AAPG Annual Convention
Salt Lake City, Utah
May 11-14, 2003

Geothermal Energy Discharge from Mud Volcano Channel

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Introduction. Mud volcanism is one of the most interesting nature phenomena encountered in many countries of the world. A number of geological factors stipulate development of mud volcanism in the South Caspian basin. The thickness of the sedimentary pile reaches 30 km; the upper 10 km being composed of the Pliocene-Quaternary dominantly clayey lithologies deposited at extremely high sedimentation rates (up to 1300 m/m.y.). Among special features of the basin are low heat flow, abnormally high formation pressure, high degree of dislocation and seismicity etc. In the South Caspian Basin, the general region of onshore and offshore Azerbaijan is home to over 200 mud diapirs and/or mud volcanoes (fig. 1). These mud structures are associated with the production of copious oil and gas, and production wells are to be found on the flanks of many onshore mud diapirs. This association is no mere coincidence but is related to the dynamical development of mud diapirs and the generation, migration, and accumulation of hydrocarbons in the South Caspian Basin, as has been detailed elsewhere [Yakubov et. al., 1971]

Geothermal Researches. Temperature measures of mud volcanoes in Azerbaijan were first mentioned, in 1904-1905 [Krasnov, 1905]. It was defined that the water temperature of mud volcanoes could be compared with average annual temperature on this locality [Abramovich, 1916; Shnyukov and Lebedev, 1971].

More deep geothermal research on mud volcanoes was developed in exploration of oil and gas fields. It can be explained mud volcanoes fill the majority of oil-gas structures. In the result of these researches the different anomalies of field were defined including the reduction of geothermal gradient by the depth, and in area of mud volcanism development [Sukharev et al., 1969; Kurbanmuradov, 1970; Mekhtiyev et al., 1971; Kutas and Gordienko, 1971; Yakubov and Atakishiyev, 1973]. It turned out, that mud volcanoes are known by the high values of heat flow density (fig. 2). At the same time in districts of mud volcanism development regional values of heat flow density occurred below medium continental ones [Sukharev et al., 1969; Yakubov and Atakishiyev, 1973; Kashkay and Aliyev, 1974; Aliyev, 1988]. Besides, Lower-Kura depression is known by the lowest heat flows among the same region. In local sphere the separate structures affected by the high temperatures and of heat flow densities (fig. 2) know mud volcanoes. However, in all these case the abnormal heat flow exceeds the medium value along structure approximately in twice and gets hardly 100 mW/m2 on the mud volcanoes (fig. 2).

The results of temperature research given in this article are based, on the study of 29 mud volcanoes, caused to three oil-gas regions in Eastern Azerbaijan (fig. 2). Some of them are situated, on the southern slope of eastern part of Great Caucasus and its southeastern submersion, and the others- in plain part of the Eastern Azerbaijan territory

Temperature Measurements. Measurements have been made at three sites within the Lokbatan mud volcano crater at depths of 0.5m, 1.0m and 1.5m into the mud, using a thermistor thermocouple and a balancing Wheatstone Bridge, with resistance calibrated to true temperature in the laboratory to a precision of ± 0.01 ºC using a high accuracy mercury thermometer. Thermal probe consists of metallic pipe; with the diameter 15 mm. Calibrating of thermoresistors was made before the field works for the calibrating the thermostat was used, working exactly 0,01ºC, mercury thermometers with division 0,01ºC (Mukhtarov and Adigezalov, 1997).

Calibrating tables were made with the using of computer on the dependence base electric resistance of thermo resistor from temperature in following form:

$$\mathbf{RT = AeB/T}, \qquad (1)$$

which permits to provide the error of measurements not more the 0.01ºC [Sheftel, 1973]. Here are **T**- Kelvin temperature,

R- the electric resistance of thermo resistor, **A** and **B**- calibrating coefficient. Thus, summary errors in temperature measurement do not exceed 0,03-0,05oC.

Results. Different anomalies of geothermal field were recorded in areas of mud volcanism development. Mud volcanoes are known by the high value of heat flux density. At the same time, in regions of mud volcanism development, regional values of heat flux density are generally below median continental values. Values of temperature gradients defined in depth interval 0.3 – 1.5 m are very high, and very variable, ranging from 0.02 – 21.25 ºC/m (table 1). There is also a diminution of temperature gradient with depth [Mukhtarov, 2002].

