

MUD VOLCANOES OF THE WORLD: CLASSIFICATIONS, ACTIVITIES AND ENVIRONMENTAL HAZARD (INFORMATIONAL-ANALYTICAL REVIEW)

Baloglanov E.E., Abbasov O.R., Akhundov R.V.

*Institute of Geology and Geophysics of the National Academy of Sciences, Baku,
e-mail: elnur1001@mail.ru*

There are 2508 mud volcanoes and mud volcanic manifestations in 42 geographical regions of the world. The territory of Eastern Azerbaijan and the adjacent water area of the Southern Caspian Basin characterize by the widest spread of mud volcanoes on a global scale. The total number of mud volcanoes and mud volcanic manifestations in Azerbaijan is 353 (154 of them are marine). In comparison with other geographical regions, mud volcanoes of Azerbaijan also distinguish by the number of eruptions and daily gryphon, sopka and salse activity. In addition, Azerbaijan is a unique country, because all types of mud volcanoes were registered here. From this point of view, mud volcanoes of Azerbaijan provide favorable conditions for research of their activity and environmental hazard. Related to the daily activity of mud volcanoes, the composition and quantity of the emitted gases into the atmosphere, as well as mineralization degree and chemical types of waters, and the organic and element composition of the breccias were studied. The zones with high anomalous-radioactive background on the crater area of the volcanoes were revealed and the reasons for their occurrence were explained. It was established an associative relationship between the increasing of gamma level and the concentration of uranium for the breccia samples selected from the area has high radioactive background. In connection with the environmental hazard, a comparative analysis was performed on chemical and radioactive indicators of water and breccia samples, respectively, with norms for drinking water and an average concentration of elements for sedimentary rocks.

Keywords: mud volcano, distribution area, classification, activity, environment, hazard

Mud volcanoes provide very important and useful information about complex geological and geochemical processes occurring on inaccessible depths for prospecting and exploration wells, and also play an important role in the evaluation of hydrocarbon deposits of great depths [1-4, 6, 7, 9, 11, 13-16, 18, 20, 22-24, 33, 34, 38, 41-46, 48, 50-52, 54]. One of the most important areas of the study of mud volcanism is associated with eruptions and daily activity which forms an environmental hazard. Various methods and approaches have been considered by many scientists [26-34, 35, 39, 40, 47, 49, 53] in studying this problem.

Distribution areas of mud volcanoes in the world and their classifications

There are 2508 mud volcanoes and mud volcanic manifestations within the 42 geographical areas in the world, as well as Alpine-Himalayan, Pacific and Central Asian folding zones, in the deep-water zones of the Caspian, Black and Mediterranean seas and on the passive margins of the continents [21] (Fig. 1).

Quantitatively, mud volcanic areas may conditionally be divided into the largest (more than 100 volcanoes), large (50 to 100 volcanoes), moderate (10 to 50 volcanoes), and small ones (less than 10 volcanoes) [21]. Taking it as a basis, the largest mud volcanic areas are: Azerbaijan and western slope of

South Caspian Basin, Eastern Mediterranean (Mediterranean Ridge, Nile delta), Trinidad and its eastern offshore area, China, the USA (Gulf of Mexico and its coast, Barbados and Lesser Antilles Margin; large areas are: Gulf of Cadiz, Italy, Romania, Black sea, Russia (Taman peninsula and Western Kuban), Pakistan, Myanmar, Indonesia, Columbia, Costa Rica; moderate mud volcanic regions are: Western Mediterranean, Turkmenistan and eastern slope of South Caspian, Ukraine (Kerch peninsula), Iran, India, Japan, Malaysia, Georgia, Nigeria, Papua-New Guinea, New Zealand, Nicaragua, Panama, Venezuela; small areas are: Central Mediterranean, Albania, South Sakhalin, Alaska, the Philippines, Namibia, SAR, Canada, Mexico, Ecuador and Peru (Table 1).

The South Caspian Basin a zone of subsidence with a thick sedimentary stratum (more than 30 km) and a wide spread of mud volcanism [21]. The largest number of mud volcanoes, including the biggest, most frequently erupting ones and in general, all their known types (Table 2) are located in Eastern Azerbaijan and the adjacent water area of the South Caspian. It is in accordance with these factors that Azerbaijan is considered to be the "Motherland of mud volcanoes". There are 353 mud volcanoes and their manifestations on the territory of the country (Table 3), 199 of which are terrestrial [21].



Fig. 1. Geographical location of the areas of mud volcanoes over the world: 1 – Gulf of Cádiz; 2 – Western Mediterranean (Alboran Sea); 3 – Central Mediterranean (Calabrian Arc); 4 – Eastern Mediterranean; 5 – Italy; 6 – Albania; 7 – Egypt; 8 – Romania; 9 – Black Sea; 10 – Ukraine; 11 – Russia; 12 – Georgia; 13 – Azerbaijan; 14 – Turkmenistan; 15 – Iran; 16 – Pakistan; 17 – India; 18 – Myanmar; 19 – Indonesia; 20 – Papua New Guinea; 21 – Malaysia; 22 – Brunei; 23 – Philippines; 24 – Japan; 25 – China; 26 – New Zealand; 27 – Nigeria; 28 – Namibia; 29 – South Africa; 30 – Canada; 31 – USA; 32 – Mexico; 33 – Costa Rica; 34 – Nicaragua; 35 – Panama; 36 – Columbia; 37 – Venezuela; 38 – Trinidad and Tobago; 39 – Barbados and Lesser Antilles Margin; 40 – Ecuador; 41 – Peru; 42 – Antarctica

Mud volcanic areas and environmental hazard

The territory of Azerbaijan has a very complex tectonic structure and active seismogeodynamic properties [5, 8, 10, 12, 17, 19, 21, 25, 27-31]. In this regard, about 5-6 eruptions were recorded in the territory of the republic recent years (Table 4). The eruption of the mud volcano is accompanied by a powerful explosion, deep cracks extending for several kilometers, a 300-350 m high flame (with the predominance of carbon, the eruption occurs without flame) and the release of a large volume of mud volcanic breccia onto the Earth's surface. The amount of organic matter and chemical elements of volcanic products exceeds the average statistical norms for sedimentary rocks, and this factor disrupts the natural balance of the environment. The gryphon and salse activity of mud volcanoes is accompanied by the release of gas, highly mineralized water, mud-water mixture, and in

some cases, a large amount of oil. As a result, saline soils, unique volcanic landscapes, as well as oil-impregnated zones form in the mud volcanic and adjoining areas. Such landscapes are rare from the geochemical point of view and have a negative impact on the living organisms that depend on each other [27-32].

Unlike the areas of mud volcanoes spreading around the world, the eastern territory of Azerbaijan is characterized by their widest distribution (Table 1), as well as by the presence of all existing types of mud volcanoes (Table 3). This factor creates favorable conditions for the study of mud volcanism and the problems associated with it. From this point of view, Azerbaijan is a unique country for studying the impact of mud volcanoes on the environment. Taking into account the facts mentioned above, the mud volcanoes of Azerbaijan were chosen as an object of study of volcanic activity and environmental hazard.

