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Excursion to the Kamchatka Geysers

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Abstract: This paper serves as a brief introduction to the Kamchatka geyser basin. Included are explanations of geyser behavior, a description of significant features, and some results of recent studies related to the Kamchatka geysers.

Historical Background

The geysers in the valley of the river Geysernaya were first described by T.I. Ustinova, who discovered them in 1941. She also gave names to the most powerful or notable of these thermal springs. Because of the remoteness of the region, descriptions of the geysers were sporadic until 1972. As a rule, observations were limited to a few hours at a time. Systematic, lengthy observations of geyser activity were begun under the direction of V.M. Sugrobov, who carried out a complex study of Kamchatka's high-temperature hydrothermal system.

Research into the behavior of the geysers was carried out with the aid of flow meters that were placed in the overflow channels of the geysers almost annually during the period of fieldwork, *i.e.* for one to three months per year. During 1974 and 1975, with the aid of an automatic telemetric conductor system, V.N. Nechaev succeeded in capturing a series of observations for a period of over 13 months. Since 1990, data has been collected by means of a telemetric system.

The dynamic properties of the geysers (such as the velocity and force of the eruption, the height of the water column, and the volume of discharge) were determined by various means: devices that measured the discharge of water (V.M. Sugrobov); visual recording (O.P. Rulenko); hydrometrical devices (V.A. Droznin); and by a specially devised method of hydrometrical sounding (G.S. Steinberg). There are no studies of this region, which constitutes part of the Kronotsky Nature Preserve, which utilize the various methods of geophysical reconnaissance, except for geothermal surveys which were limited to determining the acoustic and seismic parameters of the noise generated by the geysers themselves.

In the over 50 year period of observation there have been no considerable changes in the function of the majority of the geysers. The general nature of activity is the same as that described by T.I. Ustinova. At the same time, quantitative changes in periodic activity have been determined for practically all principal (consistently observed) geysers. If one does not take into account the changes in function of several geysers (Pervenets, Shchel, Grot), which were due to observed exogenous breaches of the ground surface, changes in activity could be connected to the deepening of the bed of the river Geysernaya, to the tectonic life of a geologically young region, as well as perhaps to overall changes in volcano-tectonic conditions on the peninsula.

Distribution of the Geysers

About 300 springs have been identified and hydrochemically tested in the valley of the river Geysernaya. They all appear to be pulsating springs; that is, they do not have a constant discharge. About 90 springs are geysers, which is to say their activity is cyclical, and during that cycle there is a rest phase, during which neither water nor pressurized steam reach the surface. About 30 of the major springs have been named.

The overwhelming majority of the thermal springs and formations are found on the left bank of the river Geysernaya. This seems to be indisputable proof of the source and drainage of the thermal waters — they flow from the sides of the Kihpinych volcano. The general area containing manifestations of thermal activity,

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delimited by the 20^0 C isotherm at the depth of 1 meter, comprises 1.3 x 10 km^2. Geysers are found along the middle and lower portions of the river Geysernaya and along the central portion of the brook Vodopadnaya. The excursion path of the joint stock company Sogzhoi was lengthened along the central region of the Geysernaya Valley and from it only two of the most powerful geysers — Pervenets and Troynoi — are not visible. They are found a significant distance downstream from the helicopter landing area. Geyser Malyi is an analogous geyser to Pervenets in its strength and manner of eruption. Usually, excursions into the Valley of the Geysers begin with the observations of its periodic activity. Side by side with Malyi is the geyser Bolshoi.

After that, the path leads past the geyser Shchel and the pulsing spring Malachitovyi Grot, then across a small bridge to the central observation area. Here the broad view of the Vitrazh (Stained-Glass Panel) (Fig. 1) opens up (including the geysers Grot, Novyi Fontan, Nepostoyannyi, and Dvoynoi), along with a view of the boiling spring Averii, and geysers Paryashchii, Zhemchuzhnyi, and Velikan. The return path leads along the small multicolored lakes and mud pots, including Dantov Ad (Dante's Hell) and Bolshoi Kotel. During the course of the excursion, one can observe that in addition to the named springs there are many that have not been named.

