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## ГЕОТЕРМИЧЕСКОЕ ПОЛЕ И ГЕОЛОГИЯ РЕГИОНА КАСПИЙСКОГО МОРЯ

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Каспийское море и прилегающие территории являются обширным нефтегазоносным мегабассейном. Он состоит из Северо-Каспийского, Средне-Каспийского и Южно-Каспийского осадочных бассейнов. Гранитно-метаморфический фундамент бассейнов с севера на юг становится моложе в направлении от раннекембрийского до раннекиммерийского возраста. Он представляет зону перехода от южной окраины Восточно-Европейского кратона к складчатости альпийского возраста. Геотермические исследования выполнялись как в сотнях глубоких скважин, так и в Каспийском море, было опубликовано несколько предварительных карт для региона Каспийского моря. Все они не рассматривают южную часть региона в пределах национальных границ Ирана. Нами подготовлена новая карта теплового потока, включающая северный Иран. Целью статьи является рассмотрение распределения теплового потока во всем Каспийском регионе, в том числе южной его части. Две обширные аномалии высокого теплового потока более 100 мВт/м<sup>2</sup> выделены на карте: в северо-западном Иране и акватории Каспийского моря к северу от Апшеронского выступа. Они разделены удлинённой полосой теплового потока менее 50–55 мВт/м<sup>2</sup>. Прослеживается общая тенденция возрастания теплового потока от блоков коры докембрийского возраста Прикаспийской впадины к альпийской складчатости в пределах территории Ирана. Проводится анализ распределения теплового потока, составлены два профиля изменения плотности теплового потока.

**Ключевые слова:** Каспийское море; геотермическое поле; карты теплового потока; геология; скважины.

## GEOHERMAL FIELD AND GEOLOGY OF THE CASPIAN SEA REGION

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The Caspian Sea and adjacent areas form the vast oil and gas-bearing megabasin. It consists of North Caspian, Middle Caspian, and South Caspian sedimentary basins. The granite-metamorphic basement of the basins becomes from north to south younger in the direction from Early Precambrian to Early Cimmerian age. It represents a transitional zone from the southern edge of the East European Craton to Alpine folding. Geothermal investigations have been carried out both in hundreds of deep boreholes and within the Caspian Sea and a few preliminary heat flow maps were published for the

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Caspian Sea region. All they excluded from consideration the southern part of the region within Iranian national borders. We prepared a new heat flow map including the northern Iran. The purpose of the article is to consider heat flow pattern within the whole Caspian Sea region including its southern part. Two vast high heat flow anomalies above 100 mW/m<sup>2</sup> distinguished in the map: within the southwestern Iran and in waters of the Caspian Sea to the North of the Apsheron Ridge, separated by elongated strip of heat flow below 50–55 mW/m<sup>2</sup>. A general tendency of heat flow from growing was distinguished from the Precambrian crustal blocks of the North Caspian Depression to the Alpine folding within the territory of Iran. Analysis of the heat flow pattern is discussed and two heat flow density profiles were compiled.

**Keywords:** Caspian Sea; geothermal field; heat flow maps; geology; boreholes.

## Introduction

The Caspian Sea is a vast land-locked water reservoir on our planet. A number of rivers flow into it and there are no outlet rivers. Until the fall of the Soviet Union in 1991, the southern part of the Caspian Sea have been under jurisdiction of Iran and the rest part belonged to the USSR. After 1991, the number of littoral states of the Caspian Sea increased to five: Azerbaijan, Russia, Kazakhstan, Turkmenistan and Iran. The Caspian Sea itself and its adjacent areas form the Caspian oil and gas-bearing megabasin.

Mainly Soviet scientists conducted geothermal studies in the Caspian Sea and adjacent lands before 1991. Heat flow data (HFD) of this period were published in several articles and monographs [1; 4; 5; 7; 11; 14, and others]. After 1991, some new heat flow data were reported by scientists of the Azerbaijan Republic and recently by colleagues from Iran [22; 27]. Until present time geothermal investigations absent for the deep-water area of the South Caspian Depression.

## Geology of the region

The Caspian Sea has close to meridional stretching from north to south. A number of crustal blocks of different age from the territory of Russia and Azerbaijan land underlie its waters and continue into Kazakhstan and Turkmenistan. Their age ranges from Precambrian North Caspian Depression until the Alborz Alpine folding in the northern Iran (fig. 1).

The Caspian Sea was formed in site of the Meso-Cenozoic sea basins of Tethys and Paratethis existing there. Five main crustal blocks exist within the Caspian Sea region. They are: the North Caspian Basin (NCB), the Middle Caspian Basin (MCB), the Apsheron Sill, the Mangyshlak Sill and the South Caspian Basin (SCB). The North Caspian Basin includes the northern part of the Caspian Sea and adjoining land area and stretches into Russia and western Kazakhstan. It is mainly a low-lying plain with the thickness of sedimentary cover deeper than 4.5 km.

The northern and western boundaries of the region within the North Caspian Basin are steep flexures where the basement abruptly deepens up to 10–12 km. In the central part of the basin, a depth to the Precambrian basement reaches at least to 20 km according to available estimates. The eastern boundary of this basin lies along the Ural Folded Belt and its southern continuation, it is buried under a thin veneer of Mesozoic rocks. In the south, the basin is bounded by the Karpinsky Fold Belt in the west of the Caspian Sea and by the South Emba Uplift to the east of the sea [24].

An oceanic type of the crust is believed to exist within the South Caspian Basin. There are two areas of relatively deep water from 400 to 700 m within the sea separated by the Apsheron Ridge (Apsheron Sill). They are the Central Caspian Basin to the north of this ridge and the South Caspian Basin to the south of it (fig. 2).

The crustal structure was studied by seismic methods within the South Caspian Basin. The results show an existence of folded deep sedimentary cover beneath the Caspian Sea. Three cross sections give a brief information on the crustal structure of the South Caspian Basin (fig. 3). The extension of these profiles is shown in a small scale in the left and central corners of the figure. Productive series for commercial availability of hydrocarbons are marked as PS.

All three cross sections show that a rapid accumulation of sediments was pronounced within the South Caspian Basin, and an avalanche sedimentation happened during the Mesozoic/Paleogene time. Their thickness has a tendency to increase from north to south. According to estimates the sedimentation rate in the Jurassic time in the SCB was 120–180 m/My. During Cretaceous and in Paleogene it became lower, but in Pliocene it reached avalanche values – 1.8 km/My [30]. According to other opinions the sedimentation rate during Jurassic in this basin ranged from 10–25 to 50 m/My. The Cretaceous in the Caspian Sea and adjoining land

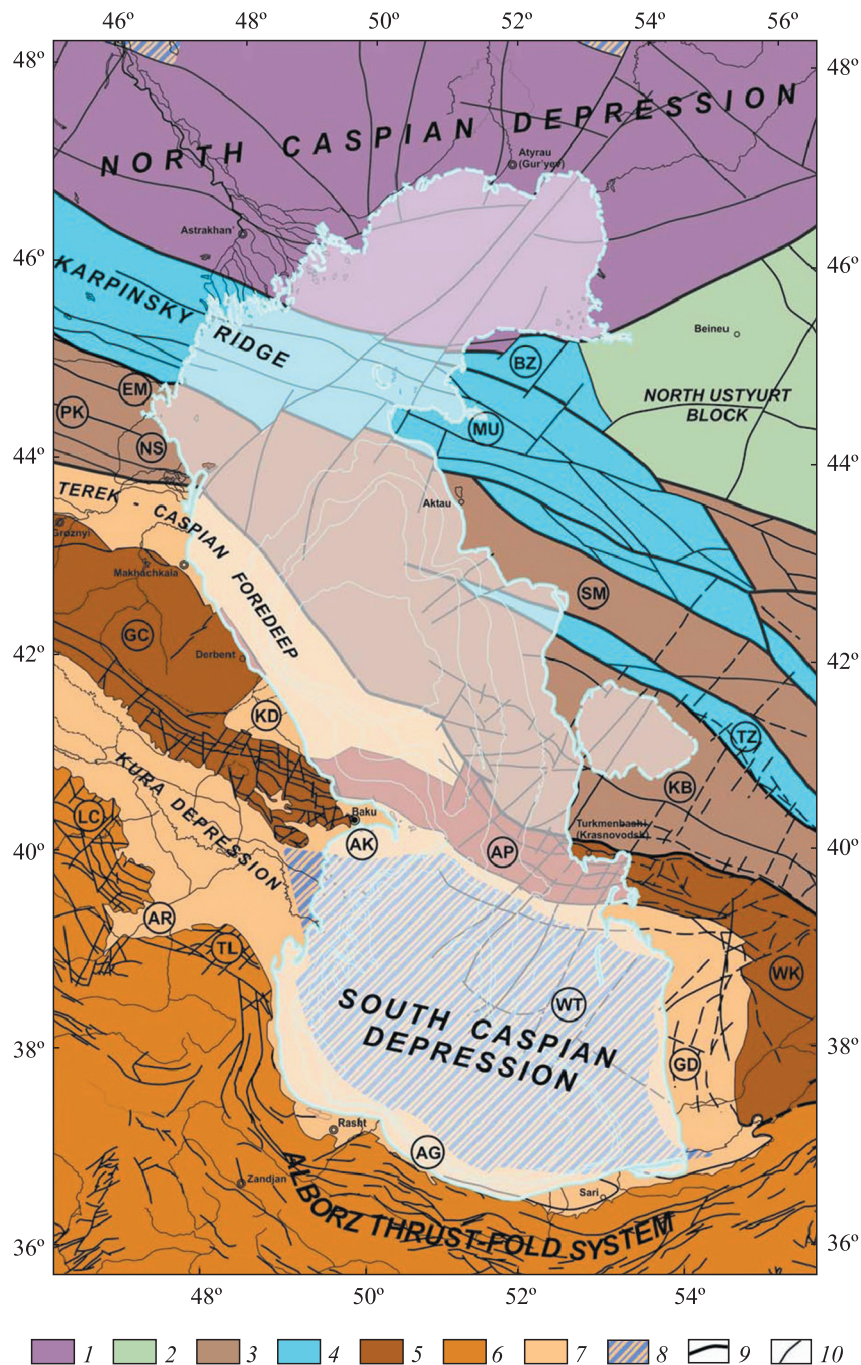


Fig. 1. Main structural elements of the Caspian Sea region.