Table 1

The distribution areas of mud volcanoes in the world

Geographical area	Number of mud volcano and mud volcanic manifestation	Geographical area	Number of mud volcano and mud volcanic manifestation
Gulf of Cádiz	50	Malaysia	29
Western Mediterranean	10	Brunei	7
Central Mediterranean	6	The Philippines	3
Eastern Mediterranean	230	Papua-New Guinea	20
Italy	71	New Zealand	12
Albania	3	Nigeria	13
Egypt	160	Namibia	1
Romania	66	South Africa	8
Black Sea	70	Canada	3
Ukraine	43	The USA	139
Russia	46	Mexico	1
Georgia	13	Nicaragua	11
Azerbaijan	353	Costa-Rica	59
Turkmenistan	48	Panama	40
Iran	25	Columbia	50
Pakistan	52	Venezuela	18
India	12	Trinidad and Tobago	202
China	200	Barbados and Lesser Antillas Margin	250
Japan	26	Ecuador	2
Myanmar	52	Peru	2
Indonesia	97	Antarctica	5
Total: 2508			
Terrestrial: 1107			
Marine: 1401			

Table 2

Classification of mud volcanoes and mud volcanic manifestations

Mud volcano					Mud volcanic manifestation	
Terrestrial	Marine	Morphological type	Crater type	Activity type	Mud-water mixture emitting (with oil films)	Oil emitting
Active	Island Underwater	Cone-shaped	Plano-convex	Erupting periodically		
Extinct (more than 100 years)		Dome-shaped	Shield-shaped	Characterized by gryphon-salsa activity		
Buried		Ridgy	Deep-seated			
Richly oil emitted		Plateau-shaped	Caldera-shaped			

Table 3

Statistical indicators of mud volcanoes and mud volcanic manifestations in Azerbaijan by geological regions

Geological region	Number of mud volcano	Number of mud volcanic manifestation	Total
Pre-Caspian-Guba	2	5	7
Shamakhi-Gobustan	86	34	120
Absheron	45	24	69
Lower Kura	25	8	33
Baku archipelago	85	7	92
Deep part of the South Caspian	32	-	32
Total	277	76	353

Table 4

Mud volcano eruptions recorded within petroleum regions in Azerbaijan (during 1810-2018)

Volcano name	Eruption date	Volcano name	Eruption date
Pre-Caspian-Guba region		Lower Kura region	
Zarat-deniz	1953	Kalamaddin	1872
		Akhtarmaardy	1990
Absheron peninsula		Akhtarma-Pashaly	1948, 1962, 1969, 1982 (twice), 1986, 2013, 2018
Kechaldag	2000	Kichik Harami	1912
Uchtepe	1967, 1986, 1992, 1998, 2002, 2004, 2005	Hamamdag	1938, 1947, 1967, 1984, 1996
Beyukdag	1921, 1922	Agzybir	1964, 1978, 2002
Zikh Pilpilesi	1993 (twice)	Bendovan	1932, 1989
Keireki	1824, 1830, 1865, 1882, 1885, 1902, 1915, 1952, 1953, 1957, 1964, 1966, 1968, 1989, 1991, 2001, 2002, 2014, 2017	Kursengi	1965
		Durovdag	1953
		Duzdag	1941
Bozdag-Geokmaly	1926, 1965, 2001	Oil salse	1882
Bozdag-Gobu	1827, 1894, 1937, 1953, 1957, 1974, 1986, 1987, 1999	Neftchala Pilpilesi	1947 (twice)
Bozdag-Gyuzdek	1839, 1867, 1902, 1969, 1986, 1988, 1995, 2003, 2009	Dovshandag	2003
Saryncha	1936, 1976	Baku archipelago	
Gyzyltepe	1914 (twice)	Zenbil Island	1961, 1995
Akhtarma-Puta	1923, 1933, 1950	Khare-Zire Island	1810, 1857, 1859, 1886, 1940, 1947, 1959, 1960, 1962, 1974, 1993, 1997, 2006
Lockbatan	1829, 1864, 1887, 1890, 1900, 1904, 1915, 1918, 1923, 1926, 1933, 1935, 1938, 1941, 1954, 1959, 1964, 1972, 1977, 1980, 1990, 2001, 2010, 2012, 2017		
Otmanbozdag	1854, 1904, 1922, 1951, 1965, 1985, 1994, 2004, 2017	Gil Island	1810, 1859, 1860, 1895, 1896, 1913, 1926, 1937, 1960, 1962
Absheron archipelago		Garasu Island	1876 (twice), 1923, 1977, 1993
Absheron shoal	1888	Balygly shoal	1868, 1913
Buzovna Pilpilesi	1892, 1915, 1923, 1950, 1953 (twice), 2001	Chigil Island	1967
		Sabail shoal	1907, 1915, 1970
Palchyg Pilpilesi	1935, 1950	Sengi-Mugan Island	1903, 1923, 1932, 1933, 2002, 2008
		Dashly Island	1920, 1945
Neft Dashlary	1904, 1949, 1951, 1957	Mugan-deniz shoal	1942, 1957
Shoal "1906"	1906	Chigil-deniz shoal	1861, 1927 (twice), 1928, 1939, 1950, 1959, 2001
Shoal "1908"	1908		
Shoal "1933"	1933		
Shoal "1960"	1960	Yanan-Tava shoal	1813, 1825, 1843, 1868
Bahar-deniz shoal	1876, 1912, 1917, 1921, 1925, 1941, 1958, 1963, 1984		
Kapaz	1980		

Shamakhy-Gobustan region			
Damirchi	1958, 1969, 1971, 2008	Agnohur	1927, 1940, 1948, 1976, 1986
Zeiva (Basgal)	1926	Cheildag (west)	1970
Kyurdamich	1971	Cheildag (east)	1870, 1957, 1968, 1970, 2004
Gizmeydan	1987, 2001	Davalidag (east)	1975
Gasymkend	1993	Dashmardan	1866, 1954, 1976, 1986, 2011
Jeirly	1951, 1983, 2001	Shekikhan (west)	1988, 1989 (twice), 2001, 2004, 2006, 2010, 2017
Hajily	1970	Shekikhan (east)	1989, 2006
Melikchobanly	1926, 1967, 1977	Gotur	1989, 2001, 2004, 2005
Gushchu	1913, 1917, 1924, 1941, 1952, 1954, 1958, 1960, 1965, 1968, 1986, 1992, 2008, 2018	Toragay	1841, 1901, 1924, 1932, 1947, 1950, 1984, 1985, 1987, 1988, 2018 (twice)
Kyolany	1845, 1962, 1969	Beyuk Kyanizadag	1950, 1996
Kichik Maraza	1848, 1970, 1986	Durandag	1960, 1968, 1986, 2001, 2004
Bozaakhtarma	1902, 1969, 1970, 1987, 2017	Agtime	1913, 1971 (twice), 1985, 1988, 1989, 1998, 2000
Shikhzarli	1844, 1848, 1868, 1872, 1902, 1927, 1929, 1939, 1944, 1946, 1949, 1955, 1969, 1974, 1980, 1986, 1987, 1991, 1992, 1997, 2004, 2011, 2013, 2017	Garabujag (Hajive-lieri)	1954, 1963, 2001
Jengi	1851, 1873	Solakhay	1949, 1989 (twice), 2001
Garyja	1970, 1987, 2003, 2007, 2011, 2017	Garakyura	1928, 1951
Shorsulu	1986	Oyug	1988 (twice)
Sheytanud	1975	Ayrantoken	1964, 1969, 1977, 1988, 1990, 2004, 2008
Chapylmysh	1929, 1933, 1973, 1984, 1989, 2001, 2010	Goturdag	1926, 1959, 1966, 1970, 1977, 1987
Ayazakhtarma	1926, 1969, 1973 (twice), 1985, 1989, 2001, 2005, 2006, 2007	Dilyangyaz	1902, 1912, 1951
Nardaranakhtarma	1948, 1970, 1972, 1982, 1984,	Dashgil	1882, 1886, 1908, 1926, 1958, 2001
Suleymanakhtarma	1986, 1996, 2001, 2004		
Bahar	1853, 1859, 1885, 1886, 1911, 1926, 1967, 1992	Alat Pilpilesi (Bala Bahar)	1909, 1953, 1962

The Kichik Maraza volcano is located 38 km south-east of Shamakhi (40°30'36.37"N, 49° 1'55.21"E), to the north of Shikhzarli volcano, at the hill summit of 600 m in absolute height. The hill has steep western and southern slopes and gentle northern and eastern slopes surrounded with shallow gorges and scours. An area covered with breccia is 79 ha. The mentioned volcano is placed at the Miocene sediments and confined to the northwestern pericline of the Mushkemir anticline. An outflow tongues, 40-60 m long and 5-10 m wide, are seen on the slopes. The Kichik Maraza volcano crater field is rather vast, with numer-

ous gryphons and 0.5 m to 14 m high sopkas. Some of them are distinguished by an abundant emission of gas, water and mud with oil films. The Kichik Maraza volcano first eruption was recorded in 1848, the last one in 1986 (Table 4). The volcano is surrounded by closely adjoining agricultural and cattle breeding areas (Fig. 2 (a) and 2 (b)).

