

RESULTS OF GEOCHEMICAL MONITORING OF THE ACTIVITY OF EBeko VOLCANO (KURILE ISLANDS) USED FOR ERUPTION PREDICTION.

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ABSTRACT

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The monitoring of the state of active volcanoes, carried out using different parameters, including geochemical, is very important for studies of deep processes and geodynamics. All changes which occur within the crater before eruptions reflect the magma activation and depend on the deep structure of volcano. This paper gives the results of prolonged monitoring of Ebeko volcano, located in the contact zone between the oceanic and continental plates (the Kurile Island Arc). The geochemical method has been used as the basis for eruption prediction because the increase in the activity of the Ebeko in the period from 1963 to 1967 that ended in a phreatic eruption was not preceded by seismic preparation. Investigations carried out at Ebeko volcano give evidence that change of all the chosen geochemical parameters is a prognostic indicator of a forthcoming eruption. This change depends on the type of eruption, and the deep structure and hydrodynamic regime of the volcano.

INTRODUCTION

The first volcanological observatory in Kamchatka was established in 1935 and work immediately began on the systematic study of the active volcanoes, including monitoring of Klyuchevskoy, Bezymianny and Shiveluch, the most active volcanoes of Central Kamchatka (Basharina, 1956; 1963; 1966). Monitoring included annual surveillance of the state of volcanoes, temperature measurements, and sampling and analysis of fumarolic gases, their condensates and mineral incrustations. During the past 50 years, Soviet volcanologists have developed and improved methods of sampling and analysis of volcanic gases. The present paper discusses the results of many years of monitoring the state of Ebeko volcano carried out by the authors to find precursors to volcanic eruptions in variations of tem-

perature and fumarolic gas composition in order to forecast the onset of forthcoming eruptions. Results of monitoring of the state of active volcanoes are very important for understanding deep processes and geodynamics since they reflect the prolonged temporal variations in the energetic, heat and chemical regimes of volcanoes.

Sampling and Analysis of Volcanic Gases

A method of gas sampling is based on the separation of gas mixtures *in situ*. A gas-collection system includes a quartz tube, vessels for the absorption of acidic gases and a measuring pipette (Fig. 1). In the first absorption vessel a condensate is formed and HF, HCl and SO₂ are absorbed. In the next absorption vessel, filled with cadmium-acetate solution, H₂S is absorbed.

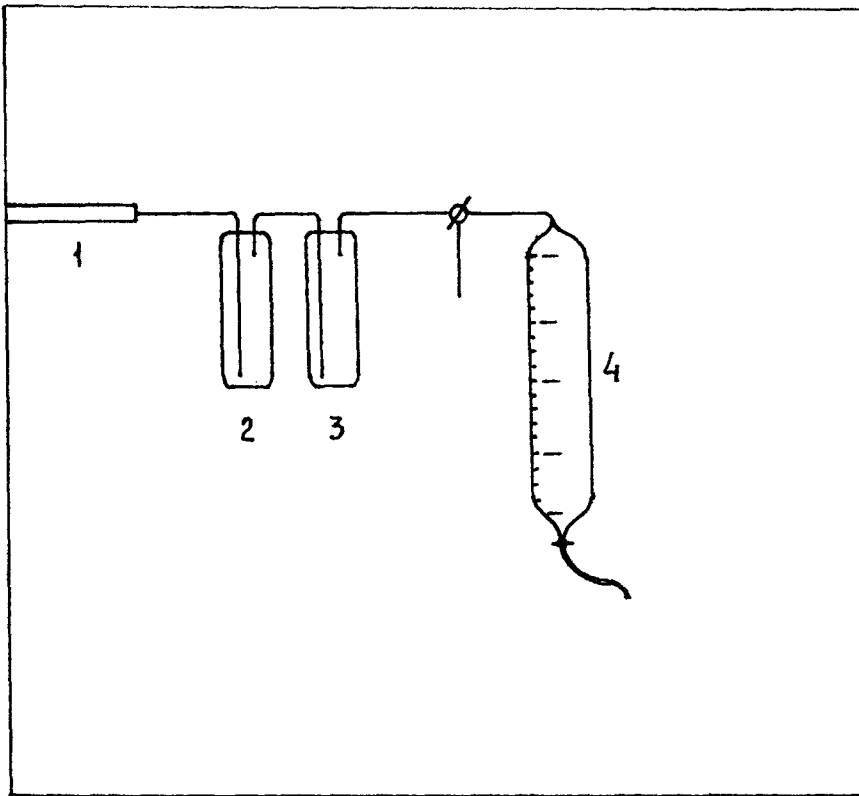


Fig. 1. The system of gas sampling used at Ebeko volcano. 1. quartz pipe, 2. absorption vessel with tridistilled water for H₂O, HF, HCl, SO₂ and metal absorption, 3. absorption vessel with cadmium-acetate solution for H₂S absorption, 4. measuring pipette for unabsorbed gases (CO₂, CO, H₂, CH₄, O₂, N₂, Ar).

H₂S is absorbed. Separately, a sample is placed into the suspended vacuum absorption vessel, filled with cadmium-acetate solution, to check the H₂O and CO₂ contents. The measuring pipette is used to determine the volume and to sample the unabsorbed gases (CO₂, CO, H₂, CH₄, O₂, N₂, Ar, and He). Small amounts of CO and CH₄ are determined using a separate sample of enriched gases from which CO₂ is preliminarily absorbed by the caustic-soda solution.

