porphyry copper deposits of the Ordubad ore region are present in this deposit. The central area of the deposit is considered to be of economic interest owing to commercial concentration of porphyry copper–molybdenum mineralization.

The Geydagh deposit

The Geydagh porphyry copper deposit is located in the confluence of the Alindjachay and Gilyanchay rivers. The area of the Geydagh deposit hosts the Khanaga-Ortakend and Bashkend occurrences as well as the major Djadakhli,

Dikyurt, Muradkhanli, and Gyumushdara individual stockwork ore bodies localized in intensively dislocated and hydrothermally altered andesite–dacite porphyrites, quartz–syenite–diorites, tuff–sandstone, tuff–gravelites, and other rocks. The length of ore bodies varies from 390 to 500 m and the width from 200 to 470 m. Copper–molybdenum mineralization has been traced at a depth from 420 to 680 m. The average content of copper in ore bodies varies from 0.28 to 0.66 % and that of molybdenum from 0.008 to 0.011 %. Associated lead–zinc mineralization is confined to selvages and dykes of diorite–porphyries. Galenite and sphalerite are mainly of fissure filling and disseminated types. A thickness of mineralized intervals varies from 16 to 50 m grading 0.35 % of lead and 1.19 % of zinc. The inferred reserves of copper have been estimated. The deposit requires additional mineral exploration to judge its economic prospects.

The Gekgyundur deposit

The Gekgyundur deposit is confined to a zone of intensive jointing along the main Ordubad and Vardanichay faults composed of rocks of early adamellite phase of the Megri-Ordubad intrusive massif and late quartz syenite–diorites, porphyry granosyenites being intruded by dykes of diorite, and granodiorite–porphyries. The ore-bearing zone is confined to a contact area of granodiorites and was traced from 1200 to 1500 m long and from 480 to 600 m wide. Mineralization is presented by stringer-impregnated, stockwork, and vein types. The major stockwork of the deposit with copper mineralization reaches a thickness up to 168 m grading 0.85 % of copper.

On the southwest flank of the deposit, the thickness is decreasing being split into several steeply dipping bodies with a thickness from 14.5 to 28 m found at a spacing interval from 200 to 300 m. The grade of copper in these bodies varies from 0.53 to 0.65 % and that of molybdenum does not exceed 0.001 %. Similar situation is observed on the northeastern flank of the deposit where three individual bodies have been traced from 300 to 500 m with a thickness from 10 to 20 m. The grade of copper is from 0.74 to 0.77 % and that of molybdenum is up to 0.001 %. Such morphology of the stockwork deposit is defined by its tectonic position and peculiarities of internal structure of the ore-bearing zone of the deposit. Chalcopyrite, molybdenite, and pyrite are the basic ore minerals. Secondary minerals of copper are covellite, bornite, malachite, and chrysocolla. Copper reserves are unknown.

The Shalala deposit

The Shalala deposit is hosted by quartz and syenite–diorites of the second intrusive phase of the Megri-Ordubad

granitoid massif. The deposit is represented by a zone of stockwork mineralization of up to 300 m wide and 800 m long hosting four closed ore bodies of a complex morphology with a thickness from 7 to 100 m. Basic ore minerals, chalcopyrite, bornite, molybdenite, and pyrite, form impregnations and stringers. The content of copper in the ore bodies varies from 0.11 to 7.8 %. The most intensive mineralization was found in an isolated ore body of up to 300 m from 410 m deep with an average thickness of 41.5 m. The average grade of copper is 0.5 % and that of molybdenum is 0.006 %. Two zones with a thickness of 30 and 14 m were found in interdyke interval running in parallel to the major ore body. The grade of copper is up to 0.84 % and that of molybdenum is from 0.005 to 0.025 %. Further mineral exploration is likely to lead to new discoveries of porphyry copper–molybdenum mineralization of economic interest.

The Darridag-Paradash ore region

This region represents the area of development of the Oligocene–Early Miocene volcanism associated with concentration of numerous small-scale occurrences of ferrous metals. Copper mineralization in this region is close to one of the most productive copper sandstone types. Numerous occurrences of copper of the Ashabi-Kahf group are confined to rocks of volcanosedimentary series of the Oligocene age along the north–northeastern flank of the Nakhchivan superimposed trough being controlled by the Nakhchivan Fault. Three copper-bearing beds within the Oligocene rocks form a copper belt of up to 60–70 km long hosting around twenty areas with a high copper mineralization. The number of copper-bearing beds within this belt varies from one to four with a variable thickness from 0.6 to 9.0 m. The grade of copper in beds varies from 0.25 to 1.56 %. Impregnated copper mineralization is represented by native copper, cuprite, chalcocite, azurite, and malachite. The Ashabi-Kahf group of occurrences is of potential economic interest owing to a polymetallic character of mineralization.

Mercury

Mercury mineralization is present in all metallogenic provinces of Azerbaijan, but its intensity is uneven in various zones due to tectonic faults separating different structural and formational zones of the Greater and Lesser Caucasus (Kashkay et al. 1970; Azizbekov et al. 1972; Suleimanov and Babazadeh 1974; Kashkay and Nasibov 1985). Mercury deposits are traced in the form of isolated zones or chains along the extended folded and tectonic structures of the Lesser Caucasus. Based on a distribution pattern of mercury mineralization, the southern, central, and the northern zones of mercury mineralization have been distinguished within

Table 2.20 Classification of mercury deposits and occurrences in Azerbaijan

Formational type	Mineral type	Typical mineral associations	Host rocks	Structural and orphological types	Shape of ore bodies	Hydrothermal alterations	Sample of deposits and occurrences
Mercury	Magnesite–carbonaceous	Cinnabar Pyrite Chalcopyrite Bornite Orpiment Magnetite Millerite Quartz Calcite Dolomite Dikkite Alkerite	Serpentine Magnetite Schists Andesite–dacite Sandstone Argillites	Lenses and veins in tectonically reworked areas along and in intersection of faults and structural zones	Lenses, veins	Magnesite, Schists Silicification Argillization	Shorbulag Agkaya Agyatag Sarydash Kamyshly Nagdolychay Chilgyazchay Guneyplin
Mercury	Carbonate–cinnabar	Cinnabar Pyrite Chalcopyrite Realgar Quartz Calcite	Limestone	Lenses and veins along steeply dipping tectonic dislocations and fractures	Lenses and pillars of complex morphology	Silicification Pyritization Calcitization	Narzali Arzuni Dumanli Millin and other deposits
Antimony–mercury	Quartz–carbonate–antimony–cinnabar (gasper type)	Cinnabar Antimony Pyrite Realgar Barite Orpiment Chalcopyrite Quartz Calcite Dolomite Dikkite Hydromicakaolinite	Limestone Volcanogenic Rudaceous Rocks Sandstone	Lenses-bearing veins and pillars along steeply dipping thrusts and interbeds' fractures	Stratiform and pillar-like veins	Silicification, pyritization, argillization, jasperization	Levchay Novolev Eliz-gel
Antimony–arsenic		Realgar Antimony Quartz				Horfelns Selicitization Silicification	Deveboyin Turschuin

the Lesser Caucasus. Analysis of numerous data on distribution patterns of mercury mineralization identified the stratigraphic–lithologic, structural, and magmatic factors.

Mercury mineralization has been found in rocks of various lithology and stratigraphic intervals. The oldest mercury mineralization is associated with the Middle Jurassic volcanogenic formations and the most recent with the Mio-Pliocene tuffs and dykes of liparite–dacites. The intensity of mercury mineralization tends to increase from the Middle–Upper Jurassic–Lower Cretaceous deposits to the Upper Cretaceous formations. The Lower Senonian volcanosedimentary formations overlain by the Upper Jurassic limestone have been proved to be the most productive stratigraphic section hosting around 70 % of known mercury deposits in Azerbaijan. The major lithological varieties of the Upper Cretaceous interval are magnesite schists, limestone, conglomerates, rudaceous tuffs, sandstone, breccia, and clayey–siliceous rocks. Classification of

mercury deposits and occurrences of Azerbaijan is given in Table 2.20.