The Duzdag mud volcano is located 600 m of the Salyan-Neftchala highway (39°22'53.76"N, 49° 8'46.64"E), 4 km of Khylly village. Volcanic cone, 0.6 km in diameter and 18 m in relative height, is clearly distinguished over the surrounding flat plain. The volcano is

situated on the same named anticline composed of upper Pliocene and Quaternary sediments. Mudvolcanic manifestations are confined to the western regional faulting having an amplitude of 400 m and passing through the southwestern limb of the fold. A several active gryphons and salses emitting gas, muddy water, some with oil, occur on the Duzdag volcano. The last eruption

of the mud volcano was recorded in 1941 (Table 4). Currently, the northern, northeastern and southwestern parts of the volcano are surrounded by an artificial lake used for agricultural and fishing purposes (Fig. 3 (a) and 3 (b)). Various phase volcanic products, ejecting from the active gryphons and salses of the mud volcano directly flow to the lake (Fig. 3 (c)).

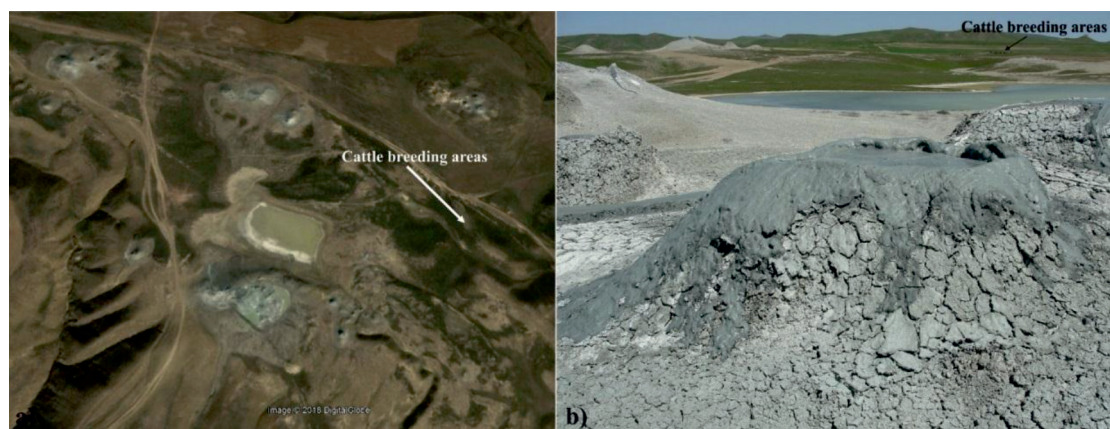


Fig. 2. Satellite image (a) and photo of the crater field (b) of the Kichik Maraza mud volcano

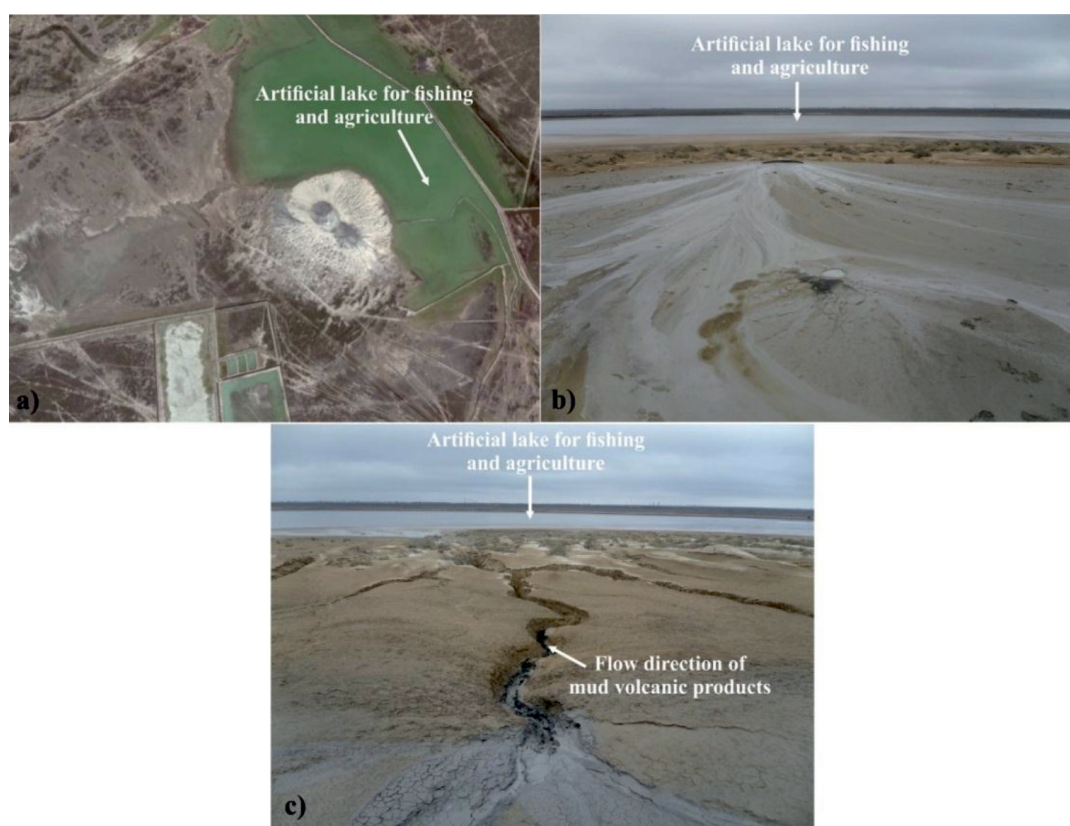


Fig. 3. The Duzdag mud volcano: (a) satellite image, (b) active salse on the crater field, (c) flows of volcanic products (water and mud mixture) towards the lake



Fig. 4. Active gryphon and salse of the Kechaldag mud volcano located in close proximity to the Jeiranbatan water reservoir

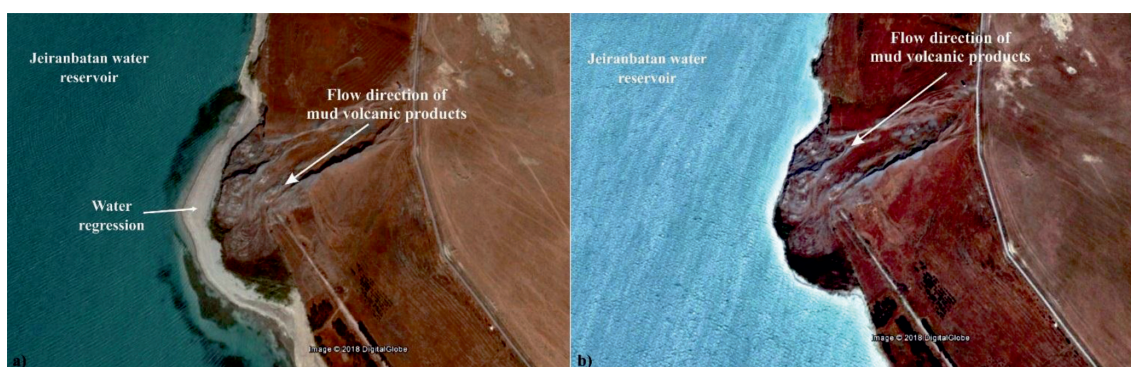


Fig. 5. Satellite image of the Kechaldag mud volcano: (a) – 2016, (b) – 2018

The Kechaldag mud volcano of 114 m in absolute height, is located 17 km northwest of Baku ($40^{\circ}29'34.49''\text{N}$, $49^{\circ}42'10.66''\text{E}$), in southeastern coast of Jeiranbatan reservoir. Fragmental product of the volcano covers an area of 1000×600 m overlapping the sediments of Middle and Upper Eocene, Oligocene and Miocene which are exposed on the earth surface. Two eruptive centres of the volcano are confined to the most elevated parts of the locality (141.1 and 97.9 m). The largest, southeastern centre, towering to 44 m above surrounding locality, has 350 long and 250 m wide crater, bordered with 1.2 m high rampart (Fig. 4). The second eruptive centre located at a distance of 675 m northwest from the first centre, has a small crater. The Kechaldag volcano is confined to the northwestern pericline of a large Kechaldag-Zigilpiri anti-

cline. The fold is complicated by longitudinal rupture with which a volcano is related. The last registered eruption of the volcano (Table 4) was related to the construction works carried out in 2000 on its slope [21].