Analyses of volcanic gases are made in a field or a stationary chemical laboratory. Acid gases are determined by chemical analysis of liquid solutions. The unabsorbed gases are determined by gas chromatography. Simultaneously, condensate sampling is carried out to determine the isotopic composition of volcanic water. The isotopic composition of CO₂ and noble gases is determined by gas analysis from a measuring pipette. Metals are analysed in absorbent liquids or by the direct method using filters or, after preliminary concentration, by the methods of "wet" chemistry, atomic absorption and neutron-activation (Menyailov *et al.*, 1980).

The method of sampling and analysis of volcanic gases developed and improved upon at the Institute of Volcanology was used at numerous volcanoes of Kamchatka, the Kurile Islands, Italy and Nicaragua. The method is simple, reliable in work at active volcanoes, and the main feature is that it allows determination of numerous geochemical parameters, including the chemical and isotopic compositions.

Geology of Ebeko Volcano

In 1964 the team from the Institute of Volcanology charged with the sampling and analysis of volcanic gases began the monitoring of geochemical parameters at Ebeko volcano located on Paramushir Island, North Kuriles. Prior to 1964, our colleagues from the Sakhalin Complex Institute carried out analogous studies (Surnina and Voronova, 1964; Voronova and Sidorov, 1966; Experience in Cooperative Study . . . , 1966). These works are of great practical importance because the volcano threatens a town which is located at a distance of 12 km from the crater.

The Quaternary Ebeko volcano formed in the Vernadsky Ridge prior to the epoch of the first glaciation (Experience in Cooperative Study . . . , 1966). The preglacial volcanic edifice was composed of bipyroxene andesites and andesite-dacites. The contemporary cone, with a chain of craters at the summit, formed in the post-glacial epoch. The products of recent activity are lava flows of andesite composition. Gigantic bombs of the "bread-crust" type found on its slopes are composed of andesites and are associated with recent Ebeko activity (Experience in Cooperative Study . . . , 1966). The

eruptive activity of Ebeko volcano was accompanied by strong hydrothermal processes and by solfatar activity. As a result, andesites composing the volcanic edifice are strongly altered, forming opalites, quartzites, alunites, etc. The altered rocks contain significant accumulations of native sulfur.

The absolute altitude of the volcano is 1037 m. The relative altitude of the active cone is about 250 m. The top of the cone is crowned by three craters (Fig. 2). The middle crater contains a cold lake; another lake, filled with hot water, lies in the northern (lower) crater. Numerous solfataras occur on the floors of the craters and on the outer slopes of the cone. They form a few solfatar fields. Continuous temperature measurements and sampling of the "Gremuchaya" and "Revushchaya" solfataric gases were carried out (Tables 1, 2). In addition the state of solfataras in other fields was also investigated.

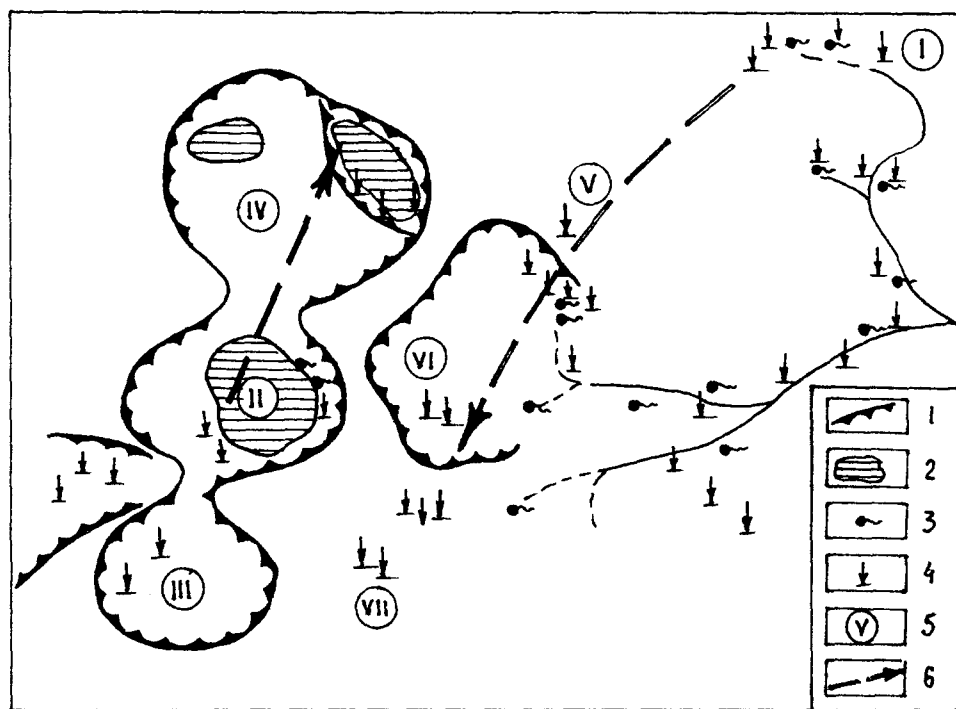


Fig. 2. Schematic map of the summit portion of Ebeko volcano. I. Northeastern field where the "Revushchie" solfataras occur; II. Middle crater lake; III. Upper crater; IV. Northern crater and the 1967 phreatic eruption funnel; V. "Gremuchaya" solfatar; VI. Eastern circus fields where the temperature increase was observed in 1983; VII. Western field.

1. scarps; 2. warm lakes; 3. hot springs; 4. solfataras; 5. solfatar fields.

TABLE 1
Composition of "Gremuchaya" solfatatic gases.