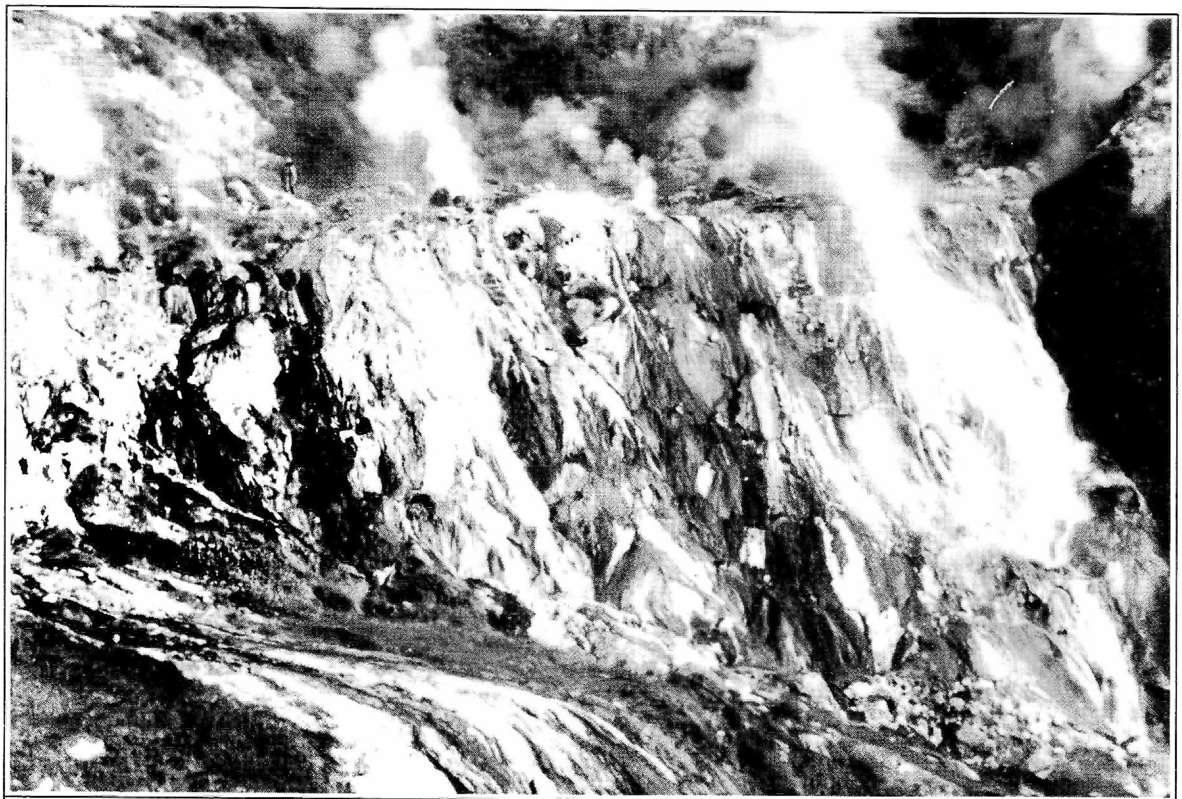

Figure 1. The Vitrazh. The vent of Grot is at the upper right of the picture. For scale, note the volcanologist on the upper left. (Vachuda photo).

Theory of Geyser Activity

Two identical geysers hardly exist. The activity of geysers differs fundamentally in their periodicity, regularity, height of water column, length of intervals and periods of rest, character of eruptions, et cetera. Such variety explains the absence of a single general theory to explain the mechanism by which all geysers function.

In the most general sense, one can separate the activity of a geyser into four phases: rest, overflow, eruption, and steam phase. For most geysers, including the majority of the large Kamchatka geysers, all of the four phases are very pronounced. However, for some geysers, for example Shchel, Dvoynoi, Nepostoyannyi and Sakharnyi, the overflow phase is not pronounced; and for the last three of these, the steam phase is also not obvious.

Formerly, the periodic activity of geysers was linked to the peculiarities of their underground structure. In a general survey work (Allen and Day, 1935), it was presumed that the presence of an underground cavity was necessary for the existence of geysers. The second main condition specified in that work is that two underground currents mix within this cavity: cold water, and hot water or steam. In a later, more specialized work (Rinehart 1980), it was argued that geyser activity could be explained using a combination of two primary models: the "pot" model and the "tube" model. In the first case, the conditions necessary for an eruption are reached within the area of a cavity that forms a part of an underground system of channels that feed the geyser. In the second case, these conditions occur within the long geyser channel itself. While there are many descriptions of the moment the boiling point is reached at some depth in the underground geyser system as the main precondition for the beginning of an eruption, there is no satisfactory explanation of why this process has a periodic character. Clearly, with the rise towards the surface of thermal waters greater than 100° C, at some depth the boiling point is reached and vaporization begins, but it is not necessary for this process to be periodic. Exploited geothermal wells, for instance, produce a stable discharge, the temperature distribution within in the well's tube corresponding to the line of thermal saturation.

Let us consider the possible models for the attainment of geyser function, giving special emphasis to a description of the physical factors which determine their fundamental characteristics: periodicity and the existence of a rest phase.

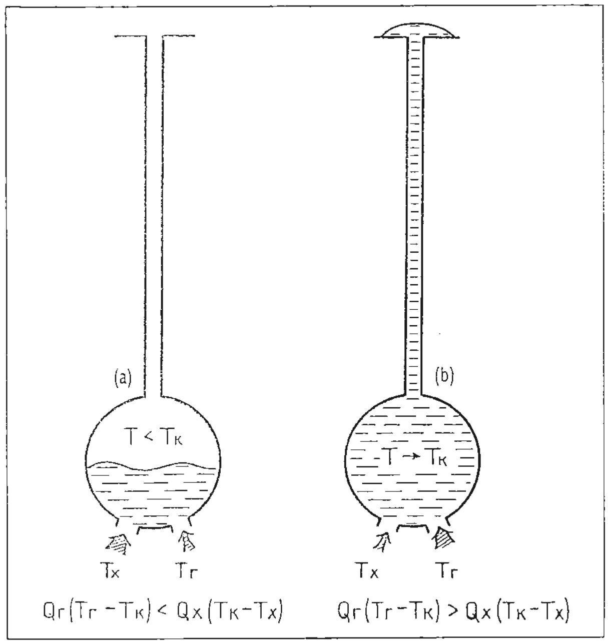

Figure 2. The "Mixing Model". Two streams, "hot" (T_Γ) and "cold" (T_X), enter the underground cavity. At time (a), at the end of an eruption, the temperature of the water in the cavity corresponds to the boiling point T_K. Refilling of the cavity occurs primarily with water colder than T_K and the temperature in the cavity is lowered. At time (b), during an eruption, primarily "hot" water ($T>T_K$) enters the cavity and the temperature in the cavity rises

"The Mixing Model"

Figure 2 represents the schematic of a model that is in accordance with the mechanism of geyser function described in the text of Allen and Day (1935). A mathematical description of the model is provided in the works of G.S. Steinberg.

The model adequately demonstrates that a certain ratio in temperature and discharge of hot and cold water is necessary for the geyser regime to function. It is necessary that the sum total of the temperatures in the two flows after the eruption, while the cavity is being filled, be less than the corresponding Tk temperature at the boiling point, but it must then be higher before an eruption. In the mathematical model, this condition is attained by a decrease in the cold water input coupled with an increase in the hydrostatic head within the geyser tube.

