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ON THE RELATIONS BETWEEN SEISMIC AND VOLCANIC PHENOMENA AND THE ENERGY BALANCE OF THE BEZYMIANNY VOLCANO ERUPTION

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On the 22nd of October 1955, for the first time in history, an eruption of the Bezymianny Volcano on Kamchatka began, which lasted for over a year and proved to be very interesting.

The eruption can be divided into five stages:

I. Pre-eruption stage from the first volcanic earthquake to the first gas-explosion of the volcano, from September 29 to October 22, 1955.

II. Stage of strong ash eruptions of a volcanian type: from October 22 to the end of November 1955.

III. Stage of a moderate activity, from December 1955 to March 1956.

IV. Gigantic paroxysmal explosion on March 30, 1956.

V. Growth and development of the extrusive dome in the newly formed crater: from April to the end of 1956.

I. PRE-ERUPTION STAGE

The eruption was preceded by numerous earthquakes, the total number before the eruption being 1285. The first shock of this swarm of earthquakes was recorded on September 29, 1955; the displacement at the Volcanological Station in Klyuchi (45 km from the volcano) reached II μ. The number of shocks and their energy increased every day. From October 9, the earthquakes were already counted in one-two hundred per 24 hours.

On October 11th, the ground displacement in Klyuchi exceeded 100 μ; for the first time the epicentre (the region of the Bezymianny) and the focal depth were determined. From October 18 shocks were registered with amplitudes of 1000 μ and more. The nature of this earthquake swarm enabled us to be very confident of an eruption to follow soon and indeed the eruption point was determined quite correctly.

II. STAGE OF STRONG ASH ERUPTIONS

The eruption began at about 6.30 a.m. on the 22nd of October. During the first days the eruption was moderate, an ash-gas cloud not exceeding 1 or 2 km. rose above the crater. However, the energy of the explosions grew daily. From October 26 on, ever-growing ash-falls were taking place in a radius of 40-60 km. from the volcano. Judging from the starting points of the ash streams

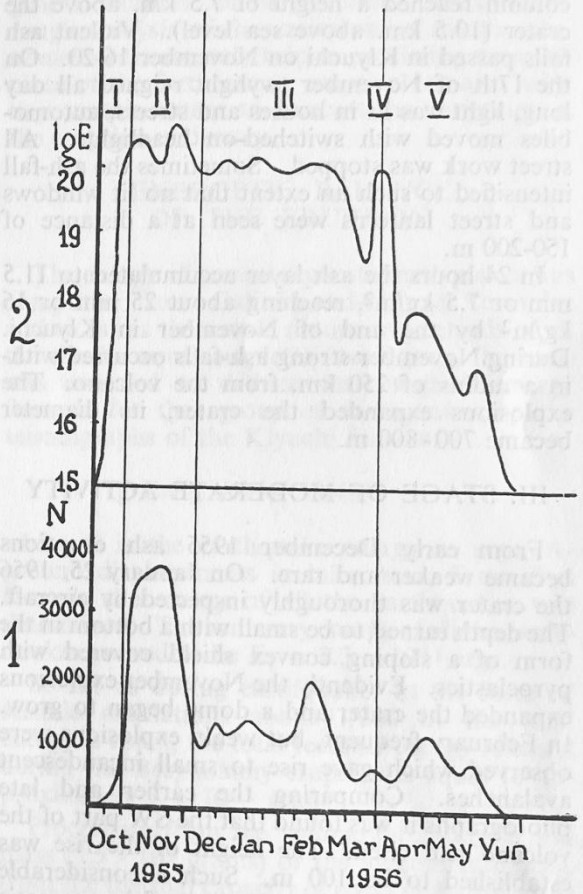

Fig. 1.—Diagram showing changes in number (1) and energy of earthquakes (2) in the course of the eruption. Roman figures indicate periods of eruption.

the diameter of the new crater did not exceed 250 m.

On November 7, the activity increased considerably. On the night of November 13 the ash cloud reached a height of 5 km. above the crater. All night long giant bright lightnings flashed in the eruptive clouds, the ash cloud moved to the East, reached the Pacific Coast, and moved further into the open ocean. On November 14 the ash column reached a height of 7.5 km. above the crater (10.5 km. above sea level). Violent ash falls passed in Klyuchi on November 16-20. On the 17th of November twylight reigned all day long, light was lit in houses and streets, automobiles moved with switched-on headlights. All street work was stopped. Sometimes the ash-fall intensified to such an extent that no lit windows and street lanterns were seen at a distance of 150-200 m.