No.	Date of sampling	T°C	H ₂ O	Volcanic gases		Volcanic gases other than H ₂ O									
				mol. %		ppm									
				3	4	5	6	7	8	9	10	11	12	13	14
1	1967	380	98.67	3.13	69.45	19.66	5.68	3.14	-	-	5731	14169	716	107	
2	1969	320	97.83	3.17	71.04	15.49	7.17	4.44	0.21	-	4218	1152	584	36	
3	5.IX.1975	220	98.49	1.51	75.25	12.24	8.31	3.85	0.04	-	1761	704	634	-	
4	7.IX.1975	235	98.51	1.49	79.27	9.29	7.43	3.42	0.39	-	1055	344	711	-	
5	1.X.1976	235	98.83	1.17	76.53	8.54	8.80	4.81	1.17	-	802	325	390	-	
6	1.X.1976	235	98.80	1.20	77.12	9.17	8.54	4.22	0.85	-	650	314	-	-	
7	24.VIII.1977	170	98.79	1.21	76.54	6.39	9.88	5.25	1.88	-	440	155	12	-	
8	21.VIII.1979	160	98.80	1.20	75.39	7.00	9.80	5.93	1.81	-	445	62	0.8	7	
9	21.VIII.1979	160	98.73	1.27	74.83	6.16	11.63	5.62	1.72	-	382	76	0.9	0.05	
10	25.VIII.1979	160	98.64	1.36	74.36	7.27	9.75	7.00	1.57	-	484	7.6	2.3	7.6	
11	24.VIII.1979	160	98.63	1.37	76.17	7.24	9.11	5.81	1.61	-	543	7.0	1.5	0.015	
12	24.VII.1980	150	98.57	1.43	79.33	5.86	8.45	4.62	1.58	-	131	60	9.3	-	
13	24.VII.1980	150	98.60	1.40	81.02	5.48	7.97	4.05	1.42	-	128	30	2.1	-	
14	23.VII.1981	144	98.60	1.40	79.16	7.00	7.63	4.75	1.53	-	237	49	6.8	-	
15	23.VII.1981	144	98.56	1.44	78.92	7.36	8.82	4.52	0.39	-	161	65	3.9	-	
16	30.VII.1981	144	98.51	1.49	77.57	8.01	8.59	4.63	1.00	0.18	162	57	1.2	-	
17	30.VIII.1983	117	98.87	1.13	85.42	5.75	7.49	0.43	0.88	-	233	17	4.3	-	
18	18.VI.1984	120	98.93	1.07	84.92	5.28	9.23	0.46	-	0.04	293	44	-	-	
19	24.VI.1984	120	98.96	1.04	82.12	6.12	8.75	0.51	2.46	-	265	34	-	-	
20	30.VI.1984	120	98.98	1.02	84.10	6.77	8.41	0.44	0.25	-	298	27	-	-	

Analyses are given taking air dilution into account. A dash means that the content of a component is below the sensitivity of the method of determination.

TABLE 2
Composition of the "Revushchie" sulfataric gases, Northeastern field.

No.	Date of sampling	T°C	Volcanic gases		Volcanic gases other than H ₂ O									
			H ₂ O	mol. %	CO ₂	H ₂ S	SO ₂	HCl	N ₂	O ₂	HF	H ₂	CH ₄	CO
			mol. %		ppm									
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
21	1957	107	98.34	1.66	78.92	-	19.88	1.20	-	-	-	-	-	-
22	1959	114	95.95	4.05	99.26	-	-	-	-	-	-	7425	-	-
23	18.VIII.1960	106	96.66	3.34	87.57	1.19	12.08	0.30	-	-	-	8902	-	-
24	21.VIII.1961	105	85.11	14.89	86.91	0.27	4.90	3.62	-	-	-	-	28878	1410
25	27.VIII.1962	110	92.98	7.02	80.88	0.83	12.95	5.31	-	-	-	-	99	100
26	29.VIII.1963	101	90.37	9.63	95.79	0.72	2.57	0.92	-	-	-	-	-	-
27	14.IX.1964	104	95.08	4.92	97.57	-	2.03	0.40	-	-	-	-	-	-
28	5.IX.1965	96	94.54	5.46	96.42	0.02	3.54	0.02	-	-	-	-	-	-
29	8.X.1966	115	97.30	2.70	97.63	0.07	2.22	0.07	-	-	74	-	-	-
30	22.II.1967	100	98.37	1.63	96.30	-	3.68	0.02	-	-	-	-	-	-

