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Some Results of Seismometric Investigations at the Kamchatka Volcanological Station.

(With 5 text-figures)

The Kamchatka Volcanological Station of the USSR Academy of Sciences is situated in the settlement Kliuchi at the foot of the highest volcano on the Eurasian continent the Kliuchevskaya « sopka », at a distance about 30 km from its summit.

Uninterrupted seismic observations at the Station are carried on from 1948. In 1948-1951 registration of earthquakes was done by means of two horizontal Nikiforov seismographs with optical recording (To = 2.0 sec., V = 350) and of two horizontal Bosh-Omori seismographs with mechanical recording (To = 22,0 sec., V = $\sim$ 2). In 1951, these devices were replaced by a three-component installation of Kirnos seismographs with a galvanometric recording upon photographic paper (magnification about 500 in an interval from 0,2 to 10,0 sec.) to which (in 1954) was added a three-component set of Kharin seismographs with a galvanometric record upon photographic paper (magnification 10000 at a period of 0,2 sec.).

During the time elapsed since 1948, there occured four eruptions of the Kliuchevsky volcano (lateral outbreaks in 1951, 1953 and 1956, a summit eruption in 1954) and one eruption of the sopka Bezymiannaya (1955-1956), in relation to which were recorded numerous earthquakes. Besides, in 1948, was noted a swarm of powerful earthquakes, that had no obvious connections with volcanic phenomena.

A part of the earthquakes as to the record character on seismograms and, apparently, as to origin, is not distinguishable from usual local tectonic earthquakes in non-volcanic regions (fig. 1). They have a

highly sharp beginning of P and S phases with a period of about 0,2 sec. The most powerful among those earthquakes are felt as sharp vertical shocks, force up to VI. It is logically inexpedient to call earthquakes, provoked by tectonic causes « volcanic », only for the reason that their epicenter is situated in the volcano region. For such earthquakes we propose the name « volcanotectonic » in the aim of

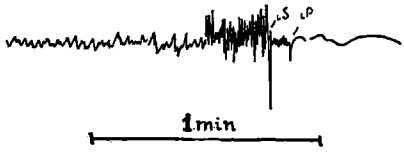

Fig. 1 - Volcano-tectonic earthquake from a swarm, fore-runing to Bylinkina crater eruption.

underlining their tectonic character and their relation to zones and phenomena of volcanism.

The other part of earthquakes according to the record's character is strikingly different from tectonic ones by great wave periods and a less clear start of the P and S phases, and also by the presence of a peculiar maximum phase after preliminary phases (fig. 2). The most powerful among these earthquakes with displacement amplitudes at

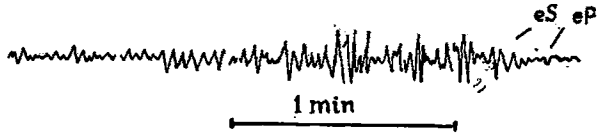

Fig. 2 - Volcanic earthquake, connected with Bezymianny Volcano eruption.

the Station up to 1000 μ and more are not felt due to a long vibration period and can be recorded (without any seismograph) only due to the vibration of hanging objects. Close to the epicenter, they are felt as usual earthquakes. Such earthquakes are unknown outside regions of active volcanism and are purely « volcanic ». A particular case of volcanic earthquakes is the « volcanic tremor ».

Particularities of earthquakes connected with the Kliuchevskaya sopka

Formation of new lateral craters was preceded by a swarm of earthquakes. According to the record character, among them prevailed volcano-seismic shocks. Only in one case — in 1948 — after an

