

Increased Activity on Ebeko Volcano, Paramushir I., North Kurils in 2005–2006

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Abstract—In recent years the gas hydrothermal activity of Ebeko Volcano has been characterized by a constant heat flow and a constant chemical composition of water and fumarole gases. The volcano's activity suddenly increased on January 27, 2005. Two high-output steam–gas jets 5 m across formed in the Active Funnel of the North Crater. A new high-output, high-temperature, fumarole field originated in the funnel in July 2005. Changes have been recorded in the chemical composition of fumarole gases. Ratios between individual components of the gas were calculated, with the ratios being geochemical precursors of eruptions for the volcano under study. Based on these results and on the very fact of increased fumarole activity on Ebeko, an intermediate-term forecast of explosive eruptions has been developed. Atmospheric contamination by a toxic gas (hydrogen sulfide) is described. It was previously thought that toxic gases pose a short-lived threat only to the population of the town of Severo-Kuril'sk because of frequent strong winds prevailing there. It is shown that the presence of a snow cover during increased activity on Ebeko sharply enhances the hazard of contamination by toxic gases, the hazard being constant both on the volcano itself and in the Severo-Kuril'sk area.

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INTRODUCTION

Ebeko Volcano is situated in the northern Vernadskii Range on Paramushir I., Kurils, 6 km of the town of Severo-Kuril'sk. It is a typical example of an active andesitic volcano characterized by phreatic and phreatic–magmatic eruptions. The pre-Quaternary base of the volcano is composed of volcanogenic sedimentary rocks of the Paramushir series complex with associated (or penetrating) sills, dikes, and subvolcanic formations of various shapes [2, 5, 16]. The oldest exposed rocks date back to the Upper Miocene/Pliocene. They are layered volcanogenic micritic sandstones, tuffs, tuff gravelites, and tuff aleurolites (the Okhotsk series). The deposits are estimated to be 1400 to 3000 m thick [2]. The volcanogenic sedimentary deposits of the Okhotsk and oceanic series are overlain by thick andesite lavas with basaltic lava–pyroclastic deposits on top, supposedly of Lower/Middle Pleistocene age. The widely abundant bipyroxene andesites identified as interglacial [5] have ages between 110000 and 20000 years. Ebeko Volcano is composed of young postglacial bipyroxene andesitic or (less frequently) basaltic andesite lavas. The present-day edifice formed between 1000 B.C. and the beginning of our era. The outpouring of lava flows on Ebeko according to [9] dates back to between 400 B.C. and the beginning of our era. All subsequent eruptions were explosive [9]. Structurally speaking, the volcano is confined to a major north-northeast

trending fault zone where most of the volcanoes situated in the Vernadskii Range are, and it is part of a major elongate volcanotectonic feature beneath which basaltic andesite melt has been migrating during a long time [2, 5].

Ebeko Volcano is an elongate (in the north–south direction), low (~200 m) cone which is composed of andesite lavas and pyroclastics. On the cone summit are three coalesced craters (Fig. 1). Fumaroles and hot springs are in continual activity on the volcano. The fumarole fields are situated in the South Crater and in the Active Funnel, North Crater, as well as on the volcano's eastern slope. Small fields (both as to size and output) are situated on the western slope of the South Crater and 300 m southeast of its rim. The hot springs on the eastern slope are at the source of Lagernyi Brook, the big group of Verkhne-Yur'eva hot springs is situated on the volcano's western slope. A detailed systematic study of surface hydrothermal occurrences on Ebeko has been conducted since the 1950s and has been reported in many publications [1, 6–8, 12, 15, 16, 19, etc.].

The volcano's activity involves four types of activity: (1) Vulcanian-type paroxysmal eruptions, (2) interparoxysmal phreatic eruptions and continual fumarole activity, (3) moderate, and (4) increased activity. Eruption periods last 2–4 years, while the intereruptive periods last 20–30 years [11, 12].