Basement of platform areas (1–4): 1 – Early Precambrian; 2 – Baikalian; 3 – Hercynian; 4 – Early Cimmerian; 5, 6 – Alpine fold-thrust systems: 5 – Greater Caucasus and Kopet Dag, 6 – Lesser Caucasus, Talesh, Alborz;

7 – foredeeps and depressions; 8 – depressions with oceanic-type crust;

9 – tectonic lineaments corresponding to boundaries of large structures; 10 – other important lineaments.

Main structures (letters in circles): AK – Apsheron – Kobystan Periclinal Trough, BZ – Buzachi Arch, MU – Mangyshlak – Central Ustyurt, SM – South Mangyshlak – Ustyurt system of troughs, TZ – Tuarkyr Zone, KB – Middle Caspian Karabogaz Antecline, EM – East Manych Trough, PK – Kuma system of uplifts, NS – Nogai Scarp, GC – Greater Caucasus Fold System, KD – Kusary – Divichi Trough, AP – Apsheron Balkhan Zone, WK – West Kopet Dag Zone, LC – Lesser Caucasus Fold System, AR – Lower Araks Trough, TL – Talesh Zone, AG – Alborz – Gorgan Foredeep, WT – West Turkmen Trough, GD – Gograndagh – Okarem Zone.

Source: [24], modified



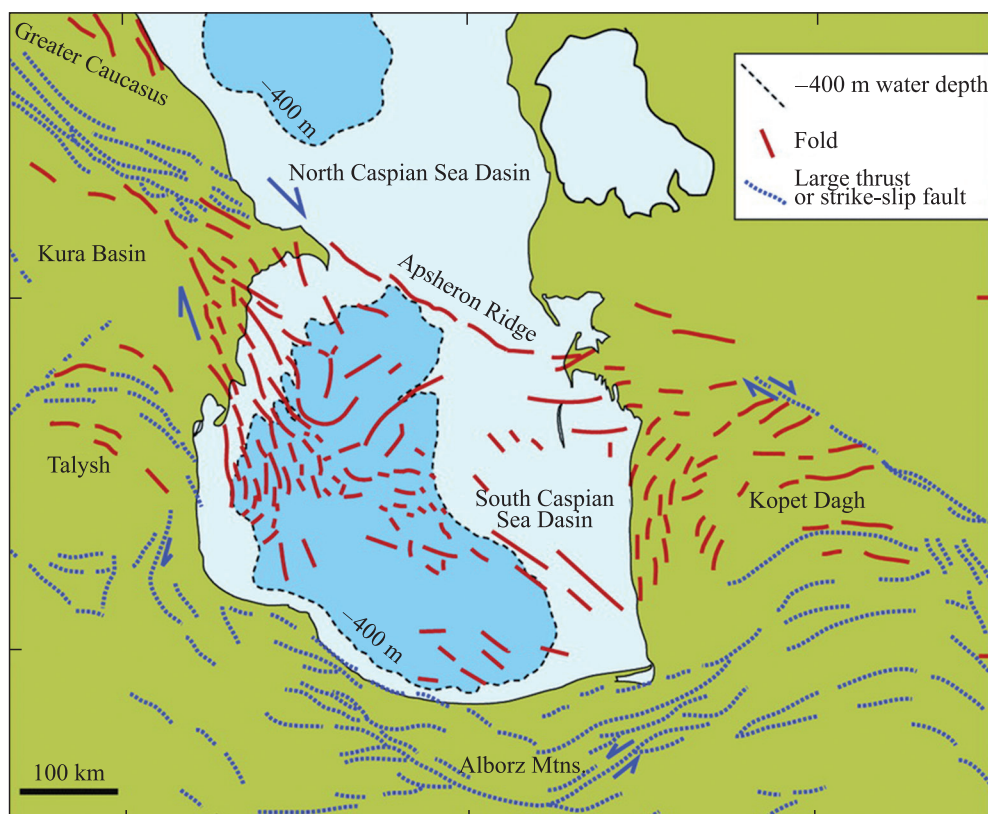


Fig. 2. Main faults and deep-water areas  
within the Central Caspian and South Caspian Basins, respectively.  
Source: [29]

areas continued tendencies of the Jurassic. During Cretaceous it was 2.5–10 m/My. In the SCB the maximum thickness of Cretaceous deposits exceeds 4 km. It is reduced in the Middle Caspian Basin approximately to 2.4–2.5 km and within the NCB it is around 1.4 km. During the Oligocene – Miocene time the rate of sedimentation within the South Caspian Basin ranged from 0.025 till 0.4 km/My, during Pliocene – Quaternary time it changed from 0.75 to 1.75 m/My, respectively [24].

Total thickness of Neogene – Quaternary deposits in the SCB is estimated to be up to 10 km and in the NCB it is around 4 km [20].

### Availability of heat flow data within the region

A number of researchers starting from early seventies studied the heat flow distribution within the considered area including the Caspian Sea [1; 8; 10–12; 30, and others] and adjacent land territory [2; 4; 9; 17; 18; 34, and others].

There are a sparse heat flow data from the adjoining territory of Iran and only several local parts of the country were studied in heat flow. Within this study region the heat flow determination is available for the Tehran well [22]. Others estimates were published for the Persian Gulf (18 heat flow values) [26]. 17 heat flow values were reported from the northwestern part of the country in the vicinity of the Sabalan Mountain [27], which is located in the Ardebil Province within the northwestern part of Iran. The heat flow data are available as well from a small area in the southwestern oil-bearing part of Iran [26]. However, in the northwestern part of the country the heat flow density estimates were derived using an indirect approach from the analysis of the magnetic field, where the depth to the Curie surface (+580 °C) and the top of the causative magnetic body was calculated. Thus, knowing the base of the causative body and its temperature it is possible to estimate the heat flow density.

Positions of well with determined heat flow density, as well as marine heat flow stations within the studied Caspian region are shown in fig. 4. Very uneven position for boreholes or marine stations with studied heat flow within this area is evident. There are very sparse HFD determinations within the land territory adjoining the northern part of the Caspian Sea, as well as marine data because the sea is shallow here. It was found experimentally that seasonal mixing of water during storms resulted in temperature perturbations reaching on average the depth up to c. a. 300 m, sometimes even more.



