Acid Volcanism and Thermal Manifestations in the Area of Mutnovsky and Gorely Volcanoes (Southern Kamchatka) *

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The area of Mutnovsky and Gorely volcanoes is a part of the territory of Southern Kamchatka 70 km south of Petropavlovsk - Kamchatsky. From a structural-tectonic point of view it is in a junction zone of three heterochronous structures: a horst-anticlinorium of Miocene age in the eastern part, the South-Bystrinsk uplift of Pliocene-Lower Quaternary age in the northern part, and the Tolmachevsk graben-syncline of Quaternary age in the western part.

A most active development of these structures took place during the Pliocene-Quaternary time. Most intense manifestations of acid volcanism also took place during this period. The main eruption centres of acid material were associated with the central parts of the volcanoes and their edifices, as well as with areas subjected to intense block tectonic movements (Fig. 1).

In the area described, acid volcanism associated with central structures resulted in the formation of Mutnovsky and Gorely volcanoes, which are now in an active state.

It is assumed that these volcanoes began their development during the Upper Pliocene and Lower Quaternary time. They are associated with the intersections of submeridional and sublatitudinal faults distinctly established on the surface by zones of crush, minor rock displacements and smaller (as compared with the volcanoes) volcanic forms (slag cones, extrusions and fissure effusions of lavas).

Acid formations on these volcanoes play a substantial role, each of them having of a different character.

Mutnovsy volcano is represented by four merged cones the peaks

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of which are crowned by several large (up to 2 km in diameter) craters, two of which are active (Fig. 2). As a whole the structure can be classified as a compound strato-volcano consisting of bands of consolidated lavas, tuff-breccia, tuffs and pumices, their composition

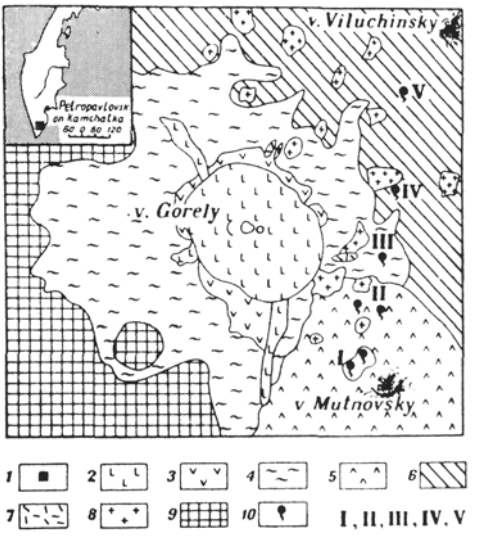

FIG. 1 - Distribution territory of acid volcanism and thermal manifestations in the area of Mutnovsky and Gorely volcanoes.

1. Location of the area on the territory of Kamchatka.
2. Andesite-basalts of the recent cone of Gorely volcano.
3. Basalts, andesites and dacites of the old structure of Gorely volcano.
4. Baked andesites of the old structure of Gorely volcano.
5. Basalts, andesites and dacites of Mutnovsky volcano.
6. Basalts, andesites, dacites and liparites of Pliocene-Lower Quaternary age.
7. Recent dacitic and liparitic extrusions.
8. Old dacitic and liparitic extrusions.
9. Quaternary forms of plateau-basalts and of areal volcanism.
10. Thermal manifestations:
    - I. Thermal manifestations in the crater of Mutnovsky volcano.
    - II. Severo-Mutnovsk hot springs.
    - III. Dachnye hot springs.
    - IV. Verkhne-Mutnovsk hot springs.
    - V. Viliuchinsk hot springs.

varying from basic to acid. The main place in the sequence of the volcano belongs to andesitic tuff-breccia. Acid material is represented by minor extrusions, lava flows and pumices of an andesite-dacitic composition (Table 1). Extrusive forms are associated with radial faults on the flanks and separate sections of the craters, whereas lava flows and pumice bands with the top and bottom parts of the

sequence. Altogether all the acid forms of Mutnovsky volcano come to about 25 % of the structure.

Gorely volcano consists of two big structures: an old shield vol-

FIG. 2 - Western part of Mutnovsky volcano with active craters.

cano, the top of which is crowned by a 13 km caldera, and a recent structure of the type of a composite strato-volcano (Fig. 3).

The recent edifice is of a rather interesting structure, it is located in the centre of the caldera, but consists mostly of basaltic and andesite-basaltic lavas, which makes it unsuitable for the present paper.