In 24 hours the ash layer accumulated to 11.5 mm or 7.5 kg/m^2, reaching about 25 mm or 16 kg/m^2 by the end of November in Klyuchi. During November strong ash-falls occurred within a radius of 250 km. from the volcano. The explosions expanded the crater, its diameter became 700 - 800 m.

III. STAGE OF MODERATE ACTIVITY

From early December 1955 ash eruptions became weaker and rare. On January 25, 1956 the crater was thoroughly inspected by aircraft. The depth turned to be small with a bottom in the form of a sloping convex shield covered with pyroclastics. Evidently the November explosions expanded the crater and a dome began to grow. In February frequent, but weak, explosions were observed which gave rise to small incandescent avalanches. Comparing the earlier and late photographs it was found that the SW part of the volcano had risen. The height of the rise was established to be 100 m. Such a considerable rise suggests an extremely powerful magmatic pressure which could not have discharged itself by pressing up but one dome inside the crater.

IV. PAROXYSMAL EXPLOSION

Indeed, on March 30, 1956 the eruption reached its culmination. An enormous explosion occurred on that day and destroyed the top of the volcano and changed not only its shape but also the surrounding relief completely. This explosion and the accompanying phenomena are treated in a separate report ("Kamchatka Valley of Ten Thousand Smokes").

V. FINAL STAGE OF THE ERUPTION

Following the explosion on March 30 was the upheaval of an extrusive (endogenous) dome in the new crater. The growth of the dome was as usual followed by weak and moderate explosions and the formation of incandescent avalanches. At the end of July 1956 the formation of the dome was completed, its height reaching 320 m. above the crater bottom.

In late autumn 1956, the eruption ended entirely and in December, the dome, except the very summit, was already covered with snow.

EARTHQUAKES RELATED TO THE ERUPTION

The Bezymianny eruption was preceded and followed by numerous earthquakes. Their registration was made at the Klyuchi Volcanological Station, 45 km. from the volcano, with Kirnos seismographs with equal magnification 500 and intervals from 0.2 to 10 sec., as well as with Kharin seismographs with "peak" characteristics (magnification 10,000 at the period of 0.2 sec.). In both cases the registration was galvanometric on photographic paper.

The total number of shocks in Klyuchi for 9 months (from October 1955 to June 1956) was 33,150. The number of earthquakes and their energy are graphically expressed in fig. 1. The lower curve gives the summary figure of earthquakes for each decade in months, the upper the logarithm of seismic energy expressed in ergs for the same periods of time. As can be seen from the graph the number of earthquakes and their energy do not coincide. In the course of the eruption the number of earthquakes drastically changed, its energy being approximately on the same level for a long period of time.

In the pre-eruption stage the number of earthquakes and their energy rapidly increased and; by the end of that period the earthquake energy reached a constant value of the order of 10^{19} ergs per 24 hours whereas the number of earthquakes did not yet reached the maximum, being 200-220 shocks per 24 hours at the end of the period.

At the beginning of the eruptive stage the number of earthquakes rapidly reached maximum values of 350-400 per 24 hours. The drastic rise in number of earthquakes during that period was mainly due to very weak shocks which had practically no reflections on the energy balance. Corresponding computations showed that the drastic increase in the number of earthquakes

could be stipulated by intensity rise of the explosions. By the end of the stage of intense ash eruptions a decrease of explosions occurred simultaneously with no less rapid lessening of the number of shocks. On November 24, 303 shocks were registered, while next day the number was down to 100 per 24 hours.

Later, such high values as in the middle of November were no longer observed.

Despite the fact that in December 1955 and January 1956 the number of earthquakes drastically dropped and the visible volcanic activity decreased considerably, the energy of earthquakes retained its former level and a further eruption progress was expected.

In February 1956 a certain rise in the number of shocks took place which is likely to be related to movements of the dome and explosions giving rise to incandescent avalanches.

From the end of February there was a steady decrease of earthquake energy. It seemed that the eruption had been exhausted and came to an end. But precisely at the moment of seismic energy drop a giant explosion took place on March 30 which produced a sharp "peak" on the energy curve. Following this "peak" the seismic energy dropped down to 10^{14} ergs per 24 hours by late June 1956.

Despite a general drop of seismic energy during the growing phase of the dome the number of shocks in April and May 1956 noticeably increased reaching 300 per 24 hours on some days of April. This rise of shocks was likely to be related to the processes of the dome growth. By the end of June 1956 the number of earthquakes lowered down to 1 per 24 hours. By this time the dome was already mainly shaped. Extremely weak seismic activity continued gradually decreasing till the end of 1956.