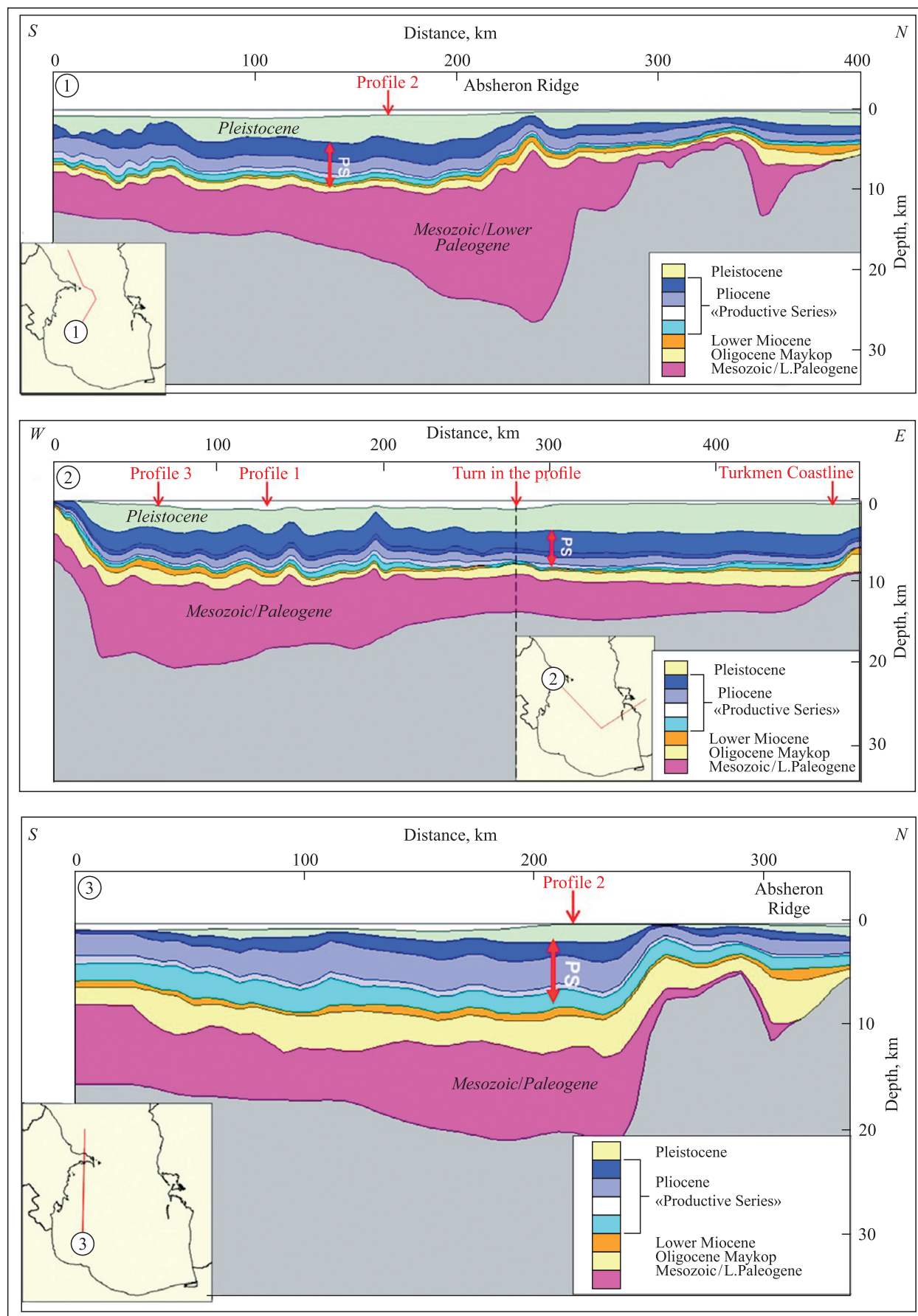


Fig. 3. Seismic profiles through the South Caspian Basin.  
Source: [20], modified

Until now, the Iranian part of the sea was not studied in heat flow. Nevertheless its sparse data are available in the northern Iran, they are absent along the Turkmenistan border. A few data was published within the territory of Kazakhstan [7], as shown in the map. Territories of Azerbaijan, adjoining Russian area, excluding the Greater Caucasus are studied much better in geothermal respect in numerous wells drilled mainly in the process of oil exploration. Many heat flow determinations were fulfilled within Caspian Sea adjoining shores of Azerbaijan and Dagestan (Russian Federation). A number of oil wells were geothermally studied also within the West Turkmenian Depression.

The heat flow histogram for the marine territory of the region is shown in fig. 5. It includes available data from marine heat flow stations and boreholes drilled at shallow depths. The main portion of individual HFD data fall within intervals of 9–34 and 34–59 mW/m<sup>2</sup>, in seldom cases the heat flow reaches high values (intervals 109–134; 134–159 and 184–209 mW/m<sup>2</sup>).

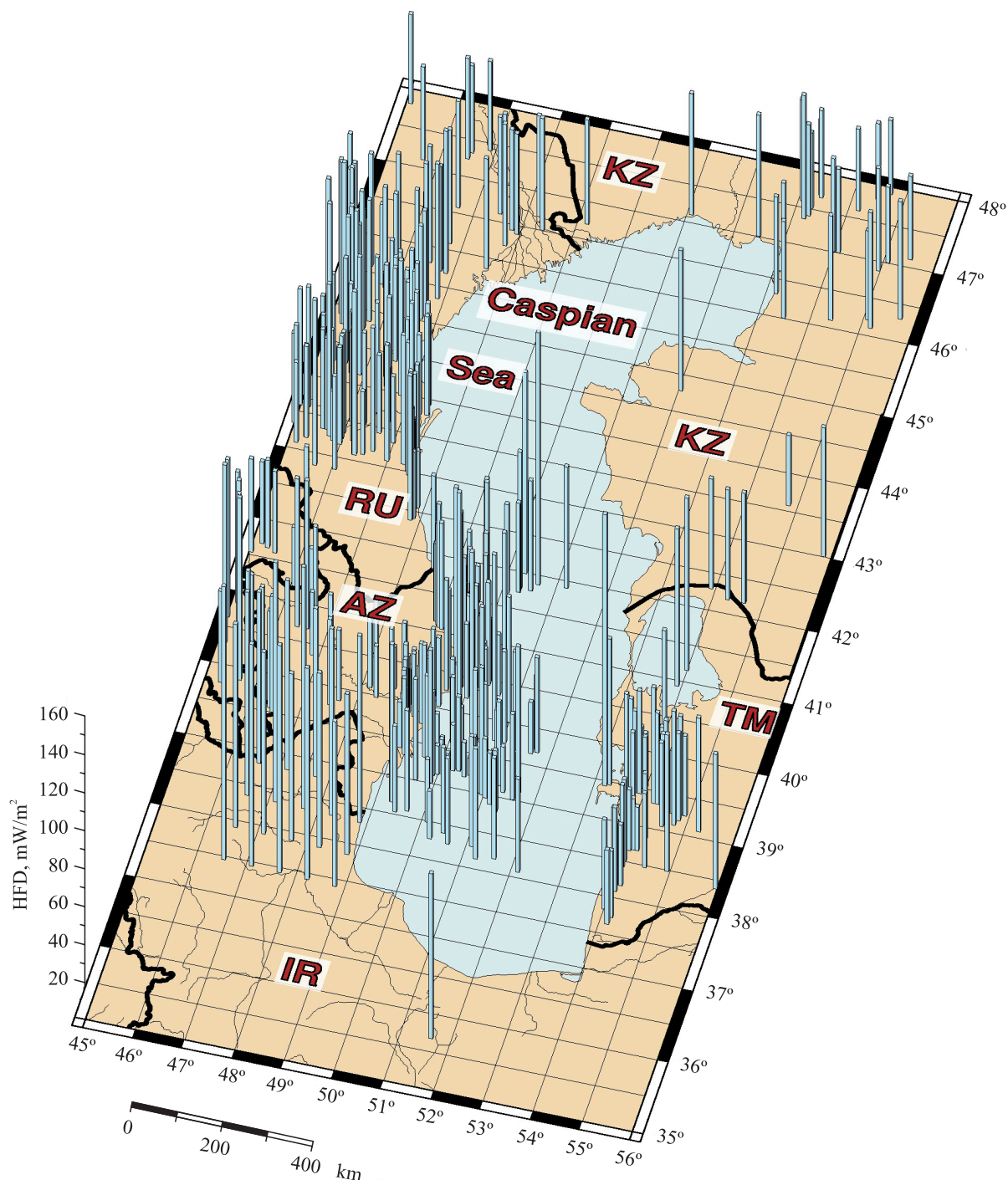


Fig. 4. Available heat flow data and locations of studied wells and marine HFD stations. Abbreviations for countries: AZ – Azerbaijan, IR – Iran, KZ – Kazakhstan, RU – Russia, TM – Turkmenistan. Source: [28], modified

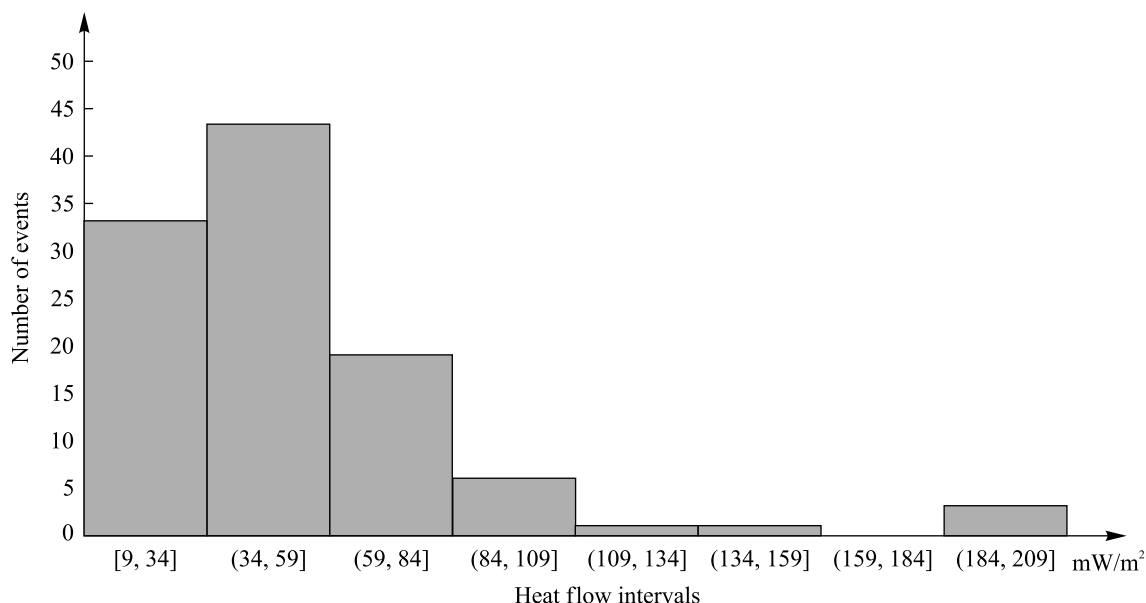


Fig. 5. Heat flow density histogram for the Caspian Sea

The heat flow interval 34–59 mW/m<sup>2</sup> belongs mainly to the central and central-northern areas of the Caspian Sea. At present, a number of marine boreholes were drilled within marine waters belonging to Russian, Kazakhstan, Turkmenistan and Iranian sectors of the Caspian Sea, but their geothermal data of investigations are not accessible yet from drilling companies.