Such conditions may occur in nature in those cases where the discharge of hot and cold water depends in some way on the height of the water column in the geyser tube. For example, there are geysers whose erupted water, cooled off in the open area, then flows back into the geyser channel, ending the eruption.

It is generally known that the hydraulic resistance of a two-phase current is substantially higher than that of a one-phase liquid current with the same gravimetric discharge. Therefore, it is possible to assume that the necessary temperature ratio can be attained when the level of vaporization during an eruption reaches progressively deeper zones, entering into poorly permeable areas. As a result, the influx of hot water is sharply reduced and the total heat content of the waters entering the cavity becomes less than the boiling point (T_K).

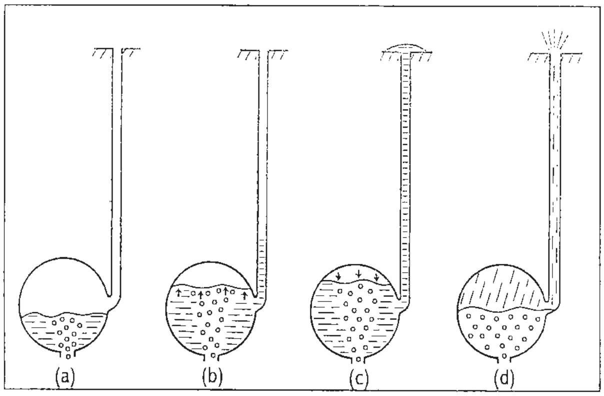

Figure 3. The "Chamber Model". The outflow is lower than the roof of the cavity. Time (a) shows the filling of the cavity and a free exit of steam. By time (b), the exit from the cavity is blocked, and pressure builds. At time (c) sufficient pressure has formed to expel water from the vent, causing overflow. During the eruption at time (d), the pressure declines as water and steam are expelled from the system.

"The Chamber Model"

Figure 3 shows a schematic of the model described in the work of I. Iwasaki (1962). The characteristics of the geyser process that can be realized pursuant to this model can occur in any two-phased mixture — for example gas and water — as the periodicity of its function is basically determined by hydraulic parameters. The thermal parameters play a secondary role. The main condition is the presence of a cavity with a special configuration that guarantees the separation of the volatile component, *e.g.*, steam or gas.

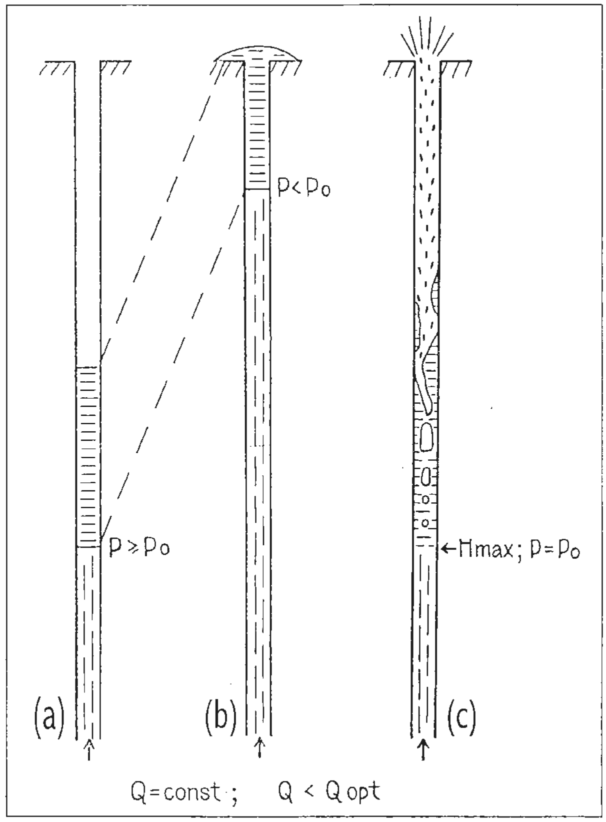

Figure 4. The "Well Model". A constant source of "hot" water (Q) enters the system, its temperature higher than the boiling point at atmospheric pressure. During the quiet period (a) the water does not boil due to the pressure of the overlying "cold" water. With overflow (b) the quantity of overlying water is decreased. During the eruption (c), if the expenditure of water is less than optimal, the level of boiling reaches its possible maximum at (P), a separation of hot and cold water occurs, and the pressure of the overlying water ends the eruption.

"The Well Model"

This model (Fig. 4), as well as the "pipe model", was first proposed by R. Bunsen (1848). A.S. Nehoroshevyi (1956) first described the process that occurs within the geyser tube, while the conditions necessary for geyser activity were formulated by V.V. Averiv (1960). V.A. Droznin (1980) developed a mathematical formula for the discrepancies between the mixing capacities of the vent channel and the heat conductivity of the water strata, based on the general theory of hydrodynamics for a stratified steam/water well system, which compared favorably to experimental data from stratified wells in the Pauzhetska field.

The geyser activity described by the "well model" can occur not only with superheated water, but also with any liquid saturated with gas, for example oil and lava. Therefore, the periodic activity of volcanoes, oil wells and mud volcanoes can also be explained within the framework of "the well model".

Dynamic Characteristics of The Kamchatka Geysers

The geysers that have the largest eruptions and can be observed from the excursion path are described below. The data cited was collected in 1994.

