Prediction of Volcanic Eruptions and Seismic Methods of Location of Magma Chambers - A Review *

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Prediction of Volcanic Eruptions

Catastrophic volcanic eruptions are one of the most formidable natural phenomena, which sometimes take away the lives of hundreds and thousands of people and lead to enormous property losses. A prompt prediction of time, place, intensity and nature of eruption would allow us to reduce to a minimum such losses. Therefore the prediction of eruptions is one of the basic practical problem of volcanology.

The International Association of Volcanology has already discussed the questions connected with prediction of eruptions in two symposia, in Paris in 1959 and in Tokyo in 1962. The Paris symposium of 1959 has worked out special recommendations which are still valuable (GEZE, 1960). At present, UNESCO is paying much attention to this problem. Consequently a review of the work made and of the results obtained, and the discussion of the direction of further studies on prediction seem to be extremely important. This review deals with the works accomplished and published only in the last 10 years, *i.e.* from 1959.

Prediction studies are based on the observation of reliable premonitory symptoms of eruptions. Such forerunners may be either of geophysical nature — earthquakes; tilt of surface caused by defor-

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* Paper presented at the Symposium « Volcanoes and Their Roots », Oxford, England, Sept., 1969.

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mation of the volcanic edifice; variations in the magnetic or electric field, etc. —, or of geochemical nature — variations in composition and temperature of fumarole gases and volcanic mineral springs and crater lakes.

A significant role is played by volcanic zonation, *i.e.* a preliminary delimitation of the zones dangerous during eruptions.

Geophysical methods of prediction

a) *Preliminary earthquakes*

Studies on the possible relation between preliminary earthquakes and subsequent eruptions have most intensively been carried out in Japan, USSR, Hawaii and New Zealand (Gorshkov, 1959, 1960, 1961; Tokarev, 1963, 1964, 1966; Macdonald, 1959, 1960; Minakami, 1959, 1960; Minakami *et al.*, 1959, 1960; Suwa, 1965; Yasui, 1963; and others).

Nearly every eruption or increase in volcanic activity is preceded by a swarm of earthquakes. Preliminary earthquakes were observed in the small islands (Macdonald, 1960; Taylor, 1963; Adams and Dibble, 1966), in the inner parts of the continents (Berg and Janssen, 1960), and in the island arcs (Gorshkov, 1960; Minakami, 1960). One can say quite definitely now that no significant eruption will be unexpected in those volcanic regions where there is a continuous seismological control. Unfortunately, relationships between seismic and volcanic activities are specific for each volcano. So far, it is impossible to give a general formula valid for all the volcanoes to predict a precise time of eruption. However, epicenters of preliminary earthquakes indicate rather accurately the place of the forthcoming eruption.

In certain cases as, for instance, during the outbreak of adventive craters of the Kliuchevskoy volcano (Gorshkov, 1960; Tokarev *et al.*, 1968) or at the Sakurajima volcano (Yasui, 1963) eruptions began during a sharp decrease in the number of preliminary earthquakes, and earthquakes actually completely ceased at the beginning of the eruption. In other cases, for example at the Bezymyanniy volcano (Gorshkov, 1959, 1961) or at the Asama volcano (Minakami, 1959, 1960), eruptions began during a sharp increase in the number of preliminary earthquakes, which did not end even with the beginning of eruptive activity. For the Asama volcano, where continuous observations have been carried out for almost 60 years, an empiric relationship is deduced to correlate the number of earthquakes in the swarm and the probability of an eruption.

A quite promising method takes into account not only the number of earthquakes but also their energy. Thus it was observed with regard to the Bezymyanniy volcano that between eruptive phenomena and energy of accompanying earthquakes these exist certain connections. A paroxysmal explosion on March 30, 1956 tock place during a decrease of the total energy of earthquakes (GORSHKOV, 1959, 1960, 1961).

P. I. TOKAREV (1963, 1966) suggested a method of prediction of eruption based on the curve of accumulation of conventional deformation ($\Sigma \sqrt{E}$) (strain-release parameter of Benioff), and gave the following equation for the Bezymyanniy volcano:

$$T_{ui} = t_i \left(1 - \frac{a}{\varepsilon_i} \right) + a$$

where T_{ui} is the day of the beginning of the eruption; ε_i is a conventional deformation for t_i days; a is an experimental coefficient.