The histogram for land areas adjoining the Caspian Sea within territories of Azerbaijan, Iran, Turkmenistan, Kazakhstan and Russia is shown in fig. 6. Practically all heat flow determinations here were fulfilled using thermograms and thermal conductivities of rock samples, collected from drill cores and measured in laboratory conditions by many researchers from Azerbaijan, Russia and Turkmenistan.

The heat flow is ranging from 17 until more than 120 mW/m<sup>2</sup> and the histogram has more symmetrical form. The maximal number of HFD determinations falls into intervals of 43–52 and 52–61 mW/m<sup>2</sup> after which the number of its observations gradually drops to values of 96–105 mW/m<sup>2</sup> and ceases further. A wide range of heat flow values reflects many factors, such as depths of studied intervals in boreholes, local tectonic activation, ground water circulation, folding, proximity of deep faults to studied boreholes and their activity, etc.

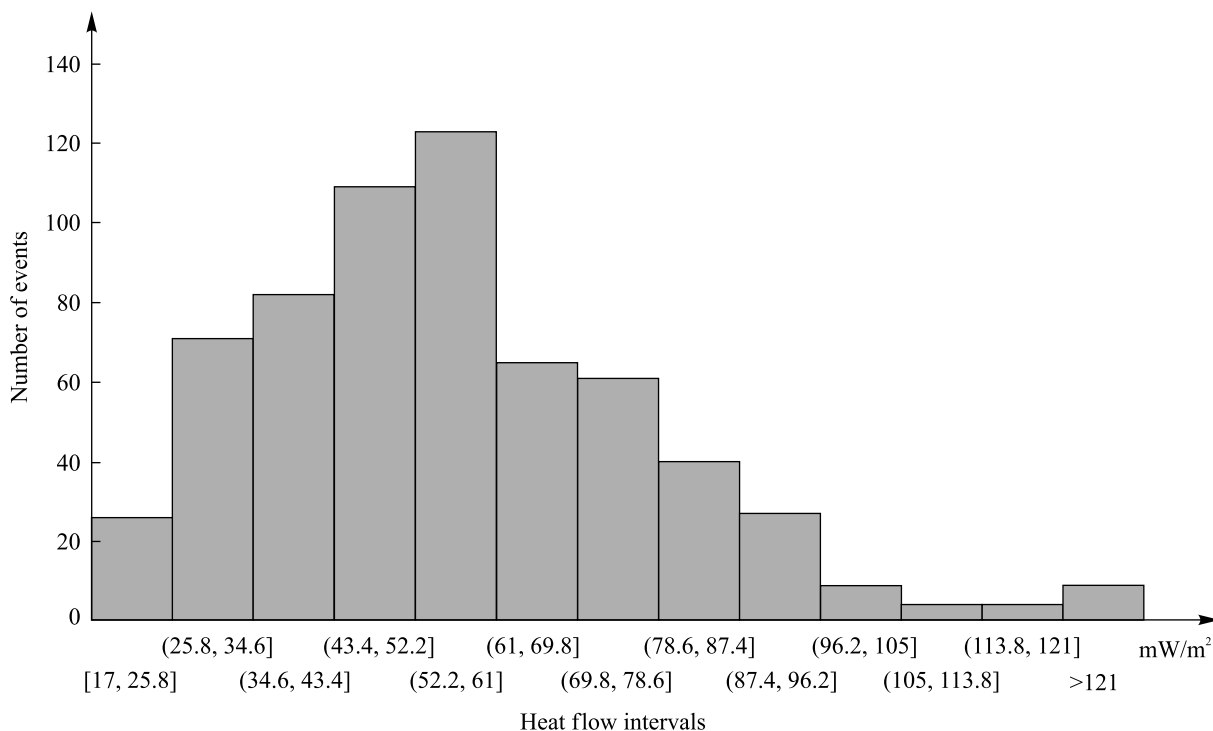


Fig. 6. Histogram of heat flow density for land territories around the Caspian Sea



A total histogram of heat flow density for the whole region under investigations is shown in fig. 7. It's configuration is close to the normal distribution of the considered parameter within the whole studied region with a trailing tail in the right side of the diagram, which is formed by a small number of high heat flow values exceeding 102 mW/m<sup>2</sup>. The biggest number of heat flow observations fall into the following intervals: 37–46, 46–56 and 56–65 mW/m<sup>2</sup>.

It is possible to conclude that the prevailing heat flow values within the whole considered region are close to 50 mW/m<sup>2</sup>, which is typical also for adjoining Precambrian crustal blocks. The lowest and highest HFD values observed within the territory of the Caspian Sea are 9 and above 200 mW/m<sup>2</sup>, respectively.

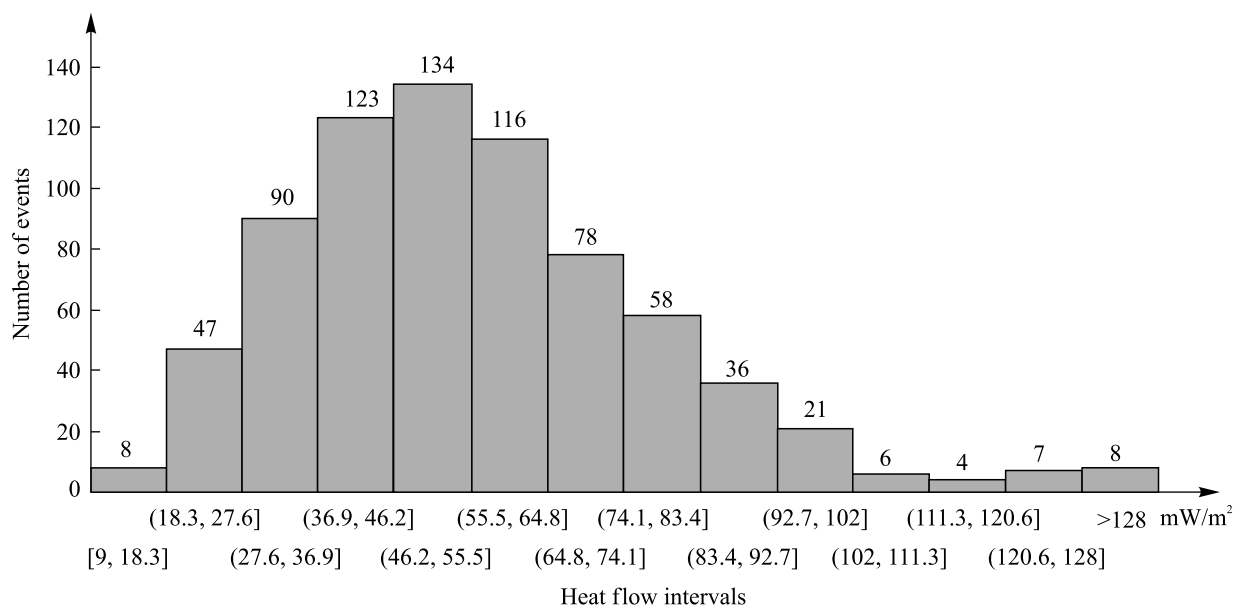


Fig. 7. Total HFD histogram for the Caspian Sea region

### Heat flow density map

During a number of decades, geophysical investigations including geothermal observations were organized in relation to the growing attention to exploration for hydrocarbons within the Caspian Sea, as well as investigations of its internal structure.

A number of researchers discussed heat flow in the water area of the Caspian Sea earlier [11; 21]. Geothermal data from the region include results of measurements fulfilled by means of marine heat flow probes. They were supplemented by results of its determinations based on thermograms, recorded in wells, drilled in the shelf zone of Azerbaijan [30].

A few versions of heat flow sketches and maps were compiled within the studied region, both within the Caspian Sea waters and onshore parts of adjacent countries [6; 11; 13; 14; 30]. Their authors used different databases. In particular, in all heat flow maps of the Caspian Sea anomalies of differentiated, both high and low heat flow were shown. However, the geometry of HFD isolines are to some extent different. In all these maps, the southern part of the Caspian Sea within Iranian waters was left as a blank area. For many of maps HFD isolines were manually drawn and reflect opinions of their authors.

A new heat flow density map for the Caspian Sea region, which takes into account available HFD data including the Iranian territory within area E 45–56° and N 35–48° was recently compiled using the *Generic Mapping Tools (GMT) package*, release 5.1, developed in the Hawaii University, USA [33; 35] (fig. 8).

Two wide areas of elevated heat flow density above 60 mW/m<sup>2</sup> are clearly distinguished at the map and shown in warm colors, separated by moderate to low heat flow below 50–55 mW/m<sup>2</sup> in the center of the map and indicated by cold colors. Two very high heat flow areas exceeding 100 mW/m<sup>2</sup> are distinguished in the left lower corner of the map and within the central part of the Caspian Sea. The high heat flow in the northwestern part of the Iranian territory corresponds to the area of Alpine folding, accompanied by recent volcanic activity with a number of destructive earthquakes, periodically happened both in Iran, Armenia (e. g. Spitak earthquake), Turkey and adjoining Zagros Mountains.