6	31	18.IV.1967	100	93.64	6.31	96.41	0.78	1.56	1.25	-	-	-	-	-	-	-	-	-	-
	32	19.IX.1967	96	93.49	6.51	92.52	5.32	1.60	0.31	0.08	-	36	905	775	-	-	-	-	-
	33	28.VIII.1969	96	94.90	5.10	94.90	2.93	1.56	0.32	0.30	-	30	67	-	-	-	-	-	-
	34	5.IX.1975	115	95.13	4.87	95.13	2.41	1.85	0.34	0.27	-	30	19	-	-	-	-	-	-
	35	7.IX.1975	115	93.47	6.53	95.68	1.89	1.73	0.41	0.29	-	20	20	7.8	-	-	-	-	-
	36	IX.1976	115	93.44	6.56	95.93	1.56	1.43	0.30	0.77	-	15	10	-	-	-	-	-	-
	37	I.X.1976	115	93.68	6.32	94.75	2.03	1.81	0.42	0.99	-	31	9.5	-	-	-	-	-	-
	38	24.VIII.1977	108	93.90	6.10	96.28	0.95	1.62	0.32	0.81	-	103	-	68	-	-	-	-	-
	39	27.VII.1979	107	93.00	7.00	95.93	1.17	1.46	0.45	0.98	-	23	10	76	-	-	-	-	-
	40	26.VII.1979	107	94.27	5.73	95.71	0.97	1.97	0.38	0.97	-	28	1.9	48	0.09	-	-	-	-
	41	24.VII.1980	96	94.35	5.65	95.58	1.02	1.86	0.46	0.96	-	32	902	302	-	-	-	-	-
	42	24.VII.1980	96	94.58	5.42	95.41	1.12	1.96	0.41	0.96	-	21	805	472	-	-	-	-	-
	43	23.VII.1981	101	94.99	5.01	96.28	1.12	1.64	0.41	0.53	-	36	97	58	-	-	-	-	-
	44	23.VII.1981	101	93.45	6.55	96.47	1.17	1.54	0.33	0.47	-	26	87	43	-	-	-	-	-
	45	30.VII.1981	101	93.72	6.28	96.23	1.19	1.48	0.37	0.72	-	28	11	24	-	-	-	-	-
	46	11.IX.1983	103	94.79	5.21	96.78	1.04	2.08	0.05	0.01	-	24	-	-	-	-	-	-	-
	47	30.VI.1984	101	94.81	5.19	96.60	1.20	2.15	0.05	-	-	20	10	-	-	-	-	-	-

Analyses are given taking account of air dilution. A dash means that the content of a component is below the sensitivity of the determination method. 21-22-recalculated based on data of Surnina and Voronova (1964), 23-26-Voronova and Sidorov (1966), 27-28-Scripko *et al.* (1966), 29-31-Basharina and Khranova (1971).

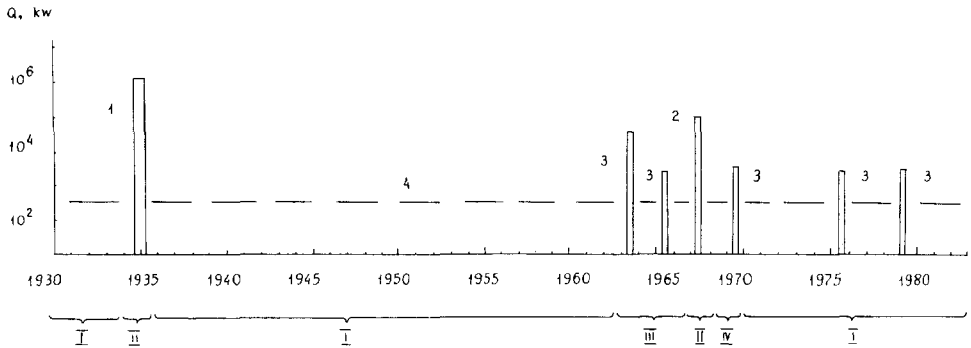


Fig. 3. Intensity of explosive and fumarolic activity in the different periods of Ebeko's eruptive cycle. Q(KW)-heat power of gas pyroclastic and fumarolic plumes calculated according to Fedotov's formula (Fedotov, 1982). The height of plumes is given based on data of Gorshkov (1967), Kirsanov *et al.* (1964) and Menyailov *et al.* (1969).

1. the 1934–1935 paroxysmal Vulcanian eruption; 2. the 1967 interparoxysmal phreatic eruption; 3. intensification of gas emission in 1963 through 1975; 4. the usual fumarolic activity.

I. intereruptive period; II. eruptive period; III. pre-eruptive period; IV. post-eruptive period.

Eruptive History of Ebeko Volcano

During the XXth century, several eruptions of the volcano were recorded. Four types of activity could be distinguished in the eruptive cycle* of the volcano, namely, paroxysmal eruption of Vulcanian type, possibly with lava effusion; interparoxysmal eruption of phreatic type; intensification of gas emission and constant solfatara activity (Fig. 3). The paroxysmal eruption which was taken to be the beginning of the most recent eruptive cycle of the volcano occurred in 1934–1935 from the middle crater (Gorshkov, 1967). As a result of this eruption, about 1×10^6 t of andesitic ash and bombs were ejected. Intensification of gas emission from the funnel-like vent on the eastern slope of the volcano, accompanied by self-ignition of native sulfur and by the formation of melted sulfur flows, was observed in 1963 (Kirsanov *et al.*, 1963). In 1965 another intensification of gas emission from the middle crater was observed (Scripko *et al.*, 1966). Intensifications of gas emission preceded an interparoxysmal eruption of phreatic type which occurred from the northern crater in February 1967 (Menyailov *et al.*, 1969). As a result of this eruption, a funnel was formed on the floor of the crater and about 1.2×10^5 t of strongly altered fragments and ashes of andesite composition were ejected. After the 1967 phreatic eruption, intensification of gas emission was again observed in 1969.

* The bounds of eruptive cycles are fixed by large paroxysmal eruptions (after Piyp, 1956).

Intereruptive Activity of Ebeko Volcano

Before the intensification of volcanic activity in 1963–1967, the most violent “Revushchie” solfataras occurred in the region of the northeastern field. Approximately fifty percent of the heat ($\sim 2.5 \times 10^7$ kkal/h) was released by solfataras from all gas vents at the volcano (Nekhoroshev, 1960). After the 1967 eruption, up to 1983, approximately 50% of the heat was released by the “Gremuchaya” solfataras and the total amount of heat released by all gas vents, according to our measurements in 1979, did not change significantly. In 1983 the center of the heat emission migrated 200–250 m west of “Gremuchaya” solfatara. Here, in the region of the Eastern circus solfataras, an increase in temperature and gas discharge was observed. In 1983, as previously, the total amount of heat released by fumaroles did not change. Figure 2 shows the migration of the centers of the activity of Ebeko.