The old volcano occupies a rather big territory of Southern Kamchatka. Its gently sloping flanks can be traced northwards up to the up-streams of Paratunka river; in the north-east, up to the up-streams of Zhirovaia river; in the south, up to the northern flanks of Asachi volcano, and in the west, up to Tolmachev Dol. The volcano consists mostly of lavas and pyroclastic material of andesite-dacitic and dacitic composition (Table 1).

Andesite-dacitic lavas are not widely developed; they are exposed on the rims of the caldera and at a certain distance from it. The thickness of some flows varies from 3 to 20 m. Locally in the caldera the thickness of the lavas comes to 150-200 m.

The main role in the structure of the edifice belongs to pyroclastic deposits. They crown the sequence of the volcano and are mostly represented by ignimbrites, baked tuffs and pumices of an andesite-dacitic composition (SiO_2 60-64 %).

In the walls of the caldera ignimbrites, baked tuffs and pumices are found only locally. At a certain distance from the rims of the caldera they are observed everywhere; they cover the flanks of the volcano and the adjacent territory by a thick sheet 500 sq.km large.

The thickness of these deposits over the area is uneven. On the rims of the caldera it varies from a few meters to a few tens of meters. Farther away from the caldera it gradually increases becoming on the periphery, especially in the river valleys, 200-250 m, and, sometimes, even 300 m thick.

The sequence of these deposits is characterized by the following transitions in facies. A loose pyroclastic material with a predominance of pumice fragments is recorded in the lower part of the rock mass, higher up they are followed by baked tuffs and then by typical ignimbrites with fiammae. Locally, in the top part of the sequence there are accumulations of slag bombs of an irregular or round shape with a rough surface and of other debris, by their appearance reminding one of deposits of incandescent agglomerate flows (Fig. 4).

In the central parts of the sequence the process of refusion and recrystallization is, sometimes, so far advanced that the pumice structure of ignimbrites disappears and the rock acquires a tuff-

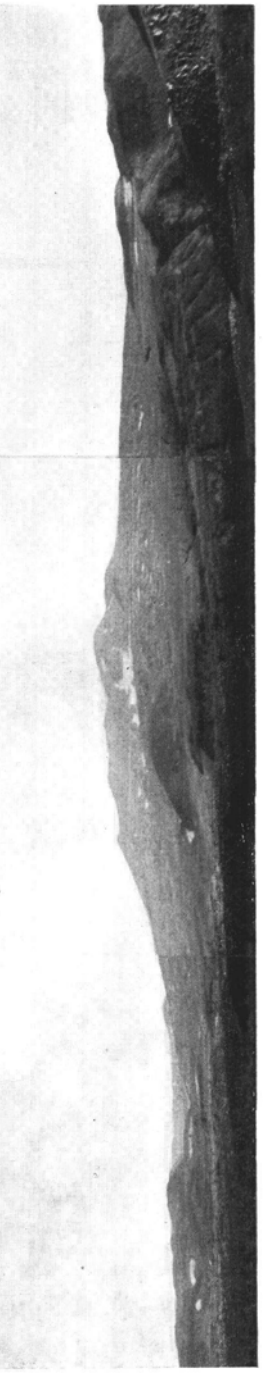

Fig. 3 - Gorely volcano. Recent andesite-basaltic cone in the centre of the thirteen kilometers caldera, the rims of which consists of an acid effusive-pyroclastic material.

TABLE 1 - Chemical composition of acid rocks in the area of Mutnovsky and Gorely volcanoes.

No.	No. of sample	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	SO_3	Ign. loss	H_2O^-	H_2O^+	Total
1	22[b]/60	67,36	0,40	16,33	3,66	0,50	0,02	1,00	3,47	2,21	3,86	0,08	1,13	—	—	100,02
7	141/64	63,90	0,85	15,43	2,98	4,45	0,14	1,87	4,68	3,68	1,92	—	—	0,42	0,33	100,65
3	18/64	60,52	1,15	16,69	3,31	4,05	0,23	2,43	5,84	4,40	1,07	—	—	0,18	0,20	100,07
4	152/60	66,24	0,80	14,36	2,98	3,48	0,03	1,95	3,58	4,44	2,55	0,02	0,18	—	—	100,61
5	209[a]/61	63,02	1,10	18,24	2,69	2,01	0,20	0,74	3,81	5,02	2,40	—	0,40	—	—	99,63
6	261[b]/61	60,36	0,53	17,23	2,16	6,55	0,14	1,69	5,10	3,67	2,58	0,11	—	—	—	100,12
7	248/61	77,22	0,31	12,69	0,92	0,50	0,03	0,91	2,27	2,92	3,00	—	0,20	—	—	100,97
8	1520-I/63	71,00	0,24	15,04	0,87	1,20	0,14	0,74	3,02	4,01	2,63	—	—	—	0,17	99,06
9	791/62	68,08	0,44	16,55	2,18	1,93	0,04	1,09	3,57	3,47	2,12	0,16	0,09	—	—	99,72
10	2012/63	59,81	1,18	1,72	0,24	—	tr.	—	3,88	0,22	0,08	24,18	—	3,48	5,52	100,31