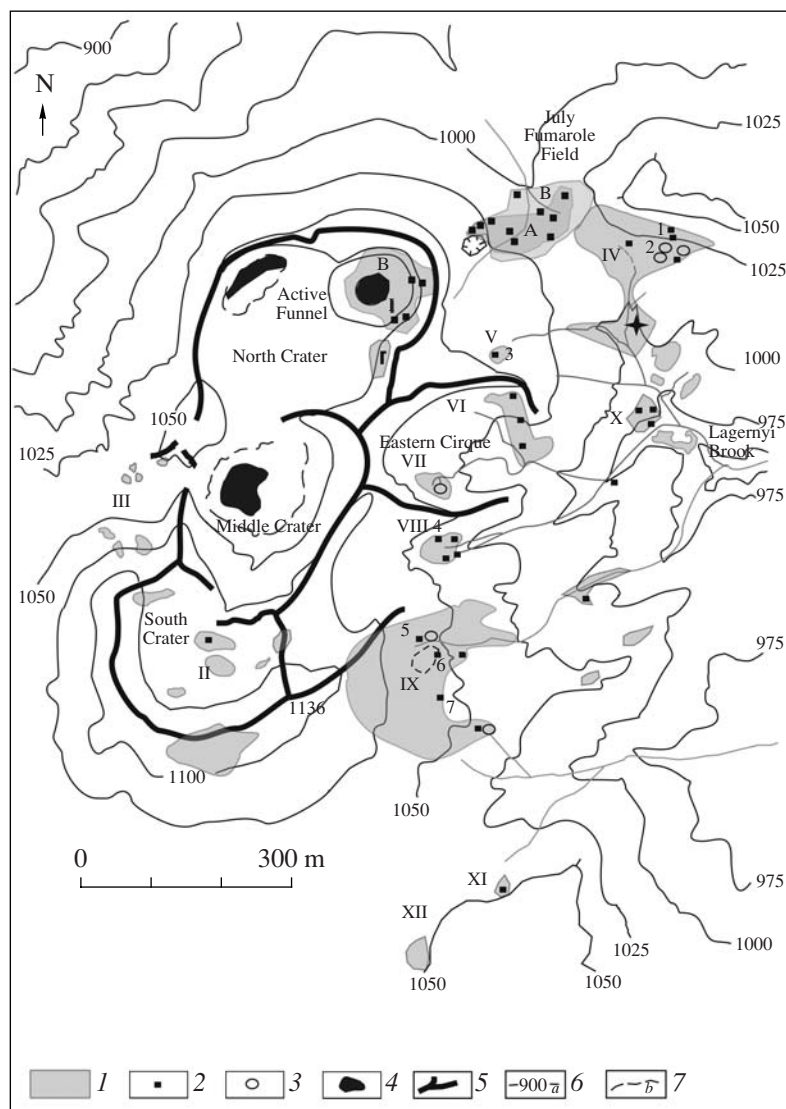


Fig. 1. Map of Ebeko Volcano thermal fields as of September 28, 2006, after V.N. Dvigalo (1989) and supplemented by these authors: (I) thermal fields, (2) fumaroles, (3) pots of thermal water, (4) crater lakes, (5) rims of major craters, (6) lines of equal altitude: (a) horizontals at intervals of 25 m, (b) half-horizontals at intervals of 12.5 m. Roman numerals denote thermal fields: (I) Active Funnel, (II) South Crater, (III) West Field, (IV) Northeastern Field, (V) Gremuchaya fumarole field, (VI) Florenskii fumarole field, (VII) First Eastern Field, (VIII) Second Eastern Field, (IX) Southeastern Field, (X) Lagernyi Brook field, (XI) Second Southeastern Field, (XII) Third Southeastern Field. Larger fumaroles and pots prior to the volcano's activation: (1) Revushchaya, (2) Big Pot in Northeastern Field, (3) Gremuchaya, (4) Uragnaya, (5) Fallicheskaya, (6) Rogataya, (7) Bol'shaya. Letters denote areas of the July Field as of: (A) July 16, 2005, (B) September 28, 2006, (C) Active Funnel thermal field, (D) heated areas in North Crater, September 28, 2006. The dotted line marks the region of incandescent material ejected from the Rogataya fumarole. The star marks the Active Funnel.

According to historical evidence supplemented by tephrochronologic studies [5, 9], we know of Ebeko eruptions during the 18–19th centuries, viz., 1793, 1833–1834, and 1859. Dense sulfur steam covered the neighboring Shumshu I. in September 1859, causing nausea and headache.

The single documented paroxysmal eruption took place in 1934–1935. The explosions occurred on a nearly north–south fissure in the bottom of the Middle Crater where there was no lake at that time yet. The hot

lake formed following the eruption. No lava flows were discharged, but bread-crust bombs were ejected in great numbers. The erupted material was about 1 million tons in weight [5].

The next eruptive period, 1967–1971, consisted of three phreatic eruptions at the North Crater. These were preceded by precursors in the form of increased fumarole activity and gas temperature, lower ground water table, and rapid changes in water level in the Middle Crater lake. The eruption produced an explosion funnel