Depends on regular changes in the water level in the Jeiranbatan water reservoir, the products of the Kechaldag mud volcano directly contact the water of the reservoir (Fig. 5 (a) and 5 (b)).

The Gaynarja mud volcano is located 8-10 km southwest of Shabran district ($41^{\circ}9'16.31''\text{N}$, $48^{\circ}59'2.31''\text{E}$). Occurring on the Miocenic-Pontian sediments it is expressed as a hill of 60 m in relative height. A 100 m diameter crater field has many mud cones and gryphones up to 2-3 m in height and 1.5-2.0 m in base diameter, and salses of 3.0-3.5 m

in diameter (Fig. 6). Gaynarja volcano is confined to the same name northeasterly trending fold which is the central link of Talabi-Zaratdeniz anticlinal belt. The fold is asymmetric with a steep (55-600) northeastern limb and gently sloping (40-500) southwestern limb. The two longitudinal dislocations of the thrust pattern have been traced on the crest. In recent years there have been no any eruptions of the Gaynarja volcano (Table 4) [29].

The artificial reduction of the minimum distance between the Takhtakorpu water reservoir and the volcano reached a peak (Fig. 7 (a) and 7 (b)). Thus, the boundaries of the reservoir were expanded without taking into account the minimum distance between the mud volcano and the basin of reservoir. Most of the crater field of the volcano, with the exception of the northeastern part, was buried underwater [28] (Fig. 7 (b)). As a result, the products of the mud volcano, as in the case of the Kechaldag volcano, directly contact the water of the reservoir.

Materials and methods of research

The study were conducted on 5 active mud volcanoes (1 – Kichik Maraza, 2 – Duzdag, 3 – Kechaldag, 4 – Gaynarja, 5 – Otmanbozdag (Fig. 8)) of Shamakhi-Gobustan, Lower Kura, Absheron and Pre-Caspian-Guba regions. The visual, satellite, geological, geochemical and radioactive surveys, as well as laboratory analyzes were performed. 10 water and sopka breccia samples were collected on each volcano, and their chemical composition was determined at the Institute of Geology and Geophysics using the “S8 TIGER Series 2 WDXRF” spectrometer

and the “Agilent 7700 Series ICP-MS” mass spectrometer. The organic properties of rocks (oil shales) found among mud volcanic breccias were determined in the process of two-stage pyrolysis. Radiometric measurements were carried out on multidirectional profiles passing through the crater field using radiometers “CPII-88M” and “Inspektor-1000”. A gamma spectrometric analysis of water and breccia samples was conducted to study the anomalous nature of radioactivity. In addition, based on the eruption and daily activity of some volcanoes, an approximate calculation was made to estimate the amount of gases released into the atmosphere [27-29, 39-41]. According to the data obtained, the extrapolation was carried out and the annual emission of total gas for the mud volcanoes of Azerbaijan was calculated.

Results of research and their discussion

The gas composition of the studied mud volcanoes mainly consist of CH_4 , CO_2 and N_2 (Table 5).

Table 5

Composition and average value of gases emitted from the studied mud volcanoes

Mud volcano	Emitted gas (%)		
	CH_4	CO_2	N_2
Kichik Maraza	95.38	1.20	1.04
Duzdag	95.73	0.53	1.74
Kechaldag	95.31	0.64	2.3
Gaynarja	92.73	5.64	1.08



Fig. 6. Active gryphon and salses located on the crater field of the Gaynarja mud volcano

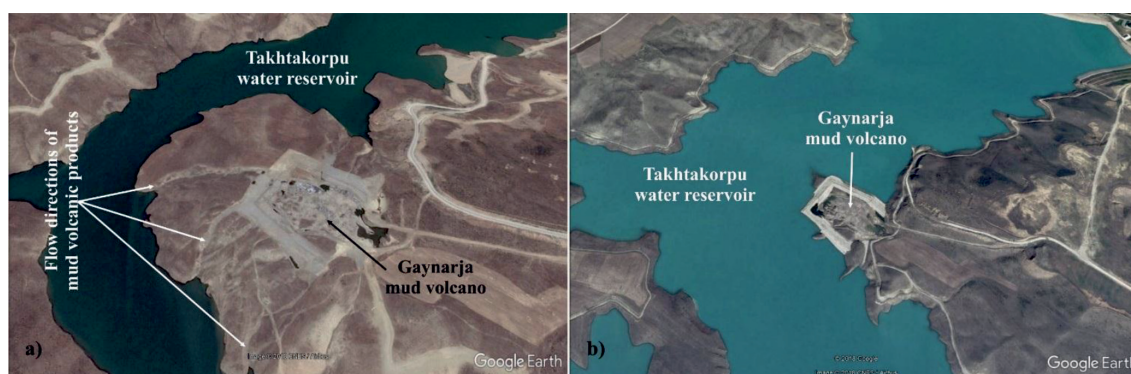


Fig. 7. Satellite image of the Gaynarja mud volcano: (a) – 2013, (b) – 2018

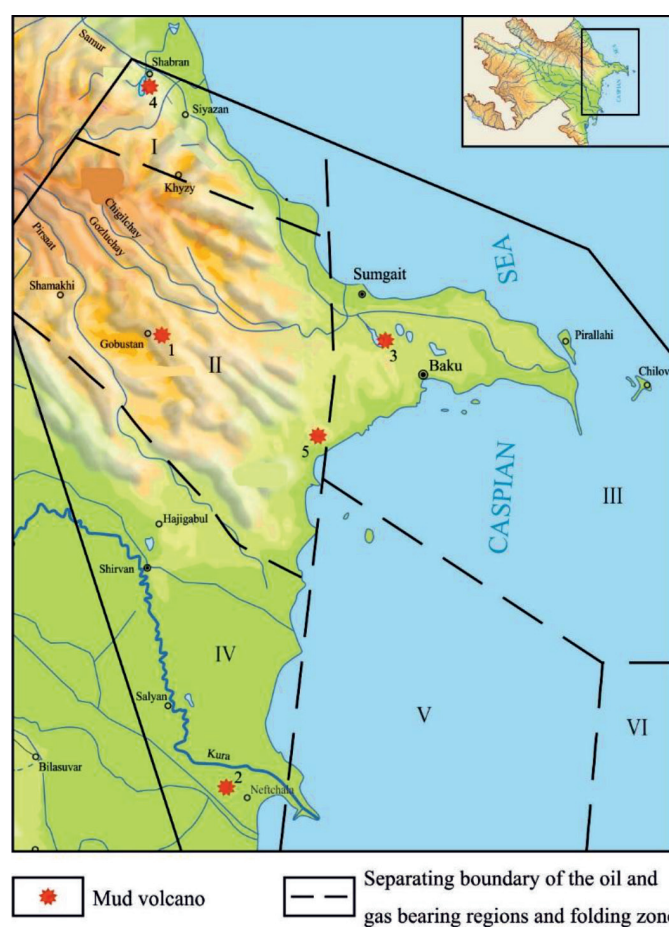


Fig. 8. Location map of the studied mud volcanoes (1 – Kichik Maraza, 2 – Duzdag, 3 – Kechaldag, 4 – Gaynarja, 5 – Otmanbozdag) within the oil and gas bearing regions and folding zone: I – Pre-Caspian-Guba, II – Shamakhi-Gobustan, III – Absheron, IV – Lower Kura, V – Baku archipelago, VI – folding zone in the deep South Caspian

According to calculations, 69.12 m^3 of gas emitted from one active gryphon or salse of mud volcano (an average of 12 in each volcano (Table 4)) into the atmosphere, the total volume of which is 25228.8 m^3 per year. Taking into ac-

count the fact that the most part (about 70%) of total mud volcanoes in Azerbaijan is characterized by active gryphon and salse activity, the annual release of gas into the atmosphere is about 6231513.6 m^3 . Due to the fact that the volume

of emitted volcanic gas mainly depends on the seismic events occur in the region [27-32], the annual total amount of gas may increase in proportion to the volcanic activity.