22[b]/60 — extrusion of dacites on the western flank of Mutnovsky volcano.
141/64 — andesite-dacites lava flow in the top part of Mutnovsky volcano.
18/64 — andesitic lava flow in the middle part of the sequence of Mutnovsky volcano.
152/60 — dacitic lava flow in the caldera sequence of Gorely volcano.
209[a]/61 — ignimbrites of an andesite-dacitic composition in the caldera sequence of Gorely volcano.
261[b]/61 — andesitic lava flow in the caldera sequence of Gorely volcano.
248/61 — extrusion of liparites of Skalistaia mountain.
1520-I/63 — Pliocene extrusion of liparites on the northern flank of Gorely volcano.
791/62 — extrusion of dacites on Dvugorbaia mountain.
2012/63 — altered rock on the territory of Severo-Mutnovsky springs.

Analysts 22[b]/60, 152/60 — E. K. SERAFIMOVA.
141/64, 18/64, 1520-I/63 — G. F. NEKRASOVA.
209[a]/61, 261[b]/61, 248/61, 179/62 — TZIGANKOVA, Iliina.
2012/63 — BELETZKAIA.

lava appearance and locally becomes indiscernible from a lava.

Such a facies relation over the area of development does not always remain the same. In some places there is a predominance in the sequence of ignimbrites and ignimbrite-like varieties, while in other places there are more baked tuffs, and, in the third there is a predominance of pumices. There is also a variation in colour: from light and variegated to completely dark shades.

Acid volcanism associated with block tectonics is recorded north and north-east of Mutnovsky and Gorely volcanoes.

In the northern part of the area (upstreams of the rivers Levaia Karymchina, Paratunka nd Viliucha) acid forms are represented by extrusions and liparitic lava flows with a small amount of quartz and hornblende, as well as by pyroclastic deposits of a dacitic composition (Table 1). Their thickness is 600-800 m; they form about 80 % of the sequence. Structurally acid forms in this locality are associated with the junctions of big blocks, which can be distinctly outlined in the given area.

In the north-eastern and eastern parts of the area (upstreams of the rivers Zhirovaia and Falshivaia) acid forms are associated with the junction zone of the Eastern horst-anticlinorium and the Tolma-

TABLE 2 - Chemical composition of fumarolic gases

No	No of samples and date of sampling	Place of sampling	T°C of fumarole	Composition of volcanic (in volumetric			
				HF	HCl	SO_2	H_2S
1	No 8 / 8/8-1964	V. Mutnovsky, NE crater 2nd fumarolic field. Northern active locality.	95°	0,00	0,08	0,03	0,32
2	No 6 / 8/8-1964	V. Mutnovsky, NE crater 2nd fumarolic field. Central active locality.	112°	0,001	1,72	0,43	1,30
3	No 10 / 27/8-1964	V. Mutnovsky, NE crater. Active volcanic funnel.	480°	1,65	8,09	18,90	0,00
4	No 36 / 1963	Severo - Mutnovsk hot springs. Western group of issues.	96°	0,00	0,30	0,45	4,14
5	No 14 / 1963	Severo - Mutnovsk hot springs. Eastern group of issues.	96°	0,00	0,00	1,28	0,53

Analyst E. K. SERAFIMOVA.

chevsk graben-syncline. On the surface this zone is represented by a number of tectonic disturbances of a submeridional strike and can be traced from Mutnovsky volcano up to Viliuchinsk volcano (a distance of about 50 km). In its relief the zone is represented by a small, comparatively narrow subsidence of a graben type with an indistinctly expressed eastern edge of the graben. At the bottom of the graben and on its flanks there are badly fractured and differently altered rocks, mainly of an intermediate and acid composition.