The Shorbulag deposit

The deposit occurs in volcanogenic formations of the Bathonian suite, sedimentary–volcanic rocks of the Lower Senonian stage and intrusive rocks of ultrabasic, basic, and acid composition. Ultrabasites are represented by serpentinized dunites and peridotites of a lens shape elongated along tectonic faults of the northwestern direction. Mercury mineralization is controlled by tectonic dislocations of thrust type and hosted by tectonically reworked, crushed, schistose, and loose rocks being subjected to intensive silicification, carbonatization, and other hydrothermal metasomatic alterations. The major enclosing environments of mercury mineralization are hydrothermal metasomatic carbonate rocks. In some areas, cinnabar is confined to crushed and altered

porphyrites, argillites, as well as talcose and carbonatized serpentinites. Cinnabar is the main ore mineral with a limited presence of chalcopyrite and pyrite. Steeply dipping fissures filled by calcite and quartz create mercury-bearing zones in various directions.

In ore-bearing zones, cinnabar is observed in the form of impregnations, small nests, selvages, stringers, and other accumulations of various shapes. Among seven ore-bearing zones of the deposit, the first, third, and fourth zones have been found to be the most prospective. The position of the first zone is closely controlled by a fault along a contact of serpentinites with sedimentary–volcanogenic rocks of the Lower Senonian hosting a lens of magnesite schists with intensive cinnabar mineralization. The structural position of the third zone is very similar to that of the first zone. Mineralization here is represented by frequent impregnations and thin and short stringers of cinnabar in hydrothermal metasomatic carbonate and quartz rocks and altered porphyrites. Mineralization of cinnabar in the most extended fourth zone is confined both to listvenites and to dykes of diabase porphyrites occurring among listvenites. Ore bodies have irregular complex pillar and column shape elongated along the main ore-controlling fault dipping gently to the southeast. The grade and reserves of mercury in this deposit are not available.

The Agkaya deposit

The deposit is hosted by volcanosedimentary sequence of the Lower Senonian represented by silicified brown argillites with interbeds of tuff–sandstone, porphyrites, tuffs and quartz–sericite–chlorite shales and thick pelitomorphic limestone of the Upper Senonian age outcropped in the northwestern part of the deposit. Intrusive rocks are represented by serpentinitized peridotites, gabbroids, stockwork bodies of diorite porphyrites, granodiorites and the recent Mio-Pliocene andesites, andesite–dacites, and rare liparites forming dykes and stockworks. The deposit occupies a small part of the Agkayachay anticlinorium and is confined to a zone of intersection of tectonic faults dividing the Geydara–Almali anticline and the Chichekli–Kongur syncline located to the north.

Mercury mineralization has been found in listvenites and metasomatic varieties of listvenites. In six ore-bearing zones discovered in the Agkaya deposit, only three ore bodies have been studied on the surface. The grade, reserves, and prospects of the deposit are unknown.

The Agyatag deposit

The deposit contains three areas of mercury mineralization confined to the Agyatag tectonic block. The first mineralized

area is composed, mainly, of the Santonian tectonic breccia, jasperous brown argillites, dacites, serpentines, and listvenites. The distribution of mercury mineralization of stringer-disseminated type within the only ore body in this area is very uneven. The second ore area is also confined to a crossing tectonic block and composed, mainly, of tectonic breccia, listvenites, and dacites. Similar to the first area, the mercury mineralization of irregular stockwork shape is being structurally controlled by tectonic fault of upthrust–overthrust nature. The geologic and tectonic environment of the third mineralized area is very similar to that of the above two areas. The morphology of ore bodies within the deposit is rather complex reflecting an uneven distribution of mercury mineralization. In most cases, ore bodies are of column, pillar, lens, or irregular complex shape.

The major textural types of mercury ore are brecciated, impregnated, massive, crustal, veined, and earthy, where the first four types are dominant. Main ore mineral of the deposit is cinnabar, with quartz and calcite as cementing minerals. Secondary minerals are pyrite, arsenopyrite, rare chalcopyrite, sphalerite, hematite, and schwazite. Hypergene minerals are represented by metacinnabarite, linolite, scorodite, malachite, eruzite, chalcocite, and covellite. The grades and reserves of the deposit are unknown.

The Gamishli deposit

The deposit is located at a distance of 1.5–2.0 km to the south from Gamishli village of the Kelbadjar region on the left bank of the Levchay River. The deposit occurs in schistose, silicified, and partially brecciated sandy–calcareous–clayey deposits of the Santonian suite dislocated by numerous longitudinal and rare near-meridional faults with accompanied schistose serpentinites and gabbroids.

The deposit is confined to a recumbent contact of the Garabagh fault of upthrust–overthrust nature, where mercury mineralization in a form of scattered small impregnations of cinnabar was localized in silicified, brecciated, and pyritized listvenites being traced in latitudinal direction along the overthrust strip dipping at (60°–80°) to the north. A total thickness of a zone of altered, schistose, and unconsolidated rocks varies from 50 to 100 m reaching 200 m. This zone has been traced over a distance of 10 km running via the Tala occurrence till the middle stream of the Bulandyhsu River.

The ore body dips to the northeast at 50°–60° being composed of silicified, strongly brecciated and pyritized listvenites hosting fine disseminations, small nests, and thread stringers of cinnabar. The proved mercury reserves of this ore body up to a depth of 30 m are 20 tons. The size of the second ore body on the surface is 140 m², and the average mercury content is 0.17 %. Mercury mineralization

is hosted by silicified and brecciated listvenites bearing everywhere fine disseminations and impregnations of cinnabar, rare chalcocite, chalcopyrite, pyrite, ezurite, and malachite. A hanging side of the ore body is composed of silicified, brecciated, and pyritized argillites and a recumbent side of schistose serpentinites. The proved mercury reserves of this ore body up to a depth of 36 m are 22 tons.

The Chilgyazchay deposit

The deposit is located in the midstream of the Chilgyazchay River basin southeast of the Mt. Agkaya. The geological environment of the deposit in its southwestern part consists of the Cenomanian sandy-clayey sequence overlain by a seam of fine and medium clastic conglomerates. The mineralization is being controlled by the Nagdalichay upthrust hosting a thick zone of ore-bearing breccias overthrust on tectonically reworked argillites. Industrial concentrations of mercury mineralization are confined to feathering fractures of the Agyatag-Nagdalichay fault with a pronounced role of structural-lithologic factors. The tectonic features of the deposit are mostly of the dominated Caucasian and cross-cutting meridional directions. These dislocations are accompanied by silicification, kaolinitization, limonitization, brecciation, and crushing of host rocks. Mercury mineralization within the deposit is confined to tectonic breccias, mainly formed by red jasperous argillites of the Santonian age. A lens-shaped body along the Chilgyazchay fault of up to 40 m thick has been found.

The Narzali deposit

The deposit is located 350–400 m east of the Kalafalikh village on the eastern flank of the Chilgyaz syncline. The deposit is hosted by coarse-grained terrigenous formations of the Coniacian–Santonian age, terrigenous–carbonaceous series of the Campanian and Maastrichtian ages of the Upper Cretaceous, and clayey–carbonaceous formations of the Paleogene. Coarse-grained terrigenous series of the Coniacian–Santonian age have been intruded by undifferentiated serpentinitized ultrabasic rocks and gabbroids. Two close outcrops of small stocks of diorite, quartz, and plagiogranite have been observed in the northeastern part of the deposit. Metasomatic rocks are represented by listvenites and listvenitized rocks observed in the northern and northeastern part of the deposit along a tectonic zone and in a contact zone of serpentinitized ultrabasic rocks with the Santonian terrigenous rocks. The deposit is spatially related to a zone of the Sultangoyunuchan (Kalafalikhchay) upthrust being characterized by a complex tectonic structure. Mercury mineralization of high grades was found in several small ore bodies occurring among limestone. These ore bodies are

being controlled by steeply dipping faults and fractures of different directions. Morphologically, ore bodies of stratabound, nest, lens, vein, and irregular types have been found in various sections of a limestone interval along the strike. Grades and mercury reserves have not been reported.