Variations in Geochemical Parameters Depending on the State of Volcanic Activity

Now we shall consider the variations in geochemical parameters for gases of the routine solfataras, depending on the state of volcanic activity, during the period from 1057 to the present time.

The “Gremuchaya” solfatara formed after the 1963 intensification of gas emission. A short-term increase in temperature of solfataric gases near their vents from 120°C to 350°C was noted in September 1963 (Fig. 4). From then until December 1966, their temperature was approximately 140°C. During the 1967 phreatic eruption, the temperature increased to 380°C. In 1969 the temperature was 320°C, then it began to decrease gradually and in the period from 1980 to 1983 it was 140–150°C. In 1983 the temperature decreased abruptly to 117–120°C.

Against the background of the gradual decrease of the temperature of the “Gremuchaya” solfataric gases, the H₂O content increased and the H₂ content decreased, while the H₂O/CO₂ and CO₂/H₂ ratios increased. Such parameters as S/C, H₂S/SO₂, S/Cl and F/Cl represent ratios of poorly-soluble to readily-soluble gases. The change in values of these ratios which occurred against the background of temperature decrease is caused, in all appearance, by gradual decrease of the content of poorly-soluble gases in exhalations. In 1983–1984 the S/Cl and F/Cl ratios increased abruptly in the “Gremuchaya” solfataric gases while the tendency towards temperature decrease and other variations remained as before. Increase in S/Cl and F/Cl ratios is probably connected with the rise of ground-water level when the HCl absorption occurred. Simultaneously, the HCl content increased. The

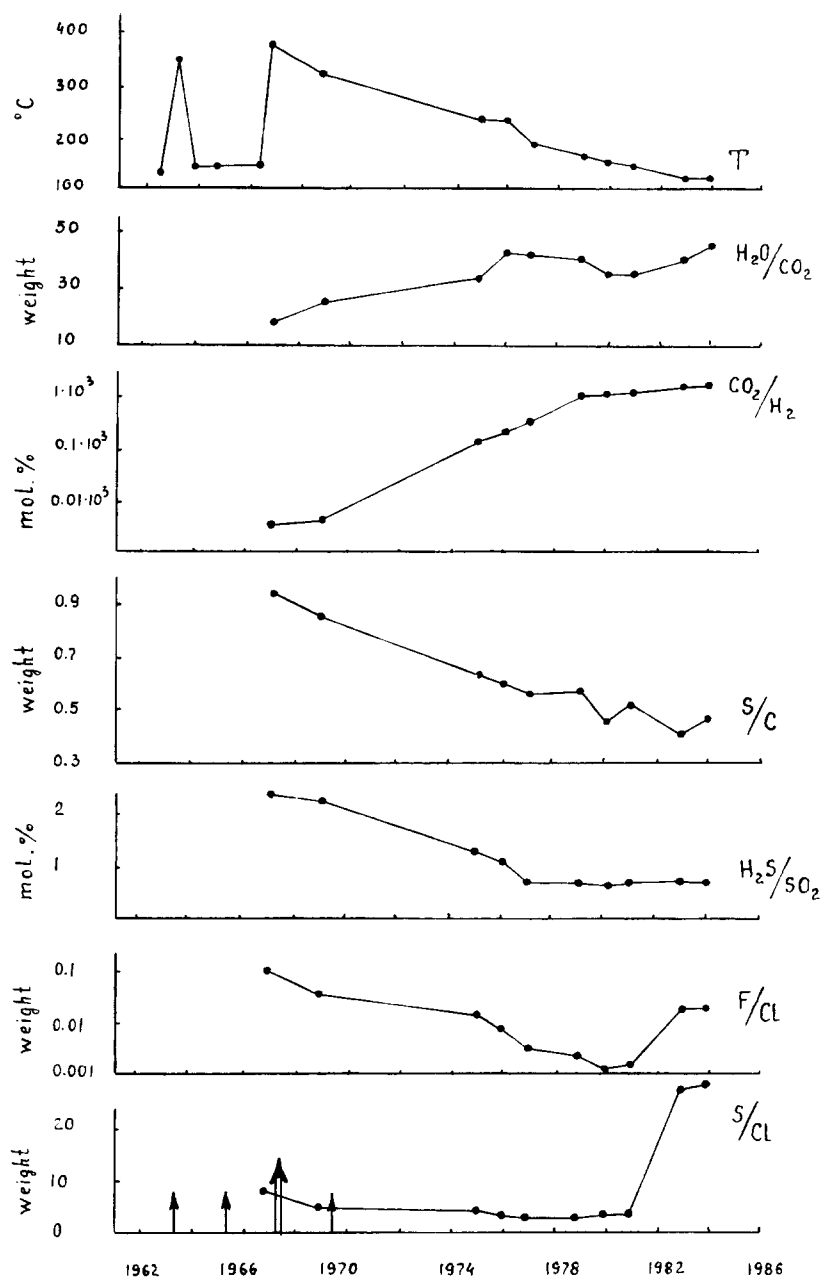


Fig. 4. Variations in temperature and gas ratios for the "Gremuchaya" solfatar depending on the activity of Ebeko (calculated based on analyses in Table I). Large arrow-the 1967 phreatic eruption, small arrows-intensification of gas emission.