In the western flank (Dvugorbaia, Skalistaia and Kamennaia mountains) and on the preserved portions of the « graben » floor complex intertwinings of acid and intermediate rocks of a varying appearance and age have been recorded in the less altered extrusives (Fig. 5). On some exposures it was possible to trace that the eruption of the material took place, it is assumed, in three stages: Pliocene, Middle-Upper Quaternary and Recent, each of the stages lasting for a rather long time, and, in some cases, the rock composition changing from andesite-dacites (SiO_2 60-65 %) to liparites (SiO_2 70-77 %). The thickness of acid forms in this part of the area comes to 300-400 m and takes up about 30 % of the entire rock mass.

By their outward appearance and chemical composition the lavas

in the area of Mutnovsky and Gorely volcanoes.

gases without N_2 and O_2 percents)					Fumarolic gases with H_2O, N_2 and O_2 (in volumetric percents)				N_2/O_2	In precipitate g/l
NH_3	CO_2	CO	H_2	CH_4	Total of volcanic gases	H_2O	O_2	N_2		
0,01	99,47	0,00	0,09	0,00	2,28	97,40	0,03	0,29	9,20	0,015
0,03	96,52	0,00	0,00	0,00	1,38	98,20	0,04	0,38	8,50	1,34
1,29	68,00	0,00	2,07	0,00	2,43	97,40	0,03	0,14	5,0	5,25
1,29	87,33	0,59	5,90	0,00	0,19	99,60	0,18	0,03	6,0	none
0,65	91,80	1,18	1,97	2,60	0,30	99,20	0,40	0,10	4,0	none

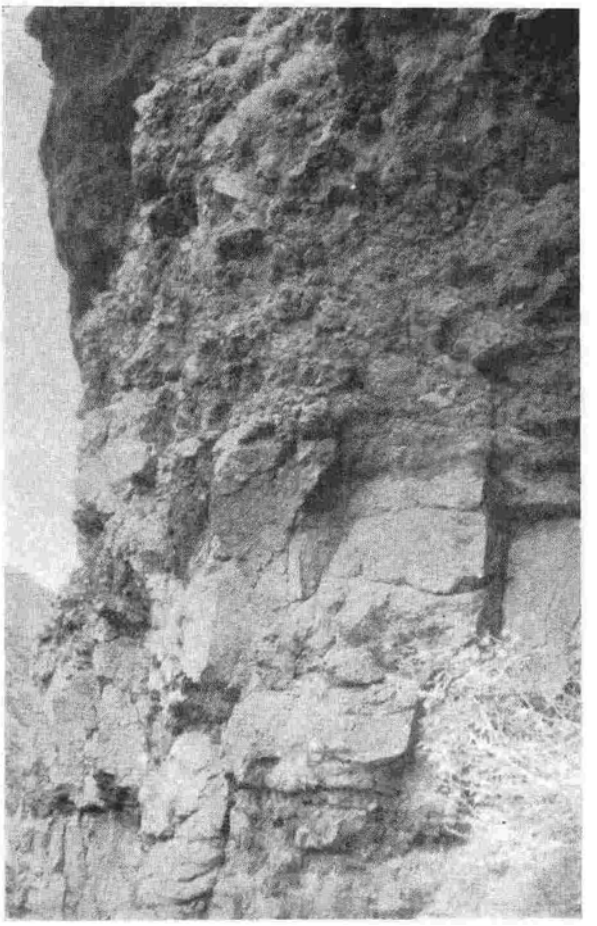

FIG. 4 - Sequences in one of the members of baked rocks. Typical ignimbrites in the bottom part, which gradually change into deposits of incandescent agglomerate flows.