The Levchay deposit

The Levchay deposit is located in the central part of the Garagaya-Elizgel anticlinal zone and composed of intensively dislocated and partially crushed sandy-clayey and calcareous rocks of the Upper Cenomanian age and sub-volcanic formations (andesite–dacites, liparite–dacites) and their tuffs of the Mio-Pliocene. Rich accumulation of mercury was observed in the western part of the deposit coinciding with a submergence of the Aghdash anticlinal fold to the west. Three ore bodies with mercury and one ore body with antimony mineralization have been delineated and evaluated in the upper sections of the central part of the deposit.

All these bodies of stockwork, complex lens or irregular shape, and morphology are confined to a submersible part of the anticline. The arch part of the anticline is composed of crushed limestone transformed into jasperoids along a zone from 50 to 150 m wide. The ore bodies are confined to knots of intersection of meridional and latitudinal faults. Main ore minerals are cinnabar, antimonite, stibnite, valentinite, realgar, orpiment, and metacinnabarite. Other minerals are calcite, quartz, bitumen, and gypsum.

2.2.2.7 Tungsten

The distribution of wolfram mineralization on the Azerbaijan territory is rather limited. For instance, are known several tungsten occurrences near the Kilit village of the Ordubad ore region of the Nakhchivan AR as well as in the central part of the Lesser Caucasus region in the Geydara, Konurdagh, Sarigash, Nadirkhanli and Nadjafli districts. The mineralization tends to be associated with the hyperbasitic belt development with adjacent outcrops of metal-bearing small intrusions of the Neogene age and skarn type mineralization in contact zone of the Dalidagh intrusive massif. The mineralization is represented, mainly, by scheelite in quartz veins, aplites, and veins of the Kilit and Dalidagh granitoid massifs. Heavy concentrations of scheelite have been panned in the Kelbadjar region in the basin of the Terter River and in upper streams of the Ildrimsu River and in the Nakhchivan AR in the Kilitchay-Pazmarachay area.

The Darridagh (Djulf) arsenic deposit

The deposit is hosted by the Campanian and Maastrichtian limestone and marls, sandstone, and clays of the Danian

stage and the Pliocene, tuffogenous–sedimentary rocks with basal conglomerates of the Middle and Upper Eocene and volcanogenic–rudaceous rocks of the Lower and Middle Oligocene, which construct the Darridagh anticlinal fold of the northwestern strike. The northeastern limb of this anticlinal fold hosts interbedded intrusive massif of hornblende diorites. The mineralization in the northern part of the deposit is represented by realgar–orpiment ores of stockwork type, in the central part by antimonite ores of nest type and in the southern zone near arsenic source, by realgar of disseminated type. Arsenic mineralization tends to be controlled by fractures of near-meridional direction.

Main proved reserves of the deposit are concentrated in the southwestern part of the Darridagh mountain ridge in the Campanian–Maastrichtian and the Eocene marls and sandstone being controlled by a tectonic fault crossing the axial part of the Darridagh anticlinal fold. The ore body is represented by a nearly vertical stockwork which tends to widen with a depth. Four main mineral types of ores have been distinguished within the deposit. The first type is represented, mainly by realgar with slight admixture of antimonite. The second mineral type has the highest quality of ores, but observed more rarely than the first one. Orpiment predominates in mineral composition with minor realgar. The third mineral type of high quality of ores is observed rarely. Mineralogically, it is represented by finely disseminated orpiment of yellowish–greenish color with films of black earthy melnikovite. The fourth mineral type of low quality of ores and of any industrial importance is represented by slightly enriched host rocks.

The Djulfa (Darridagh) deposit

The geologic and structural position of the deposit is in “Arsenic” section above. Antimonite mineralization within the Djulfa deposit was found in three areas of the deposit where it is paragenetically associated with arsenic and other mineralization. The northwestern area of the deposit hosts the main reserves of arsenic ores where antimonite is observed in a form of small admixtures. The antimony grades in this area are very poor. The southeastern area is represented by mineral springs where antimonite is accompanied by realgar and orpiment. The antimony hydrogen (SbH_3) content in arsenic-bearing mineral springs of the Darridagh deposit is about 0.005 % and that in mineralized host rocks is minor. The central area of the deposit hosts nests, impregnated, and disseminated types of ore where the grade of antimony reaches 8 %. In the mineral composition of antimony ore, realgar has a subordinate position; secondary minerals are anhydrous and complex oxides of antimony represented by valentinite, servantinite, and stibicinite.

The Levchay deposit

The geologic and structural position of the Levchay deposit is given under “Arsenic” section above. Antimony mineralization was found in significant concentrations in a form of minor admixtures in mercury ore bodies and in independent accumulations. The antimony ore body of 1.5 m thick has been open by adit No. 1. The thickness of the ore body tends to increase with a depth reaching a range of 8–10 m at a depth of adit No. 6 which is 50 m downward from the level of the first adit. The main mineral of the ore body is antimonite which forms solid veins, stringers, lenses, and impregnations. The secondary minerals are cinnabar realgar, valentinite, and servantite. Quartz is the main vein mineral. Calcite in a form of stringers in silicified limestone is subordinate. Bitumens and clayey minerals are observed somewhere. The antimony content is about 5 %.

2.2.3 Gold

Gold mining in the Transcaucasian territory including the Lesser Caucasus has been known for a long time. According to historical data, some gold-bearing areas were developed in VI–I centuries BC. Geological research, mapping programmes, and mineral exploration have led to a discovery of gold deposits and occurrences and associated genetic presence of gold in ores of copper–pyrite, porphyry copper, and copper–polymetallic deposits of Azerbaijan (Babazadeh and Malyutin 1967; Azizbekov et al. 1972; Abdullayev et al. 1979; Kurbanov et al. 1981; Kerimov et al. 1983, 1996; Hasanov and Aliyev 1984; Suleimanov and Guliyev 1986; Suleimanov et al. 1986; Mansurov 1998; Atlas 2000; Ismailzadeh et al. 2008).

In the Azerbaijanian part of the Lesser Caucasus, gold mineralization is typical for the following metallogenic belts:

- The Lok-Garabagh belt: gold–sulfide and gold–sulfide–quartz mineralization;
- The Goycha-Hakeri belt: gold–sulfide–carbonate–quartz and gold–sulfide–quartz mineralization;
- The Kelbadjar-Gochaz belt: gold–sulfide quartz mineralization;
- The Ordubad-Zangazur belt: gold–sulfide and gold–quartz mineralization;
- The Gafan belt: gold quartz mineralization.

The Lesser Caucasus region is characterized by spatial combination of development of gold, copper, lead, zinc, silver, molybdenum, and other mineralization typical for regions with rejuvenated tectonic activity and magmatism.

Due to this spatial overlapping of gold, porphyry copper, copper-pyrite, copper-polymetallic, and other types of mineralization, the Lesser Caucasus is treated as a polymetallic gold-bearing metallogenic province with a complex polycyclic metallogeny. A spatial and genetic relationship of gold mineralization with subvolcanic magmatic formations of various compositions has also been identified.

An important role of structural control in localization of gold in fractured zones and blocks of volcanoplutonic constructions has been noted and proved. There are some prospects of discovering of new types of gold-sulfide mineralization in jasperoids and dolomites of carbonate series, carbonaceous shales, and secondary quartzites. Major morphological types of gold mineralization are steeply dipping veins and stockworks and those of gold-sulfide mineralization are gently dipping interbedded bodies and stockworks. The following four formational types of gold and gold-bearing complex ores have been distinguished: (a) gold deposits of gold-sulfide, gold-sulfide-quartz, gold-sulfide-carbonate-quartz, and gold-quartz ore formations; (b) gold-bearing deposits of complex copper-gold ore and gold-copper-polymetallic ores where gold is one of the basic components; (c) deposits of copper sulfides, massive copper, and porphyry copper types with substantial associated gold; and (d) porphyry copper deposits with gold traces.