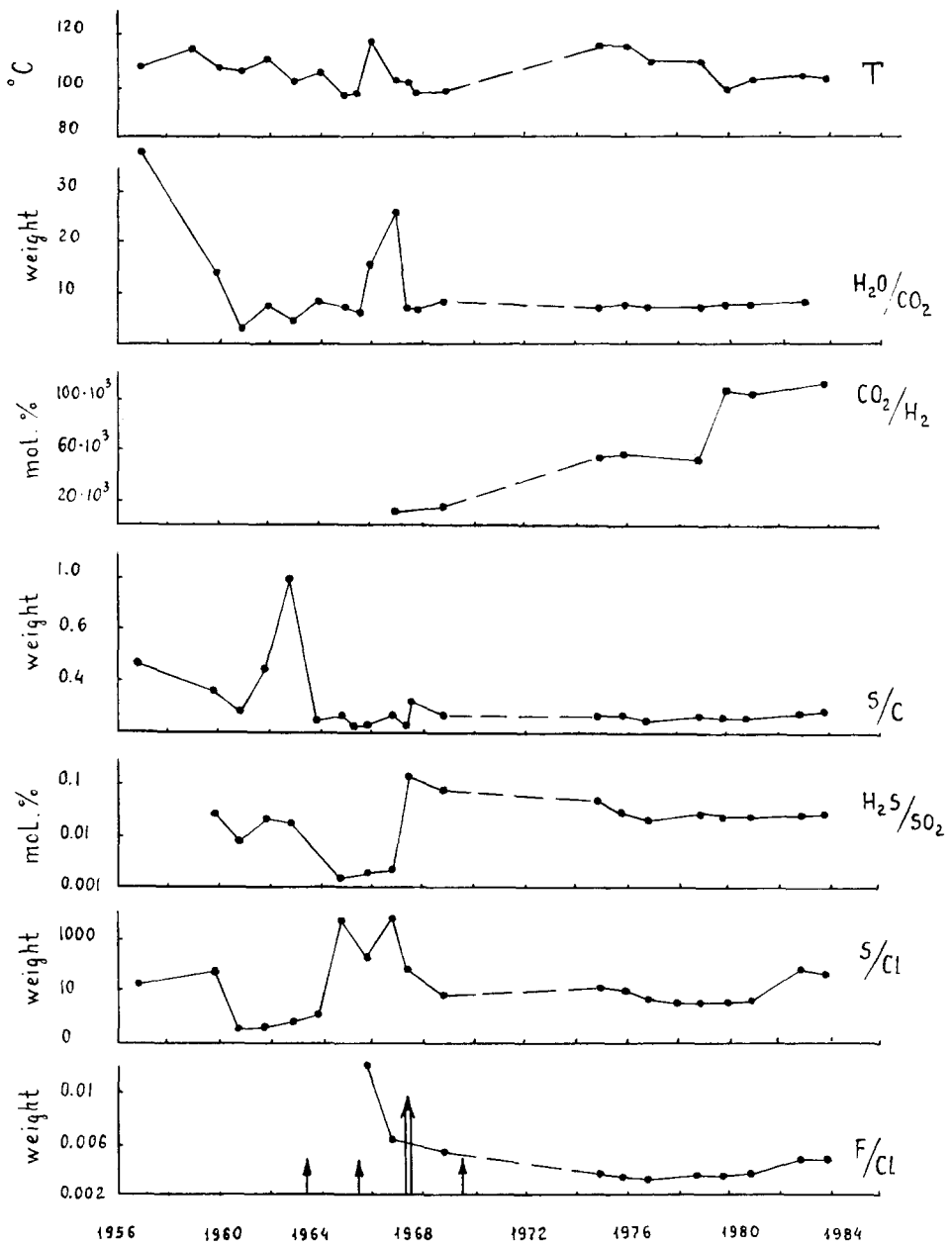


Fig. 5. Variations in temperature and gas ratios for the "Revushchie" solfataras depending on the activity of Ebeko (calculated from analyses in Table I). Large arrow-the 1967 phreatic eruption, small arrows-intensification of gas emission.

temperature of solfataras in the region of the Eastern circus, 300 m southwest of the "Gremuchaya" solfatara, also increased and this apparently was caused by the ground-water runoff. Thus, at Ebeko the variation in composition and temperature of solfataras may be caused by the change of hydrodynamic conditions. It is precisely this phenomenon that explains the intensification of activity in the region of the Eastern circus.

The "Revushchie" solfataras within the Northeastern field were under observation from the middle of the nineteen-fifties (Fig. 5). The temperatures of solfataras fluctuated within the range of 100°C, but during the intensification of volcanic activity in 1963 through 1967 their temperature increased. Then an abrupt variation in geochemical parameters was noted, namely an increase in the H_2O/CO_2 , S/C, H_2S/SO_2 , S/Cl and F/Cl ratios. Prior to and after the period 1963–1967, the values of these ratios fluctuated within rather narrow ranges. In 1983 and 1984 an increase in F/Cl and S/Cl ratios was observed. As in the case of the "Gremuchaya" solfatara, this was caused by the rise of ground-water level and by HCl absorption.

Based on the above reported data, the eruptive cycle of Ebeko volcano consists of the following periods (see Fig. 3): pre-eruptive period from 1959 to 1966; eruptive period in 1967; post-eruptive period from 1967 to 1969 and intereruptive period from 1970 until the present time. Intensification of gas emission, increase in temperature and in S/C, S/Cl, F/Cl and H_2S/SO_2 ratios for solfataric gases are noted during the pre-eruptive period. Temperatures, H_2 and CO contents and S/C, S/Cl, F/Cl and H_2S/SO_2 ratios become a maximum during the eruptive period. The decreases of temperature and other geochemical parameters are observed during the post-eruptive period. Thus, the increase in temperature, H_2 and CO appearance and the increase in S/C, S/Cl, F/Cl and H_2S/SO_2 ratios may be considered to be precursors to the forthcoming eruptive period of Ebeko volcano. These geochemical parameters were used as the basis for predicting the 1967 phreatic eruption half a year in advance.