The calculations on the amount of gas burned during the eruption were carried out on the basis of two phases of paroxysmal events (12:20:40 and 14:18:04) that occurred on February 6, 2017 on the mud volcano Otmanbozdag (Table 4, 40°14'25.00"N, 49°30'26.21"E) which the largest and highest mud volcano in the world (relative altitude 404 m) (Fig. 9 (a) and (b)) located in the Absheron region of Azerbaijan. Calculations were carried out in accordance with statistical data on recorded eruptions of the mud volcano by the Republican Center of Seismological Service under the National Academy of Sciences of Azerbaijan, according to the following formula:

$$Qb = \frac{\pi d^2}{4} \times h \times \frac{T}{t},$$

where h – height of the flame (the first phase is 310 m, the second is 370 m), d – diameter of the flame (the first phase is 8.5 m, the second is 12 m), T – duration of flame (the first phase is 3.5 minutes, the second is 5 minutes), t – time of complete combustion of the flame (according to [36] – 0.33 minutes). During the first phase of the paroxysm, the amount of released gas was approximately 186476.2 m³, in the second – 633709.1 m³. Taking into account the fact that at least 5 eruptions are recorded annually in the territory of Azerbaijan, and their above-mentioned parameters correspond to the eruption of Otmanbozdag, it can be concluded like the amount of ejected gas as a result of all these eruptions is 4,100,926.5 m³.

The average amount of the total mineralization of the waters carried to the Earth's surface

by mud volcanoes: Kichik Maraza – 10 g/l; Duzdag – 47.3 g/l, Kechaldag – 9.6 g/l, Gaynarja – 63.8 g/l. The mineralization of the Gaynarja mud volcano is much higher in comparison with other volcanoes. The estimates allow to conclude that the mineralization value in mud volcanoes of Azerbaijan increases from north to south. Classification types of studied volcanic waters for the Pre-Caspian-Guba and Absheron regions – sodium hydrocarbonate and calcium hypochlorite, Shamakhi-Gobustan region – hydrocarbonate sodium, Lower Kura region – calcium hypochlorite and sodium hydrocarbonate.

SO₄²⁻ and K⁺, Ca²⁺, Mg²⁺ in the chemical composition of the water samples taken from the Kehcaldag mud volcano are below the average standards for drinking water, but Na⁺, Cl⁻ and HCO₃⁻ are higher. The Ph values are corresponding to the norm. Na⁺, K⁺, Ca²⁺, Mg²⁺, Cl⁻, HCO₃⁻ in the chemical composition of the water samples taken from the Gaynarja mud volcano are significantly exceed the standards, but SO₄²⁻ is below. The Ph indicators do not exceed the standards (Fig. 10).

The results of a comparative analysis of the microelement composition of breccia samples from the sopkas of the studied mud volcanoes show that Li, V, Zn, Rb, La, Ce, Nd, Pb, Th in Kichik Maraza, V, Cr, Ni, Sr in Duzdag, Li, V, Cr, Zn, Sr, Pb in Kechaldag sharply exceed the norm of the average value for sedimentary rocks [37] (Fig. 11).

The amount of organic matter in the composition of oil shales, found among the solids products of the studied mud volcanoes, ranges from 9.5 to 12.65%. In the process of pyrolysis, it was established that the amount of hydrocarbons (gases) is insignificant in such rocks, and most of the organic matter is in the form of coal (Table 6).

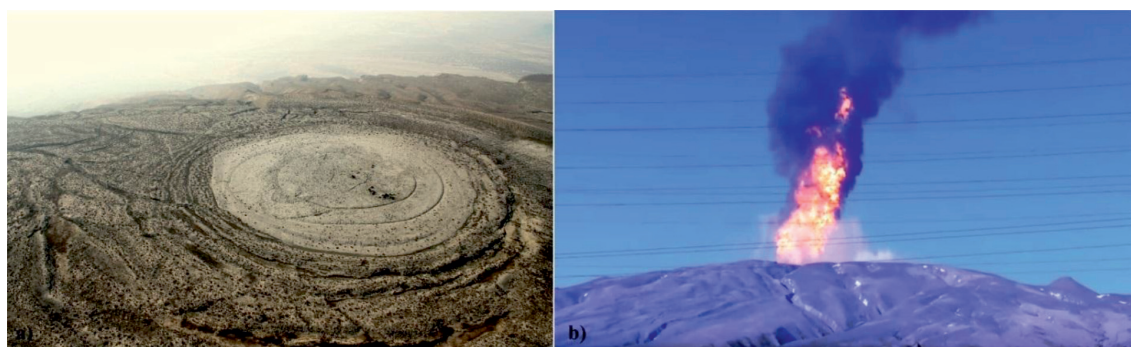


Fig. 9. The Otmanbozdag mud volcano: (a) – image from a helicopter, (b) – eruption recorded on February 6, 2017

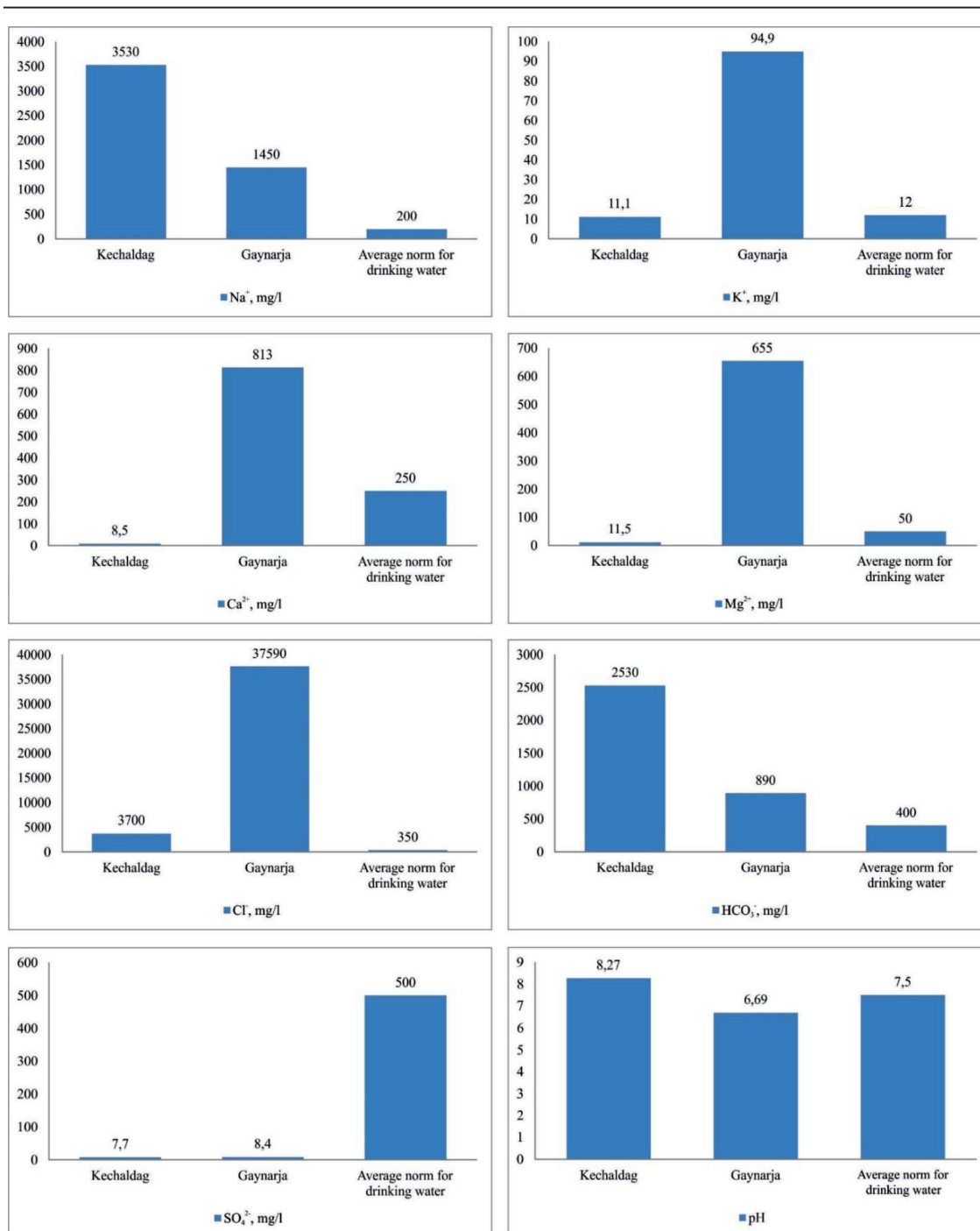


Fig. 10. Comparisons between the chemical composition of water samples taken from the studied mud volcanoes and the average norm for drinking water