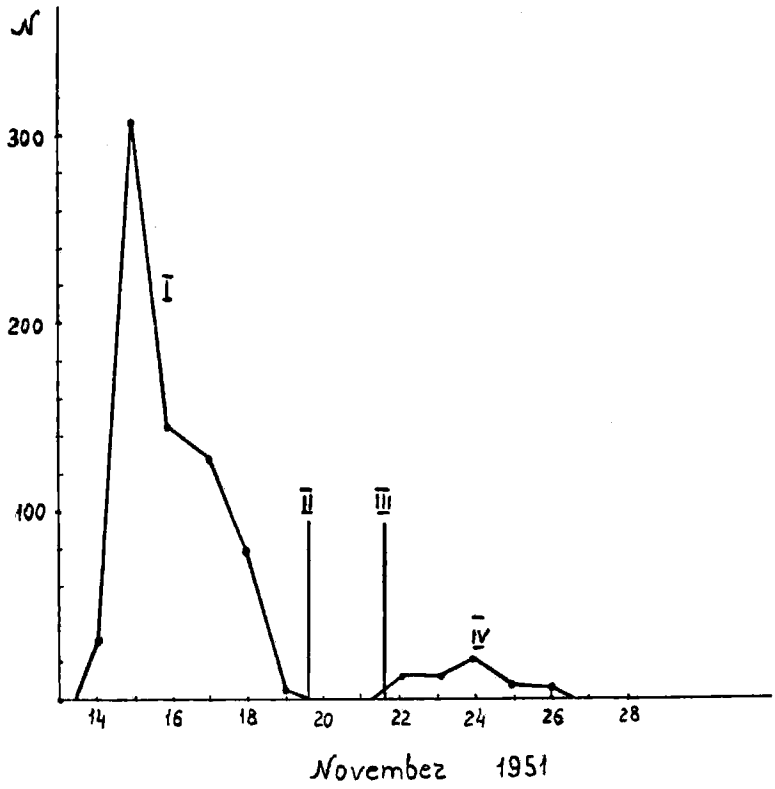

Fig. 3 - Diagram showing changes in the number of earthquakes in the course of the Bylinkina Crater eruption. I - the total number of shocks, II - the beginning of the lateral eruption and continuous volcanic tremor, III - the end of lava outpouring and continuous volcanic tremor, IV - posterior earthquakes.

intensive swarm of earthquakes followed no eruption. The force of preliminary earthquakes is usually about directly proportional to the force of the subsequent eruption. Thus, the most powerful eruption — of the Bylinkina crater (1951) — was preceded by an intensive

swarm of shocks, the epicenter of which coincided with the point of the next crater outbreak, and the very weak eruption of the Vernadsky and Krijanovsky crater (1956) was preceded by exclusively weak shocks, from which it was impossible to establish even the S - P phases difference.

The outbreak of new lateral craters starts during a sharp decrease in the number of shocks; in a most striking way, this was manifested during the outbreak of the crater Bylinkina (fig. 3). With the start

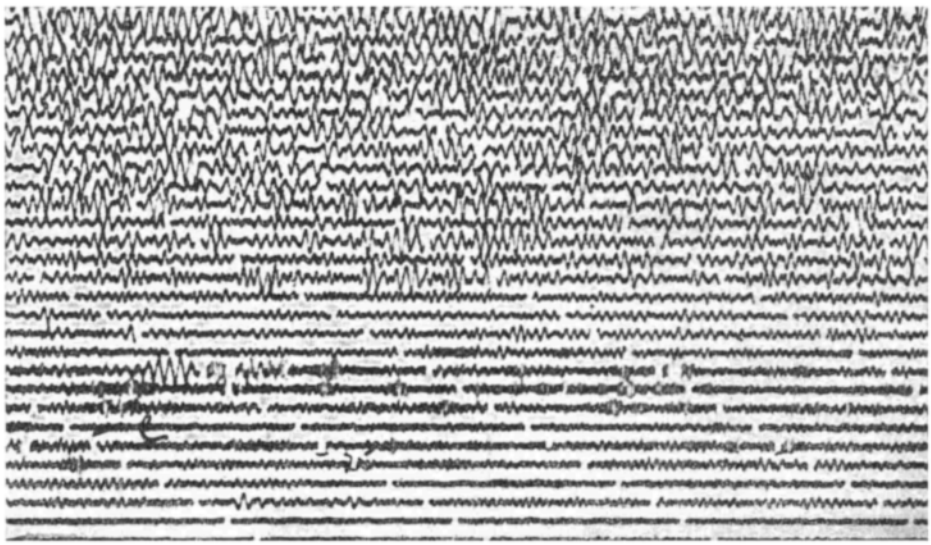

Fig. 4 - Relation and stopping of the continuous volcanic tremor (Bylinkina Crater eruption).

of lateral eruption seismic shocks stopped entirely or almost entirely. Along with this, shortly before the eruption or at its start, there can arise volcanic tremor, the intensity of which reflects, on the whole, tension of the eruption. Thus, twenty four hours before the outbreak of the crater Bylinkina, was noted a weak spasmatic volcanic tremor. At the moment of the outbreak, the tremor became uninterrupted. At the Station, 22 km away from the crater, the tremor period was 1,5 sec., whereas the amplitude — up to 15 μ. With the close of the lava effusion, the volcanic tremor weakened and sopped altogether (fig. 4).