The most productive terrains are magmatic formations of pre- and post-collisional stages associated with concentrations of polymetallic, copper, and molybdenum ores. The geochronologic dating of gold mineralization indicates a wide range in a concentration of gold ore found in all stages of the Alpine metallogenic epoch and pronounced in the Lesser Caucasus metallogenic province from the Bajocian to the Pliocene. Several small gold placers are represented by scattered alluvial, fluvial terrace, and alluvial-proluvial types being characterized by irregular gold distribution. The most prospective Gazakh, Gedabey, and Garabagh gold-bearing districts with proved gold reserves were found within the Azerbaijan part of the Lok-Garabagh metallogenic belt. Highly prospective occurrences of gold and complex gold-bearing ores were identified within the Dashkesan, Geygel, and Murovdagh ore regions and the Shusha-Fizuli potential area.

The Gazakh ore district

The Gazakh ore district is located in the northwest segment of the Lok-Garabagh zone covering the northeastern part of Ijevan-Gazakh transformal gold-bearing fractured zone from 26 to 30 km long. This ore district includes the Dagkesaman gold-copper-polymetallic deposit gold occurrences, numerous points of gold mineralization, geochemical halos, and small gold-bearing placers.

The Dagkesaman gold deposit

The deposit is represented by steeply dipping gold-bearing quartz veins containing ore intervals of a "pillars" type with a high content of gold. Gold is associated with quartz and pyrite, chalcopyrite, sphalerite, galenite, and other sulfides. More close association of gold is with quartz and chalcopyrite. The basic metal is gold with associated silver, lead, zinc, and copper. The ratio of gold to silver within the deposit is 1:4. Favorable geologic and structural position of the deposit, the cut-off grade, and scope of gold ore mineralization - all these factors indicate high prospects for its economic development.

The Gedabey ore district

The district belongs to the northern part of the Megri-Gedabey gold-bearing structure of a submeridional direction. The district incorporates the Gosha gold-sulfide and Gedabey copper-gold deposits with estimated gold reserves, the Garabagh and Khar-Khar, Maarif, Gizildja, Barum-Barsum, and Berezin deposits of fissure filling and disseminated types in porphyry copper deposits as well as the Itgiran, Mundjukhlu, Badakend, and other occurrences of gold and gold-silver ores.

The Gedabey copper-gold deposit

The deposit of copper-pyrite type is known to occur in secondary quartzites being represented by fissure filling and disseminated sulfide-quartz mineralization of chalcopyrite-pyrite-quartz polymetallic formation of stockwork type, and partly by stocks and lenses of massive copper-pyrite ores. The major ore body of stockwork type and large size contains adjacent ore bodies with high copper and gold grades. The major metals are copper, gold, and silver. Given the favorable geologic and structural position of the deposit, the intensity and scope of mineralization, grades, and reserves, the Gedabey deposit constitutes the primary target for open-pit mining.

The Gosha gold deposit

The Gosha gold-sulfide deposit is confined to the Gosha anticline located on the northwest flank of the Shamkir uplift. The deposit is hosted by layered porphyrites intercalated with bands of their pyroclasts, quartz porphyries, and their tuffs. The volcanic section is intruded by quartz-diorites and a subvolcanic body of liparite-dacites of the Upper Jurassic age. Crosscutting dykes of diabases, andesites, and, rarely, liparite-dacites are widely developed within the deposit. The deposit is structurally controlled by a dense network of faults and fractures of the northwestern,

northeastern, submeridional, and sublatitudinal directions with gold-bearing metasomatites.

Ore bodies are represented by extended subparallel hydrothermally altered zones, quartz–sulfide veins, stockworks, and fissure filling and disseminated types of mineralization. Higher grades of gold were found in quartz–sulfide veins, mineralized zones, and stockworks. The main ore minerals are pyrite and native gold; secondary minerals are sphalerite, chalcopyrite, galenite, bornite, and coverlite. Other minerals are quartz, carbonate, sericite, chlorite, and kaolinite. Hydrothermal alterations are represented by schistosity, kaolinization, sericitization, and chloritization. The basic precious components are gold and silver having irregular distribution patterns. Gold mineralization was traced over 400 m deep by underground mining (Atlas 2000).

Reserves of gold and silver have been proved to be economic for development by underground mining. The adjacent Itgiran, Mundjukhly, Shikhabat, and other gold and gold–silver occurrences on the flanks of the Gosha deposit enhance the prospects of the deposit. The Gedabey ore district is made up of the Paleozoic carbonaceous shales containing steeply dipping multiple quartz veins with sulfide mineralization and is considered potentially prospective for discovering of gold mineralization of black shale type. A wide distribution of geochemical halos of gold and hydrothermal metasomatites including gold-bearing secondary quartzites enhances the prospects of the Gedabey ore district for new discoveries of complex polymetallic deposits of base and precious metals.

The Garabagh ore district

The Garabagh ore district represents a part of the Lok-Garabagh metallogenic zone being confined to the Khachinchay–Terter uplifted isolated block of the northeastern part of the Dalidagh–Mekhmata transformal uplift. The ore district has been developed in the Middle Upper in the Jurassic volcanogenic, volcanosedimentary, and the Cretaceous terrigenous–carbonaceous formations. Mineralization is genetically associated with intensive volcanic activity during the Jurassic time being traced by numerous volcanostructural constructions. The most typical Djanyatag intrusive massif is composed mainly of quartz diorite, banatites, tonalites, and its varieties. Dykes of granite–porphyry, liparites, and granodiorite–porphyries are widely developed within the massif. A rather intensive gold mineralization has been superimposed on massive sulfide, copper–polymetallic, and porphyry copper mineralization. A clear zonation and distribution of porphyry copper, gold, gold–copper–polymetallic, and copper–gold deposits have been traced from the east to the west within the Garabagh ore district. The Garabagh ore district incorporates the

Gyzylbulagh copper–gold and Mekhmata gold–copper–polymetallic field, the Damirli porphyry copper deposit, the Khatinbeyli, Sampas, and Eddikhirman groups of gold–sulfide–quartz occurrences, gold-bearing placers in the valleys of the Terter, Kabartichay, Gyulyatagchay, and Khachinchay rivers, as well as numerous halos of gold, copper, lead, zinc, molybdenum, and other metals.

The Gyzylbulagh deposit

The Gyzylbulagh copper–gold deposit is hosted by sedimentary–volcanogenic formations of the Middle–Upper Jurassic represented by polymictic conglomerates, tuff–sandstone of the Callovian–Oxfordian stage, lithoclastic tuffs of andesites of the Bathonian stage and covers and lithoclastic tuffs of liparite–dacites and andesite porphyrites of the Bajocian stage. This volcanosedimentary sequence is intruded by subvolcanic bodies, dykes of andesites, andesite–basalts and liparite–dacites and small intrusions of quartz diorites and diorite porphyrites of the Late Jurassic age. A dense network of faults and fractures has defined a block structure of the deposit. Mineralization is confined to a thick zone of crushed and schistose rocks in liparite–dacite porphyrites and their detrital facies. Two ore bodies are represented by elongated irregular stockworks hosting dense fissure filling stringer, impregnated, and nest-shaped mineralization. Ores are mainly represented by pyrite, pyrite–chalcopyrite, and quartz–pyrite–chalcopyrite mineral associations. The basic ore minerals are chalcopyrite, pyrite, and native gold; secondary minerals are sphalerite, bornite, galenite, marcasite, melnikovite, and arsenopyrite. Gold of irregular and isometric form has been found in chalcopyrite and pyrite as inclusions. The basic precious components are gold, silver, and copper.