Table 6

The results of the two-stage pyrolysis of rock samples taken from the Gaynarja mud volcano

Sample	Organic matter, %	500-550°C		800-850°C	
		Oil	Gas	Oil	Gas
1	12.2	-	2.43	-	2.67
2	12.65	-	4.99	-	1.88
3	9.5	-	5.24	-	1.20

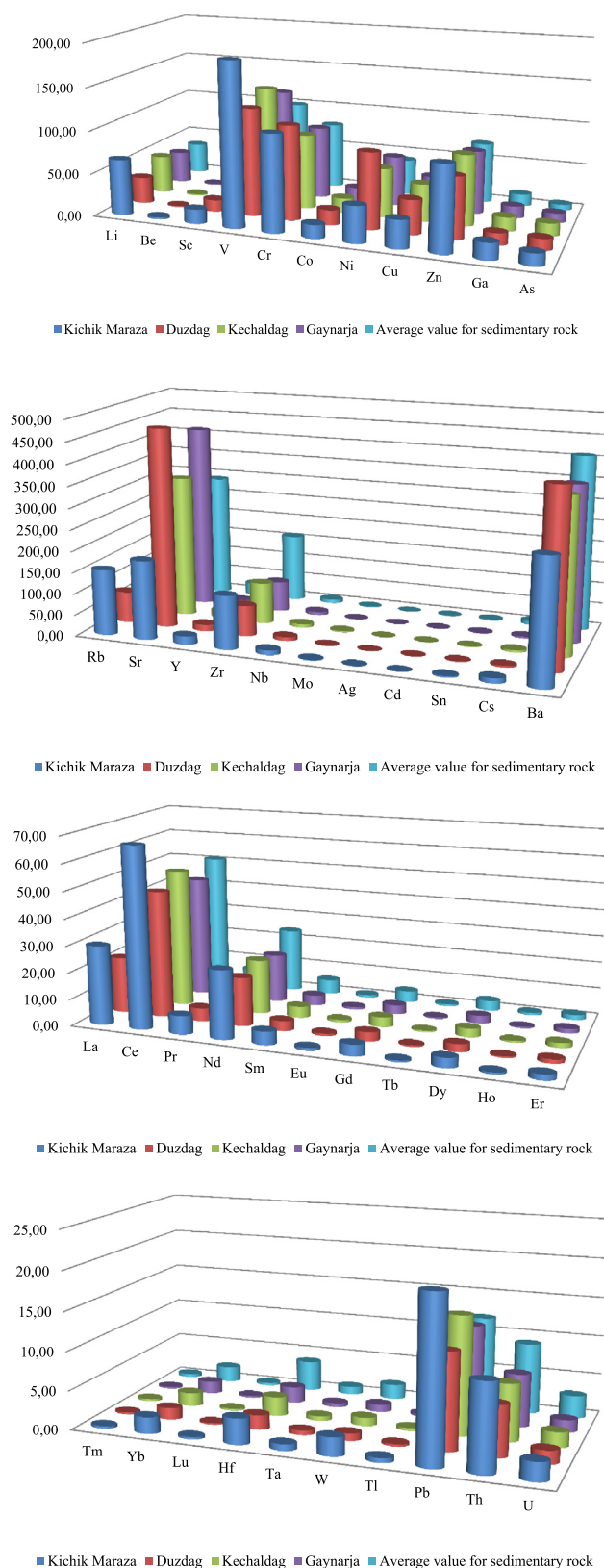


Fig. 11. Comparative analysis between the microelement composition of breccia samples taken from the studied mud volcanoes and average values for sedimentary rock [37] (ppm)

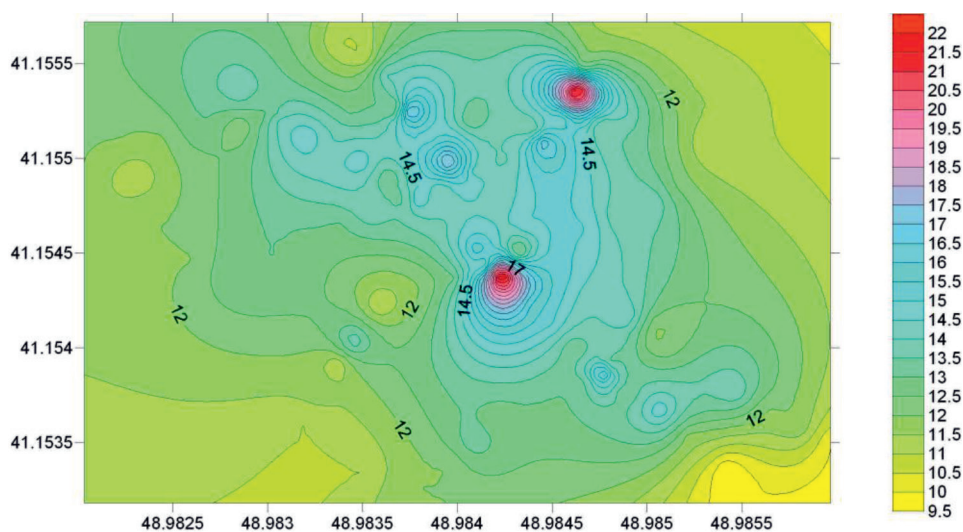


Fig. 12. Distribution map of the radioactivity in the crater field of the Gaynarja mud volcano

Table 7

The content of radionuclides in the water samples from gryphons and salses of the Gaynarja mud volcano

Radionuclide, Bk/l	Sample			Average concentration for drinking water Bk/l
	1	2	3	
K 40	25.6 ± 4.2	15.2 ± 1.4	16.6 ± 1.9	22.0
Ra 226	0.228 ± 0.054	0.154 ± 0.024	0.126 ± 0.028	0.5
Ra 228	0.138 ± 0.010	0.324 ± 0.050	0.644 ± 0.036	0.2
Rn 222	0.20 ± 0.12	0.18 ± 0.10	0.10 ± 0.06	120.0
U 235	0.0144 ± 0.0032	0.0064 ± 0.001	0.0120 ± 0.0016	3.0
U 238	0.312 ± 0.069	0.139 ± 0.021	0.261 ± 0.034	3.1

Table 8

Specific activity and content of radionuclides in the breccia samples of the Gaynarja mud volcano

Sample	Integral radioactivity mR/h	Activity, Bk/kg	U, Bk/kg	Th, Bk/kg	K, Bk/kg
1	23	481.56	431.81	–	634.61
2	14-15	106.4	50.19	0.45	704.87
3	16-17	118.51	12.15	77.99	208.42
4	23	515.12	480.15	–	671.71

The radioactivity of the breccia on the crater field of the Gaynarja mud volcano is 9.5-23 mR/h. Lower values of radioactivity were recorded in the central, northern and northeastern parts of the volcano (Fig. 12). This can be explained by the presence of tectonic dislocations in these zones.

The amount of radionuclides (Ra 228 in two samples, K 40 in one sample) in water samples taken from the active gryphons and salses of Gaynarja mud volcano sharply ex-

ceeds the average concentration of radionuclides for drinking water. The concentration of radionuclides Ra 226, Rn 222, U 235 and U 238 is much lower than the norms (Table 7).

Radionuclides Ra 228 and Ra 222 were not detected in the breccia samples. Analyzed samples were selected in the zones of both weak and relatively high radioactivity. Thus, the average indicator of radioactivity of rocks ranges between 106.4 and 515.12 Bk/kg (Table 8). These indicators reflect the overall complex level of

gamma rays, and depend on the amount of radionuclides in the rock composition. Exceeding the level of gamma rays in two rock samples can be explained by the presence of a uranium element in their composition. The amount of thorium does not exceed the mean value, and potassium is present in all volcanic rocks.

Conclusions

The content of gases released into the atmosphere as a result of the eruption and daily activity of mud volcanoes in Azerbaijan, mainly consist of CH_4 , N_2 and CO_2 . The total amount of these gases per year is more than 10 300 000 m^3 , that CH_4 dominates in concentration (more than 90%). The obtained results show that volcanic gas emissions have a serious influence on the overall gas budget of the atmosphere.