It is necessary to note that separate explosions in lateral (and in

the central) craters were not accompanied by earthquakes and left no trace on the seismograms.

Data obtained at the Station allow to think that, at present, there is a possibility to predict eruptions of new lateral craters of the Kliuchevsky volcano according to seismic data. The epicenter of preliminary earthquakes indicates the region of the awaited outbreak, and their force — the intensity of the subsequent eruption. There is no sufficient material accumulated in order to predict summit eruptions of the Kliuchevsky volcano, as there was observed only one weak eruption (1954), preceded and accompanied by a weak volcanic tremor with no preceding swarms of seismic shocks. It is possible to presume that strong eruptions will also precede by preliminary earthquakes with an epicenter in the region of the volcano summit.

Particularities of earthquakes connected with the volcano Bezymianny

The volcano Bezymianny is situated at 43 km from the Volcanological Station. Seismometric studies were carried on its first historical eruption (1955-1956). During the time of the eruption were recorded more than 30000 volcanic earthquakes. A swarm of earthquakes with an epicenter in the volcano region began three weeks before the eruption. The start of the eruption coincided, contrary, to the one that took place at the Kliuchevsky volcano, with a period of sharp increase in the number of shocks, but when the earthquakes energy reached already a maximum. The greatest number of shocks was observed during the Volcanian phase of the eruption and then there was a sharp fall in the number of earthquakes. This fall, however, was not accompanied by a decrease of the total energy of earthquakes (during 24 h).

The culmination explosion on the 30th of March 1956 coincided in time with a sharp fall in the earthquakes' energy. This explosion was accompanied by a powerful earthquake ($E = 10^{20}$ ergs) that was reflected on the energy curve by a sharp « peak »; then was renewed a further fall of energy. The course of changes in the number of earthquakes and in their power in time (as to decades) is given on fig. 5.

Obviously, in the course of the eruption of sopka Bezymiannaya, there occured two different kinds of earthquakes; the weaker one had a surface hypocenter and an unsignificant power. Increase or decrease

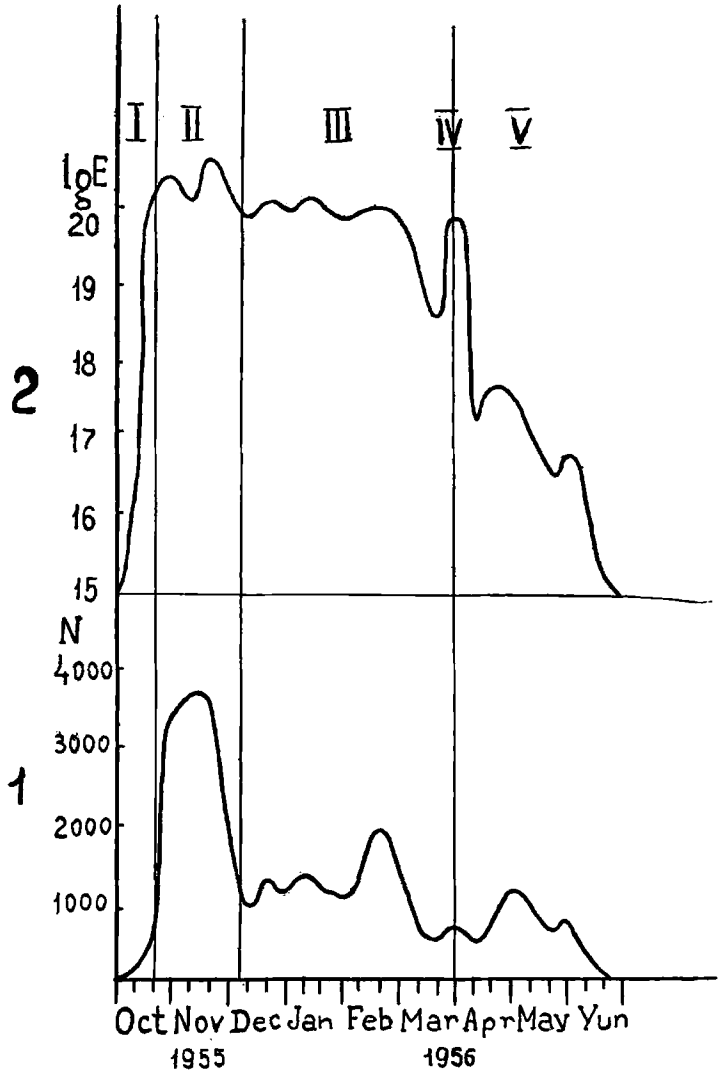

Fig. 5 - Diagram showing changes in the number (1) and energy of earthquakes (2) in the course of the Bezymianny Volcano eruption. II - Volcanian phase of the eruption, IV - culmination explosion of March 30, 1956.