Table 1

Bringing out of internal heat by mud volcanoes
(The difference of temperatures T-To = 20oC)

The eruption products	Volume, m^3	ρ, kg/m^3	C, J/(kg*K)	Carrying out of heat, J	Heat flow, W/m^2
Firm products					
For one eruption,					
Minimum	1,00E+03	1880	840	3,16E+10	87733
Maximum	5,00E+06	1880	840	1,58E+14	4E+08
For all period (Inchabel),					
Minimum	1,00E+08	1880	840	3,16E+15	0,10
Maximum	1,14E+10	1880	840	3,6E+17	11,43
100 m/v for all period, a minimum				3,16E+17	
170 m/v for all period, a maximum				6,12E+19	
Liquid products					
One mud volcano:					
Minimum	416 sm^3/hour	1000	4186	837200	0,10
Maximum	0.5 m^3/hour	1000	4186	1E+09	0,65
All active m/v on land	10 m^3/hour	1000	4186	2,01E+10	12,92
For all period				1,1E+20	
Gaseous products					
For one eruption:					
Minimum	3 млн. т		1000	6E+13	3E+08
Maximum	500 млн. т		1000	1E+16	6E+10
All active m/v for all period					
Minimum	1,25E+141	1,293	1000	3,23E+18	0,57
Maximum	3,50E+141	1,293	1000	9,05E+18	1,60

One more fact is great importance and make one to think: about the nature of mud volcanoes. As it was mentioned above, the water temperature of mud volcanoes is low, on an average about 20ºC. The research of Bahar mud volcano showed after the hard eruption (October 3, 1992) that the products of eruption were not hot. So the maximum temperature of breccia on the thirteenth day after the eruption was only 31ºC. Hence the conclusion: the region temperature where the products of eruption are ejected is not high. Thus, if the temperature of products eruption does not exceed 30-40ºC so the upper focus of eruption or the center of mud discharge is on that depth where temperature does not really exceed above-mentioned values. An additional measurement was made on 27 October 2001 just inside the crater walls, producing a temperature of 71ºC at about 1m depth into the two day old mud [Lerche et al., 2002].

The geothermal investigations, and the result of experimental determinations of thermal conductivity properties of rocks, also make it possible to evaluate the magnitude of thermal flows in wells at a number of fields on the Apsheron Peninsuala. Thus, for the Lokbatan field, thermal flows at 23 sites, uniformly arranged along the structure, have been obtained. Near the neck of the mud volcano two wells were subjected to geothermal investigations (fig.1). For these wells the maximal values for thermal flow have been noted for the Lokbatan mud volcano field, 2.6 and 1.96 HFU (Heat Flow Unit, 1HFU = 42mW/m^2), which is quite credible provided that the roots of the mud volcano are in deposits of Upper Cretaceous age, occurring at great depth (>6-12km). The eruptive process also brings about intense heat transmission from the root region along with observed rock fragments of the same age.

Above mentioned the brief review of data let get the definite idea about thermal regime of mud volcanic regions. But all these researches were not purposive; they had a reconnaissance character. In these researches the mud volcanoes were not as the separate geological body and its role in formation of thermal field for this region. A little attention was paid to thermal consequence of mass-transportation into these objects. So, up-to day the peculiarities of local thermal field have not been clarified and not developed a heat model of mud volcano.

Discussion. Thus, the results of geothermal researches on mud volcanoes create the picture of temperature distribution along the channel of substance eject. Horizontal temperature distribution around the mud volcano corresponds temperature distribution above the thermal jet [Turcotte and Schubert, 1982] (fig. 3), as in thermal case the mud volcano can be presented by thermal jet. Reaching to the Earth surface reduces the size of temperature anomaly Δ**T** and due to this there are no abrupt temperature anomalies at mud volcanoes. It is similar of temperature distributions on contours of area of a mud volcano; zones of formation of hydrocarbons are accordingly displaced upwards.

In the table shown results of calculations of quantity of thermal energy taken out are given by products of eruption of a mud volcano during eruption. These results shows, that during eruptions on a surface the colossal quantity of thermal energy, which is not comparable to a normal heat flow from bowels of the Earth, is taken out. It is necessary to note, that after eruption activity of mud volcanoes does not stop. Many mud volcanoes constantly continue the quiet activity, constantly taking out on surface gas, water and a breccia.

