

Eruption of Piip Crater (Kamchatka) *

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Abstract

In autumn of 1966 on the northern slope of Kliuchevskoy volcano a chain of new adventive craters broke out at the height of about 2200 m. Eighty-four hours before the beginning of the eruption a swarm of preliminary volcanic earthquakes had appeared. The number of preliminary shocks was 457 with total energy of 4×10^{17} erg. With the beginning of the lava flow the earthquakes stopped and a continuous volcanic tremor appeared. The total energy of volcanic tremor amounts to 10^{16} erg. During the eruption numerous explosive earthquakes with the energy of 10^{15} - 10^{16} erg were recorded and besides the microbarograph of the Volcanostation recorded 393 explosions with an energy more than 10^{13} erg and their total energy was equal to 10^{17} erg.

All together it has been formed 8 explosive craters and the lowest 9th crater was effusive. The slag cone was formed round this effusive crater, the lava effusion of basaltic-andesite composition (52,5% SiO_2) took place from the lava boccas at the cone base and from the crater. The lava flow covered a distance of 10 km along the valley of the Sopochnoy river and descended to a height of about 800 m. The lava flow velocity at the outflow reached 800 m/hr, the lava temperature was 1050°C . The effused lava volume amounts to 0.1 km^3 . The eruption stopped on December 25-26, 1966.

Introduction

On October 6th, 1966 an eruption has started from a new adventive crater on Kliuchevskoy volcano. This burst was the final stage in the eruption of the summit crater which had begun in August, 1965.

The Kliuchevskaya group of volcanoes is the largest and most beautiful cluster of volcanic structures in Kamchatka and perhaps

* Paper presented at the IUGG General Assembly, IAVCEI Session, Zürich, Sept. 1967, and accepted for publication by the organizing committee.

in the world. This volcanic group is located in the north of Kamchatka where the Kamchatka river sharply changes its stream course from north to the east. Here among lakes, swampy lowlands and foresty valleys a cluster of 12 volcanoes rises like a gigantic « island ». Six of them are higher than 3000 m and the three other rise for more than four kilometers above sea level. This volcanic group occupies an area exceeding 8500 sq. km.

It is difficult to express in words the beauty and grandeur of these volcanoes. The prominent researcher of Kamchatka volcanoes Prof. B.I. PIIP wrote: « Twelve volcanoes of this group stand out among the mountain ranges and forest valleys of the Northern Kamchatka as gigantic masses of stone and ice forming an unforgettable panorama full of majesty and severe splendour. The amazingly proportionate enormous cone of the Kliuchevskaya - sopka with a permanently smoking or fire-illuminated summit located in the north-eastern corner of the volcanic cluster gives a special charm to this panorama. In Guillemard's opinion (who before his trip to Kamchatka saw the Andes and the Alps and watched the sunrise on Cotopaxi, on Etna, on Fujiyama) the group of the Kliuchevskoy volcanoes is so majestic and perfect in its beauty that it cannot be compared with these or other famous mountains of the world. Other travelers and researches, who visited these places, give the same enthusiastic appraisal » (PIIP, 1956).

Three volcanoes of the Kliuchevskaya group are still active. They are Tolbachik, Bezymianny and Kliuchevskoy. Plosky Tolbachik is in the extreme south of the group. On the summit of it (about 3000 m) there is a flat caldera with a diameter of about 4 km. Many years ago there has been a lava lake, but now the depression is filled with ice and only in the western part there is a pit in the floor, in the bottom of which liquid lava is appearing from time to time. During the explosions this lava is extended into thin filaments forming Pele's hair.

The second active volcano Bezymianny was considered to be extinct up to 1955, but in the autumn of 1955 it suddenly began to erupt and on March 30, 1956 there has been a gigantic explosion which entirely decapitated the volcano. All over the area of 500 sq. km incandescent ash deposited and burnt down the entire vegetation; ashes were ejected into the stratosphere to a height of 40 km and then were discovered over the North Pole and even over England; the explosion wave rounded the globe one and a half times.

The flows of loose pyroclastic material rushed out of the newly formed enormous crater and passed a distance of about 20 km burying several river valleys. Over a vast territory snow melted and big mud flows were formed which having passed about 100 km poured into the Kamchatka river. This has been one of the most catastrophic eruptions of the twentieth century but fortunately it took place in an uninhabited area and did not result in any loss of human life (GORSHKOV, 1959).