All earthquakes connected with the eruption of the Bezymianny Volcano differ much from the usual local tectonic and volcano-tectonic earthquakes by their large period (2.5 to 3.0 sec. instead of 0.2) and peculiar maximum phase after the arrival of S waves. All more or less large earthquakes were analogous in every detail and had the same source and cause; they had an increased depth (about 50 km.) and were likely to occur in the zone of a volcanic hearth or in the lower part of the volcanic chimney.

The number of earthquakes and partly their intensity are directly related to the course of the eruption but as has been mentioned already, the curve of the earthquake number and their energy did not coincided. The reason for this discrepancy is that in the computation of shocks all oscillations are taken into consideration including very weak earthquakes connected with volcanic explosions and other separate surface phenomena. As to the energetic characteristics it primarily depended on stronger shocks which all without exception had an enhanced depth and were caused by deeper volcanic processes determining the general variation of the eruption. Thus, a thorough analysis of the variations of seismic phenomena can not only help in predicting time and place of the forthcoming eruption but also helps to a certain extent to forecast the variations of the eruption underway.

ENERGETIC BALANCE OF THE ERUPTION

The energy of several separate earthquakes was computed from Galitzin-and-Jeffreys formulae and so far as the record nature and periods of all the shocks were completely analogous, the basis was assumed to deduce the empirical energy formula for that group of earthquakes by the seismographs of the Klyuchi Station:

$$\lg E = \lg A^2 + 13.45,$$

where E is the earthquake energy in ergs, A-ground displacements in microns. From that formula the energy of all the earthquakes was determined. The summary energy of all the earthquakes proved to be $E_1 = 2.3 \times 10^{21}$ ergs.

So far as during earthquakes in the form of seismic oscillations about 1/300 of the total energy is spent, the total tectonic energy released during the Bezymianny eruption is equal to approximately 7×10^{23} ergs.

Proceeding from the volume (ab. 3 km.^{3}) and mass (5.5×10^9 grams) of the agglomerate flow, from the thermal capacity of rocks (1.1×10^7 ergs) and original temperature of the eruptive substance (minimum of 600°), the thermal energy of the eruption is determined to be 3.6×10^{25} ergs.

Thus, the tectonic energy of the eruption makes for no more than 2 per cent of the thermal energy. Hence it follows that magmatic energy should be considered as the primary factor, and the seismic effects as the secondary factor of the eruptions.

The energy of the explosion on March 30, 1956 can be estimated in several ways:

1. Calculations were made of the energy of the earthquakes connected with the explosion. The mean energy from data of five seismic stations in

the Far East was found to be $E = 10^{20}$ ergs. Counting that about 0.1 percent of the total energy of the eruption is emitted as seismic oscillations, it was determined to be 10^{23} ergs.

2. The explosion energy can be estimated by the air wave of the explosion (Taylor's formula)

$$E = \frac{2\pi\ RH \sin\gamma}{{}^{s}\rho_{o} V} \int P_{o}^{2} dt$$

where R is the Earth's radius, H - the height of a homogeneous layer of the atmosphere (13,000 m.), v - sound velocity, ρ_o - air density at the Earth's surface, γ - distance from the explosion source in degrees, P_o - pressure, t - time.

The average value of the air wave from records of eight meteorological stations located at a distance of 45-780 km. from the volcano made for 3×10^{22} ergs. During the volcanic explosions about 10 per cent of the total energy transforms into the air waves. Hence the explosion energy is about 3×10^{23} ergs.

3. The explosion energy can be also determined by the mass and velocity of the material ejected by the explosion.

$$E = \frac{mv^2}{2},$$

The mass of the material ejected by the explosion is estimated to be 1.2×10^9 tons, the average initial velocity of the explosion is equally 360m/sec. Hence kinetic energy of the explosion is about 8×10^{23} ergs.

The mean value of the explosive energy on March 30 is equal to 4×10^{23} ergs. Thus, the explosion energy makes for only one per cent from the total thermal energy of the eruption. As it can be seen the share of gaseous energy is more than modest. From this point of view the known state by F. Perret: "gas is the active agent and the magma is vehicle" is not correct. It is evident that the main active force of the eruption is thermal energy of the magma while gas is only a transformer of that energy into an explosive one and the efficiency of a volcano as a heat engine is very low.