The total level of mineralization in volcanic waters is high, on average more than 30 g/l. The classification types of these waters are sodium hydrocarbonate and calcium hypochlorite. Na^+ , K^+ , Ca^{2+} , Mg^{2+} , Cl^- , HCO_3^- are significantly higher than the average allowable value for drinking water in some samples. The radionuclides Ra 228 and K 40 were found in the water samples that their concentration is also much higher than the norm for drinking water.

Some microelements, such as Cr, Ni, Sr, Pb and Th were found in the breccia composition of mud volcanoes, that their concentrations are significantly higher than the average value for sedimentary rocks. The amount of organic matter in the rocks, ejected by mud volcanoes, is more than 9%. The results of pyrolysis show that the yield of hydrocarbons is insignificant, organic matter is most often in the form of coal.

Radioactive backgrounds on the crater field of the mud volcano were often increased, which is explained by tectonic dislocations in the internal structure of the volcano. An increase in the gamma level in some breccia samples selected in areas with a high radioactive background is associated with an increase in the concentration of uranium.

This work was supported by the Science Development Foundation under the President of the Republic of Azerbaijan – Grant № EIF/GAM-3-2014-6(21)-24/11/2.

References

1. Abbasov O.R. About Paleogene-Miocene combustible shales of Gobustan // Proceedings of geology institute. 2005. Issue 33, pp. 10-15.
2. Abbasov O.R. The geochemical characteristic of combustible shales of Paleogene-Miocene in Gobustan // The Second International Scientific Conference of Young Scientists and Students "New directions of investigations in the Earth Sciences". Baku, 2007, pp. 8.
3. Abbasov O.R. Geological and geochemical features of combustible shales of Gobustan (Azerbaijan) and their forecast inventories // Bulletin of the Atyrau Institute of oil and gas. 2008. Vol 2, issue 14, pp. 22-29.
4. Abbasov O.R. Regularities of extension combustible schists in Oligocene-Miocene sediments of Gobustan // The National Committee of Geophysicists of Azerbaijan. 2010. Issue 1-2, pp. 47-49.
5. Abbasov O.R. Possible resources of Gobustan fields and combustible manifestations // Azerbaijan Oil Industry. 2010. Issue 5, pp. 59-62.
6. Abbasov O.R., Baloglanov E.E., Huseynov A.R., Akhundov R.V. Hydrocarbon potential of Baku Archipelago deep deposits by data of mud volcanoes ejects // Proceeding of the 1st International Conference "Ultra deep hydrocarbon potential: future energy resources – reality and predication". Baku, 2012, pp. 137-139.
7. Abbasov O.R., Ibadzadeh A.D., Mammadova A.N. Hydrocarbon generation potential of the deeper sediments of Azerbaijan // Integrated approach for unlocking hydrocarbon resources. Baku, 2012, pp. 48.
8. Abbasov O.R., Mammadova A.N. Evolution of ideas about combustible shales of Azerbaijan and their practical importance // Proceedings the Sciences of Earth, Azerbaijan National Academy of Sciences. 2012. Issue 3, pp. 12-16.
9. Abbasov O.R., Mamedova A.N., Huseynov A.R., Baloglanov E.E. Some new data of geochemical researches of combustible shales of Azerbaijan // Geology, geophysics and development of oil and gas fields. 2013. Issue 2, pp. 32-35.
10. Abbasov O.R., Akhundov R.V. The comparative analysis of mud volcanoes of Azerbaijan and Ukraine (an example of Gobustan region and the Kerch Peninsula) // Proceeding of the 5th International Scientific Conference of Young Scientists and Students "Fundamental and applied geological science: achievements, prospects, problems and ways of their solutions". Baku, November 14-16, 2013, pp. 16-18.
11. Abbasov O.R., Akhundov R.V. Petroleum potential of Paleogene and Miocene deposits in Gobustan based on oil shale products of mud volcanoes // Baku World Forum of Young Scientists. Baku, 2014, pp. 27-28.
12. Abbasov O.R. Oil Shale of Azerbaijan: Geology, Geochemistry and Probable Reserves // IJRSSET – International Journal of Research Studies in Science, Engineering and Technology. 2015. Vol. 2, issue 10, pp. 31-37.
13. Abbasov O.R., Ibadzade A.J., Khasaeva A.B., Guseynov A.R., Akhundov R.V., Baloglanov E.E. Hydrocarbon potential of the deep-shipped deposits of Gobustan (Azerbaijan) (on the basis of combustible shales and oil-bearing breeds, emissions of mud volcanoes) // Resursovosproizvodnyashchy, low-waste and nature protection technologies of development of a subsoil. Bishkek, Kyrgyzstan, 2015, pp. 342-443.
14. Abbasov O.R., Baloglanov E.E., Akhundov R.V. Geochemical analysis of oil shale and oil-bearing rocks of Gobustan mud volcanoes // 6th International Conference of Young Scientists and Students "Multidisciplinary approach to solving problems of geology and geophysics". Baku, October 12-15, 2015, pp. 118-119.
15. Abbasov O.R., Baloglanov E.E., Akhundov R.V. Organic compounds in ejected rocks of mud volcanoes as geological and geochemical indicators: a study from Shamakhi-Gobustan region (Azerbaijan) // International Multidissiplinary Forum "Academic Science Week-2015". Baku, 2015, pp. 3-4.
16. Abbasov O.R. Geological and geochemical properties of oil shale in Azerbaijan and petroleum potential of deep-seated Eocene-Miocene deposits // European Journal of Natural History. 2016. Issue 2, pp. 31-40.
17. Abbasov O.R. Distribution regularities of oil shale in Azerbaijan // ISJ Theoretical & Applied Science. 2016. Vol. 3, issue 35, pp. 165-171. Doi: <http://dx.doi.org/10.15863/TAS.2016.03.35.28>
18. Abbasov O.R. Genesis and organic geochemistry of oil shale in Eastern Azerbaijan // Proceedings of the VII Youth Scientific Conference "Ideas and Innovations in Geosciences". Kyiv, Ukraine, October 25-27, 2017, pp. 33.
19. Abbasov O.R. Distribution regularities and geochemistry of oil shales in Azerbaijan // Mineral resources of Ukraine. 2017. Issue 2, pp. 22-30.
20. Aliyev Ad.A., Ibadzadeh A.J., Abbasov O.R., Mammadova A.N. The dynamics of genesis of organic substance in oil shales // Azerbaijan Oil Industry. 2014. Issue 07-08, pp. 3-7.