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Many mud volcanoes constantly continue the quiet activity, constantly taking out on surface gas, water and a breccia. Knowing flow rates these products and their thermal characteristics, roughly it is possible to estimate energy (or density of energy) transferable these products:

$$\boldsymbol{Q = \rho V c \Delta T}, \qquad (1)$$

here v- flow rate (quantity products, removed for day).

$$\boldsymbol{\Delta T = T - T_o}, \qquad (2)$$

T_o- the temperature on a surface, *T*- the temperature on depth, whence is taken out a product of activity of a mud volcano.

Thus, on the base of geothermal data, got in result of research of mud volcanoes one can imagine the picture of thermal field. The attempt was made to explain the process of eruption of unstable convection in multistage system of volcano centers and channels. The raising of hydrocarbon generation zone near to a surface accounted by formation of a thermal jet and redistribution of temperature in the field of a mud volcano (mud diapir).

Acknowledgments. The research described in this publication was made possible in part by Award No. NG2-2285 of the U.S. Civilian Research & Development Foundation for the Independent States of the Former Soviet Union (CRDF).

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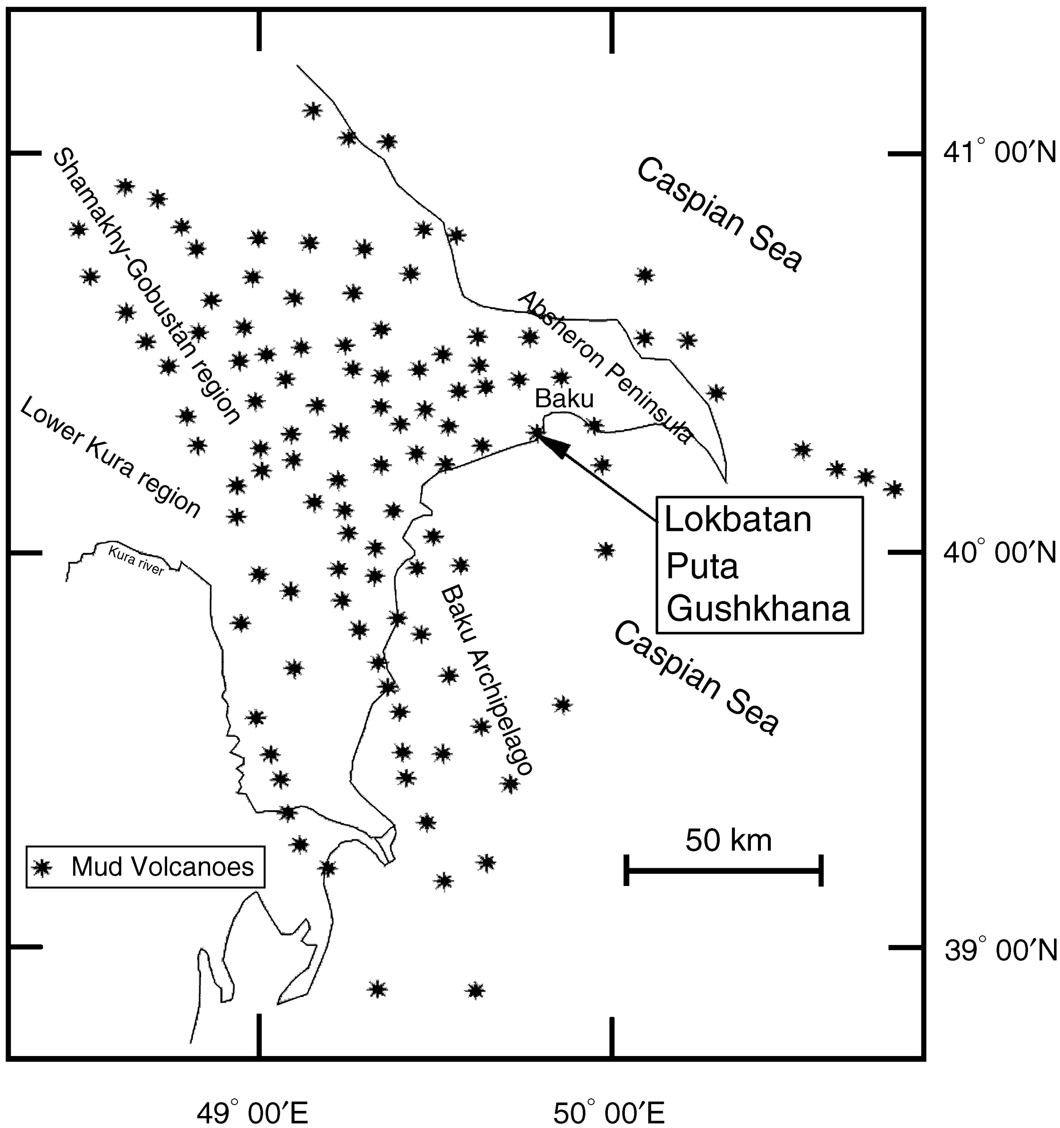