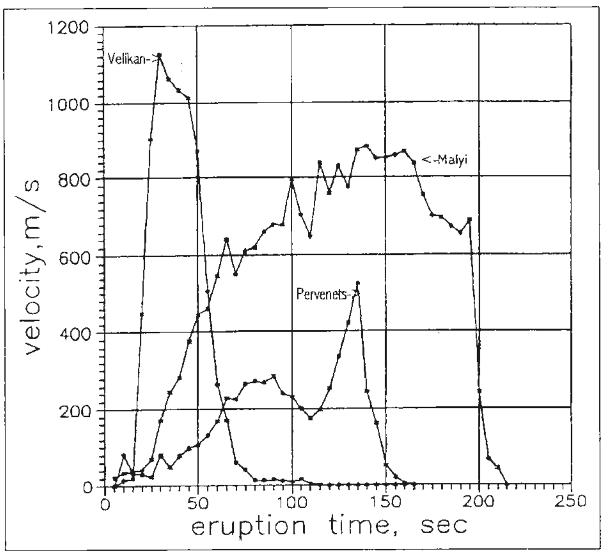

Figure 5. Velocity of discharge, measured at the vent, during the eruptions of the geysers Velikan, Malyi and Pervenets.

Velikan (Giant)

In the Valley of Geysers, Velikan is second only to the geyser Grot in its size. But the latter, unfortunately, generally functions as a pulsating spring. It periodically increases the discharge of water overflowing from its pool to 10 - 15 liters/second. When Grot was active during August – October 1991, its bursts had a length of 50 meters and enveloped the entire area of Vitrazh. The eruptions consisted of a series of four to seven bursts of gradually weakening power that occurred at 2 - 3 minute intervals. The volume of the erupted water was about 50-60 m^3. The intervening quiet period lasted about 4 hours.

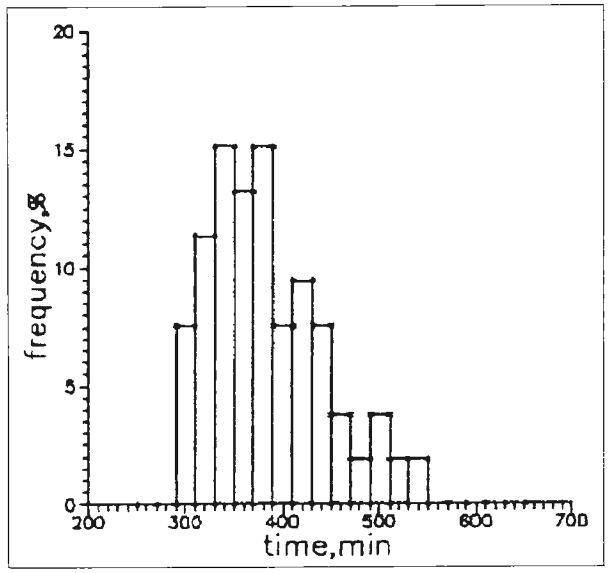

Figure 6. Frequency distribution of intervals for Velikan Geyser.

An eruption of the geyser Velikan is quite short (Fig. 5), lasting just a little over one minute. But in that time the geyser's system is emptied, discharging about 20 m^3 of water that flows westward down the runoff channel. The diameter of Velikan's water column is 1.4 m, and its height varies at 20 meters or more (the cloud of steam rises to the height of 200 - 300 m) (Fig. 23).

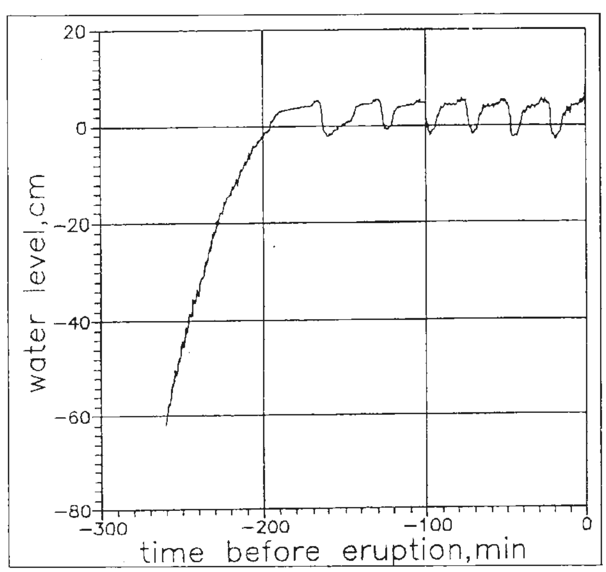

Figure 7. Typical changes in water level prior to an eruption of Velikan. In this case, Velikan erupted on the seventh hot period.

Figure 8. Velikan Geyser. Boiling and heavy overflow during a hot period. (Vachuda photo).

periods. The mechanism of the second process, which causes the main eruption, corresponds to "the mixing model". The large dimension of Velikan's pool (12 m^3) is very important in this regard, since it is able to accommodate rising steam, whose temperature is 130° C, and to cool it to 100° C. Since 1941, the average number of hot periods per cycle has increased from two or three to between 7 and 10, and correspondingly, Velikan's average interval has increased from 3 to 7 hours.

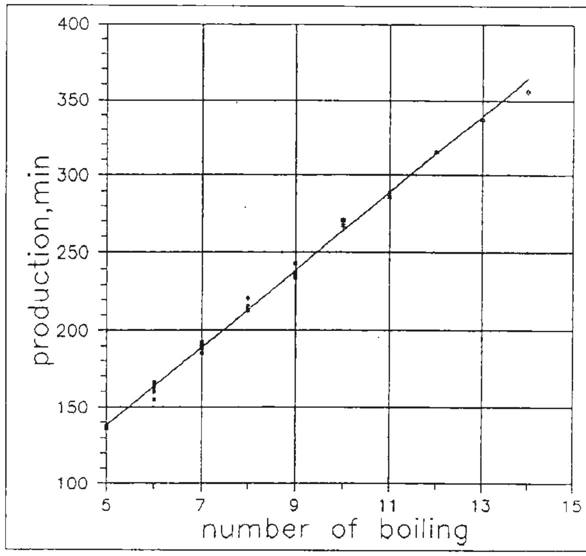

Figure 9. Velikan Geyser: correlation between number of hot periods and the length of overflow.