Elongated heat flow strip of the NW – SE orientation is formed from the Trans Caspian Depression, which is crossing the Caspian Sea, stretched and continues into the West Turkmenian Basin and probably continues into the Iranian territory. An absence of heat flow determinations beyond the Turkmenistan-Iranian border do not permit to trace contours of this low heat flow zone to the southeast.

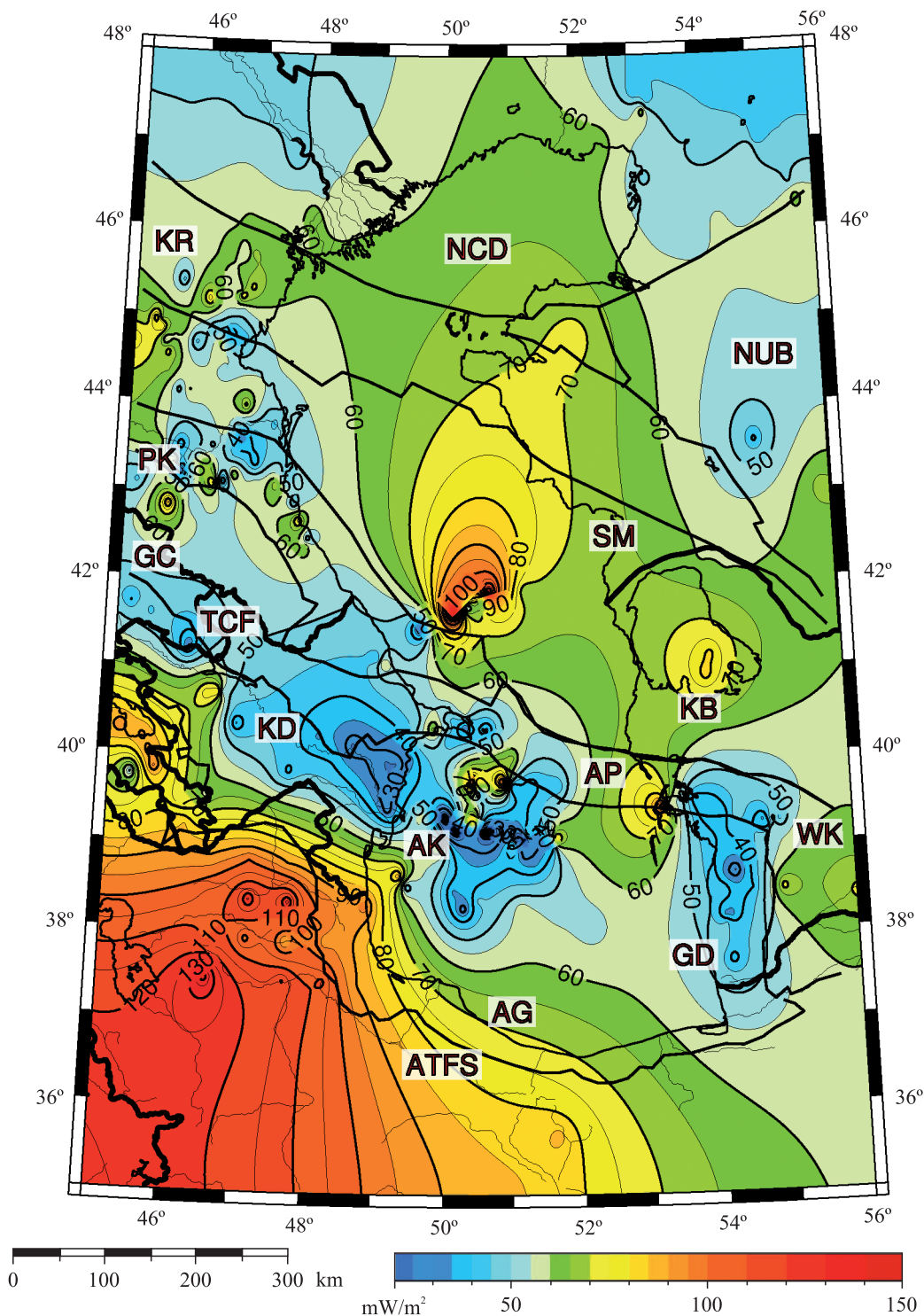


Fig. 8. Heat flow density distribution within the Caspian Sea region.

Source: [28], modified

Main structures: AK – Apsheiron – Kobystan Periclinal Trough; ATFS – Alborz Thrust Fold System; AG – Alborz – Gorgan Foredeep; AP – Apsheiron Balkhan Zone; GC – Greater Caucasus Fold System; GD – Go-grandagh – Okarem Zone; KB – Middle Caspian Karabogaz Antecline; KD – Kusary – Divichi Trough; KR – Karpinsky Ridge; NCD – North Caspian Depression; NUB – North Ustyurt Block; PK – Kuma System of Uplifts; SM – South Mangyshlak – Ustyurt System of Troughs; TCF – Terek – Caspian Foredeep; WK – West Kopet Dagh Zone.

Heat flow isolines within the North Caspian Depression showed only partly based on existing heat flow determinations, but within the prevailing part of this area, they were drawn in result of an interpolation. They require further refinement after new data will be accumulated.

## Discussion

All accessible heat flow data were used for our analysis. Nowadays a number of oil companies drill wells in Azerbaijan, Russia, Kazakhstan, Turkmenistan, and Iran from marine platforms or overhead roads of steel constructed in some localities of shallow water. In most situations, thermograms of these marine wells are not accessible for geothermal analysis.

The heat flow within the Caspian shelf, adjoining its western shores, was studied using a special heat meter [3] in combination with a thermographic recorder, but detailed coordinates of HFD stations are absent, as well as their description, therefore they are not analyzed in this article. These authors mention that heat flow density varies along the HFD profile Makhachkala – Kyzylkum from as low as minus 41 until approximately plus 42 mW/m<sup>2</sup> depending on the depth of the sea. Measurements within shallow depths (below 70–80 m) give negative HFD values due to pronounced diurnal and seasonal temperature variations at the marine bottom, amplified by water circulation. Experimentally it was established, that diurnal temperature wave reached up to the depth of 10 m. It leads to a transient phenomenon within the water column. The HFD increases to approximately 42 mW/m<sup>2</sup> when the depth to the bottom sediments exceeds 100 m, which is considered as a shelf margin for the Caspian Sea [3].

Two very high heat flow anomalies exceeding 100 mW/m<sup>2</sup> are shown in the left lower corner of the map and within the central part of the Caspian Sea. The latter one is a result of a single heat flow determination received using a marine heat flow probe. A number of researchers interpret it as a warm water discharge into bottom sediments from a deep penetrating and active fault, which warms up sediments at the marine bottom [6; 17; 30].

A number of researchers indicate that besides conductive heat transfer, which we measure in boreholes or by marine heat flow probes, there are convective cells within the sedimentary cover including bottom sediments, which influence the heat flow pattern and form heat flow anomalies. They are typical near zones of active faults, other dislocations, and mud volcanoes within both marine areas and the land [15; 19].

The heat flow distribution has a good correlation with main tectonic features of the deep tectonic structure of the crust, such as deep penetrating faults, mud volcanoes, radiogenic heat production caused by a decay of long-living isotopes. As an example of such influences, it is necessary to mention that very high HFD value around 600 mW/m<sup>2</sup> was observed at one of heat flow stations within southern part of Caspian Sea. Similar unusually high heat flows were observed also near young rift zones within the Pacific Ocean. Another example of an extremely high heat flow was observed near the mud volcano Hakon Mosby within the Barents Sea (1045 mW/m<sup>2</sup> [23]).

Concerning the high value of 600 mW/m<sup>2</sup> recorded within the South Caspian Basin, there was put forward an opinion, that it was a result of a high temperature and partially melted mantle existed at rather shallow depth [13].

Accumulated sediments have rather low thermal conductivity, which results in blanketing of heat flow entering from below and warming up the uppermost sedimentary layer [32], finally resulting in observed relatively high thermal regime within it. A very high heat flow (209 mW/m<sup>2</sup>) value was observed also to the north of the Apsheron Ridge. It could be explained both by such blanketing and by the heat production produced by friction due to folding and subduction as well as an active warm water circulation near a deep fracture.

The HFD structure within western part at the south of the Caspian Sea shows a complex pattern due to its tectonic structure, complicated by faults and marine mud volcanoes. It ranges here from 20 until 70 mW/m<sup>2</sup>. The eastern part of the sea has more uniform heat flow here. The middle part of the Caspian Sea evidences on average the heat flow around 50 mW/m<sup>2</sup>. Nevertheless, within the Derbend Depression, increased heat flow up to 134 and even 210 mW/m<sup>2</sup> was also observed.

Several possibilities were considered to explain the observed anomalies. One of the most realistic one is a warm water discharge into the marine bottom. Besides this, it is not possible to reject other mechanisms of a heat generation that within the Derbend Depression, which could increase the observed heat flow additionally to around 40 mW/m<sup>2</sup>, or even more, effects of organic matter oxidation and, as mentioned above, the mud volcanism [13].

It is considered [24] that beneath the South Caspian there is a crust of the oceanic type, which does not have the so-called granitic layer; reach in long-living radioactive elements, its cross section is shown in fig. 9. Heat flow values there range from 30 to 40 mW/m<sup>2</sup> [13] with a high thickness of sediments up to 30 km and their rapid accumulation [20]. At the same time heat flow, exceeding 60 and up to 200 mW/m<sup>2</sup>, is typical for the northern part of the Caspian Sea with the crust of continental type.