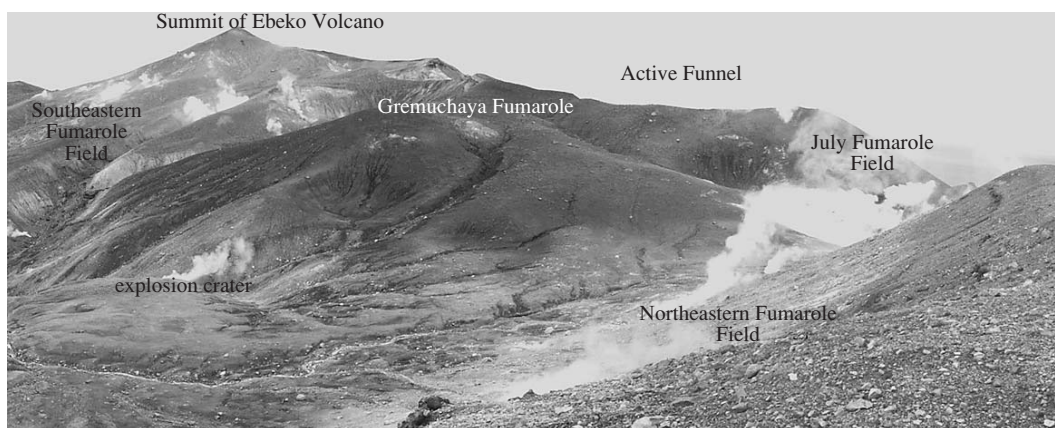


Fig. 2. Ebeko fumarole fields on August 26, 2005. Viewed from northeast. Photographed by L.V. Kotenko.

in the northeastern North Crater which was subsequently filled with a warm (up to 33°C) lake of size 50 by 35 m. Powerful fumaroles were active in the lake bottom [1, 9, 11, 18]. The ejected pyroclastic volume of resurgent composition was 10^5 t.

The next eruption was observed in 1987–1991. The eruptive center was in the Active Funnel, North Crater (the 1967 vent). Two modes of activity were recorded: a continual moderate emission of steam and gas to heights of up to 150 m, and larger explosions that occurred 8–10 times a day and hurled resurgent pyroclastics to heights of 1 to 5 km. The eruption produced considerable changes in the morphology of the Active Funnel, North Crater, the volume of ejected material being about 450 000 m³ [9, 11, 13]. Phreatic explosions occurred in 1998 after previously recorded changes in the temperature regime of the fumaroles and in the chemical composition of fumarole gases [19].

Increased activity on Ebeko in 2005. A dramatic increase in fumarole activity took place in the Active Funnel of the North Crater on January 27, 2005. This burst of activity was accompanied by a tectonic earthquake at an epicentral distance of 10 km recorded by the Severo-Kuril'sk seismic station at 18 h 10 min Greenwich time; this event was followed by small, shallow, volcanic earthquakes recorded by the station at a daily rate of 4 to 9. Since January 28, when the weather improved, a steam–gas column as high as 400 m began to be visible above the crater. Starting from the beginning of activation and until January 30 inclusive, a strong smell of hydrogen sulfide was practically continually felt in the town of Severo-Kuril'sk.

A first survey of the volcano conducted on January 29–30 showed that the gas temperature at the vents of fumaroles and pots was in the ranges that were usual for the Northeastern Fumarole Field, viz., 100–120°C for fumaroles and 93–95°C for thermal pots. The other

fields could not be reached due to strong gas presence at the crater rim. The Active Funnel of the North Crater proved to be the center of this burst of activity; a vent about 5 m across formed in the eastern inner wall of the funnel, which spurted a great jet of yellow–gray steam. The height reached by the jet was variable, 80 to 500 m, depending on weather conditions. A group of five high-output fumaroles was situated 20 m southeast of the main vent. A small (7 by 12 m) oval lake of sky blue color formed in the crater bottom at the base of the western wall. The crater morphology remained unchanged. Deposits of three ash discharges were discovered on the outer slopes of the Active Funnel; the ash thickness was 1–2 mm, with the ash being traceable as far as 500 m southeast of the Active Funnel. The ash consisted of plagioclase, pyroxene, fragments of brown-green glass, hydrothermally altered rock, and aggregates of secondary minerals.

The next survey of the crater and fumarole fields, taking gas samples at perennial fumaroles and photographing, was carried out on February 19 and April 21, 2005. There were two active vents in the Active Funnel at that time, both with a diameter of 5 m, with the later one forming in the area of the five fumaroles. Both vents were continually emitting steam and gas. The jet was white, indicating an absence of ash. The steam–gas jet was 85 m high on February 19, the survey date, with a strong temperature inversion preventing the gas from rising higher. Warmer areas devoid of snow appeared at the southern rim of the Active Funnel and on its eastern slope. Gas temperature was measured in those thermal fields that could be reached: the Northeastern, the Gremuchaya fumarole field, the Second Eastern, and the Southeastern. The temperature behavior of the fumaroles remained the same, keeping within 100–123°C; the thermal areas did not expand, except for the Active Funnel itself.