Finally Kliuchevskoy volcano is the most active and the highest volcano of the group. This is the highest active volcano in the European and Asiatic continents and one of the highest volcanoes of the world. Its flanks rise from sea level up to a height of 4850 m. In the east and north, where the volcano is not congested by other volcanoes, its cone base has a radius of 30-35 km. The summit crater has a diameter of about 650 m and its depth is more than 200 m. At the base of the cone from the north and east within a height interval from 500 to 2000 m there are several scores of adventive craters.

Since the beginning of the 1930's, when systematic observations were organized, the eruptions of adventive craters took place in 1932, 1938-1939, 1945, 1946, 1951, 1953 and 1956. The eruptions of the summit crater take place with intervals from 1 to 5-9 years. Big, paroxysmal eruptions occur with intervals of 20-30 years (at an average of 26 years). The preceding summit crater eruption took place in 1961-63 and the last paroxysmal eruption happened during the night of January 1st, 1945.

The Eruption

The eruption in 1965-1966, which we are concerned about, can be divided into four periods:

1. From August to November, 1965 slight explosions in the summit crater took place from time to time with ejections of small amounts of ash.

2. At the end of November, 1965 the activity noticeably intensified and a luminescence was appearing sometimes over the crater. Clouds of dark ashes were rising sometimes to a height of 5 km above the crater.

3. From July to October, 1966 the eruption was of Volcano-Strombolian character. Almost permanently luminescence could be observed over the crater, a roar of explosions could be heard. On September 11, 1966 one of the authors (I.T. KIRSANOV) watched the eruption from the rim of the crater. A small (30-40 m) slag cone in the floor of the crater was extended from the south-west to the north-east. Three boccas with a diameter from 10 to 50 m were active on the summit of the cone. Liquid lava was constantly bubbling in the bottom of the largest bocca; from time to time it spured out in fountains to a height of 380-800 m. The other two boccas were active periodically. Sometimes there have been intense splutters and the entire floor of the crater was covered by plastic lava. There have been virtually no ash explosions. There have been only rare outbursts of dark pyroclastic material, which was discharged in the vicinity of the crater.

4. During the final stage of the eruption — on October 6, 1966 a chain of adventive craters broke out and the eruption of the summit crater immediately stopped. The entire eruption was completed by the end of December 1966.

Already during the eruption of the summit crater a slight spasmodic volcanic tremor was recorded with a displacement amplitude of 0.1-0.2 micron recorded at the seismic station «Apakhonchich». From May, 1966 the volcanic tremor was recorded much more often and from July with the beginning of the Volcano-Strombolian type of eruption it was recorded continuously and reached its maximum in August. The total energy of volcanic tremors in August was 5×10^{14} erg, the amplitude of maximum displacements was equal up to 1.0μ . Since that time explosive earthquakes were recorded with energy up to 10^{13} erg. Before the break-through of adventive craters the number of explosive earthquakes and the volcanic tremor sharply diminished.

Volcanic earthquakes that preceded the break-through of adventive craters appeared 3-5 days before the beginning of the eruption. Slight earthquakes ($E = 10^{12}$ erg) having appeared before the break-through constantly increased in number but decreased in energy. Strong earthquakes ($E = 10^{15} - 10^{17}$ erg), having reached their maximum during the first day, continued to stay approximately at the same level up to the break-through. Altogether 457 shocks have been recorded, 111 of them with an energy exceeding 10^{13} erg. The total

energy of earthquakes is 4×10^{17} erg. The character of seismic activity unmistakably indicated a coming adventive eruption and all the staff of the Volcanostation was ready for it.

After the break-through of the adventive craters the number of earthquakes sharply decreased and volcanic tremor appeared. With the beginning of lava effusions the volcanic earthquakes stopped, while the volcanic tremor became uninterrupted.

Electromagnetic phenomena

The break-through of the adventive craters was preceded by electromagnetic perturbations, which have been recorded by the magnetic-variation station (MVS) stationed in Kliuchi in the territory of the Volcanological Station.