21. Aliyev Ad.A., Guliyev I.S., Dadashov F.H., Rahmanov R.R. Atlas of world mud volcanoes. Baku: Publishing house "Nafta-Press", "Sandro Teti Editore", 2015, 321 pp.
22. Aliyev Adil, Abbasov Orhan. Organic geochemical characteristics of oil shale in Azerbaijan // The 36th National and the 3rd International Geosciences Congress, Tehran, Iran, February 25-27, 2018, pp. 1-10.
23. Aliyev Ad.A., Abbasov O.R., Mamedova A.N. Geochemistry of oil shale in Azerbaijan // ISJ Theoretical & Applied Science. 2018. Vol. 05, issue 61, pp. 315-322. Doi: <https://dx.doi.org/10.15863/TAS.2018.05.61.52>
24. Aslanov B.S., Khuduzadeh A.I. The role of neotectonic processes in the formation of hydrocarbon deposits in the territory of Azerbaijan // STB Karotazhnik. Tver, 2017. Issue 8, pp. 57-66.
25. Babayev F.R., Abbasov O.R., Mamedova A.N., Huseynov A.R. Studying of bitumens of Azerbaijan // Actual problems of humanitarian and natural sciences. 2013. Vol. 7, issue 54, pp. 40-42.
26. Bagirov E., Nadirov R., Lerche I. Earthquakes, mud volcano eruptions, and fracture formation hazards in the South Caspian Basin: statistical inferences from the historical record. Energy Exploration and Exploitation. 1996. Vol. 14, issue 6, pp. 585-606.
27. Baloglanov E.E., Abbasov O.R., Akhundov R.V. Gas-Hydrochemical Indicators of Mud Volcanism Communication with Seismicity // XXIII International Scientific Conference of Students, Post-Graduates and Young Scientists "Lomonosov-2016". Moscow, April 11-15, 2016, pp. 1.
28. Baloglanov E.E., Abbasov O.R., Akhundov R.V., Nuruyev I.M. Daily gryphon-salse activity of mud volcanoes and geo-ecological risk (based on researches, conducted in Gaynarja mud volcano) // Water resources, hydraulic facilities and environment. Baku, 2017, pp. 512-517.
29. Baloglanov E.E., Abbasov O.R., Akhundov R.V., Huseynov A.R., Abbasov K.A., Nuruyev I.M. Daily activity of mud volcanoes and geoecological risk: a case from Gaynarja mud volcano, Azerbaijan // European Journal of Natural History. 2017. Issue 4, pp. 22-27.
30. Baloglanov E.E., Abbasov O.R., Akhundov R.V., Abbasov K.A., Nuruyev I.M. Impact of seismic activity on fluid (gas and water) and temperature regimes of mud volcanoes in Shamakhi-Gobustan region (Azerbaijan) // Proceedings of the VII Youth Scientific Conference "Ideas and Innovations in Geosciences". Kyiv, Ukraine, October 25-27, 2017, pp. 31.
31. Baloglanov E.E., Abbasov O.R., Akhundov R.V., Hasanov E.H., Abbasov K.A., Nuruyev I.M. Anomalies in gas-hydrogeochemical indicators of mud volcanoes in connection with seismic activity: on the basis of mud volcanoes data in Shamakhi-Gobustan (Azerbaijan) and Sakhalin Island (Russia) // ISJ Theoretical & Applied Science. 2018. Vol. 1, issue 57, pp. 176-185. Doi: <https://dx.doi.org/10.15863/TAS.2018.01.57.32>
32. Baloglanov E.E., Abbasov O.R., Akhundov R.V. Hydrochemical changes in mud volcanoes: a precursor of earthquakes // XXV International Scientific Conference of Students, Post-Graduates and Young Scientists "Lomonosov-2018". Moscow, April 9-13, 2018, pp. 1.
33. Bashirov O.Kh. The mineralogical investigation of the materials of the Keyreki mud volcano // Azerbaijan Geologist. 2016. Issue 20, pp. 87-90.
34. Bashirov O.Kh. Some new data of mineralogy of Shikzarli mud volcano // Proceedings of the VII Youth Scientific Conference "Ideas and Innovations in Geosciences". Kyiv, Ukraine, October 25-27, 2017, pp. 47.
35. Cothray J.E., Aliyev Ad.A. Delineation of Mud Volcano Complex, Sacrificial Mudflows, Slump Blocks, and Shallow Gas Reservoirs Offshore Azerbaijan. Offshore Technology Conference. Houston, Texas, USA, May 1-4, 2000, pp. 28.
36. Dadashev F.G. Hydrocarbon gases of mud volcanoes in Azerbaijan. Baku: Azerneshr, 1963. 65 pp.
37. Grigoryev N.A. Distribution of chemical elements in the upper part of the continental crust. Ekaterinburg: UrO RAN. 2009. 382 pp.
38. Fuad Nabiyevev and Orhan Abbasov. Geochemical study of ejected rocks (oil shale and oil-bearing rocks) of mud volcanoes in Shamakhi-Gobustan region (Azerbaijan) as indicators of hydrocarbon generation and accumulation // European Geosciences Union General Assembly 2018, Geophysical Research Abstracts. Vol. 20, EGU2018-12244. Vienna, Austria, April 8-13, 2018.
39. Hasanov E.H. Characteristics of the choice of favorable engineering and geological conditions for fulfilling of the prospecting and exploration surveys // Young Researcher. Baku, 2016. Volume II, issue 2, pp. 73-77.
40. Hasanov E.H., Yolchiyev M.R. Report on prospecting and engineering and surveys of the Garabakh field // Integrated Engineering Exploration Production. 2017. 218 pp.
41. Hasanov E.H., Khuduzadeh A.I. Assessment of perspective areas in the north Absheron uplift zone of the South Caspian basin and geological and geochemical features of the upper part of the sections: a study from the Garabakh field // ISJ Theoretical & Applied Science. 2018. Vol. 04, issue 60, pp. 50-57. Doi: <https://dx.doi.org/10.15863/TAS.2018.04.60.12>
42. Ibadzadeh A.J., Abbasov O.R. Geochemistry of combustible shales in Gobustan and use of their pyrolysis products // Proceedings of Geology Institute. 2008. Issue 36, pp. 58-67.
43. Khuduzadeh A.I., Akhundov Sh.Kh., Mustafaevev Y.R., Gurbanov M.F. Lithological-facies and paleotectonic criterias in the formation of hydrocarbon deposits of the Paleogene complex sediments in the oil and gas bearing region Kura and Gabirri interfluvies // Azerbaijan Oil Industry. Baku, 2015. Issue 12, pp. 6-12.
44. Khuduzadeh A.I. Formation and oil-gas content of thrust type structures in north-west part of Absheron archipelago // Azerbaijan Oil Industry. Baku, 2016. Issue 4, pp. 13-18.
45. Khuduzadeh A.I., Akhundov Sh.Kh., Askerov I.N., Akhundov S.Sh. Lithophatic features, structural and paleotectonic analysis of Upper Cretaceous sediments in the middle Kura basin based on new data (on the example of the Kura and Gabirri interfluvies) // Proceedings of the Azerbaijan National Academy of Sciences, Earth Sciences. Baku, 2017. Issue 1-2, pp. 37-44.
46. Matthieu Dupuis, Francis Odonne, Orxan Abbasov, Teymur Fiqarov, Anthony Dofal, Patrice Imbert, Bruno C. Vendeville. The Ayaz-Akhtarma mud volcano: an actively growing mud pie in the foothills of the Greater Caucasus, Azerbaijan // 13th International Conference on Gas in Marine Sediments. Tromsø, Norway, 2016.
47. Mellors R., Kilb D., Aliyev A., Gasanov A., Yetirmishli G. Correlations between earthquakes and large mud volcano eruptions // Journal of Geophysical Research. 2007. Vol. 112. B04304. doi:10.1029/2006JB004489. pp. 1-11.
48. Milkov A.V., Sassen R., Apanasovich T.V., Dadashev F.G. Global gas flux from mud volcanoes: a significant source of fossil methane in the atmosphere and the ocean. Geophysical Research Letters. 2003. Vol. 30, issue 2, pp. 1037.
49. Newton R.S., Cunningham R.C., Schubert C.E. Mud volcanoes and pockmarks: seafloor engineering hazards or geologic curiosities? Proceedings – Annual Offshore Technology Conference. Houston, USA, May 5-8, 1980, vol. 1, pp. 425-435.
50. Orhan Rafael Abbasov. Oil shale of Azerbaijan: geology, geochemistry and probable reserves // International Journal of Research Studies in Science, Engineering and Technology. 2015. Vol. 2, issue 9, pp. 31-37.
51. Orhan R and Abbasov. Organic compounds in ejected rocks of mud volcanoes as geological and geochemical indicators of source rock: a study of oil shale in Shamakhi-Gobustan region (Azerbaijan) // International Journal of Current Advanced Research. 2016. Vol. 5, issue 7, pp. 1042-1046.
52. Orhan Abbasov and Adil Aliyev. Geodynamic stresses and eruption paroxysm of mud volcanoes // European Geosciences Union General Assembly 2018, Geophysical Research Abstracts. Vol. 20, EGU2018-6467. Vienna, Austria, April 8-13, 2018.
53. Venikova A.L., Obzhirev A.I., Abbasov O.R., Baloglanov E.E., Akhundov R.V. Mud volcanism and seismicity (based on a comparative analysis of geochemical data of mud volcanoes located on Sakhalin Island of the Russian Federation and Shamakhi-Gobustan District of Azerbaijan) // 1st International Scientific Conference of Young Scientists and Specialists "The role of multidisciplinary approach in solution of actual problems of fundamental and applied sciences (Earth, technical and chemical)". Baku, October 15-16, 2014, pp. 5-8.
54. Yerшов V.V., Nikitenko O.A., Perstneva Y.A., Baloglanov E.E., Abbasov O.R. Geochemical studies of products related to the activity of mud volcanoes in Azerbaijan // V All-Russian youth geological conference "Geology, geocology and resource potential of the Urals and adjacent territories". Ufa, September 25-30, 2017, pp. 117-123.