A distinguishing characteristic of Velikan is the irregularity of its interval (Fig. 6). There is a rest phase, which consistently lasts between 160 and 180 minutes, during which the underground plumbing system and the pool refills (Fig. 7). The subsequent overflow, which averages about 1 liter/second, is regularly punctuated by periods of splashing and heavy overflow (Fig. 8). The number of these hot periods determines the length of the overflow and hence the length of the interval (Fig 9).

Generally speaking, two geyser processes can be discerned in Velikan's pattern of activity. One, occurring at about 26 minute intervals, is dependent on "the well model" mechanism and explains the periodicity of the intermediate hot

Bolshoi (The Large One)

This geyser, like Velikan, has a large pool (1.5 x 3.2 x 3 m^3). During an eruption, which lasts over ten minutes, no steady water column is formed. Rather, the eruption consists of separate outbursts, which can reach a height of 12 meters. The free volume within Bolshoi's plumbing system after an eruption, estimated with the addition of cold water, is approximately 16 m^3. As shown in Figure 10, the duration of Bolshoi's rest phase is consistently about 75 minutes; however, the overflow period that precedes the eruption is not constant, lasting either 10 or 40 minutes. The bimodal nature of the distribution of overflow and interval is clearly noticeable: intervals between eruptions tend to be either 90 or

120 minutes long. The frequency of long periods increases in windy conditions and on rainy days.

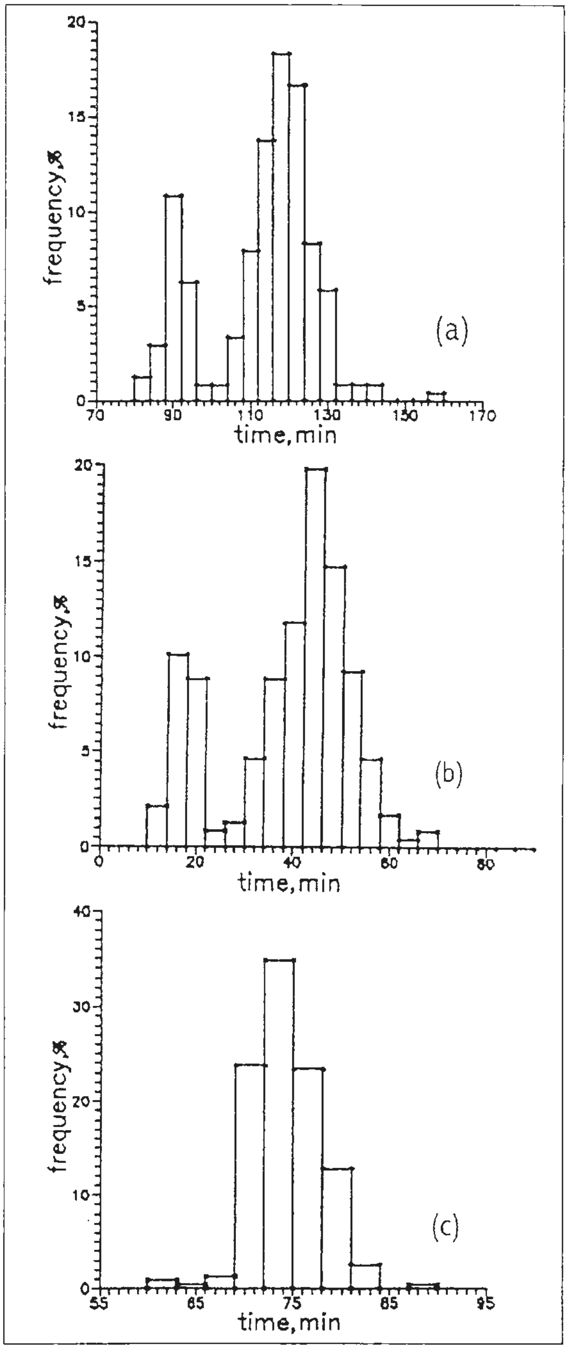

Figure 10. Bolshoi Geyser. Frequency distributions of (a) intervals, (b) overflow, and (c) rest period.

Malyi (The Little One)

The name of this geyser is justifiable only when one compares its smallish pool to those of Velikan and Bolshoi. During its eruption, which lasts about 6 minutes, a powerful, roaring column of steam and water is formed, reaching a height of 15 meters (Fig.22). A cross section of the base of the column is 0.8 x 0.4 meters, and the velocity of discharge during the eruption is about 8 m/sec (Fig.5). The rate of discharge during overflow, judging by the rate of fill, is over 6.5 l/sec. So the volume of water expended during each cycle is 2 m^3 during overflow and 9 m^3 during the eruption (of which 0.6 tons is steam). Since Malyi's interval is about 40 minutes, its average water discharge is 10 times that of Velikan and nearly twice that of Bolshoi.

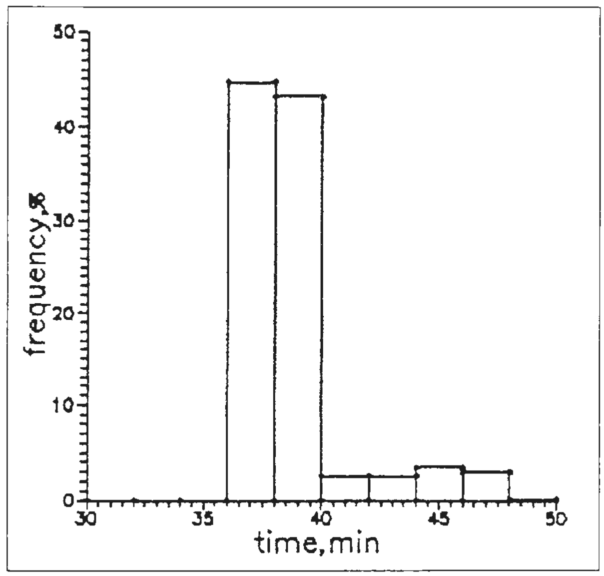

Figure 11. Malyi Geyser. Frequency distribution of intervals.