Twenty four hours before the beginning of the eruption electro-

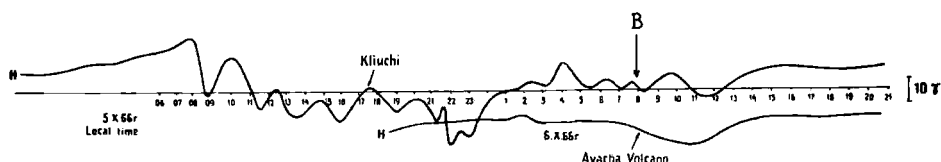


FIG. 1 - Diagram of the changes in the electromagnetic field before and during the eruption. The horizontal component of a record at the magnetic-variation station in Kliuchi and at Avacha volcanostation. B: beginning of the eruption. (Compiled by E. RYNDIN).

magnetic fluctuations of a sinusoidal shape with a period of 2.2 - 2.5 hours were clearly recorded on the horizontal component (H). The amplitude of fluctuations was $30-40\gamma$. The total field level increased by 110γ between 7 and 21 o'clock on October 5. Between 21 and 22 o'clock (9-10 p.m.) there was a marked jump in the magnetic field with a decrease in fluctuation frequency; after that the field was equalized up to the normal position (Fig. 1). On the vertical component (Z) these perturbations were less expressed because of less magnification ($E_z = 6.5\gamma/\text{mm}$, $EH = 1.2\gamma/\text{mm}$). And yet during the first period of perturbations the field level on Z component also slightly increased. Between 21 and 22 o'clock there has been also a marked decrease of the field level and then its levelling up to the normal position.

The nature of such fluctuations is yet not quite clear. In this

case the magnetic field perturbations were of a local character (which is indicated by MVS records on Avacha stationary installation) and were undoubtedly associated with the break-through of the adventive craters.

The break-through of the craters began on October 6, 1966 about 8 a.m. on the northern flank of Kliuchevskoy volcano at a height of 2000-2200 m in the edge zone of Erman glacier. At first a small jet of white steam appeared (Fig. 2). By noon a radial fissure



FIG. 2 - The beginning of the eruption from adventive craters on October 6, 1966 at 12 a.m. Kliuchevsky volcano is in the background. (Photo by I. T. Kirsanov).

about 1 km long was formed on the slope. About ten craters were active along the fissure, from which a dense swirling mass of ash, sand and bombs was bursting out with a low roar.

When it got dark the bright red fountains of incandescent bombs became visible. Shortly before midnight a lava flow began its effusion from the bottom and the eruptive fissure.

The break-through was given the name of Professor B.I. Piip; the lowest effusive crater was named « Piip crater » (Fig. 3).

The explosive activity reached its maximum the next day on October 7th and remained very intense up to the 22-23rd of October.

Altogether there have been 8 explosive craters. Up to October 10th strong gas explosions were taking place in all the craters ejecting a great amount of dark ashes. After October 10th the character of explosions somewhat changed.

The very top crater continued to emit gases saturated with dark ashes; the following two craters were less active. The explosions occurred with intervals of 5-15 minutes and ashes rose to a height