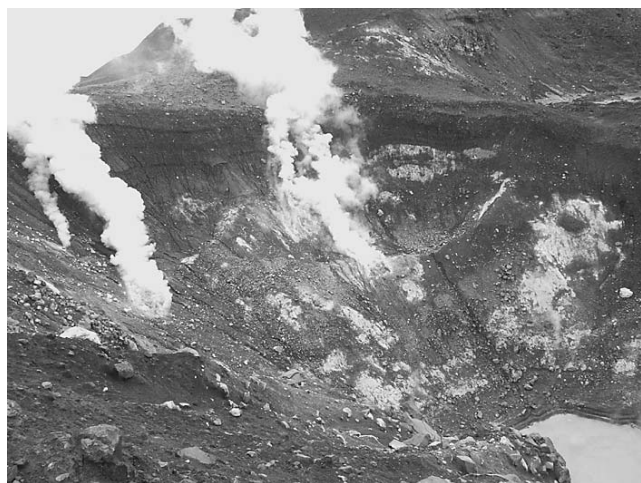


Fig. 3. Fumaroles in the Active Funnel, North Crater on August 26, 2005. Viewed from north. Photographed by L.V. Kotenko.

A new fumarole field was discovered on the outer northeastern slope of the Active Funnel on July 16, on both banks of the source of the Yur'eva River, containing three high-output fumaroles and numerous minor steam outlets (Fig. 1). Subsequently, the new fumarole field expanded to become 2.4 times as large by August 26, 2005, from 0.007 km² to 0.020 km² (Fig. 2), and gas emission became stronger. New high-output fumaroles formed during that period. Sulfur columns 0.3 to 1 m high rose around the numerous fumarole jets in the northeastern part of the field, liquid sulfur was outflowing everywhere. The group of fumarole jets in the northwestern part of the field was situated on a line, thus marking a fissure trending southwest–northeast. The temperature of gases emitted on the new fumarole field, called the Iyul'skoe (July) Field, because it was discovered in July, increased from 110–143°C to 137–250°C for different fumaroles. Fumaroles concentrated at the locations of the winter vents were active in the Active Funnel (Fig. 3), the heated area in the bottom and inner walls of the Active Funnel continued to grow. The crater fumaroles diminished their output after the formation of the July Field. The water temperature in the lake was 40°C, and gas bubbles were rising over the whole lake surface, especially along the shore. An explosion crater 1 m long and 0.3–0.6 m wide was discovered in the upper reaches of Lagernyi Brook (Fig. 4). The visible depth was 3 m. A gas jet was spurring from the explosion crater, the surface within 7–9 m of the crater was covered by a layer of the material ejected from the crater with a mixture of pyrite crystals. The crater was apparently formed on May 25, when the Severo-Kuril'sk seismic station recorded a characteristic earthquake. The gas jet rising from the crater vent had a temperature of 71°C as of July 23.



Fig. 4. Explosion crater in the upper reaches of Lagernyi Brook. Photographed by L.V. Kotenko.

By the beginning of November, the temperature of fumarole gases in the upper part of the July Field reached 529°C, while that in the lower part was 155°C. The area of the new field remained the same. Judging by visual observation, the outward transport of steam and gas from the new fumaroles considerably increased, the number of high-output fumaroles became as large as 20, apart from the numerous small jets and a general steam emission from the field. Most of the fumaroles produced sulfur columns as high as 1 to 1.5 m (Fig. 5). No sulfur cones formed around the hottest gas-ejection centers in the northwestern part of the field. Gases were escaping with great noise from numerous vents and small fissures. The walls of the fissures and vents were covered with a “sooty” coat of pyrite (Fig. 6), similarly to the vents emitting steam and gas in the Active Funnel.

The heights of fumarole jets in the Active Funnel (the greatest height was 1200 m in calm weather, see Fig. 7) and in the July Field were used to calculate the total heat flow due to them. The calculation was based on formulas suggested by the International Working Group CONCAWE (Conservation of Clean Air and Water, Western Europe) and by S.A. Fedotov in 1982



Fig. 5. Northern area of the July Fumarole Field on November 2, 2005. The sulfur columns are 0.5–1 m high. A flow of liquid sulfur can be seen between them. Photographed by T.A. Kotenko.

[20]. The heat flow from the Active Funnel, which was 7 MW before the activation [7], increased to reach 22 MW. The heat transport due to the July Field was 240 MW by late September, which is an order greater than the unchanged heat flow due to the other fumarole fields (29 MW).

Some changes were detected in the thermal behavior of the other fumarole fields. Incandescent material was ejected from the Rogataya fumarole (Fig. 1) toward southwest to a distance of 70 m during the period between September 7 and 29. The ejected material consisted of gray–green sulfide flakes. A pot of thermal water formed in a cave-like hollow near the base of the Fallicheskaya (phallic) fumarole, 5 m below the fumarole structure. The pot had a diameter of 30 cm, the water temperature was 72°C, pH 0.4. Another boiling pot formed in the First Eastern Field, at the location of a previous fumarole. The pot was 2.5 m across, the water temperature was 97°C, pH 1.3. A very small areal steam emission remained in the field of the Gremuchaya fumarole, which had been continually active since 1964.