in the number of these earthquakes reflected outer phenomena of the eruption, but did not influence noticeably the total energy of earthquakes. The second category of earthquakes had an energy reaching $10^{19} - 10^{20}$ ergs. with a hypocenter at a depth of about 50 km. These

earthquakes did not depend upon outer manifestations of the eruption, and changes in their power stood in dependence of deeper causes, that determined the general course of the eruption.

Studies of changes in the earthquakes' energy in the course of a durable (as to time) eruption will allow, apparently, to foresee its general course.

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Seismometric observations at the Kamchatka Volcanological Station allow to think the seismic method one of the most perspective as to prediction of eruptions. At the same time, obtained results show that each volcano has its own particularities in the connection between volcanic and seismic phenomena; for aims of a certain prediction it is necessary to make a careful preliminary study of these features.

Discussion

H. Tazieff: J'aimerais savoir si vous avez des enregistrements de tremblements de terre non suivis d'éruption et si vous avez déterminé la profondeur du foyer du themblement de terre précédant l'éruption.

G. S. Gorshkov: Nous avons actuellement une seule station, qui est trop petite pour pouvoir réaliser de telles études.

J. Rothé: M. Gorshkov a soulevé la question des différents types de tremblements de terre se produisant à proximité d'un volcan. Il est certain qu'il y a toute une série de séismes différents. Par exemple, dans le cas de Faïal, certaines grandes secousses ont été inscrites dans les stations européennes; lors du début de l'éruption de l'Hekla en Islande, en 1949, un séisme a été également enregistré dans des stations à grande distance; cela se produit aussi pour des séismes des îles Hawaii. Il est évident que l'on n'a pas eu l'inscription de séismes locaux provenant du voisinage immédiat du volcan, mais de séismes volcano-tectoniques du genre de ceux dont a parlé M. Gorshkov.

Je crois que nous ferions oeuvre utile en essayant de réaliser une classification de ces séismes volcaniques, volcano-tectoniques et purement tectoniques et en publiant un petit atlas de séismogrammes typiques correspondant à chacune de ces catégories.

G. Macdonald: Je me demande comment différencier les tremblements de terre volcaniques des tremblements de terre volcano-tectoniques ou purement tectoniques.

G. S. Gorshkov: Uniquement par les enregistrements des séismographes de toutes les stations. Dans les tremblements de terre volcaniques la différence est d'environ 2, 4, 5 secondes. Je pense cependant que de tels tremblements de terre peuvent être aussi en rapport avec des mouvements tectoniques.

A. RITTMANN: Le projet de M. ROTHÉ tendant à la classification des différents types de tremblements de terre m'intéresse beaucoup. À l'Etna, par exemple, nous avons des séismes volcano-tectoniques, tectoniques régionaux et, naturellement, volcaniques; mais tous se produisant au voisinage du volcan lui-même, il n'est pas possible de les différencier par la localisation propre à chacun d'eux. La possibilité de distinction est à rechercher dans les caractéristiques mêmes des tremblements de terre, dans les périodes et la succession des différentes phases. Il faudrait que toutes les personnes qui travaillent sur cette question cherchent à se mettre d'accord sur la manière de faire cette classification et nous présentent leurs résultats.

E. BERG: Cette discussion ne peut se faire sans les séismogrammes, étant donné la diversité des appareils enregistreurs. Il y aurait d'ailleurs une instrumentation à mettre au point préalablement.

B. GÈZE: Je ne pense pas que nous ayons le temps de discuter valablement ces très grands problèmes. Il serait souhaitable que les volcanologues et les séismologues mettent la question à l'ordre du jour de la prochaine Assemblée Générale de l' U.G.G.I. ou prévoient même l'organisation d'un symposium strictement sur ce sujet.

A. RITTMANN: Chacun devra présenter ses séismogrammes et ses remarques afin de préparer la mise au point commune qui aboutira à une synthèse d'ensemble.

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