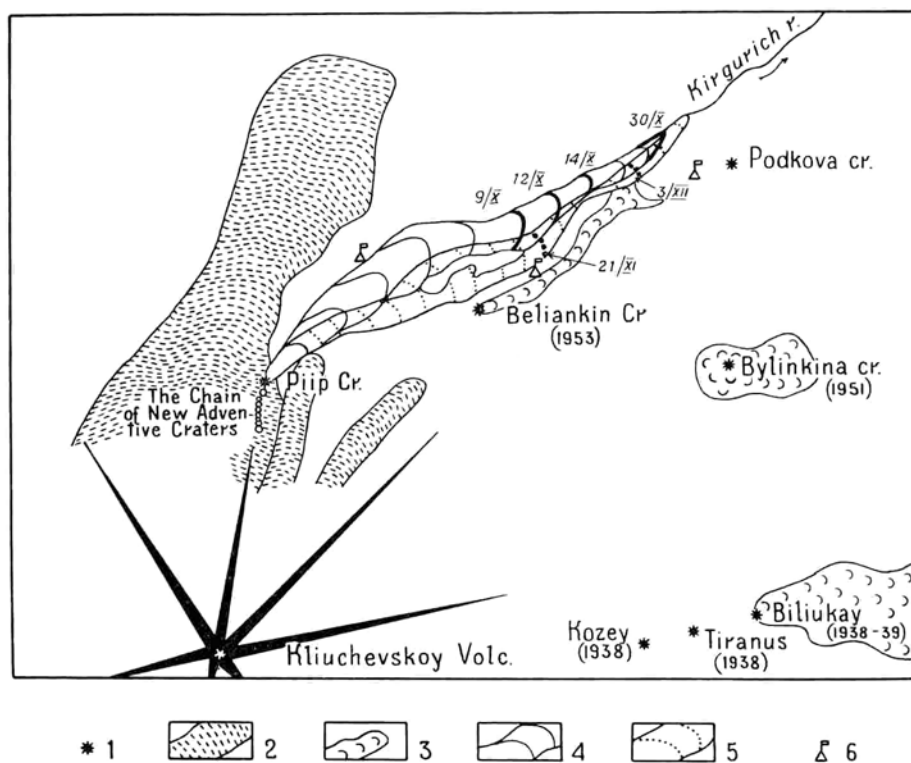


FIG. 3 - Location of the adventive craters and of the lava flows.
1 - adventive craters; 2 - glaciers; 3 - lava flows from old adventive craters; 4 - lava flow of the first portion; 5 - lava flow of the second portion; 6 - expedition camps.

of 2.5-3.0 km. After the 20th of October the explosions became more rare and on November 8-9 these craters became silent.

The 4th and 5th craters were not very active. Infrequently there has been a noisy outflow of gases or single explosions with an ejection of ashes to a height of 300-400 m.

The three low craters were the most active. With intervals from

5 to 20 minutes one strong explosion followed another with an ejection of dark ashes and a small amount of glowing bombs. Lava fragments fell at a distance up to 2 km from the crater. The activity of all explosive craters stopped at the end of October - beginning of November.

Two lava fountains and some lava boccas were located in the lower part of the break-through continuously effusing lava (Fig. 4).



FIG. 4 - The lava fountains and sources of the lava flow, October 17, 1966 (Photo by M. V. Fedorov).

The fountains were formed at the expense of very frequent explosions, *i. e.* sort of pulsations, the number of which was equal to 90 per minute. These fountains rose to a height of 400-600 m. In the top part of the column the lava fountain «broke up» into a mass of plastic slag bombs, whose falling down gradually increased the cone.

By October 9th a slag cone with a height up to 30 m was formed around the fountains and it had an open wide horseshoe-like crater to the north.

At the end of October and the beginning of November the activity of the lava fountains sharply diminished. The eastern vent start-

ed to eject fountains of incandescent slags only 3-5 times a day and then died down completely. The western vent continued its activity, but the frequency of the ejections dropped first to 25-30 per minute and then the explosions almost stopped completely.

On November 16th the eruption gained a new force. The west-

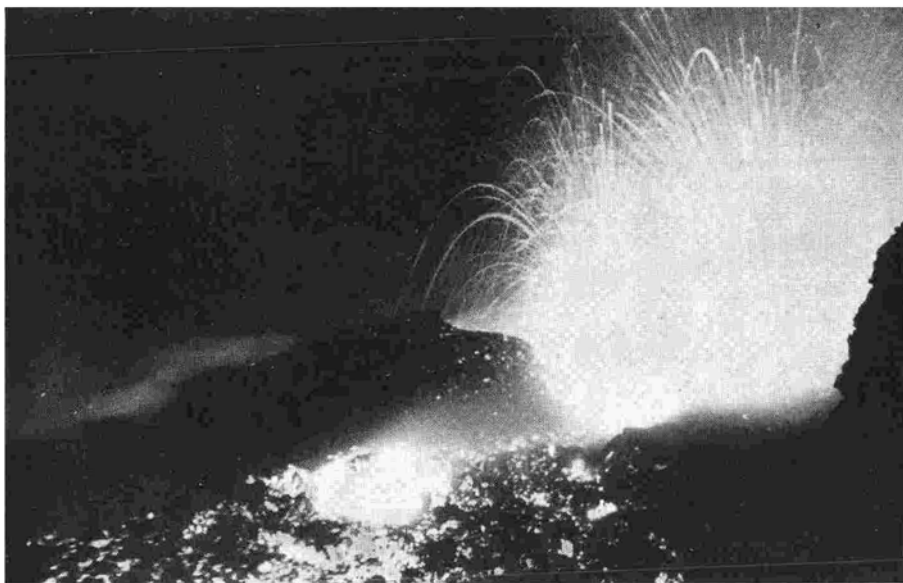


FIG. 5 - Piip crater and sources of the lava flow, December 1, 1966 (*Photo by G. S. Gorshkov*).

ern vent started to eject sheaves of incandescent slags up to 25-30 times per minute; around this vent in this previously indivisible horseshoe-like crater a new cone began to grow with a small enclosed crater on the summit (Fig. 5).

Gradually getting weaker the explosions stopped on December 1, 1966 and the cone that grew by this time to a height of 80 m was covered with snow.