Feasibility studies on technological properties and enrichment of ores in laboratory and semi-industrial conditions have proved the applicability of gravitational–floatation technology of ores reworking for obtaining conditional gravitational gold-bearing and floatational copper–gold concentrates. Mineral exploration by underground mining and drilling has proved the existence of reserves of gold, silver, copper, and other associated minerals of industrial categories suitable for development by open-pit mining. Stripped rocks of overburden have been found to be suitable raw material for production of rock aggregates and vitrified ceramic products.

The Mekhmata field

The Mekhmata gold–copper–polymetallic field contains more than 30 ore-bearing veinlet zones and veins. The detailed mineral exploration has been carried out over four

major veins. Calcite–quartz veins contain galenite and sphalerite mineralization of disseminated, nest types, and stringers of massive sulfide ore. Ores are mainly of gold–silver–copper and lead–zinc-bearing types. The major metals are lead, zinc, silver, and gold with associated cadmium, selenium, and tellurium. More detailed description of the Mekhmana deposit is given in (Atlas 2000). Given the intensity and scope of mineralization, the Garabagh ore district is referenced as one of the highly prospective targets for noble and complex polymetallic deposits of the Lesser Caucasus region.

The Goycha-Hakeri metallogenic zone

This zone is located southward of the Lok-Garabagh metallogenic belt coinciding with the ophiolite belt of the Lesser Caucasus. The geological structure and mineralization are defined by abyssal fault being traced by outcrops of ophiolite rocks. The zone is characterized by the development of early, middle, and late stages of endogenous mineralization of the Alpine epoch being represented by chromite, gold–sulfide–quartz, and arsenic–antimony–mercury formations.

The Azerbaijanian part of the Goycha-Hakeri metallogenic belt contains a part of the Zod and Tutkhun deposits, the Soyutluchay, Gilichli-Alchalilg, and other groups of gold–sulfide–quartz and gold–sulfide–carbonate–quartz occurrences and the small Soyutluchay placer gold deposit. The zone is potentially prospective for discovery of deposits of finely dispersed gold in jasperoids and antimony–mercury deposits and occurrences. The larger part of gold reserves of the Zod gold–sulfide–quartz deposit is located in the Kelbadjar district of Azerbaijan at the border with Armenia.

The Tutkhun deposit

The Tutkhun gold–sulfide–quartz deposit is also located in the Kelbadjar district and includes the Gazikhanli, Agzibir, Gizilistan, Zargulu, and Galaboynu group of gold-bearing areas. The deposit is confined to the area of junction of the Goycha-Garabagh tectonomagmatic zone with the Dalidagh-Mekhmana transformal uplift. Gold mineralization was found along the longitudinal Agyatag-Zod strip of hyperbasites and granitoids. The deposit occurs in volcanic rocks of intermediate and alkaline composition and terrigenous–sedimentary rocks of the Cretaceous and Paleogene ages being intruded by complex ultrabasic and basic intrusions of the pre-Upper Cretaceous and alkaline magmatic rocks of the post-Middle Eocene. Widely developed

metasomatites are represented by quartz–kaolinite, quartz–sericite, and mono-quartz facies of secondary quartzites.

The dominant part of gold–sulfide–quartz veinlets and veins is confined to granitoid massif. Ore bodies in steeply dipping vein zones of pillars and pipe shape are confined to areas of junction of faults and fractures of various limbs. The basic ore minerals are quartz, pyrite, galenite, sphalerite, tetraedrite, native gold, molybdenite, antimonite, and burnonite, and secondary minerals are carbonates, chalcopyrite, sericite, and chlorite. The major economic components are gold with associated silver, tellurium, bismuth, and antimony. Despite limited mineral exploration, the geologic and structural position of the deposit coupled with the intensity and scope of gold mineralization, wide distribution of metasomatic rocks, and a presence of gold occurrences on the flanks of the deposit contribute all to high prospects of the deposit for gold and complex polymetallic gold–silver-bearing ores.

The Agduzdag deposit

The Agduzdag deposit occurs in the upper streams of the Zarchay River in the Kelbadjar district. Mineralization here is associated in andesites, andesite–dacites, liparite–dacites, and their detrital facies. Morphologically, ore bodies are represented by steeply dipping vein zones and veins. Three major veinlet zones out of more than 30 vein zones and veins have been identified within the deposit. Hydrothermal alterations are expressed by schistosity, sometimes by kaolinization, carbonatization, serialization, and, in some places, by fine-dispersed pyritization. The main minerals of ore bodies are quartz, which occupies from 80 to 95 % of the volume being followed by calcite and kaolinite. Ore minerals are rare being represented by pyrite, magnetite, chalcopyrite, sphalerite, and other minerals. The major metal is gold with associated silver. Distribution of gold and silver is extremely uneven. Gold mineralization has been estimated by geophysics to extend to a depth from 600 to 800 m. The deposit has been explored on the surface and by underground mining up to a depth from 80 to 120 m. Based on estimated reserves of gold and vein quartz suitable for fluxes raw material, the prospects of the deposit for economic development are quite high. The Dalidagh ore district incorporates several gold–copper–molybdenum and gold–sulfide–quartz occurrences of vein type and gold–copper-bearing area in secondary quartzites (monoquartzites). Given the favorable geologic position, scale, and intensity of mineralization, the prospects of the Dalidagh ore district for development of gold and complex gold-bearing ores are very high.

The Ordubad ore district

The Ordubad ore district is located in the Ordubad-Zangazur metallogenic belt of the Nakhchivan AR occupying a vast territory of the western endo–exocontact zone of the Megri-Ordubad granitoid massif with multiple phases of magmatic activity. This ore district is characterized by a rather intensive complex polymetallic mineralization, forming substantial concentrations and various combinations of copper, molybdenum, lead, zinc, gold, and silver metals. The Agdara, Nasirvaz, and other deposits and occurrences of gold–copper–polymetallic formation and the Aport (Agyurt), Piyazbashi, Shakardara, Munundara, and other deposits and occurrences of the Ordubad group of gold–sulfide–quartz formation are the major targets for economic development within the Ordubad ore district.

The Aport (Agyurt) deposit

The deposit is confined to the area of intersection of the major Ordubad fault of the northwestern direction and the Vanandchay-Misdagh fault of the northeastern direction. The area of the deposit is composed of rocks of the Megri-Ordubad intrusive massif represented by granosyenites, quartzose, and quartzless syenite–diorites, and aplite–diorites. Quartzose syenite–diorites are prevalent. Ore bodies within the deposit are represented by zones of veins in hydrothermally altered rocks and by quartz–carbonate veins. Eight zones of veins out of twenty ore zones, which were identified within the deposit, have been studied in detail.

By its mineral composition, the deposit corresponds to gold–sulfide–quartz formation. The basic ore-forming minerals are pyrite and chalcopyrite; secondary minerals are magnetite, pyrrhotite, tennantite–tetraedrite, native gold, sphalerite, molybdenum, and others. Gold in ores is characterized by extremely irregular distribution. The basic economic metals of ores are gold, silver, and copper. Gold mineralization was traced to a depth of over 400 m by mineral exploration. The reserves of gold and silver have been evaluated. A gravitational–floatational technological scheme of ore processing has been worked out. A wide distribution of gold-bearing metasomatites, presence of a number of deposits with proved silver and gold reserves, and adjacent prospective occurrences in a favorable geological setting all substantiate high prospects of the area of the deposit for discovering new deposits of gold and gold-bearing complex polymetallic ores. By mining, technical, and geological conditions, the deposit is suitable for underground mining.

The Gafan metallogenic belt

The Gafan metallogenic belt is located in the southwestern part of Azerbaijan on the border with Armenia and includes the Vejnali ore district. Copper–polymetallic mineralization of stringer-impregnated type was found on the extent of ore-bearing zones of the Gafan deposit including the Vejnali quartz–gold deposit.