Continuous increase in fumarole activity in 2006. In mid-June 2006 the gas temperature in the northern part of the July Fumarole Field increased to reach 500°C, spontaneous combustion of sulfur occurred, and all sulfur cones and discharged sulfur sheets burned out. An area of 200 m² was added to the total area of the new fumarole field. New high-output fumaroles formed down the brook (the source of the Yur'eva River). Sulfur was being rapidly deposited on the east side of the brook and along the bed with accompanying formation of sulfur cones. Also, numerous flows of molten sulfur were observed. The temperature of gas jets in this part of the field was on order 110–132°C. Fissures trending north and north-east were detected all over the surface of the new field.



Fig. 6. Vents of steam–gas jets in the northwestern July Field on September 7, 2005. Photographed by D.V. Mel'nikov.



Fig. 7. Steam–gas discharge from the Active Funnel, North Crater on November 29, 2005. The cloud is 1200 m high. Photographed by L.V. Kotenko.

Some fissures were situated at the boundary of the thermal field, rupturing along an irregular line the loose pyroclastic deposits due to the preceding eruption. Several such fissures expanded to become as



Fig. 8. A fissure on the surface of the July Field. The knife length is 26 cm. Photographed by T.A. Kotenko.

wide as 5–6 cm by late September as against the previous 0.5–1 cm, their length increasing to 4–20 m (Fig. 8). The deepest fissure had a depth of more than 3 m, but no gas was released there. This seems to have been related to the subsidence in the axial part of the thermal field. Judging by a characteristic record on seismograms of the Severo-Kuril'sk seismic station and the report of an eye witness, two hydrothermal explosions occurred in the Active Funnel on August 28 and October 4. The first of these caused partial collapse in the dense deposits of lava flows in the northwest wall of the funnel (Fig. 9). The material ejected by the explosion (ranging from fine- to medium-grained sand with some angular fragments within 0.6 cm) was only recorded at the crater rim in the northeast direction. All the fractions were represented by fragments of hydrothermally altered rock and scoria. The deposits were not thicker than 0.5 cm. The ejecta were about 40 m wide. During the same period of time, the lake changed color from sky blue to green.

The Chemical Composition of Fumarole Gases.

Gases are the most volatile part of magma, they are sensitive to changes in the interior of a volcanic edifice, including the preparation and occurrence of volcanic eruptions. The study in the composition of volcanic gases is a promising method for use in interme-



Fig. 9. Lake in the Active Funnel, North Crater on September 28, 2006. The arrow marks the collapse in the north-western wall. Photographed by T.K. Pinegina.

diate-term prediction of the state of an active volcano (for longer times than 1–3 months). This geochemical line of research in the study of active volcanoes has been developing worldwide since the mid-1960s. The main problem in monitoring of volcanic gases is identification of informative patterns peculiar to a volcano of interest. Many researchers have conducted such work for Ebeko Volcano [1, 6, 12, 13, 18, 19], the upshot of all this work was the identification of predictive patterns. For example, the 1987–1991 eruption was preceded by increased S/Cl , H_2S/SO_2 , S/C , and F/Cl ratios [11]. Similar changes were observed prior to the March 1998 phreatic eruptions, with the predictive patterns being increased S/Cl , S/C , and H_2O/CO_2 ratios and a decreased CO_2/H_2 . The H_2S/SO_2 ratio varied for the Gremuchaya fumarole alone. The preeruptive period on Ebeko also typically exhibited concentrations of gases in the sulfur group (SO_2 , H_2S) [1, 10, 13], as well as HCl , N_2 , Ar , O_2 , and H_2 [10, 19].

In 2003 sampling of the Ebeko fumarole gases began again, but this time at the Revushchaya fumarole alone, because the Gremuchaya had become a weakly steaming thermal spot by that time. The sampling was carried out by a standard method [14]: evacuated bubblers filled with 50 ml of 4 M KOH were used. Several parallel samples were taken from a fumarole. Also, gas samples were taken from the high-output Severnaya fumarole in the July Field before the fumarole gas became hotter than 500°C (Fig. 10). The relevant means are given in Table 1. A comparative analysis of the chemical gas composition at the Revushchaya fumarole revealed considerable changes which occurred during the period of interest. The content of SO_2 , Ar , HCl , N_2 , and O_2 increased, while those of H_2S and H_2 first increased and afterwards decreased. Characteristic changes were also observed