It is noteworthy that all parameters, including the temperature and thermal survey data, must be used in monitoring the state of the volcano. The life of the volcano is very complex and fluctuations of some geochemical parameters may be caused not only by magma activation but, as in 1983 and 1984, by change in hydrodynamic conditions or, e.g., by tectonic movements. The gas-hydrothermal activity and phreatic eruptions, as well as lack of seismological precursors to an eruption (Menyailov *et al.*, 1969), are typical of volcanoes of the Ebeko type; therefore the geochemical method of prediction is the most acceptable.

The Origin of Solfataric Gases as Shown by Isotope Data

Isotopic ratios of hydrogen, oxygen, argon, helium, neon, krypton and xenon were studied using gas and condensate samples from the "Gremuchaya" and "Revushchaya" solfataras. As is seen from Table 3, these ratios differed considerably from those of local meteoric waters and the atmosphere. We may suppose that a considerable amount of noble gases from both solfataras is of abyssal (mantle) origin. This is characteristic also of CO₂ ($\delta^{13}\text{C}$ from -7 to -11% , PDB). However, the quota of deep components in the gases of the "Gremuchaya" solfatara is higher in comparison with those of the "Revushchie" solfataras; this may be accounted for by the different sites of the solfataras. The "Gremuchaya" solfatara occurs in the near-summit part of the active cone. The "Revushchie" solfataras occur hypsometrically lower, where the ground-water table rises close to the surface and where meteoric waters might have an influence. In fact, the values of δD and $\delta^{18}\text{O}$ for the condensate of the "Revushchie" solfataras are close to those of local meteoric waters.

In its isotopic composition of hydrogen, the condensate from the "Gremuchaya" solfatara hardly varies from local meteoric waters apparently representing a mixture of meteoric and sea waters. A shift of $\delta^{18}\text{O}$ values assumes the presence of a considerable amount of magmatic water in the composition of the "Gremuchaya" solfataric steam. During the observational period, the values of $\delta^{18}\text{O}$ for the steam condensates of both

TABLE 3

The isotopic composition of H₂O and noble gases at Ebeko volcano compared with the meteoric and atmospheric values.

Isotopic ratios	"Gremuchaya" solfatara, 150°C	"Revushchaya" solfatara, 100°C	Local meteoric waters and atmosphere
δD , ‰ SMOW	-36	-61	-70--86
$\delta^{18}\text{O}$, ‰ SMOW	-2.5-+1.2	-8.5	-11.3-11.8
$^3\text{He}/^4\text{He}$	6.6×10^{-6}	8.44×10^{-6}	1.4×10^{-6}
$^{40}\text{Ar}/^{36}\text{Ar}$	314-341	322	295
$^4\text{He}/^{40}\text{Ar}$	0.33	0.031	0.00056
$^4\text{He}/^{20}\text{Ne}$	254	11.8	0.31
$^{38}\text{Ar}/^{132}\text{Xe}$	74.2	123	254
$^{38}\text{Ar}/^{84}\text{Kr}$	5.35	6.58	9.07
$^{20}\text{Ne}/^{36}\text{Ar}$	0.41	0.795	0.523

$\delta^{18}\text{O}$ and δD were determined by V. Vetstein (Kiev Institute of Physics of Minerals and Geochemistry) and noble gases were determined by A. Rozhkov (Institute of Volcanology).

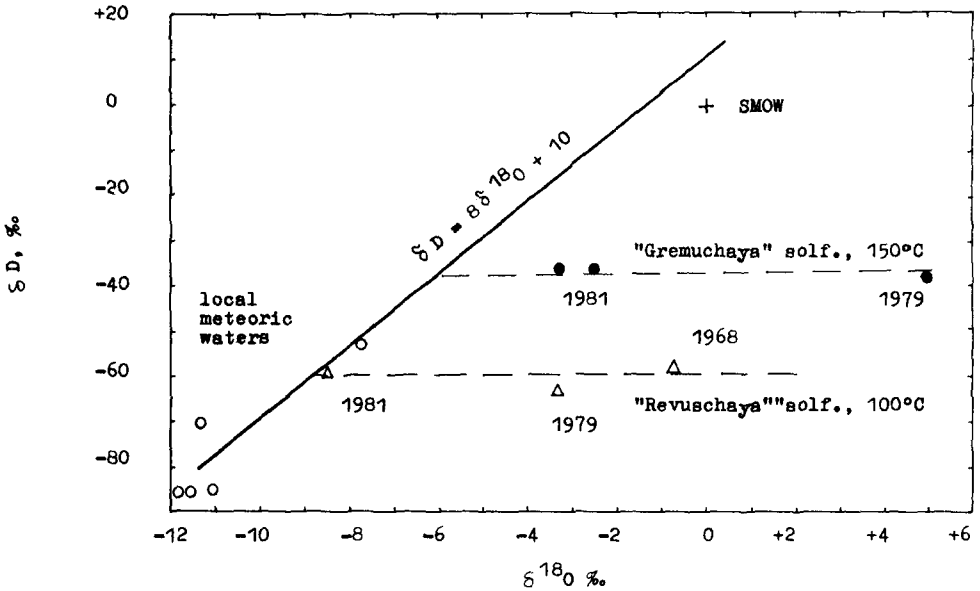


Fig. 6. Temporal variations in isotopic composition of water condensates from the "Gremuchaya" and "Revushchie" solfataras in a δD - $\delta^{18}O$ diagram.

solfataras decreased gradually and at present have reached the values for local meteoric waters (Fig. 6); i.e. the quota of magmatic water in the composition of solfataric steam decreased. Thus, the variation in $\delta^{18}O$ value for the solfataric steam condensates may be used in monitoring the state of the volcano, along with other distinguishing geochemical parameters.