From the beginning and up to the end of the eruption certain conditions of illumination permitted to see explosion waves. Each strong explosion was accompanied by an impact wave, which rapidly, as if in a jump was running along the eruptive cloud.

Liquid lava was pouring out of the eastern vent and from the boccas at the base of the cone and then only from the boccas (Fig. 6). Lavafalls were formed in the places of steep relief bends. By Oc-



FIG. 6 - Lava flow, November 1966. (*Photo by A. A. Pronin*).

tober 9th the flow covered 5 km of the valley of the Kirgurich river. By October 13th the length of the flow increased by another 1.5 km. The velocity of the flow was from 500 to 800 m/hr in the top part. The temperature was 1050° (optical pyrometer).

In the places where the flow has not yet been covered by a cooled crust, it was impossible to approach it nearer than several meters. Further down it was already possible to walk on the lava crust; here the flow was moving with a velocity of several meters per minute and though in the fissures at a depth of 2-3 cm the temperature was 900-1000°C, was possible to « swim » on the thin cooled crust of the fiery river. All the researchers of this eruption tried to experience this exciting pleasure of an unusual drift with a lava flow.

In the frontal part the width of the flow was 250 m, the thickness 4-5 m and the velocity was only 8-10 m/hour. In the front part of the flow the character of the lava movement could be traced especially distinctly. The central, most plastic lava, carrying the blocky, already cooled part of the rock, was squeezed out of the mass of the flow hanging sometimes as a ledge, coiling up downwards and breaking off as separate blocks leaving extended ragged shreds in the central part. By hitting by a hammer the lava was malleable that made it very difficult to chip off a sample. The bottom and top layers of the flow represented already cooled fragments of varying size and in some places the top layer was considerably thicker than the bottom layer. In the top layer the big blocks were often welded to the middle, plastic part of the flow.

On October 14, the lava flow reached the sloping part of the Kirgurich valley and its thickness began rapidly to increase reaching 20-30 m in some places. The movement of the frontal part had the following character. At first a narrow tongue covered the axial part of the valley, then in the sloping part of the route the flow moving more slowly filled all the depressions and then began to advance again.

On October 17th the lava effusion from the boccas had a pulsating character. The lava level in the flow either increased or decreased. At this time the flow had carved out a channel with high flank mounds for all its length. The rate of the lava movement also did not remain constant changing from 150 to 500 m per hour. Simultaneously, numerous offshoots appeared in the eastern part of the flow that substantially increased its width.

At the end of October effusions from the eastern vent stopped

but the lava boccas at the base of the cone continued to be active. By this time the flow covered a distance of 10 km and descended to a height of about 800 m (near the Podkova crater).

On November 16th owing to an intensification of the eruption from the western vent the activity of lava boccas also increased. The main bulk of lava descended in an easterly direction of the first portion considerably increasing the total width of the flow.

Usually the lava was pouring out of the boccas in a wide quiet flow, but sometimes its activity increased and lava began to gush; and orange-yellow « splashes » were appearing; the lava level in the channel became considerable higher. Usually during such periods 2 or 3 boccas were active simultaneously.

At the end of November viscosity has been determined at two points in the top part of the flow at a distance of 100 m from each other. In the axial part of the flow the viscosity amounted to 4.3×10^6 and 6.6×10^7 poise; in the margins the figures were 5.8×10^7 and 5.8×10^8 poise correspondingly.

The effusion of lava continued also in December, when the explosive activity stopped. In the middle of December only one bocca was active, the two others stopped to exist. On the 17-19th of December the rate of flow was 90 m per hour and the temperature fell to 950-1000°. Yet the lava was very liquid and even foamy. However, at a distance of 150 m from the bocca the flow consisted already of a mass of stirring fragments. On December 24th the lava was still flowing from a narrow crevice and on the 25-26th of December the effusion stopped and the eruption actually was finished.

The movement of the frontal part of the flow stopped on January 5th, 1967 and its surface began covering with snow. The last portions of lava were not reaching the end of the flow and became solidified in its middle part gradually increasing its width and thickness.

The length of the flow was equal to 10 km, the width — from 300 m to 2 km, and the thickness — from 3 to 30 m. The volume of effused lava amounts to 0.1 km³.