According to available data on modeling of geothermal field of the Caspian Basin and taking into account its transient regime, the temperature at the base of the sedimentary cover could reach to 400–500 °C [15; 16; 31].



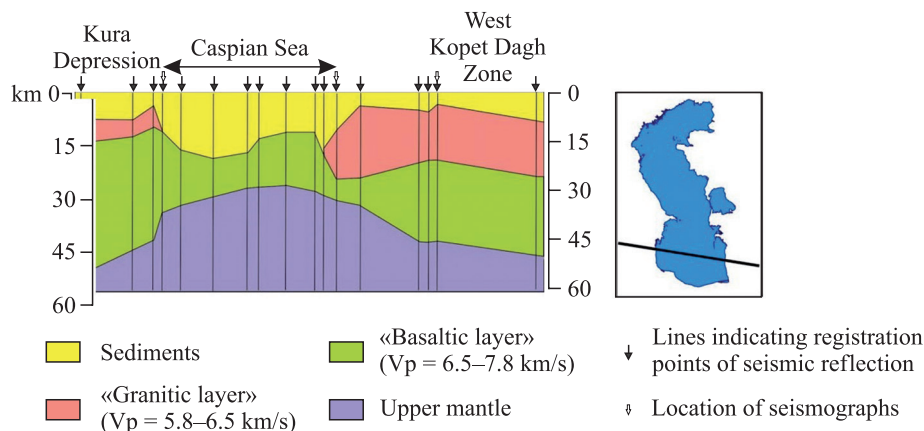


Fig. 9. Cross-section of the crust and upper mantle in the South Caspian Depression.

Source: [25]

It is necessary to mention that the sedimentation rate represents one of factors affecting its geothermal field parameters. Very rapid sedimentation results in relatively low observed heat flow values, as a transient geothermal regime takes place in accumulated sediments, which are slowly warmed up by heat flow from below. Heat flow determinations based on deep boreholes of the Baku Archipelago and the Apsheron-Balkhan Zone show low heat flow (usually 20–40 mW/m<sup>2</sup>) which is lower than the majority of values 30–50 mW/m<sup>2</sup> [30] determined using marine probes, it requires the further analysis.

The general trend of heat flow density variations for better-studied and selected window within the South Caspian Basin is shown in fig. 10. This map was constructed by means of the software package *GMT* (subprograms «Grdtrend» and «Grdtrack»).

To both sides from the HFD trend (the isoline of 55 mW/m<sup>2</sup>), the heat flow is increasing both to the southwest, where high heat flow zone above 100 mW/m<sup>2</sup> was observed, and to the northeast, where it exceeds 60 mW/m<sup>2</sup>. The Alpine folding exists in left corner of the map, when in its northern portion there is a gradual transfer to the Precambrian crustal blocs, which typically are colder.

Two profiles A–A and B–B of the heat flow density are shown in fig. 11. Along the A–A profile there are many heat flow observations. Here the heat flow varies considerably along the whole profile from around 25 until almost 90 mW/m<sup>2</sup>. The profile B–B shows smoother pattern of HFD variations. Its shape depends partly on the absence of heat flow data within its central part (no marine measurements) and it crosses another type of the crustal block, namely the Apsheron – Balkhan Ridge, where the heat flow is lower.

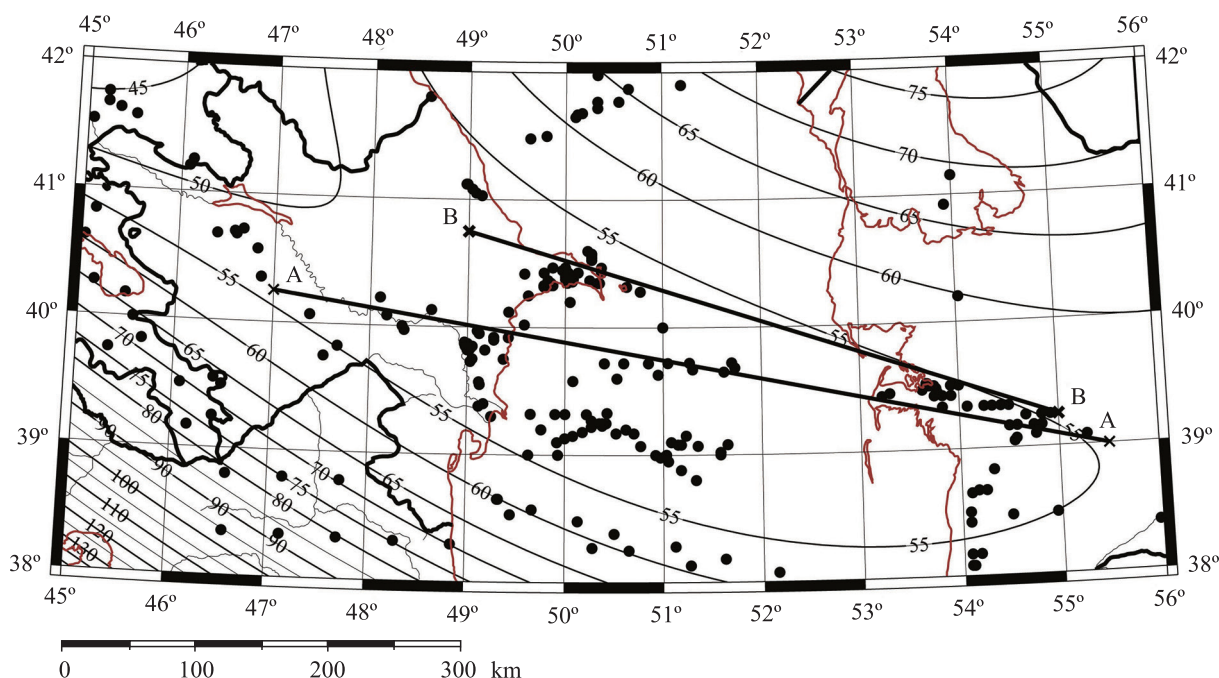


Fig. 10. Heat flow density trend (mW/m<sup>2</sup>) within the selected window of the South Caspian Basin

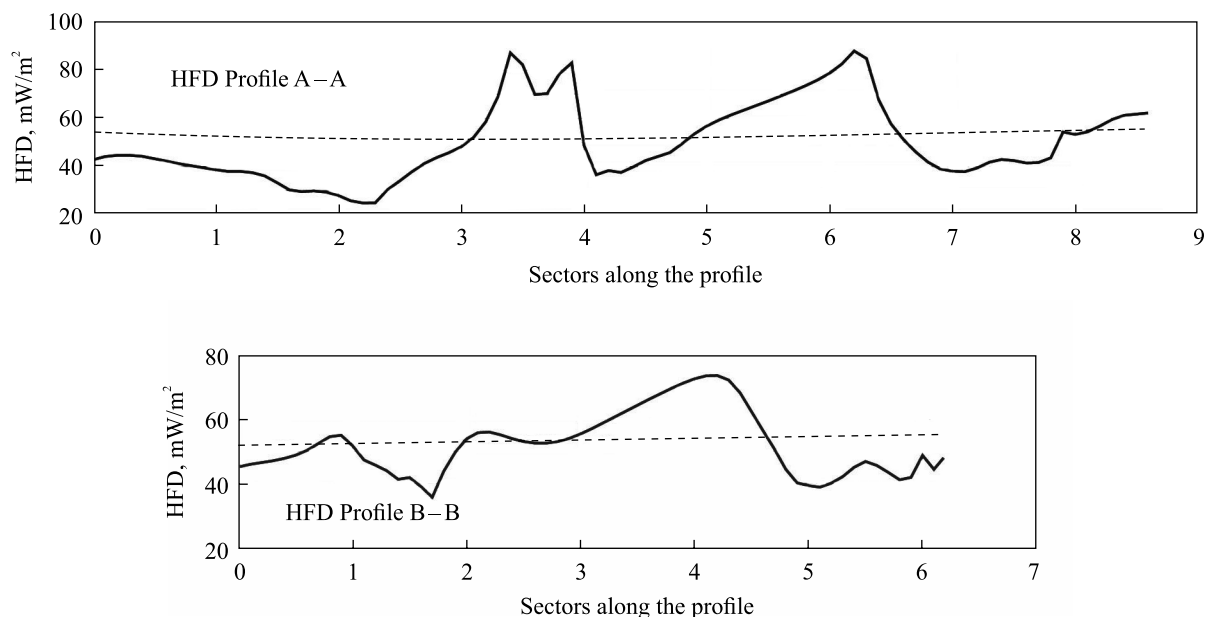


Fig. 11. Heat flow density profiles A–A and B–B

### Conclusion

A new map of heat flow density distribution was compiled both for the marine area of the Caspian Sea and adjoining onshore zones of the countries adjacent to the sea: Iran, Azerbaijan, Russia, Kazakhstan and Turkmenistan. This map reflects a wide range of heat flow variations. The highest anomaly above 100 mW/m<sup>2</sup> exists within the northwestern part of Iran which belongs to the Alpine crustal folding. Lower values within the South Caspian Basin are typical for the Apsheron – Balkhan Ridge. A general tendency of its decrease is evident in the direction to Precambrian crustal blocks of the North Caspian Basin.