The Vejnali deposit

The Vejnali deposit is located at the territory of the Zangelan district on the border with Armenia and incorporates twenty-five gold-bearing vein zones. Proved mineable reserves have been so far evaluated within six vein zones. Ore veins and zones of the deposit are mainly represented by quartz–sulfide and, rarely, by quartz–carbonate–sulfide veins and hydrothermally altered disintegrated and brecciated rocks. Sulfides are dominated by pyrite with subordinate chalcopyrite. Arsenopyrite, tennantite, sphalerite, tellurium–bismuth, and native gold are met in low grades. Basic components of commercial value are gold, silver with associated copper, tellurium, and bismuth. A gravitational–floatational technological scheme of ores processing has been worked out enabling to obtain a high percentage of gold (96.5 %) and silver (97.4 %) extraction.

2.2.4 Non-metallic Minerals

Azerbaijan possesses abundant resources of non-metallic minerals which play an essential role in economic development of the country and constitute a substantial part of the mineral resources base in terms of a number of explored deposits, proved and potential reserves, and a variety of mineral types. The main genetic types of deposits of non-metallic minerals on the territory of Azerbaijan are endogenous, exogenous, and metamorphogenic, but a majority of the deposits belongs to a group of exogenous–sedimentary origin incorporating rock salt, gypsum, anhydrite, and phosphorites and all kinds of carbonate raw material, clays, sands, and sand–gravel deposits. Reserves of major non-metallic minerals and building materials of Azerbaijan are provided in Table 2.21. Distribution of non-metallic mineral deposits and occurrences in Azerbaijan is shown in Fig. 2.31.

2.2.4.1 Chemical Raw Materials

The deposits of chemical raw material group incorporate sulfuric pyrite, rock salt, dolomites, phosphorites, and barite.

Table 2.21 Reserves of non-metallic minerals and construction materials in Azerbaijan (Atlas 2000)

No.	Non-metallic minerals	Unit	Number of deposits	Reserves
1	Gypsum	Million tons	2	40.3
2	Anhydrite	Million tons	1	18.1
3	Alum	Million tons	5	5.6
4	Bentonite clay	Million tons	2	99.3
5	Saw stone, including	Million m ³	65	570.2
	Limestone,	Million m ³	54	512.7
	Sandstone,	Million m ³	1	0.44
	Tuff and tuff-sandstone,	Million m ³	9	51.0
	Travertine	Million m ³	1	6.1
6	Facing stone, including	Million m ³	23	58.3
	Limestone,	Million m ³	2	7.4
	Marbled limestone,	Million m ³	13	27.6
	Porphyrite,	Million m ³	1	0.92
	Travertine,	Million m ³	2	14.42
	Tuffs,	Million m ³	1	0.94
	Gabbro,	Million m ³	1	2.03
	Conglomerate,	Million m ³	2	3.23
	Teschenite	Million m ³	1	1.76
7	Cement raw mineral, including	Million tons	10	373.7
	Limestone	Million tons	4	242.02
	Clay,	Million tons	4	120.07
	Trass,	Million tons	1	4.56
	and volcanic ash	Million tons	1	7.05
8	Rock salt	Million tons	4	1301.6
9	Dolomites	Million tons	2	10.02
10	Quartz and quarzites	Million tons	2	7.59
11	Flux limestone	Million tons	1	50.8
12	Limestone for soda production	Million tons	1	244.6
13	Zeolite	Million tons	1	12.5
14	Quartz sands	Million m ³	3	20.0
15	Ceramic raw material	Million tons	2	19.0
16	Barite	Million tons	2	0.38
17	Pyrofillite	Million tons	1	6.5
18	Porcelain stone	Million tons	1	3.4
19	Bituminous sands	Million tons	3	3.5
20	Building stone, including	Million m ³	26	152.6
21	Clays	Million tons	94	191.7
22	Gravel-sand	Million m ³	68	1059.3
23	Building sand	Million m ³	16	68.0
24	Perlite-pumice	Million m ³	2	6.6
25	Mineral pigments	thou. tons	2	46.4
26	Iodine-bromine water	thou. m ³ /day	5	250.5
27	Fresh underground water	thou. m ³ /day	59	6 758.9
28	Mineral water	thou. m ³ /day	29	19.8

Fig. 2.31 Distribution of non-metallic mineral deposits and occurrences in Azerbaijan (Atlas 2000)



NON-METALLIC DEPOSITS AND OCCURRENCES

PYRITE

45. Chiragidzor deposit
37. Chiragidzor-Toganalı deposit
46. Toganalı deposit

PHOSPHORITES

89. Geran galasi occurrence
88. Gumushlug occurrence

ROCK SALT

98. Nekhran deposit
93. Nakhchivan deposit
91. Pusyan deposit

DOLOMITE

99. Nekhran deposit

BENTONITE

10. Dashsalakhli deposit
9. Ali Bayramli deposit
7. Kaimakhli deposit

41. Upper Agdjakend deposit
15. Shamkhor deposit

FLUX LIMESTONE

43. Khachbulag deposit

KAOLIN AND REFRACTORY CLAYS

17. Chardakhli deposit
19. Gotul deposit
34. Kara-Murad occurrence

29. Anshapur deposit
28. Agekhush deposit
30. Danner deposit

27. Zaglik occurrence
38. Mirzik deposit
32. Karabulakh deposit

SECONDARY QUARTZITES

20. Kizildjin deposit
31. Getashen deposit
35. Chovdar deposit

PYROPHILLITE

39. Kirvakar (Sharukar) deposit

ANDALUSITE

100. Paragachay deposit

SERPENTINE

53. Geidara zone
55. Zaidara zone
59. Nikolaev zone
60. Kiazimbin zone

TUFF-SANDSTONES

94. Daralin deposit

TUFF

MARBLED LIMESTONE AND MARBLE

57. Kilisalin deposit

90. Ulya-Novashen deposit
68. Vararak deposit
73. Zariimbakh deposit
74. Gorov deposit

85. Arakul deposit
5. Kazma-Kryg deposit
2. Akhchai deposit
4. Tengin deposit

44. Dashkesan deposit
76. Shushin deposit
65. Gulabli deposit

SAND AND GRAVEL

70. Bagramtapin
101. Lenkoran deposit
16. Mingechaur deposit
61. Boglypın occurrence
58. Khovratay occurrence
54. Adjaris occurrence
62. Dzhamard occurrence
56. Leusky occurrence

ASBESTOS

71. Ipyak occurrence
52. Geidara occurrence

LIMESTONE AND CLAYS

42. Karadag deposit
11. Dash-Salakhli deposit
14. Upper Oksuzli deposit
63. Chobandag deposit
13. Aidag deposit
72. Shushikend deposit

TRASS, VOLCANICASH, PUMICE

8. Kaimakhli deposit

GYPSUM

47. Upper Agdjakend deposit
48. Monashid deposit
50. Dostagir deposit
96. Shakhtraktin deposit
97. Azazin deposit

CALCIUM CARBONATE

21. Kirovabad deposit
51. Mardakert deposit
12. Kazakh occurrence
22. Khailar occurrence

DIMENSION AND FACING STONE

33. Guzdek deposit
40. Karadag deposit
82. Dovhyaterlin deposit
6. Dashsalakhli deposit
64. Shakhbulag deposit

TRAVERTINE

95. Shakhtraktin deposit

PERLITE AND OBCIDIAN

92. Buzgov deposit
67. Kechaldag deposit
66. Deve-gezu small deposit (obcidian)

GLASS SAND AND QUARTZ FOR GLASS INDUSTRY

49. Adjavelin deposit
3. Cuba deposit
24. Khyrdalan deposit
23. Geokmalin deposit
26. Kirmakin deposit
25. Stepan Rasin deposit