Malyi's intervals are fairly regular (Fig.11). In comparison to 1941, the interval has increased by 8 or 9 minutes, although the length of the overflow (6 min.) and of the duration of the eruption has not changed.

Shchel (Crack)

A peculiarity of this geyser is that its eruption is not preceded by overflow. The eruption lasts only a minute and its height is only 2.5 - 3 meters (Fig. 13), but this geyser's proximity to the excursion path makes it especially attractive for observation. In addition, it erupts regularly, with a very small variation in its intervals (Fig. 12). In 1994 its periodicity suddenly changed due to a landslide, from 36-37 minutes to 26 minutes.

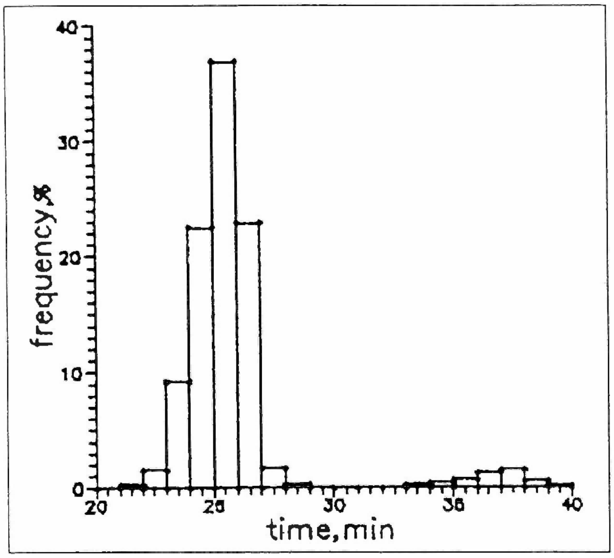

Figure 12. Shchel Geyser. Frequency distribution of intervals.

Figure 13. Shchel Geyser. (Vachuda photo).

Zhemchuzhnyi (Pearly)

During its eruption, which lasts 8 to 10 minutes, a symmetrical water column is formed, which is surrounded by large drops of water that glisten in the sun like pearls (Fig. 15). The initial velocity of the water column is 6 m/sec., and the height of the water column reaches 10 - 12 meters. The length of Zhemchuzhnyi's interval is characterized by a normal distribution, with an average period of about 3.5 hours. The length of the Zhemchuzhnyi's quiet phase is roughly equal to the length of the overflow and eruption.

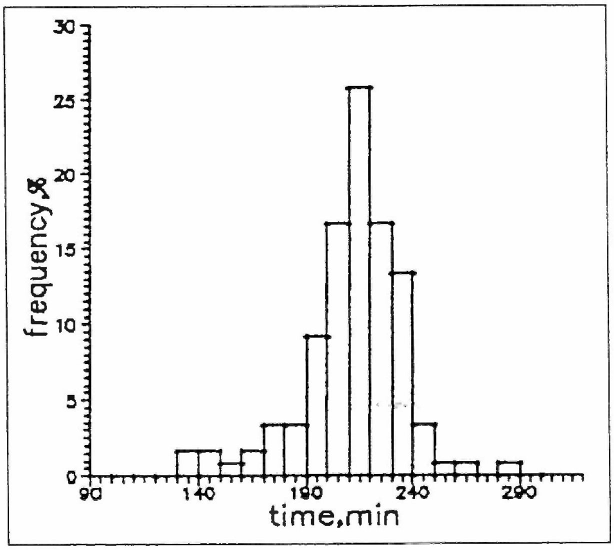

Figure 14. Zhemchuzhnyi Geyser. Frequency distribution of intervals.

The average interval of this geyser has been decreasing for some time, from 5.5 hours in 1941, to 4.2 hours in 1974, to 3.5 hours in 1994 (Fig. 14).

Paryashchii (Steamer)

This geyser does not operate regularly. For several days or hours it remains in the rest phase, then for various lengths of time it pours out boiling water at a rate of 1-3 l/sec.

Averii

This is now considered a boiling hot spring with a pulsating discharge of 10 - 15 l/sec. It had previously functioned as a geyser.

Figure 15. Zhemchuzhnyi Geyser. (Vachuda photo).

Figure 16. Fontan Geyser. The volcanologist on the lower left provides scale. (Vachuda photo).

Fontan (The Fountain)

Long term, uninterrupted observations of Fontan have not been undertaken. Nearby Novyi Fontan is active most of the time and erupts to 2 or 3 meters. Fontan erupts every 20 - 25 minutes, and its eruption lasts for about 3 - 4 minutes. At first, its eruption is not high — 6 to 8 meters — but then after a short pause it begins to spurt to 12 - 17 meters. It is typical for the water from Fontan to flow partly into the vent of Novyi Fontan, and, at times, to extinguish its activity.

Nepostoyannyi (Inconstant One) and Dvoynoi (The Double)

Both of these geysers, located near each other on the slope of the Vitrazh, produce a sizeable volume of overflow. Their frequent activity consists of irregular, but powerful bursts of water. It is especially interesting to look for the moment of synchronized activity by both vents of the Dvoynoi.

Figure 17. Konus Geyser, also known as Konus Khrustalnyi. (Vachuda photo).