According to Tokarev this equation is valid universally for predicting eruptions of all volcanoes.

To predict an eruption it is important studying not only the numeber and energy of preceding earthquakes but also the mechanics and the depth of the focus (MINAKAMI, 1964; MINAKAMI *et al.*, 1960) and spatial distribution of epicenters. Thus at the Aso volcano in 1965-66, before the eruption, epicenters were concentrated in a narrow zone while after the eruption they were scattered over a vast area. The character of the first movement changed as well (WADA and SUDO, 1967).

Epicenters of earthquakes may be situated beyond the limits of a volcano. In this case the eruption is improbable and thus it is possible to prevent unreasonable fears in the population. This, for instance, was the case of the Kotsu-sima island in 1965 (SHIMOZURU and HORIGOME, 1967).

At present a system of teleseismographs with transmission of data by radiochannel is being arranged (KUBOTERA and YOSHIKAWA, 1963; LATTER, 1969, pers. comm.). Such installations would simplify to a great extent the control of vast areas. Recording on magnetic tape (DBBLE, 1966) allows a direct introduction of data into the electronic computer, for instance for a continuous counting of energy. Combination of teleseismographs and tape-recording with electronic computers will automatize seismic computations and facilitate greatly the problem of prediction of eruptions.

During recent years Blot and Priam have drawn attention to the fact that many eruptions are preceded by strong deep tectonic earthquakes several months earlier (BLOT and PRIAM, 1963; PRIAM, 1964; BLOT, 1965). WARD and MATUMOTO (1967) deny such a connection though TOKAREV (1959) pointed out earlier that a positive correlation is observed in the Kurile-Kamchatka zone between eruptions and earthquakes with $M \geqslant 6$ and with depth of 70-150 km. A further statistical control of the available data is necessary.

Before the eruptions and more often during them, a specific type of volcanic earthquake is recorded — volcanic tremor. There are many types of tremors, connected with explosions in the crater, with effusion of lava flows, with underground magma movement, and so on. The source of tremors is usually at a small depth; however, subcrustal sources are evidently also possible (GORSHKOV and DUBIK, 1970). Inspite of the vast literature on volcanic tremor this phenomenon is still insufficiently studied. It is possible that volcanic tremor would be an additional source of information for the prediction of eruptions and their types.

As it was said at the beginning of this report, almost every eruption is preceded by earthquakes bur earthquakes are not always an undisputable indication of eruption. Sometimes, after a rather intensive earthquakes swarm the volcano does not intensify its activity (GORSHKOV, 1960; EIBY, 1966; MINAKAMI, 1964). This fact makes the prediction of eruptions an even more difficult task. Therefore it is necessary to combine seismic observations with other methods, of which one of the most common is the geodetic method.

b) *Geodetic methods*

Observations of tilting of the Earth's surface and deformation of volcanic edifice are carried out most widely in Japan (MOGI, 1958; YOSHIKAWA, 1961-1962; KUBOTERA and YOSHIKAWA, 1963; etc.) and in the Hawaiian islands (MACDONALD, 1959, 1960). Observations of tilt became considerably simpler thanks to the Eaton portable watertube tiltmeter (EATON, 1959) (¹).

As a result of tilt observations it was shown that before the eruptions of the Hawaii volcanoes the summit part elevates and the tilt increases, while after the eruption the reverse process takes place.

At the Sakurajima volcano before the eruption an anomalous tilt occurs in a definite direction. The direction of tilt is evidently specific of each volcano. However, by combining earthquake and tilt observations, the accuracy in predicting eruptions increases.

Observations of deformations are carried out also with the help of extensometers. Thus at the Sakurajima volcano it was observed that a compression along the vertical occurs before eruption.