Highly differentiated heat flow density at relatively short distances is a typical feature for the Caspian Sea area. Very sharp changes also take place within the transition zone from Caspian Sea waters to the northwestern part of Iran, which represents young tectono-thermal activated crustal blocks of the Alpine-Himalayan mobile belt.

### Библиографические ссылки

1. Алиев СА, Аширов Т, Липсиц ЮМ, Сопиев ВА, Судаков НП. Новые данные о тепловом потоке через дно Каспийского моря. *Известия Академии наук Туркменской ССР. Серия физико-технических, химических и геологических наук*. 1979;2: 124–126.
2. Алиев СА. *Геотермические поля депрессионных зон Южно-Каспийской впадины и их связь с нефтегазоносностью* [автореферат диссертации]. Баку: Институт геологии Академии наук Азербайджана; 1988. 30 с.
3. Амирханов ХИ, Ровнин ЛИ, Суетнов ВВ, Гаирбеков ХА, Бойков АМ. *Опыт применения нефтегазовой терморазведки*. Махачкала: [б. и.]; 1975. 223 с.
4. Аширов Т. *Геотермическое поле Туркмении*. Москва: Наука; 1984. 160 с.
5. Аширов Т. О тепловом поле в пределах западного борта Южно-Каспийской депрессии. *Известия Академии наук Туркменской ССР. Серия физико-технических, химических и геологических наук*. 1985;2:70–74.
6. Глузов ИФ, Маливицкий ЯП, Новиков АА, Сенин БВ. *Региональная геология и нефтегазоносность Каспийского моря*. Москва: Недра; 2004. 342 с.
7. Гордиенко ВВ, Завгородняя ОВ. Тепловой поток Прикаспийской впадины. В: Щербаков АВ, Дворов ВИ, редакторы. *Геотермические исследования в Средней Азии и Казахстане*. Москва: Наука; 1985. с. 251–255.
8. Любимова ЕА, Поляк БГ, Смирнов ЯБ. *Каталог данных по тепловому потоку на территории СССР*. Москва: Наука; 1973. 64 с.
9. Кашкай МА, Алиев СА. Тепловой поток в Куринской депрессии. В: Субботин СИ, Кутас РИ, редакторы. *Глубинный тепловой поток в Европейской части СССР*. Киев: Наукова Думка; 1974. с. 95–109.
10. Лебедев ЛИ, Томара ГА. О некоторых особенностях формирования теплового потока в Южном Каспии. В: Любимова ЕА, Глебовицкий ВА, редакторы. *Геотермометры и палеотемпературные градиенты*. Москва: Наука; 1981. с. 156–161.

11. Любимова ЕА, Томара ГА, Власенко ВИ, Смирнова ЕВ, Зекцер ИС, Месхетели АИ. Первые данные по изучению тепловых потоков через дно Каспийского моря. *Известия АН СССР. Серия: Физика Земли*. 1974;4:98–103.
12. Любимова ЕА, Никитина ВН, Томара ГА. *Тепловые поля внутренних и окраинных морей СССР: Состояние наблюдений и теория интерпретации двумерных неоднородностей*. Москва: Наука; 1976. 224 с.
13. Мухтаров АШ. Тепловой поток восточной части Кавказской зоны коллизии. В: Попов ЮА, редактор. *Тепловое поле Земли и методы его изучения*. Москва: Российский государственный геолого-разведочный университет; 2008. с. 155–160.
14. Мухтаров АШ. Некоторые аспекты формирования теплового поля в Каспийском регионе. *Труды Института геологии*. 2004;31:141–147.
15. Мухтаров АШ, Адигезов НЗ. Тепловая эволюция Нижне-Куринской впадины и условия для образования углеводородов (на примере месторождения Кюровдаг). *Известия Академии наук Азербайджана. Серия: Науки о Земле*. 1999;1:14–20.
16. Мухтаров АШ, Тагиев МФ, Имамвердиев РА. Модели нефтегазогенерации и прогноз фазового состояния углеводородов в Бакинском Архипелаге. *Известия Академии наук Азербайджана. Серия: Науки о Земле*. 2003;2:17–25.
17. Смирнов ЯБ, Аширов Т, Меркушов ВН, Сопиев ВА, Дубровская ЕВ. Каспийское море. В: Кропоткин ПН, Смирнов ЯБ, редакторы. *Методические и экспериментальные основы геотермии*. Москва: Наука; 1983. с. 129–134.
18. Сухарев ГМ, Власова СП, Тарануха ЮК. Теплофизические свойства горных пород и величины тепловых потоков некоторых районов Большого Кавказа и Предкавказья. *Доклады Академии наук СССР*. 1966;171(4):851–853.
19. Якубов АА, Ализаде АА, Зейналов ММ. *Грязевые вулканы Азербайджанской ССР. Атлас*. Баку: Издательство Академии наук Азербайджанской ССР; 1971. 257 с.
20. Abdullayev NA, Kadirov F, Guliyev IS. Subsidence history and basin-fill evolution in the South Caspian Basin. In: Brunet MF, McCann T, Sobel ER, editors. *Geological Evolution of Central Asian Basins and the Western Tien Shan Range*. London: Geological Society; 2015. 427 p. DOI: 10.1144/SP427.5.
21. Alexandrov AL, Lubimova EA, Tomara GA. Heat flow through the bottom of the inner seas and lakes in the USSR. *Geothermics*. 1972;1(2):73–80.
22. Coster HP. Terrestrial heat flow in Persia. *Monthly Notices of the Royal Astronomical Society. Geophysical Supplement*. 1947;5: 131–145.
23. Eldholm O, Sundvor E, Vogt PR, Hjelstuen BO, Grane K, Nilsen AK, Gladchenko TP. SW Barents Sea continental margin heat flow and Hakon Mosby Mud Volcano. *Geo-Marine Letters*. 1999;19:29–37.
24. International Tectonic Map of the Caspian Sea Region (Khain V, Bogdanov N, editors. *Explanatory notes*). Moscow: Nauchnyi Mir; 2005. 1 : 2 500 000.
25. Jackson J, Priestley K, Allen M, Berberian M. Active tectonics of the South Caspian Basin. *Geophysical Journal International*. 2002;148:214–245.
26. Jahantigh Pak Z, Biyabangard H, Bakhshi MR, Shabani F. Hydrocarbon generation from candidate source rocks in the Persian Gulf. *Researcher*. 2014;6(2):8–19.
27. Khojamli A, Doulati Ardejani F, Moradzadeh A, Nejati Kalate A, Roshandel Kahoo A, Porkhial S. Estimation of Curie point depths and heat flow from Ardebil province, Iran, using aeromagnetic data. *Arab Journal Geosciences*. 2016;9:383. DOI: 10.1007/s12517-016-2400-3.
28. Mansouri-Far S. Geothermal field in the Caspian Sea region. В: Махнач АА, редактор. *Проблемы геологии Беларуси и смежных территорий: материалы Международной научной конференции, посвященной 100-летию со дня рождения академика НАН Беларуси Александра Семёновича Махнач; 21–22 ноября 2018 г.; Минск, Беларусь*. Минск: СтройМедиаПроект; 2018. p. 140–144.
29. Morley CK, King R, Hillis R, Tingay M, Backe G. Deepwater fold and thrust belt classification, tectonics, structure and hydrocarbon prospectivity: a review. *Earth-Science Reviews*. 2011;104:41–91.
30. Mukhtarov ASH. Heat flow distribution and some aspects of formation of thermal field in the Caspian region. In: Akif A. Ali-Zadeh, editor. *South-Caspian Basin: geology, geophysics, oil and gas content. 32<sup>nd</sup> International Geological Congress; 2004 August 20–28; Florence, Italy*. Baku: Nafta-Press; 2004. p. 165–172.
31. Mukhtarov ASH, Adigezalov NZ. Thermal regime of mud volcanos in the East Azerbaijan. *Proceedings of Geology Institute*. 1997;26:221–228.
32. Sass JH, Lachenbruch AH, Munroe RJ. Thermal conductivity of rocks from measurements on fragments and its application to heat flow determinations. *Journal of Geophysical Research*. 1971;76:3391–3401.
33. Smith WHF, Wessel P. Gridding with continuous curvature splines in tension. *Geophysics*. 1990;55:293–305.
34. Hurtig E, editor. *USSR, Black Sea and Caspian Sea. Geothermal Atlas of Europe*. Gotha: Geographisch-Kartographische Anstalt; 1991. p. 132–152.
35. Wessel P, Smith WHF. Free software helps map and display data. *Eos Transactions American Geophysical Union*. 1991;72:441, 445–446.

## References

1. Aliev SA, Ashirov T, Lipsits YuM, Sopiev VA, Sudakov NP. [New data on heat flow through the Caspian Sea bottom]. *Izvestiya Akademii nauk Turkmenskoi SSR. Seriya fiziko-tekhnicheskikh, khimicheskikh i geologicheskikh nauk*. 1979;2:124–126. Russian.
2. Aliev SA. *Geotermicheskie polya depressionnykh zon Yuzhno-Kaspiiskoi vpadiny i ikh svyaz's neftegazonosnost'yu* [Geothermal field of depressional zones of the South Caspian Depression and their relation to oil and gas bearing capabilities] [dissertation]. Baku: Institut geologii Akademii nauk Azerbaidzhana; 1988. 30 p. Russian.
3. Amirkhanov KhI, Rovnin LI, Suetnov VV, Gairbekov KhA, Boikov AM. *Opyt primeneniya neftegazovoi termorazvedki* [An experience to use oil and gas thermal exploration]. Makhachkala: [publisher unknown]; 1975. 223 p. Russian.