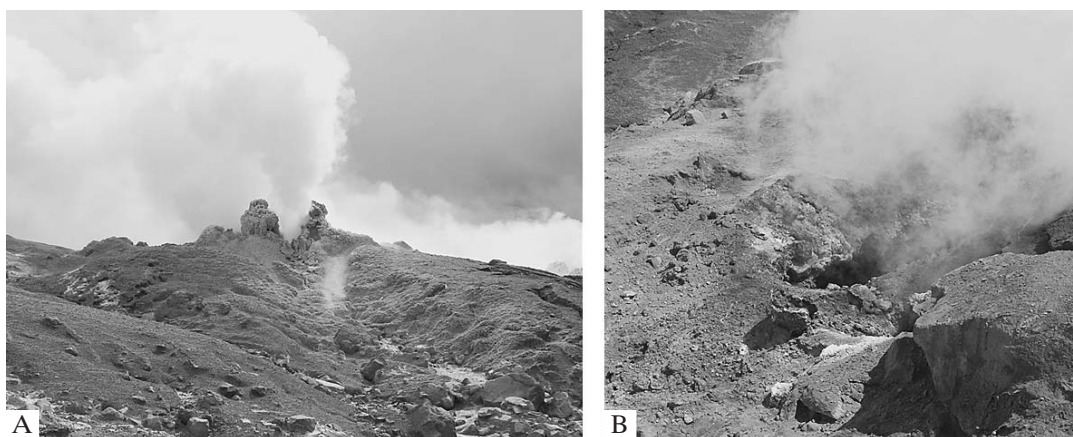


Fig. 10. The Severnaya fumarole in the July Field: (A) September 16, 2005, gas temperature is 147°C, (B) June 13, 2006, gas temperature is 508°C. Photographed by L.V. Kotenko.

in the S/Cl and $\text{H}_2\text{S}/\text{SO}_2$ ratios (an increase before an activation followed by a decrease), and in S/C and $\text{H}_2\text{O}/\text{CO}_2$ (an increase only) (Fig. 11). These parameters were identified previously [1, 10, 13, 19] as geochemical precursors of eruptions. The above changes were occurring upon the background of a considerable temperature increase in the July Field. The steam–gas jets of the Severnaya fumarole (Table 1) were enriched with SO_2 , H_2S , and HCl. One notable event was the detection of considerable concentrations of HCl that had not been recorded previously either in the fumarole or eruptive gas on Ebeko. Based on these findings, we hypothesize a transition from intereruptive to preeruptive phase on the volcano, i.e., we infer an active preparation for an explosive eruption.

Ecologic consequences of activation on Ebeko. Starting from the onset of the activation, a strong smell

of hydrogen sulfide was felt almost continually between January 27 and 30 in the town of Severo-Kuril'sk. For this reason the concentration of hydrogen sulfide began to be measured on a regular basis since January 28 in the air of the town using a Colion-1 gas analyzer. The analyzer is based on a photoionization detection method using molecules ionized by a vacuum ultraviolet source. The device is operated in real time and is a quick technique, the time of measurement being three seconds. Until recently, the opinion was that, although the hazard of atmospheric air contamination by toxic gases emitted by Ebeko eruptions is indeed present, it is very low because of frequent strong winds [9, 11]. However, adsorption and high gas permeability of snow in wintertime have not been taken into account in this assessment. Gas adsorption is the absorption of gas on the surface of snow and ice crystals. In the general case, this phenomenon is due to the

Table 1. Composition of fumarole gases on Ebeko Volcano, in mol %

Fumarole name	Date of sampling	T, °C	Components											
			H ₂ O	Without H ₂ O taken into account										
				CO ₂	SO ₂	HCl	H ₂ S	N ₂	O ₂	Ar	CH ₄	H ₂	He	CO
Revu-shchaya	19 Oct 03	110	98.01	86.824	10.704	0.9	0.380	0.978	0.191	0.015	5.0×10^{-4}	1.0×10^{-3}	1.77×10^{-3}	1.1×10^{-4}
Revu-shchaya	1 Jul 04	110	98.7	61.229	22.022	0.613	1.672	2.795	0.636	0.034	6.17×10^{-4}	1.3×10^{-3}	1.54×10^{-3}	3.2×10^{-4}
Revu-shchaya	10 Feb 05	125	97.76	54.432	29.585	2.15	1.520	9.477	3.074	0.134	1.26×10^{-4}	0.9×10^{-3}	1.48×10^{-3}	0.9×10^{-4}
Severnaya	26 Aug 05	147	90.45	23.719	35.309	28.952	2.651	7.592	1.664	0.097	4.5×10^{-4}	1.6×10^{-3}	0	4.2×10^{-4}

Note: Analysts V.N. Shapar' and I.F. Timofeeva, the 2003 sampling was carried out by D.Yu. Kuz'min.

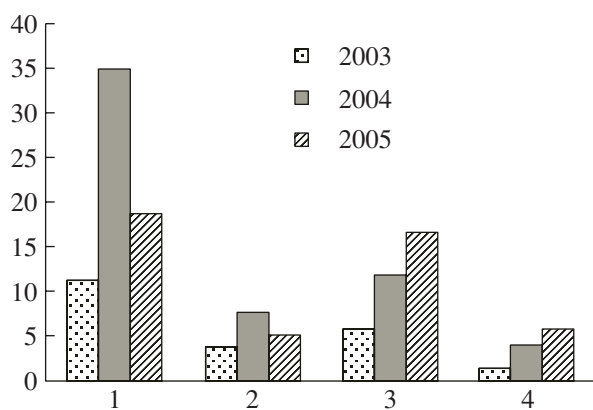


Fig. 11. Time-dependent changes in the predictive ratios of gas components at the Revushchaya fumarole: (1) S/Cl, (2) $H_2S/SO_2 \times 10^2$, (3) $H_2O/CO_2 \times 10^{-1}$, (4) $S/C \times 10$.