By its composition the lava belongs to basaltic andesite. Phenocrysts are represented by labradorite An₅₇₋₅₈ and by magnesian olivine with 14-20% of FeSiO₃; there is also an admixture of augite. The groundmass amounts to 80-85% of the rock, its structure is hyalopilitic. The chemical composition of the lava is:

SiO ₂	52.48%	CaO	8.80%
TiO ₂	1.31%	Na ₂ O	3.70%
Al ₂ O ₃	17.82%	K ₂ O	1.17%
Fe ₂ O ₃	2.68%	H ₂ O ⁺	0.32%
FeO	5.86%	H ₂ O ⁻	0.08%
MnO	0.25%	P ₂ O ₅	0.13%
MgO	5.43%		

(analyst N. R. GUSSAKOVA)

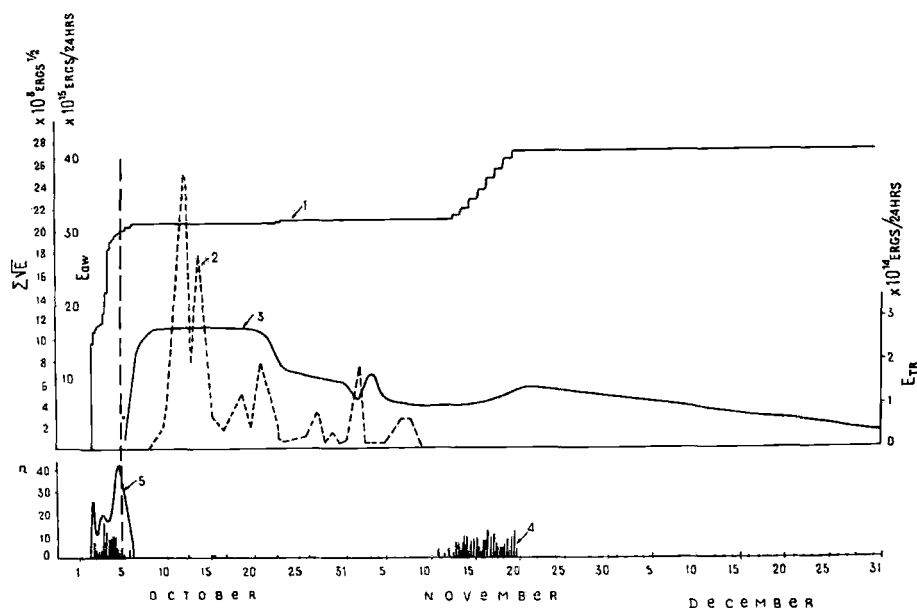


FIG. 7 - Characteristics of seismic activity. (1) - strain-rebound; sequence of all volcanic earthquakes ($\Sigma \sqrt{E}$); (2) - energy of air waves (E_{aw}); (3) - energy of volcanic tremor (E_{tr}); (4) frequency of volcanic earthquakes with $K > 5$ (n); (5) frequency of slight volcanic earthquakes with $K < 5$ (n). (n) - number of earthquakes for a six-hour period. The vertical dotted line represents the time of the beginning of the eruption. (After TOKAREV *et al.*, 1967).

In the conclusion — a few words about seismic activity. With the beginning of lava effusions the preliminary volcanic earthquakes completely stopped. It has appeared continuous volcanic tremors and a great number of explosive earthquakes.

The lava effusion was accompanying by volcanic tremor fully reflecting its character. The volcanic tremor maximum took place on October 8th (0.2μ). To October 22nd it was uninterrupted. With

the appearance of pulsations in the lava boccas and decreasing of the amount of the supplied lava the volcanic tremor began to decrease sharply at first and then gradually until a new intensification of the eruption.

On November 11-20 a swarm of earthquakes is recorded (210 earthquakes) and a certain intensification of volcanic tremors, and then its gradual extinction until the end of December. The total energy of volcanic tremors amounts to 10^{16} erg.

The eruption of the top explosive craters were accompanied by explosive earthquakes also entirely reflecting the character of their activity. Especially active they have been from the 10th to the 15th of October when their daily energy was equal to $3 \cdot 10^{15}$ erg. At the end of the activity of explosive craters the number of explosions dropped to one per day, while their energy increased to 10^{16} erg.

The microbarograph of the Volcanological Station has recorded 393 explosions from October 6th to November 9th with a wave energy $E = 10^{13}$ erg. The maximum of explosions is recorded for October 10-15th; after November 9th microbarograph did not record any explosions. The total energy of waves was 10^{17} erg.

Data of earthquakes and air waves are given in Fig. 7.

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