OPTICAL MINERALS

78. Martunin occurrence
75. Minishend (Archinprak) Occurrence
77. Ningin occurrence
69. Agkend (Siptakshen) Occurrence
79. Aranzamin occurrence
84. Tsakur deposit
80. Bagyin-Bashin area
81. Eoku area

CRYSTALLINE QUARTZ

1. Khavanchai, Komsomolsk Group of occurrences

AGATE

36. Adjikend group of deposits
87. Elvazin deposit
86. Gurdzhulu occurrence
83. Gara-kishlak occurrence

Mineral commodities	Deposits under exploitation	Mineral occurrences
Pyrite	Δ	Δ
Rock salt	□	□
Dolomite	□	□
Phosphorite	▽	▽
Bentonite	□	□
Flux limestone	□	□
Kaolin and refractory clays	□	□
Secondary quartzites	□	□
Pyrophyllite	Δ	Δ
Andalusite	Δ	Δ
Serpentine	Δ	Δ
Asbestos	Δ	Δ
Building materials and expanded clays	□	□
Trass, volcanic ash, pumice	□	□
Gypsum	□	□
Calcium Carbonate	Δ	Δ
Dimension and facing stones	□	□
Travertine	□	□
Tuff-sandstones	□	□
Tuff	□	□
Marbled limestone	□	□
Gravel, sand	□	□
Perlite and obcidian	□	□
Ballasts	Δ	Δ
Craft and semi-precious stones (agate)	□	□
Optical minerals	□	□
Crystalline quartz	□	□
Glass sand and quartz for glass industry	□	□

Compiled by: Eniramov A.A., Gadzhiev T.G., Agakishibekova R.R. and Nagiev A.N.

Sulfuric Pyrite

Sulfuric pyrite is contained in all ore widespread formations of the Lesser and Greater Caucasus of Azerbaijan. The deposits of sulfur–pyrite, polymetallic, and copper–polymetallic ores of pyrite formation have an economic value. The deposits where sulfuric pyrite is the constituent of complex ores have been described in the section “Metallic minerals” above. All known large sulfuric pyrite deposits are concentrated within the Lesser Caucasus and confined to positive structures. These deposits are characterized by similar conditions of formation being confined to a series of quartz plagioporphyrries of the Upper Bajocian age. Accumulations of sulfuric–pyrite ores of this series are linked with subvolcanic facies of the Upper Bajocian volcanism being represented by plagiogranite–porphyries.

The ore-enclosing quartzose plagioporphyrries and their subvolcanic facies are distinguished by a high intensity of hydrothermal–metasomatic changes which have led to the formation of secondary quartzites. The formation of sulfur–pyrite deposits has occurred simultaneously with post-magmatic hydrothermal–metasomatic processes. The largest accumulation of sulfur–pyrite ores in Azerbaijan belongs to the Chiragideresi-Toganali group of deposits. The Chiragideresi, Chiragideresi-Toganali, and Toganali deposits and some occurrences are closely connected with each other owing to similar geologic and structural positions and chemical and mineral composition. The deposits differ from each other by morphology of ore bodies and textural types of ores. The deposits are hosted by volcanogenic–sedimentary rocks of the Middle Jurassic represented by quartzose plagioporphyrries and being overlaid by the Cretaceous volcanogenic and volcanogenic–sedimentary formations. The deposits of sulfide pyrite ores are confined exclusively to quartzose plagioporphyrries.

The Chiragideresi deposit

Sulfuric pyrite ores of this deposit with a high sulfur content are enclosed in stockworks of complex irregular shape and are widespread within the deposit. The contours of ore bodies are easily distinguished by a sharp decrease of a sulfur content. Other morphologic types of mineralization are nests and lenses. Out of seven ore stockworks known within the deposit, four ore stockworks have been mined out during the periods from 1905 to 1918 and intermittently from 1923 to 1968.

The Toganali deposit

Ore bodies of the Toganali deposit are localized in the upper part of quartzose plagioporphyrries series near a contact with overlapping rocks of volcanogenic series. Mineralization of

high grades and finely disseminated and impregnated types is concentrated in the upper sections of the quartzose plagioporphyrries series and decreases with a depth. Small nests of massive pyrite mineralization are observed in some places.

The Chiragideresi-Toganali deposit

Ore bodies of the Chiragideresi-Toganali deposit represent a transition type of mineralization from impregnated ores of the Toganali deposit to massive ores of the Chiragideresi deposit forming stratabound a lens-shaped deposits of 120–300 × 100–400 m size. Sulfide mineralization in the above three deposits is basically represented by pyrite, with an exception of the Chiragideresi deposit wherein a presence of copper–zinc ores (chalcopyrite, sphalerite, tetrahedrite) has been observed. Marcasite, magnetite, ilmenite, hematite, and galenite are found sporadically. Massive and brecciated textures are typical for continuous ores and vein and impregnated textural types for discontinued mineralization with lower grades.

Besides, the above-mentioned deposits, the Slavyan, Gandazar, and Gyulyatag sulfuric pyrite occurrences are known to exist in the Agdara district of the Lesser Caucasus. Mineralization is represented by vein-impregnated types with rare veins and lenses. The grade of sulfur varies from 15 to 18 % reaching 30 % in areas of continuous mineralization. A widespread distribution of ore-bearing quartzose plagioporphyrries on the territory of Azerbaijan suggests high prospects for discovering of new deposits of sulfuric pyrite ores.

Phosphorites

Despite the absence of large deposits of phosphorites on the territory of Azerbaijan, an increased phosphorization has been identified in terrigenous–carbonaceous formations of the Middle and Upper Devonian in the Nakhchivan AR, in the Upper Cretaceous formations in the area of the southeastern submersion of the Greater Caucasus and in the Maykop suite of the Shdmakha-Gobustan area. A weak phosphorization was observed in the Middle Jurassic sandstone and the Upper Cretaceous conglomerates in the southern slope of the Greater Caucasus. Detailed exploration on the territory of the Nakhchivan AR has identified a presence of phosphorites in a cross section of the Famennian and Frasnian stages of the Upper Devonian in the East Arpachay River basin. The sequence is represented by alternation of clayey shales, limestone, quartzites, and sandstones. The interbeds of phosphorites are confined to beds of clayey shales with a variable thickness from 5 to 40 m.

Five neighboring areas of phosphorite-bearing rocks have been distinguished within the Arpachay River basin. Phosphorite-bearing seams strike in concordance with

enclosing series of rocks in the northwestern direction at the angle of 320°–340° dipping to the southwest with the angle from 25° to 45°. In some areas, the number of phosphorite-bearing beds varies from 3 to 17 with a thickness from 0.2 to 0.7 m each. Three natural types of phosphorites, namely the dominant oolitic, nodules, and phosphoritized host rocks, were distinguished within this area. The content of P_2O_5 varies in wide ranges for different strata from 1.17 to 15.75 %. The content of P_2O_5 in the most representative Gerangalasi occurrence varies from 3 to 8 % in eight phosphorite-bearing intervals, 5 to 8 % in three intervals of the Gumushlug occurrence, and 15.75 % in the fourth seam of the Ayvazkhan occurrence.

Barite

Around twenty barite deposits and occurrences that have been found on the Azerbaijan territory are represented by a vein type and often confined to marginal parts of anticlinoria in volcanogenic formations of the Middle Jurassic. The Chovdar, Gushchu, Zaglik, Bayan, and other barite deposits are located within the Shamkir anticlinorium. The Chaikend, Azad, Bashkishlak, and other deposits are confined to the Goygel uplift, and the Tonashen barite deposit was found within the Aghdam anticlinorium.