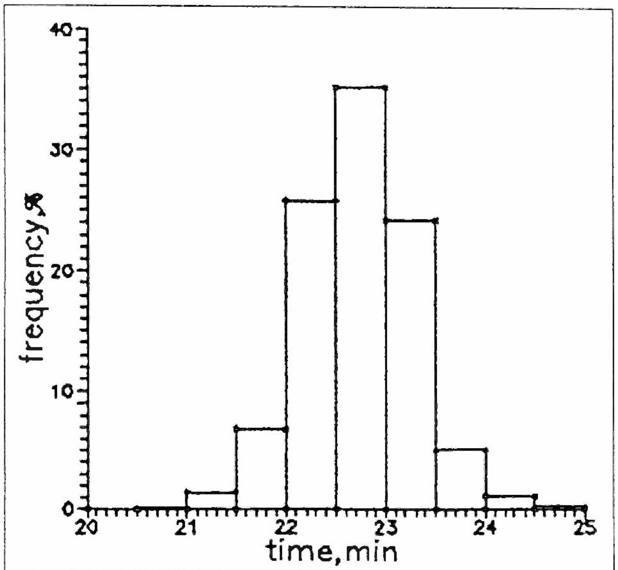

Figure 18. Konus Geyser. Frequency distribution of intervals.

The Chemical Structure of Thermal Water

The chemical structure and the character of the thermal waters undergo definite and regular changes from the presumed area of their source (the massif of the volcano Kihpinych) to the discharge zone in the lower reaches of the river Geysernaya. A change is apparent from the acid sulfates and mixed cation water composition of the grottos of the Kihpinych volcano, to the steam and carbonaceous gas vents of the upper portions of the geyser field, to the alkaline springs and geysers. The mineral content of the water of the boiling springs and geysers, reflecting the composition of the thermal water complex, is generally of the chloride-sodium type. Mineral content does not exceed 2.4 g/l, the pH is alkaline, with elevated levels of silica (up to 430 mg/l), boric acid (up to 150 mg/l), and arsenic (0.4 - 1.7 mg/l).

The variety in the observed compositions of underground waters is determined by hydrothermal differentiation during steam formation and degassing, mixing with groundwater, and discharge conditions. The fluid temperature of water at depth in the areas that supply the geyser basin, determined by use of the hydrochemical geothermometers (Na, K, Ca and SiO), averages 250°C, with the maximum recorded of 330°C).

The total thermal water discharge, determined from the concentration of Cl at the lower stream channel of the Geysernaya River, is 250-300 l/sec.

The natural heat power, determined according to the volume of discharge, is 300 megawatts.

For the analyses of the chemical structure of the geyser water (Fig. 19), samples were taken at the moment of the eruption or immediately beforehand.

	Malyi Geyser			
Sample dates:	7/28/94		8/15/94	
pH	8.82		8.74	
	Mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	0.1	0.005	0.1	0.01
Na^+	460.0	20.01	423.2	18.41
K^+	25.8	0.66	26.2	0.67
Ca^{2+}	15.2	0.76	16.0	0.80
Mg^{2+}	0.2		0.2	
Cl^-	613.0	17.30	614.2	17.30
SO_4^{2-}	115	2.40	134.4	2.80
HCO_3^-	65.9	1.08	65.3	1.07
CO_3^{2-}	3.0	0.10	2.1	0.07
H_3BO_3	74.8		77.5	
H_4SiO_4 (sol.)	180		169.5	
H_4SiO_4 (col.)	147		75.5	

	Konus Geyser			
Sample dates:	7/28/94		8/17/94	
pH	8.65		9.03	
	mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	0.1	0.01	1.25	0.07
Na^+	437.0	19.01	433.7	18.87
K^+	30.8	0.79	28.6	0.73
Ca^{2+}	16.0	0.80	16.40	0.82
Mg^{2+}	0.2		0.2	
Cl^-	609.9	17.20	617.7	17.40
SO_4^{2-}	134.5	2.80	134.4	2.80
HCO_3^-	65.9	1.08	59.8	0.98
CO_3^{2-}	1.8	0.06	4.3	0.14
H_3BO_3	73.4		78.9	
H_4SiO_4 (sol.)	173		183	
H_4SiO_4 (col.)	98		107	

	Bolshoi Geyser			
Sample dates:	7/28/94		8/15/94	
pH	8.75		8.71	
	Mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	0.85	0.04	0.4	0.02
Na^+	535.3	23.28	549.9	23.74
K^+	31.8	0.81	34.3	0.88
Ca^{2+}	24.0	1.20	22.0	1.10
Mg^{2+}	0.2		0.2	
Cl^-	766	21.6	766.8	21.60
SO_4^{2-}	144	3.00	144.0	3.00
HCO_3^-	53.7	0.88	53.7	0.88
CO_3^{2-}	1.8	0.06	1.8	0.06
H_3BO_3	104		89	
H_4SiO_4 (sol.)	188		185	
H_4SiO_4 (col.)	152		106	

	Zhemchuzhnyi Geyser			
Sample dates:	7/29/94		8/16/94	
pH	8.85		8.9	
	mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	0.4	0.02	0.1	0.01
Na^+	591.4	25.73	608.5	26.47
K^+	38.4	0.98	40.2	1.03
Ca^{2+}	23.6	1.18	22.6	1.13
Mg^{2+}	0.2		0.2	
Cl^-	830	23.40	866.2	24.4
SO_4^{2-}	178	3.70	172.8	3.60
HCO_3^-	67.1	1.10	61.6	1.01
CO_3^{2-}	3.0	0.10	3.3	0.11
H_3BO_3	102		90.3	
H_4SiO_4 (sol.)	180		172	
H_4SiO_4 (col.)	110		214	