presence of a force field in atoms and molecules of the adsorbent and depends on the structure of the latter. Adsorbed gas layers one molecule thick (monomolecular) or several molecules (multimolecular) thick can form on the surface of snow crystals under various environments, depending on the intensity of the associated force field. Adsorption is usually reversible. The high gas permeability of snow is in turn due to a ramified system of interconnected pores. The permeability is both vertical and horizontal, depends on snow porosity and stratification, although in varying degrees, increases with increasing grain size, and only stops when ice interbeds are formed [4]. These properties of snow crystals and of the very snow cover actually have determined the presence of a persistent hydrogen sulfur

contamination in atmospheric air since the volcano's activation.

The hazard due to a single toxic gas alone (H_2S) during increased fumarole activity on the volcano is determined by (1) persistent background exceedance (by factors of 14–20) of the PMC as to the concentration of hydrogen sulfur in air, and (2) peak exceedances of the MPC by factors of 100 or greater for favorable wind directions (westerly and northwesterly) (Fig. 12). In addition, when several gases that have similar effects on the human body are in the air simultaneously, their negative effects are summed. In the case under consideration, such gases include H_2S , SO_2 , and HCl [3].

We note that concentrations of hydrogen sulfur in atmospheric air were measured before the appearance of the July Fumarole Field. The production rate of this field was much in excess of the total production due to the fumaroles of the Active Funnel and to all the other thermal fields of the volcano (Fig. 13). Based on our data relating to the chemical gas composition at the Severnaya fumarole (Table 1) and the data on the total amount of gases released by the new field (6720 t/day on an average), we calculated the release of toxic components (Table 2). The 1979–1985 data were used for comparison with the intereruptive state of the volcano [12]. We found that, during 2005–2006, the July Field alone gave off an amount of sulfur dioxide 73 times that due to all the Ebeko fumarole fields prior to the activation, with the respective figures being 81 for hydrogen chloride and 7 for hydrogen sulfur. Daily observations of gas contamination in the town of Severo-Kuril'sk showed that the smell of volcanic gases was felt with varying degrees for as long as 6 to

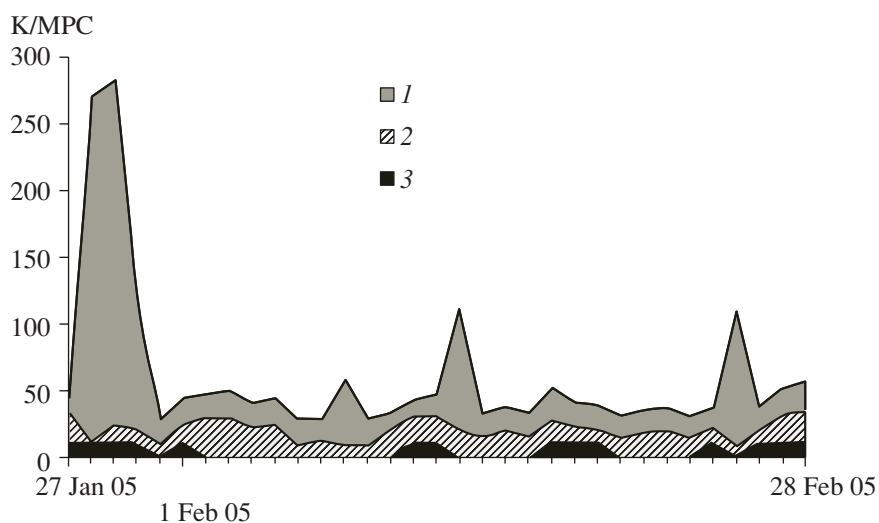


Fig. 12. Level of contamination by hydrogen sulfur between January 27 and February 28, 2005. K/MPC is the ratio of hydrogen sulfur content in air (mg/m^3) to maximum permissible concentration: (1) exceedance above the MPC for hydrogen sulfur (by a factor of n), (2) wind velocity during gusts (m/s), (3) favorable wind direction.



Fig. 13. Eastern slopes of Ebeko Volcano as of September 29, 2005. Numerals mark fumarole fields: (1) Southeastern, (2) July, (3) Northeastern. The July Field has a much higher output. Photographed by L.V. Kotenko.

15 days during the September–May period (only those days were sampled in which some smell was felt for at least one hour). The greatest recorded duration of strong air contamination was 4 days with a short intermission (March 1–5, 2006). At first a weak smell of volcanic gas was felt on March 1 with a westerly wind (occasionally as great as 17–19 m/s) in snow bursts. The smell became very strong between 10 and 11 h a.m. on a calm morning on March 2. A weak northeasterly wind stopped these gas attacks until 8 h a.m. March 3. From March 3 to 5, the gases propagated, coming to the town and port in waves (the port is 2 km east of the town), a strong cough-inducing, irritating smell was felt, at times it was difficult to breath at all. Periods of two or three days with volcanic gases in the air under a steady westerly wind of 10–12 m/s was the commonest situation. During the period between June and August, thanks to the summer monsoon (the prevailing wind is southeasterly) and a developing breeze situation, volcanic gases very rarely reached the town.