4. Ashirov T. *Geotermicheskoe pole Turkmenii* [Geothermal field of Turkmenia]. Moscow: Nauka; 1984. 160 p. Russian.
5. Ashirov T. [On the thermal field within the western side of the South Caspian Depression]. *Izvestiya Akademii nauk Turkmenskoi SSR. Seriya fiziko-tekhnicheskikh, khimicheskikh i geologicheskikh nauk*. 1985;2:70–74. Russian.
6. Glumov IF, Malovitskii YaP, Novikov AA, Senin BV. *Regional'naya geologiya i neftegazonosnost' Kaspiiskogo morya* [Regional geology and oil and gas bearing capabilities of the Caspian Sea]. Moscow: Nedra; 2004. 342 p. Russian.
7. Gordienko VV, Zavgorodnyaya OV. [Heat flow in the North Caspian Depression]. In: Shcherbakov AV, Dvorov VI, editors. *Geotermicheskie issledovaniya v Srednei Azii i Kazakhstane* [Geothermal investigations in the Middle Asia and Kazakhstan]. Moscow: Nauka; 1985. p. 251–255. Russian.
8. Lyubimova EA, Polyak BG, Smirnov YaB. *Katalog dannykh po teplovomu potoku na territorii SSSR* [Heat flow data catalogue within the territory of the USSR]. Moscow: Nauka; 1973. 64 p. Russian.
9. Kashkai MA, Aliev SA. [Heat flow within the Kura Depression]. In: Subbotin SI, Kutas RI, editors. *Glubinnyi teplovoi potok v Evropeiskoi chasti SSSR* [Terrestrial heat flow within the European part of the USSR]. Kyiv: Naukova Dumka; 1974. p. 95–109. Russian.
10. Lebedev LI, Tomara GA. [On some features of the heat flow generation in the South Caspian]. In: Lyubimova EA, Glebovitskii VA, editors. *Geotermometriya i paleotemperaturnye gradienty* [Geothermometers and paleo temperature gradients]. Moscow: Nauka; 1981. p. 156–161. Russian.
11. Lyubimova EA, Tomara GA, Vlasenko VI, Smirnova EV, Zektser IS, Meskheteli AI. [First data on heat flows studying through the bottom of the Caspian Sea]. *Izvestiya Akademii nauk SSSR. Seriya: Fizika Zemli*. 1974;4:98–103. Russian.
12. Lyubimova EA, Nikitina VN, Tomara GA. *Teplovyie polya vnutrennykh i okrainnykh morei SSSR: Sostoyanie nablyudeniya i teoriya interpretatsii dvumernykh neodnorodnostei* [Thermal fields of the inner and marginal seas of the USSR: Status of observations and the theory of interpretation of two-dimensional heterogeneities]. Moscow: Nauka; 1976. 224 p. Russian.
13. Mukhtarov ASH. [Heat flow in eastern part of the Caucasian collision zone]. In: Popov YuA, editor. *Teplovoe pole Zemli i metody ego izucheniya* [Thermal field of the Earth and methods of its investigations]. Moscow: Russian State Geologic Exploration University; 2008. p. 155–160. Russian.
14. Mukhtarov ASH. [Some aspects of the heat flow generation within the Caspian Region]. *Proceedings of the Geology Institute*. 2004;31:141–147. Russian.
15. Mukhtarov ASH, Adigeev NZ. [Thermal evolution of the Lower-Kura Depression and conditions for generation of hydrocarbons an example of the Kyurovdag deposit]. *Izvestiya Akademii nauk Azerbaidzhana. Seriya: Nauki o Zemle*. 1999;1:14–20. Russian.
16. Mukhtarov ASH, Tagiyev MF, Imamverdiyev RA. [Models of oil and gas generation and prognosis of the phase condition of hydrocarbons in the Baku Archipelago]. *Izvestiya Akademii nauk Azerbaidzhana. Seriya: Nauki o Zemle*. 2003;2:17–25. Russian.
17. Smirnov YaB, Ashirov T, Merkushov VN, Sopiev VA, Dubrovskaya EV. [Caspian Sea]. In: Kropotkin PN, Smirnov YaB, editors. *Metodicheskie i eksperimental'nye osnovy geotermii* [Methodical and experimental basis of geothermics]. Moscow: Nauka; 1983. p. 129–134. Russian.
18. Sukharev GM, Vlasova SP, Taranukha YuK. [Thermophysical properties of rocks and heat flow values within some of regions of the Great Caucasus and Ciscaucasia]. *Doklady Akademii nauk SSSR*. 1966;171(4):851–853. Russian.
19. Yakubov AA, Alizade AA, Zeynalov MM. *Gryazeve vulkany Azerbaidzhanskoi SSR. Atlas* [Mud volcanoes of the Azerbaijan SSR. Atlas]. Baku: Izdatel'stvo Akademii nauk Azerbaidzhanskoi SSR; 1971. 257 p. Russian.
20. Abdullayev NA, Kadirov F, Guliyev IS. Subsidence history and basin-fill evolution in the South Caspian Basin. In: Brunet MF, McCann T, Sobel ER, editors. *Geological Evolution of Central Asian Basins and the Western Tien Shan Range*. London: Geological Society; 2015. 427 p. DOI: 10.1144/SP427.5.
21. Alexandrov AL, Lyubimova EA, Tomara GA. Heat flow through the bottom of the inner seas and lakes in the USSR. *Geothermics*. 1972;1(2):73–80.
22. Coster HP. Terrestrial heat flow in Persia. *Monthly Notices of the Royal Astronomical Society. Geophysical Supplement*. 1947;5: 131–145.
23. Eldholm O, Sundvor E, Vogt PR, Hjelstuen BO, Grane K, Nilsen AK, Gladchenko TP. SW Barents Sea continental margin heat flow and Hakon Mosby Mud Volcano. *Geo-Marine Letters*. 1999;19:29–37.
24. International Tectonic Map of the Caspian Sea Region (Khain V, Bogdanov N, editors. *Explanatory notes*). Moscow: Nauchnyi Mir; 2005. 1 : 2 500 000.
25. Jackson J, Priestley K, Allen M, Berberian M. Active tectonics of the South Caspian Basin. *Geophysical Journal International*. 2002;148:214–245.
26. Jahantigh Pak Z, Biyabangard H, Bakhshi MR, Shabani F. Hydrocarbon generation from candidate source rocks in the Persian Gulf. *Researcher*. 2014;6(2):8–19.
27. Khojamli A, Doulati Ardejani F, Moradzadeh A, Nejati Kalate A, Roshandel Kahoo A, Porkhial S. Estimation of Curie point depths and heat flow from Ardebil province, Iran, using aeromagnetic data. *Arab Journal Geosciences*. 2016;9:383. DOI: 10.1007/s12517-016-2400-3.
28. Mansouri-Far S. Geothermal field in the Caspian Sea region. In: Mahnach AA, editor. *Problemy geologii Belarusi i smezhnykh territorij: materialy Mezhdunarodnoj nauchnoj konferencii, posvjashhennoj 100-letiju so dnja rozhdenija akademika NAN Belarusi Aleksandra Semjonovicha Mahnacha; 21–22 nojabrja 2018 g.; Minsk, Belarus'* [Problems of geology of Belarus and adjacent territories: materials of the International Scientific Conference dedicated to centenary of academician of the National Academy of Sciences of the Republic of Belarus Alexander S. Mahnach; 2018 November 21–22; Minsk, Belarus]. Minsk: StrojMediaProekt; 2018. p. 140–144. Russian.
29. Morley CK, King R, Hillis R, Tingay M, Backe G. Deepwater fold and thrust belt classification, tectonics, structure and hydrocarbon prospectivity: a review. *Earth-Science Reviews*. 2011;104:41–91.
30. Mukhtarov ASH. Heat flow distribution and some aspects of formation of thermal field in the Caspian region. In: Akif A. Ali-Zadeh, editor. *South-Caspian Basin: geology, geophysics, oil and gas content. 32<sup>nd</sup> International Geological Congress; 2004 August 20–28; Florence, Italy*. Baku: Nafta-Press; 2004. p. 165–172.

31. Mukhtarov ASh, Adigezalov NZ. Thermal regime of mud volcanos in the East Azerbaijan. *Proceedings of Geology Institute*. 1997;26:221–228.
32. Sass JH, Lachenbruch AH, Munroe RJ. Thermal conductivity of rocks from measurements on fragments and its application to heat flow determinations. *Journal of Geophysical Research*. 1971;76:3391–3401.
33. Smith WHF, Wessel P. Gridding with continuous curvature splines in tension. *Geophysics*. 1990;55:293–305.
34. Hurtig E, editor. *USSR, Black Sea and Caspian Sea. Geothermal Atlas of Europe*. Gotha: Geographisch-Kartographische Anstalt; 1991. p. 132–152.
35. Wessel P, Smith WHF. Free software helps map and display data. *Eos Transactions American Geophysical Union*. 1991;72:441, 445–446.

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