Fig. 1. Scheme of mud volcanoes location.

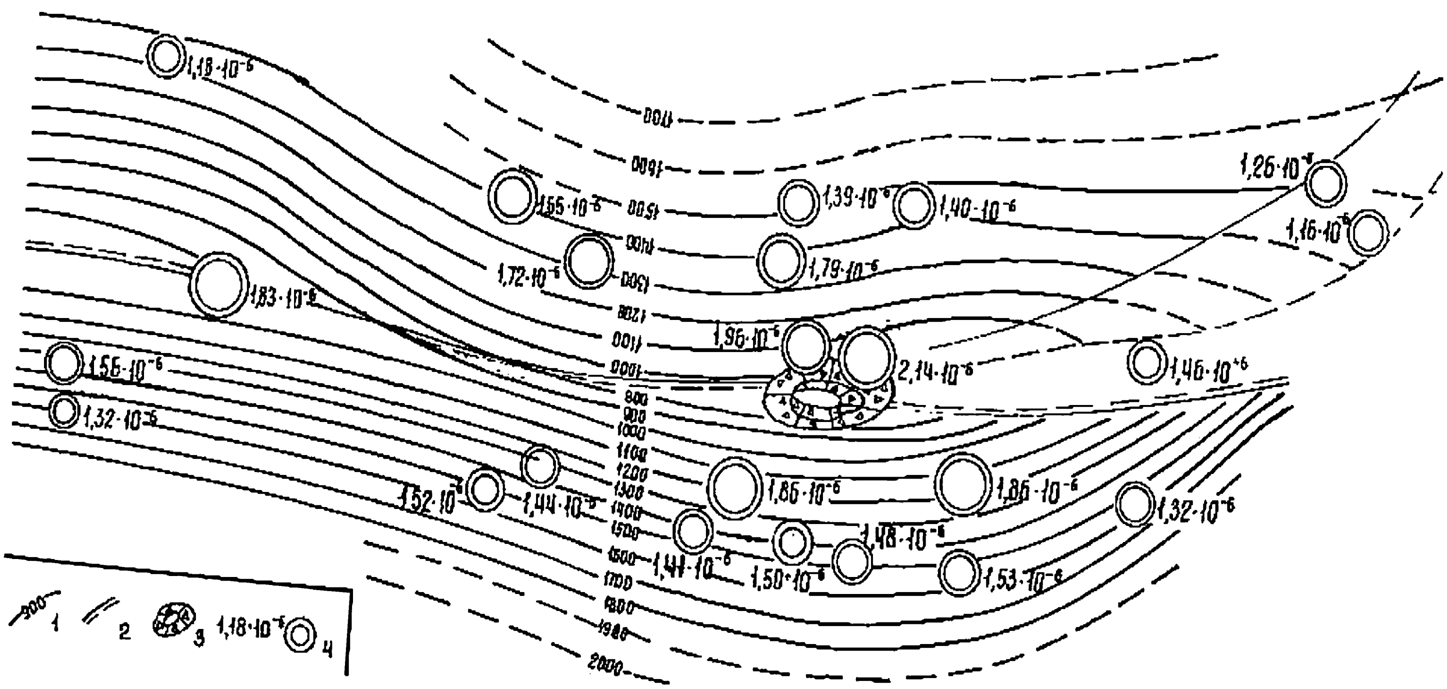

Fig. 2. Heat flow distribution of the Lokbatan mud volcano area 1 – contour line along the suite NKP roof; 2 – tectonically dislocations; 3 – Lokbatan mud volcano; 4- the value of heat flow density in wells, HFU kal/($cm^2 \cdot s$)