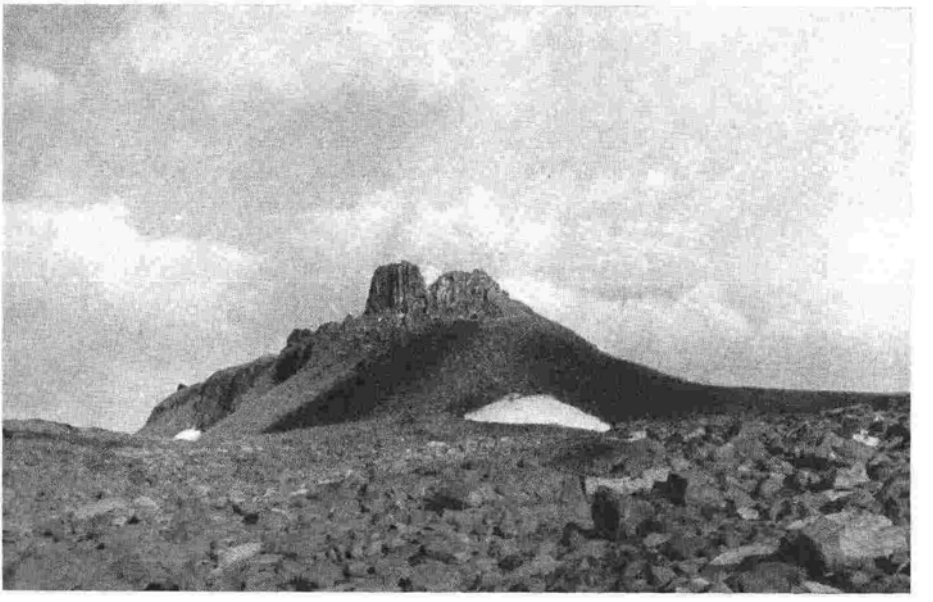

FIG. 5 - Extrusion of liparites. South-eastern termination of Skalistaia mountain.

of old extrusions in this part and of the flows (Dvugorbaia, Skalistaia and Kamennaia mountains) are very similar to the lavas of the extrusions and flows at the base, in the lower and middle parts of the sequence of Mutnovsky volcano, whereas the younger forms of these mountains are similar to the acid forms developed in the crater and in the top parts of the edifice sequence.

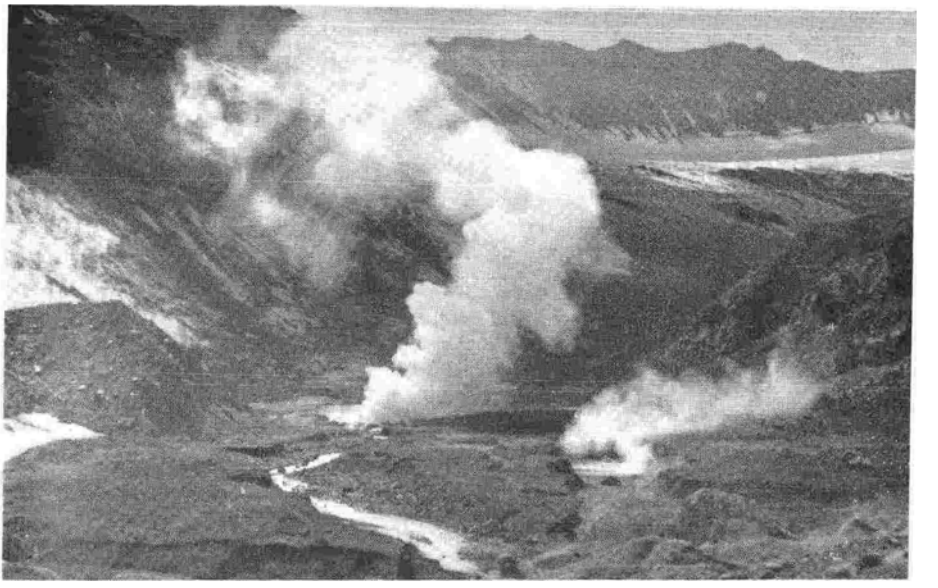

Fig. 6 - Thermal manifestations in the crater of Mutnovsky volcano.

Along with acid forms, there is also a wide development in this area of thermal manifestations of a varying nature. Nearly all their issues gravitate towards the extrusions of acid rocks, but, inasmuch as they are developed on a territory subjected to an intense block tectonics, their position is determined by the intersection of differently oriented faults.

The greater part of thermal issues — Severo-Mutnovsk, Dachnye, (also called Skalistye), Verkhne-Zhirovsk, and, possibly, Viliuchinsk — are associated with the active zone of tectonic disturbances that can be traced north of Mutnovsky volcano. This zone includes also thermal issues from the crater of the volcano (Fig. 6).

By the character of issues, all of them, with the exception of Viliuchinsk springs, belong to the fumarolic type, each group being

represented by several localities occurring at different hypsometric levels. On some of them (Severo-Mutnovsk, Dachnye and Verkhne-Zhirovsk) all the transitions are recorded from fumaroles of varying activity to hot springs.