CONCLUSIONS

Based on studies of the chemical and isotopic composition of solfataric gases carried out since 1957, a geochemical model of the activity of Ebeko was developed (Fig. 7). This model may help to explain the variations in gas composition connected with volcanic activity satisfactorily.

It is supposed that there is a sea-water aquifer above the shallow magma chamber. Above the sea-water aquifer, fresh ground-waters are accumulated. Magmatic emanations ascending to the surface leak through the aquifers. As a result, the decrease in temperature of emanations, condensation and significant dilution of magmatic water, as well as the loss of readily-soluble acidic gases, haloid in the first instance, occur. When the magma becomes more active in the pre-eruptive period the flux of magmatic emanations increases. In this connection, the temperature of solfataric gases, the amount of magma components and, above all, the quota of relatively

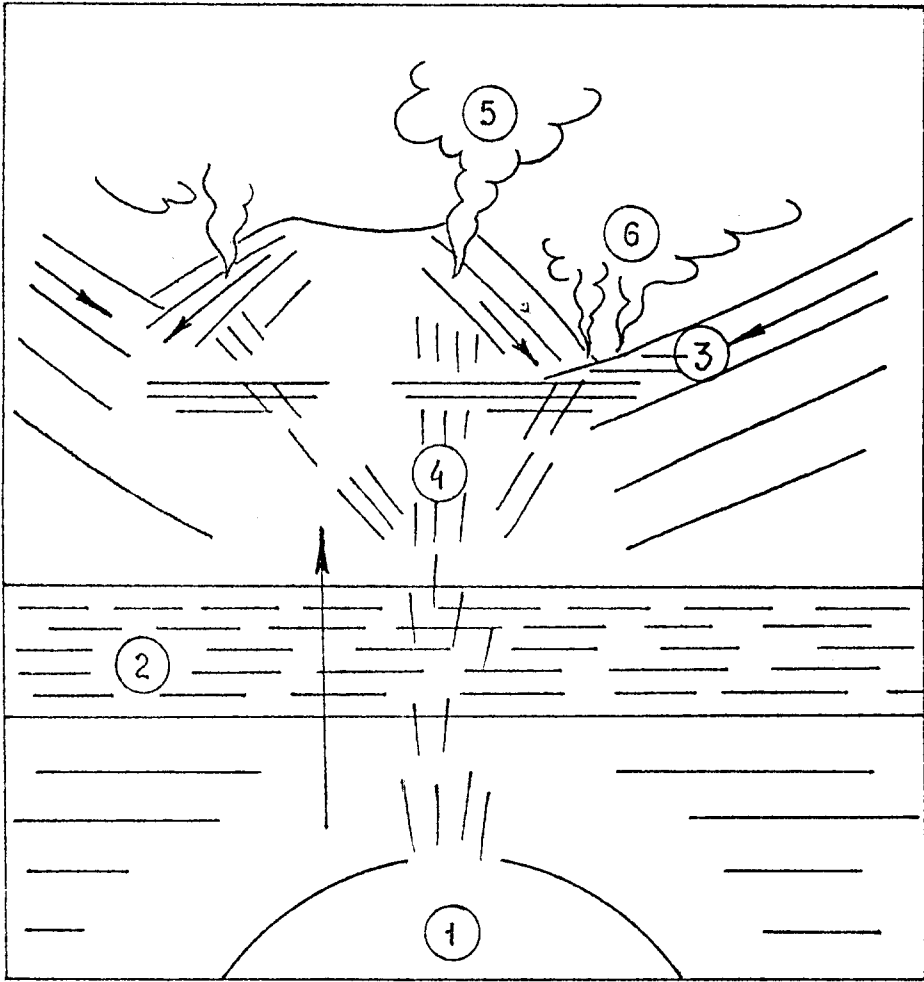


Fig. 7. The model of activity of Ebeko. 1. magma chamber; 2. sea-water aquifer; 3. ground-waters; 4. magmatic emanation flux; 5. "Gremuchaya" solfatara; 6. "Revushchie" solfataras.

poorly-soluble gases in the magma increase (Menyailov and Nikitina, 1967; Menyailov, 1976). All this, against the background of "gas-water" interaction accompanied by a loss of emanations readily-soluble in water, occurs along with increasing S/C, S/Cl, F/Cl, and H_2S/SO_2 ratios.

The main results of monitoring the Ebeko volcano during the period from 1964 to the present time, in the course of which a phreatic eruption occurred in 1967, are as follows: the distinction of the eruptive cycle and periods of volcanic activity; the determination of variations in the main geochemical parameters (the temperature of gases, S/C, S/Cl, F/Cl, H_2S/SO_2 , H_2O/CO_2 , CO_2/H_2 and $\delta^{18}O$ values) depending on the change of

activity of the volcano; and the determination of the main geochemical parameter values during the 1967 phreatic eruption. It is supposed that the increase in the temperature of gases and in geochemical parameter values may be precursors to future eruptions.

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