A general chemical analysis of potable water samples taken since the beginning of the activation showed

that the water did not conform to the maximum permissible concentration as to acidity (4.69–4.85), magnesium content (2.4 mg/l with the maximum permissible concentration (MPC) equal to 0.1 mg/l), the water deteriorated as to the content of aluminum (3.4 times the MPC by April 13, 2005) (Table 3). The concentration of chloride ion and sulfate ion, as well as of cations, also increased.

Simultaneously, samples of natural water were also taken from other streams for which water-balance calculations have revealed substantial release outlets of deep-seated aquifers [17]. These are the Ptich'ya, Nasedkina, and Gorodskaya rivers. Increased temperature and concentrations of chloride ion at some outlets of these waters suggest the influence of deep fluids [17]. It is noteworthy that a growth in both anions and cations has been recorded in these rivers 10 days after the beginning of the activation. A direct influence of volcanic ejecta on the chemical water composition is ruled out, because all brooks were under a snow cover several meters thick at that time. Pitting in the snow revealed 2 to 3 ice interbeds that were blocking gas transfer and rapid material transport between the sepa-

Table 2. Outward transport of main gases by fumaroles on Ebeko Volcano

Component	1			2
	mol %	wt %	t/day	t/day
H ₂ O	90.45	77.93	5237	1804.5
CO ₂	2.26	4.77	320	79
SO ₂	3.37	10.32	694	9.5
HCl	2.77	4.82	324	4
H ₂ S	0.25	0.41	28	3.8

Note: (1) outward transport of gases by the July Field in 2005–2006; (2) outward transport of gases by all fumaroles of the volcano in 1979–1985 after [12].

Table 3. Chemical composition of potable water at the town of Severo-Kuril'sk

Concentration of components (mg/l)						
Components	MPC	26 Aug '01	2005			
			8 Feb	25 Feb	8 Mar	13 Apr
HCO ₃ ⁻		6	4.3	1.2	1.2	
Cl ⁻	350	6.4	4.3	8.5	8.5	9.9
SO ₄ ²⁻	500	34.2	95.7	46.1	51.9	53.8
F ⁻	0.7–1.5	–	0.1	0.19	0.07	0.1
Sum of anions		46.6	104.4	55.99	61.67	63.8
H ⁺		–	–	–	–	0.02
NH ₄ ⁺		–	<0.1	<0.1	<0.1	<0.1
Na ⁺	200	4.8	6.4	5	6	5.6
K ⁺		1.5	1.2	1.4	1.2	1.6
Ca ²⁺		6.3	27.3	12.8	13.2	13.6
Mg ²⁺	0.1	1.4	4.7	2.4	2.9	2.4
Fe ²⁺		–	–	<0.3	<0.3	
Fe ³⁺ total	0.3	–	–	<0.3	<0.3	<0.3
Al ³⁺	0.5	0.98	0.9	1.4	1	1.7
Sum of cations		14.98	40.5	23	24.3	24.9
H ₃ BO ₃		–	<0.6	<0.6	<0.5	<0.6
H ₄ SiO ₄ in solution		–	32.4/5.9	44/2.8	48.9/36.4	49.3/23.9
pH	6	4.53	4.85	4.77	4.76	4.69
Total mineralization		61	183.2	126.99	170	161.9

Note: All analyses of water samples were made at the Central Chemical Laboratory, IVS FED RAS by Analysts S.V. Sergeeva, A.A. Smyshlyaeva, and O.V. Shul'ga.

rated parts of the snow mass. It thus appears that the changes referred to can only have been caused by changes in the deep component.

CONCLUSIONS

(1) A new phase of activity began on Ebeko Volcano on January 27, 2005, involving increased fumarole activity, hydrothermal explosions, and the generation of a new high temperature fumarole field.

(2) Changes in chemical gas composition and in certain ratios of gas components have been found for the Revushchaya fumarole for the period 2003–2005. These changes are geochemical precursors of eruptions for Ebeko Volcano [1, 13, 19]. An analysis of these changes, as well as changes in the surface manifestations of the volcano's hydrothermal activity, suggests preparation for an explosive eruption on the volcano. This precursory period may last a few months to 2–3 years, as shown by previous eruptions.

(3) The changes in the volume and composition of fumarole gases combined with the adsorption by snow and the wind behavior have led to a continual contamination of atmospheric air by toxic components, in par-

ticular, by hydrogen sulfide. It has been previously thought that this was unlikely because of frequent strong winds.

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