A typical composition of fumaroles in the crater is characterized by the presence of HF, HCl, SO_2, H_2S, etc. In the fumaroles of springs there are lesser amounts of HF, HCl, CO_2 and a higher share of H_2S, NH_3 and CH_4 (Table 2). In all thermal manifestations in the crater and in the springs CO_2 predominates over all other gases.

The chemical composition of thermal waters in the crater is characterized by the presence of Cl^-, SO_4^{2-} in the anion part and H^+, Ca^{2+}, Al^{3+}, Mg^{2+} in the cation part. On the territory of Severo-Mutnovsk springs the anion part contains SO_4^{2-} and the cation part NH_4^+, Al^{3+}, Fe^{3+}, Ca^{2+} and Mg^{2+}; on the territory of Dachnye springs in addition to SO_4^{2-} contain a certain amount of HCO_3, while in the cation part there is a predominance of Na^+, K^+ and Mg^{2+}. On the territory of Verkhne-Zhirovsk hot springs, the role of HCO_3 in the anion part increases even more. In the cation part there are virtually the same components as on the territory of Dachnye springs with a certain increase in the amount of Ca^{2+}. The waters of Viliuchinsk hot springs are of a mixed chemical composition, but in general they approach hydro-carbonate-alkaline springs (Table 3).

At the points of issue of fumaroles and hot springs the rocks are altered to grey propyllites, opal-alunitic varieties, kaoline and montmorillonite clays under the influence of HCl, H_2SO_4 and other acids. Very often nearly all petrogenetic components except silica are evacuated from the rock. In this way the area of Mutnovsk and Gorely volcanoes is characterized by the following main features.

1. *Wide development of acid volcanism of two types* — local, which is associated with volcanic structures, and areal that is associated with a disjunctive tectonics. In both cases the composition of the rocks changes from andesite-dacites to liparites, the first being mainly characterized by andesite-dacites established in deposits of explosions — tuffobreccias, pumices and rocks baked to a varying extent, sometimes up to ignimbrites; the second type is characterized by dacites and liparites in effusions of lava flows and extrusive formations.

TABLE 3 - Chemical composition of thermal waters in the area of Mutnovsky and Gorely volcanoes.