A distribution of barite mineralization is controlled by relatively large faults and adjacent fractured zones, originated in archy zones of anticlines and in axial planes of folds. These fractured and compression zones of 5–6 m thick are often accompanied by brecciation and intensive hydrothermal alteration pronounced by silicification, kaolinization, sericitization, and chloritization. Typical morphological types of barite mineralization are veins and fissure fillings. A total number of barite-bearing veins within the barite deposits of Azerbaijan vary from ten to twenty, except the Chovdar and Bashkishlak deposits where the number of veins varies from 30 to 45. The veins of mainly northwestern direction are normally steeply dipping with variable angles from 40° to 85°. A thickness of veins varies normally from 0.15 to 2.0 m with an increased thickness in swellings of the Chovdar deposit up to 6 m. A general length of veins varies from 200 to 500 m with an exceptional length of some veins at the Chovdar exposit from 1000 to 1500 m.

A specific feature of barite-bearing veins at the Chovdar, Bayan, and some other deposits is their clear morphology stipulated by an alternation of barite veins with barren intervals. Hydrothermal alterations of host rocks along barite-bearing fractures are represented by quarzitization, calcitization, epidodization, sericitization, and chloritization. Textural varieties include foliated, latticed, and cellular types of barite in the upper sections of ore veins and cryptocrystalline and dense varieties in the lower sections. Well-formed crystals of barite are rare. Barite is the major ore mineral, and rarely associated minerals are quartz, calcite, fluorite, and

fine-disseminated galenite. Within the Chovdar, Bashkishlak, and Bayan deposits, the concentration of galenite increases noticeably in the lower sections of barite-bearing veins. Minor pyrite, chalcopryrite, tennantite–tetraedrite, and sphalerites are observed in paragenesis with galenite.

A vertical zonation in all barite deposits is being traced by a dominant barite mineralization in the upper parts of veins through gradual transition to a lead–barite mineralization in the middle part to a completely polymetallic mineralization in the bottom sections of veins. Downward, barite is gradually replaced by quartz and, partially, by calcite and in lower sections by noticeable fluorite in association with polymetallic mineralization. The content of $BaSO_4$ varies from 70 to 95 %, density from 3.7 to 4.5 g/cm³, CaO from 5 to 10 %, SiO_2 up to 10 %, and Fe_2O_3 from 1 to 2 %.

Zeolites

Zeolites are widely used in industry as sorbents, molecular sieves, catalysts for drying and refining of gas, extraction of valuable admixtures, filters of natural water, and other purposes. Among natural zeolites, the most valuable industrial varieties are highly siliceous clinoptilolites, mordenites, erionites, and chabasites. These minerals of zeolite group are widespread in Azerbaijan in volcanogenic–pyroclastic and sedimentary rocks of the Upper Cretaceous and Tertiary ages.

The Aidagh zeolite deposit

The deposit has been found 7 km northwest of Tauz town near the Baku–Tbilisi railway in carbonaceous–tuffogenic rocks of the Campanian stage of the Upper Cretaceous. The zeolite-bearing strata is represented by massive fine-grained heat tuffs of light, light-cream, and light-green colors, which has been raced over a distance of 2000 m with a variable thickness from 10 to 80 m with a dipping angle from 15° to 40°. The main minerals are clinoptilolite, quartz, and calcite with associated biotite and chlorite. The detailed mineral exploration has contoured two beds of zeolite-bearing tuffs with proven reserves of 10 million tons.

The average content of clinoptilolite is 30.4 % in the upper layer and 63.3 % in the lower bed. The central part of the deposit shows a high content of clinoptilolite from 60 to 99 %. The average chemical composition of the productive strata is 60 % of SiO_2 , 1.24 % of MgO, 11.92 % of Al_2O_3 , 2.12 % of K_2O , 1.4 % of Fe_2O_3 , and 5.77 % of CaO. A lead content varies from 0.001 to 0.01 %.

There are good prospects for increased reserves of zeolite-bearing heated tuffs at the Aidagh deposit and the Upper Cretaceous trass bluish tuffs within the Koroglu deposit in the Gazakh district. A chain of zeolite occurrences similar to the Aidagh deposit was traced on the northeastern slope of the Lesser Caucasus. The presence of large reserves of analcimite enhances the value of these occurrences for zeolite production. Besides the Upper Cretaceous

formations, the Tertiary formations of the Talysh Mts. area contain zeolites in volcanogenic–sedimentary formations of the Paleogene–Neogene age. Beds of heated tuffs, tuffites, and traces among the Pliocene rocks are of special interest for zeolites. Prospects for zeolites are also associated with the Paleogene volcanogenic–sedimentary rocks in the Nakhchivan fold area and in the Kelbadjar superimposed trough.

Mineral Pigments

Geologic prospecting for mineral pigments on the territory of Azerbaijan has succeeded by discovering the large Danaeri and Chovdar deposits in the Dashkesan district and the Mirzik deposit in the Khanlar district. The deposits are hosted by hydrothermally altered rocks of volcanogenic series of the Middle Jurassic age. Pigments are related to a group of ferrum-oxide pigments corresponding to clayey ocher.

The Chovdar deposit

The deposit is located at a distance of 19–20 km southwest of the Ganja railway station partially coinciding with the Chovdar barite deposit. Technological properties of mineral ochers, occurring in stratified layer from 4 to 8 m thick, comply with the State's standards. The remaining reserves of ochers grading 32 % of Fe_2O_3 are 38,000 tons.

The Mirzik deposit

The deposit is located on the southern end of Mirzik village of the Khanlar district. The deposit of clayey ocher of golden color is confined to a large tectonic fault of the northwestern direction and gentle dip from 10° to 20° . A faults zone is filled with limonitized epidote–chlorite disintegrated rocks of lemon-golden-yellow color. Enclosing rocks as a result of supergenous processes have been completely reworked and transformed into dispersal ocher mass. Technological tests of paints made from the above pigments have showed good gentle coverage and susceptibility of vanish. The remaining reserves of the deposit are 8000 tons of ocher with a content of Fe_2O_3 from 40 to 49 %. The detailed mineral exploration for increasing the reserves has identified the new Danaeri and Sariyal deposits of orchres with a variable Fe_2O_3 content at the Danaeri deposit from 35 to 50 %. Other targets for development of mineral orchres are pigments of secondary origin known in the Jabrail district near Sumgayit city.

The Dashveisal occurrence

The occurrence is located 2.5 km northwest of the Jabrail district center in deluvial–eluvial sediments. A pigment-bearing

layer from 0.5 to 3 m thick consists of detrital material with a clayey fraction of 48.57 %. The minerals are hydromicas, quartz, kaolinites, apatite, hematite, limonite, and calcite. The chemical composition is 46.88 % of SiO_2 , 19.62 % of Al_2O_3 , 9.38 % of Fe_2O_3 , 8.44 % of CaO , 4.13 % of MgO , and 1.23 % of SO_3 . Pigments of this occurrence are clayey ocher which is a raw material for dark-red paints of covering ability 20.4 g/m^2 and oil capacity of 27.18 %. Light-pink cement resistable to atmospheric erosion was obtained by pigments in addition to white clinker in quantity from 2.5 to 10 %. Proved reserves are estimated at 40,000 tons.

The Sumgayit occurrence

The occurrence is located on the right slope of the Sumgayit River valley, 20 km northwest of the Khyrdalan town being represented by red clays of the Tertiary age. The seam of clays with a thickness of 8 m is traced over a distance from 2.5 to 3 km. Clays are compact, of a red color with various shades; a clayey fraction is 98 %. Chemical composition is 54.88 % of SiO_2 , 18.52 % of Al_2O_3 , 7.78 % of Fe_2O_3 , 3.13 % of MgO , 0.81 % of CaO , and 1.17 % of SO_3 . Covering ability is 2.25 g/m^2 , and oil capacity is 25.3 %. Pigments of this occurrence are related to clayey red types suitable for production of colored cement and linoleum. Proved reserves are estimated at 1 million tons. Other prospective areas of Azerbaijan for mineral pigments of various types, colors, and shades are colored varieties of the Tertiary clays of the Shamakhy-Gobustan foothill zone, hematites of the Alabashli area in the Shamkir district, and limonitized clays of the Nakhchivan AR.

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