	Shchel Geyser			
Sample dates:	7/28/94		8/15/94	
pH	8.50		8.23	
	Mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	1.7	0.09	1.85	0.10
Na^+	512.6	22.30	87.6	21.21
K^+	36.2	0.93	30.3	0.77
Ca^{2+}	20.2	1.01	18.6	0.93
Mg^{2+}	0.2		0.2	
Cl^-	716	20.2	717.1	20.20
SO_4^{2-}	153.7	3.2	461.3	3.10
HCO_3^-	45.1	0.74	46.4	0.76
CO_3^{2-}	1.2	0.04	0.06	0.02
H_3BO_3	99.0		102	
H_4SiO_4 (sol.)	174		180	
H_4SiO_4 (col.)	172		154	

	Velikan Geyser			
Sample dates:	7/28/94		8/15/94	
pH	8.85		8.9	
	mg/l	mg/zkv	mg/l	mg/zkv
NH_4^+	1.25	0.07	0.4	0.02
Na^+	592.0	25.75	611.8	26.61
K^+	42.7	1.09	44.4	1.14
Ca^{2+}	22.0	1.10	24.0	1.20
Mg^{2+}	0.2		0.2	
Cl^-	851	24.0	873.3	24.60
SO_4^{2-}	153.7	3.2	163.2	3.40
HCO_3^-	66.5	1.09	67.1	1.10
CO_3^{2-}	2.2	0.07	2.1	0.07
H_3BO_3	114		117	
H_4SiO_4 (sol.)	177		137	
H_4SiO_4 (col.)	244		294	

Figure 19. Chemical composition of geyser water.

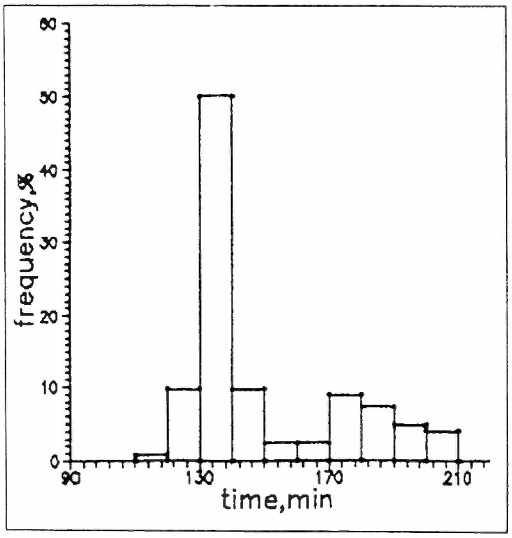

Figure 20. Troynoi Geyser. Frequency distribution of intervals.

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Figure 21. The vents and formations of Troynoi Geyser, looking towards the river. (Vachuda photo).

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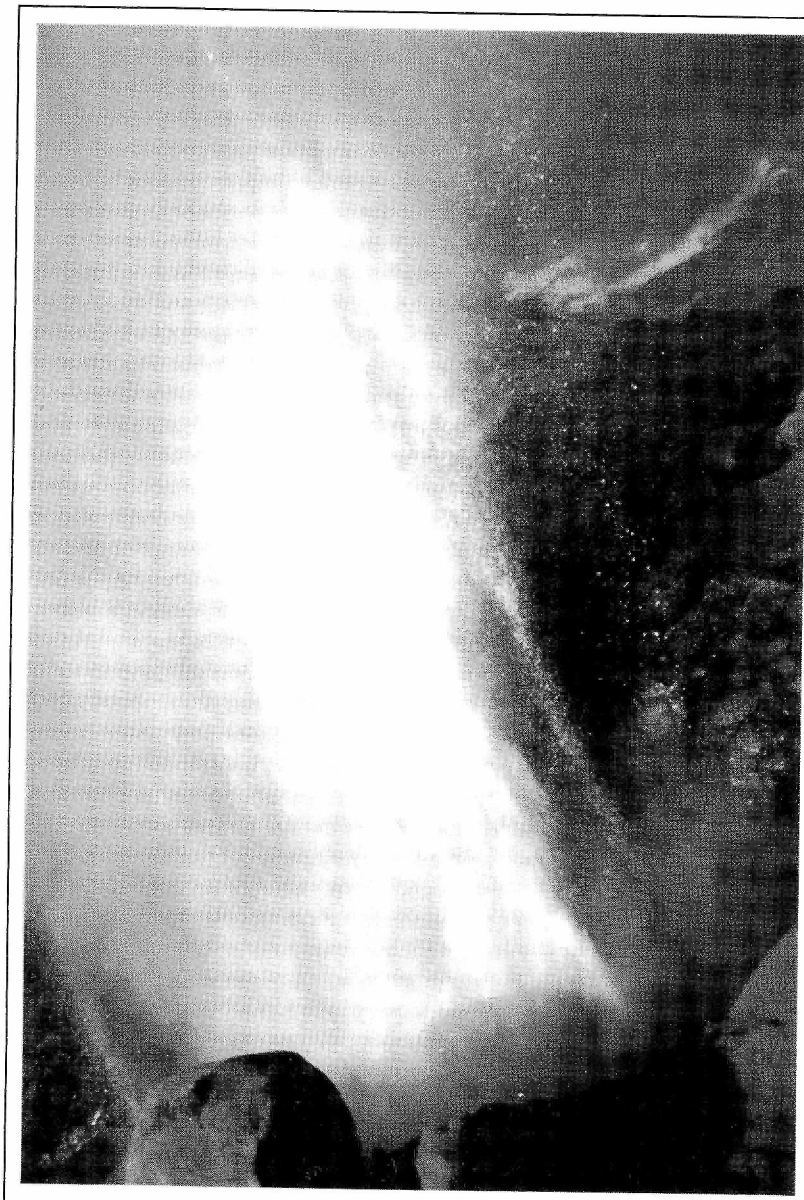

Figure 22. The lower portion of the water column of an eruption of Malyi Geyser. (Vachuda photo).

Figure 23. Velikan Geyser, during a typical eruption. The geyser gazer in the lower right foreground provides scale. (Vachuda photo).