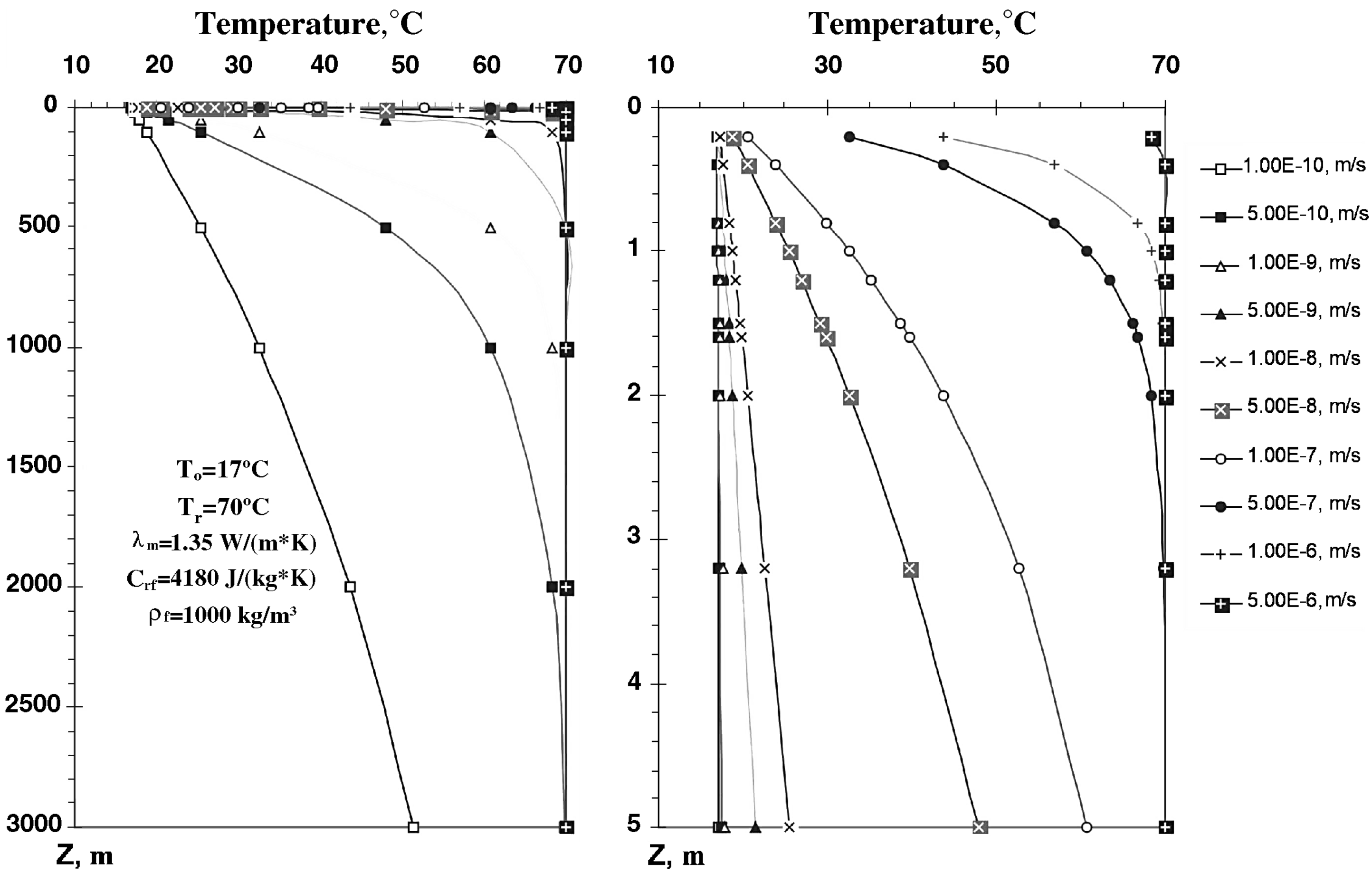

Fig. 3. Vertical distribution of temperature along mud volcano channel The speed of substance transportation in porous channel, m/c: 1 – $1x10^{-10}$; 2 – $5x10^{-10}$; 3 – $1x10^{-9}$; 4- $5x10^{-9}$; 5 – $1x10^{-8}$; 6 – $5x10^{-8}$; 7 – $1x10^{-7}$; 8 – $5x10^{-7}$; 9 – $1x10^{-6}$; 10 – $5x10^{-6}$