No	No of sample and date of sampling	Place of sampling	Cations											Anions							HBO_2 in mg/l	H_2SiO_3 in mg/l	H_2S in mg/l	General mineralization	PH	T°C	Formula of chemical composition
			H^{1+}	Na^{1+}	K^{1+}	NH_4^{1+}	Mg^{2+}	Ca^{2+}	Al^{3+}	Fe^{2+}	Fe^{3+}	Mn^{2+}	Total	Cl^{-}	F^{-}	SO^{2-}_4	HSO^{-}_4	SO^{-1}_3	HCO^{-}_3	Total							
1	230 1963	V. Mutnovsky, NE crater 2nd fumarolic field.	711,00 711,00 67,64	322,00 14,44 1,37	82,00 2,10 0,20	20,00 1,40 0,14	648,10 53,35 5,07	1635,30 81,65 7,77	1469,56 163,30 15,53	662,18 23,71 2,26	0,00 0,00 0,00	6,00 0,22 0,02	5616,14 1051,17 100,00	35251,0 993,17 92,81	400,00 21,10 1,98	845,40 17,60 1,65	3686,00 38,00 3,56	0,12 0,003 0,00	— 	40183,02 1069,90 100,0	615,60	132,29	0,00	46500,0	0,23	80°	$M_{46,0}\frac{Cl_{79}H_2SO^{4}_{4}}{H_{65}Al_{17}Ca_7Mg_5}$
2	6 1964	V. Mutnovsky, NE crater 2nd fumarolic field.	1,9 1,85 3,4	68,00 2,96 5,5	8,20 0,21 0,4	2,2 0,12 0,2	115,8 9,52 17,6	489,0 24,40 45,41	131,1 14,58 26,9	0,00	8,9 0,48 0,9	— 	825,1 54,12 100,0	226,9 6,4 13,3	15,0 0,79 1,16	1929,0 40,16 83,2	88,3 0,91 1,9	— 	— 	2259,2 48,26 100,00	4,3	26,0	0,00	3081,3	2,87	38°	$M_{50}\frac{SO^{4}_{63}Cl_{32}}{Ca_{48}Al_{22}Mg_{17}}$
3	101 1963	Severo-Mutnovsky hot springs. Western group.	4,00 4,00 12,05	18,20 0,79 2,38	5,30 0,14 0,42	86,40 4,78 14,40	91,32 7,51 22,62	111,62 5,57 16,77	73,22 8,14 24,52	19,40 0,69 2,08	28,60 1,54 4,64	1,20 0,04 0,12	359,26 33,20 100,0	3,5 0,1 0,25	— 	1796,40 37,40 93,97	223,0 2,30 5,78	0,00 	— 	1922,90 39,80 100,00	0,00	389,61	0,00	2,67	2,54	96°	$M_{3,0}\frac{SO^{4}_{91}HCO^{4}_{8}}{Al_{22}Mg_{22}Ca_{17}H_{12}}$
4	215 1963	Severo-Mutnovsky hot springs. Eastern group.	0,16 0,68	7,80 0,34 1,45	0,75 0,02 0,08	360,0 20,0 84,90	0,60 0,05 0,21	13,23 0,66 2,80	6,29 0,70 2,97	0,00 0,00	30,85 1,65 6,90	0,00 	419,68 23,58 100,0	6,3 0,15 0,49	— 	1366,18 28,46 99,51	— 	0,00 	— 	1872,48 28,61 100,0	0,00	206,22	0,00	1,99	3,80	96°	$M_{2,0}\frac{SO^{4}_{100}}{H^{+}_{35}Fe_2Al_3}$
5	39 1963	Dachnye hot springs. Spring on the territory of the 1st group.	—	239,00 10,83 82,0		6,00 0,334 2,48	100,0 0,78 5,79	27,20 1,36 10,1	—	4,00 0,14 1,04	0,5 0,027 0,20	— 	47,7 12,64 100,0	7,0 0,20 1,485	— 	565,0 11,85 88,9	— 	0,00 1,42 10,55	86,0 13,47 100,0	659,0	—	19,00	0,00	725,7	6,36	82°	$M_{3,7}\frac{SO^{4}_{89}HCO^{3}_{10}}{(Na+K)_{32}Ca_{19}Mg_8}$
6	108 1963	Dachnye hot springs. Medvezhia group.	—	50,5 2,2 22,0		3,0 0,167 1,67	86,8 7,12 71,2	8,4 0,42 4,2	—	1,0 0,035 0,35	0,00 	— 	148,7 9,94 100,0	7,00 0,2 2,0	— 	448,0 9,34 93,4	— 	— 	30,0 0,5 5,0	485,0 10,04 100,0	—	6,50	0,00	640,20	7,35	92°	$M_{10,0}\frac{SO^{4}_{91}HCO^{3}_{10}}{Mg_{21}(Na+K)_{22}Ca_4}$
7	99 1964	Verkhne-Zhirovsk hot springs. Tihrd group.	—	58,87 2,56 26,34		—	8,29 0,68 6,99	129,60 6,48 66,67	—	—	—	—	196,77 9,72 100,0	3,55 0,1 1,03	— 	316,85 6,59 67,79	— 	— 	184,83 3,03 31,18	505,23 0,72 100,0	—	58,2	—	760,00	7,6	78°	$M_{5,71}\frac{SO^{4}_{82}HCO^{3}_{31}}{Ca_{67}(Na+K)M_7}$
8	810 1963	Viliuchinsk hot springs.	—	15,00 0,38 2,45	324,50 14,11 90,85	2,00 0,11 0,71	4,1 0,34 2,69	7,4 0,37 2,38	—	—	—	6,0 0,32 1,42	344,00 15,53 100,0	195,5 5,51 35,47	0,4 0,02 0,13	171,1 3,56 22,92	0,2 0,04 0,27	— 	390,4 6,39 4,114	758,6 15,53 100,0	22,7	135,4	—	1102,6	8,0	58°	$M_{1,41}\frac{HCO^{3}_{41}Cl_{38}SO^{4}_{22}}{(Na+K)_{93}}$

Samples 39. 108 taken from data by E. A. VAKIN, samples 99, 810 — from the material by T. P. KIRSANOVA.

2. *Manifestations of acid volcanism* in this area are intimately related to tectonics. The activation of certain tectonic zones and the effusion of acid lavas has been induced, apparently, by the same causes. This is indicated by complex relations existing between heterochronous extrusive rocks and tectonic disturbances on the territory north of Mutnovsky volcano.

The similarity of rocks in fissure effusions on the territory and of the effusions associated with the Mutnovsk volcano structure shows that during definite stages acid volcanism of both the areal and local type had a common source. (A common or similar magmatic centre).

3. *In the area under discussion Gorely volcano occupies a special position.* Being located in the western part of the junction zone of the Eastern horst-anticlinorium and the Tolmachevsk grabensyncline, it is characterized by an eruption of a considerable amount of pyroclastic material, which produced varied facies of baked rocks, including ignimbrites. The facies variety in these rocks, which differed mainly by their degree of baking and their colour, indicates different deposition conditions and a varying heating of this material at the moment of eruption.

The pyroclastic nature, the character of distribution and the association of the material with a definite centre of eruption (the Gorely volcano), as well as the volume, which is estimated approximately to be 60 km^3, indicate that the formation of the 13 km caldera is related to the ejection of these masses of rocks.

4. *Wide development of thermal manifestations* of a fissure type, the nature of which changes from fumaroles of a varying activity to typical hot springs.

Despite the fact that the issues of thermal manifestations are concentrated on a territory where acid volcanism of both types is developed, their position in the structural pattern and their genesis are mainly determined by tectonic conditions. In this base, both these manifestations and the extrusions of acid rocks are associated with the most fractured and periodically living parts of the zone of tectonic disturbances.

5. *The change in the chemical composition* of thermal manifestations can, apparently, also be explained by the structural-tectonic and stratigraphic position of their issues.

a) In the most active parts of the tectonic zone (in the craters (Mutnovsky volcano) and on the flanks of the volcano (Severo-Mutnovsk springs), where thermal manifestations are directly connected with the magmatic centre by allegedly open canals and where effusive formations are predominant in the rock sequence) there is a big amount of HCl, SO_2, H_2S, HF^-, Cl^-, SO_4^{2-}, H^+, NH_3 in the chemical composition of gases and waters and a lesser amount of other petrogenetic components.

b) In less active parts of the tectonic zone, where as result of an injection of viscous lava (acid extrusions) along the fissures, thermal manifestations are associated with magmatic centres by allegedly closed canals. In the rock sequences there is a predominance of volcanic-sedimentary forms and in the chemical composition of gases and waters along with SO_2, H_2S, SO_4^{2-} and rarely Cl^-, the appearance of HCO_3 is recorded, its role increasing with a lesser activity of the localities and with a greater thickness of volcanic-sedimentary formations (Verkhne-Zhirovsk and Viliuchinsk springs).

Most probably these phenomena (acid volcanism and thermal springs) are two independent ways of volcanic manifestations. Judging by the character of issues, the scale, time and depth of effect on the surrounding rocks, thermal manifestations (contrary to the existing opinion of their greater part being fed by the cooling of acid masses at depth) are absolutely independent from acid formations. Thermal springs are supplied from deeper foci and at definite moments (during the activation of tectonic processes, a supply of new portions of heat and « fluid » with a higher temperature up to 800-900°C). On their way to the surface they can melt « granitic rocks » and, forming shallow peripheral hearths, cause manifestations of acid volcanism with a very varied chemical composition of rocks (SiO_2 from 60 to 77 %).

Bibliography

Аверьев В. В. 1964г. О соотношении между гидротермальной и магматической деятельностью. Проблемы вулканизма. /материалы ко II-му вулканологическому совещанию/ Дальневосточное книжное издательство. Петропавловск-Камчатский. (On the relations between hydrothermal and magmatic activities).

Вакин Е. А., Кирсанов И. Т., Пронин А. А. 1966г. Активная воронка Мутновского вулкана. Бюллетень вулканологических станций И. 41. Изд-во « Наука ». (Active funnel of Mutnovsky volcano).

Кирсанов И. Т., федоров М. В. 1964г. Игнимбриты в. Горелого. Проблемы вулканизма /материалч ко П-му вулканологическому совещанны/. Дальневосточное иедательство Петропавловск-Камчатский (Ignimbrites of Gorely volcano).

Маренина Т. Ю. 1956г. Геолого-петрографический очзрк Мутновского вулкана. Труды лаборатории вулканологни И. 12 Изд-во АН СССР. (Geological and geographical review of Mutnovsky volcano).

Ерлих З. Н. 1965г. О структурной приуроченности четвертичного вулканизма Камчатки. Геотектоника И. I. Изд-во « Наука ». (On the structural association of Quaternary volcanism on Kamchatka).