Deformations along the horizontal and vertical directions are also detected by levellings and triangulations. At the Hawaii islands it was observed that horizontal extension of the Kilauea crater takes place before eruption. During the last years R. W. Decker has used tellurometers (with the frequency of 10,000 MC) and geodimeters to study horizontal deformations. The accuracy of measurements with this apparatus reaches 4-7 mm per km and the measurements themselves become considerably simpler (DECKER *et al.*, 1966; DECKER and WRIGHT, 1968).

c) *Magnetometric methods*

Observations in the neighbourhood of some volcanoes showed that variations in the activity of volcanoes were accompanied by variations in the local magnetic field.

By researches on Mihara volcano carried out since 1950 it was shown that several months before eruption an increase in the westward drift of declination occurred. This phenomenon is evidently caused by demagnetization of rocks while they are heated higher than the Curie point (RIKITAKE *et al.*, 1963).

Variations in the magnetic field caused by variation in volcanic activity are observed also in the Kurile islands (BERNSTEIN, 1960), and at the Avacha volcano in Kamchatka (RYNDIN, 1964).

The author believes that variations in the magnetic field are

(¹) With a base of 4 m an accuracy of 3×10^{-6} radians is achieved. With a base of 50 m the accuracy of measurements increases up to 0.2×10^{-6} radians (0.04 sec of arc).

among the most promising forerunners of eruptions but the investigations in this direction are still few so far. Study of the magnetic field near active volcanoes must be intensified.

Geochemical methods of prediction

Researches on the composition of volcanic gases in connection with the prediction of eruptions have been carried out in Japan and in USSR (Iwasaki *et al.*, 1963; Noguchi, Kamiya, 1963; Surnina, Voronova, 1964; Menyailov, Nikitina, 1967). Usually when collecting gas samples, the temperature is measured so that chemical composition and temperature can be considered jointly.

The investigators have contradictory opinions as to the regularities in temperature variation. Thus, Neumann van Padang from observations made in Indonesia, has pointed out that before eruptions there was no remarkable rise of temperature (Neumann Van Padang, 1963). Continuous observations of temperatures in the crater of the Aso volcano over a long period of time have shown that an intensification of activity takes place usually after a sharp increase and a consequent decrease in temperature. Two-three days after the beginning of the decrease in temperature the eruption is possible (Taneda, 1963).

Temperature measurements can be made by infrared radiometers (Decker and Peck, 1967). In this case observations are possible from an airplane and even from artificial Earth's satellites (Fisher *et al.*, 1964; Moxham, 1967).

It must be pointed out that during strombolian eruptions extremely sharp and rapid variations occur both in the composition and temperature of gases (Tazieff and Tonani, 1963; Tazieff *et al.*, 1968). In fumarole fields, in inter-eruptive and pre-eruptive periods, these variations are evidently much slower.

It is observed that absolute contents of HCl and SO_2 increase before eruption. In many cases also the ratio S/Cl increases (Menyailov and Nikitina, 1967; Noguchi and Kamiya, 1963). In the waters of hot springs and crater lakes a significant increase in Cl was observed (Zelenov and Kanakina, 1962; Sidorov, 1966; Kayama *et al.*, 1963).

In recent years, chromatographic methods have been used to analyse volcanic gases, which simplifies considerably and expedites collection of results. I. Elskens has developed a gas telechromatograph with transmission of data by radiochannel (TAZIEFF, 1967). At present it is quite possible to automatize the analysis of volcanic gases and the measurements of fumarole temperature with transmitting data by wire or radio. In the near future we may expect a rapid accumulation of data on the relation between composition and temperature of fumarolic gases and state of volcanoes. The role of these date in the prediction of eruption will evidently increase.

VOLCANIC ZONATION

By volcanic zonation we mean a compilation of maps for each individual volcano with indication of the zones which could be dangerous in case of explosions, effusion of lavas, pyroclastic- and mudflows, etc.

In volcanic zonation, topography of the volcano and of adjacent areas are taken into consideration as well as composition of lava, character of the former eruptions, period of the year, wind directions, presence of crater lakes, snow and other factors. Attention is paid to the steps to be taken to evacuate people, to remove valuable property, etc. (VLODAVETZ, 1959, 1960; GORSHKOV, 1963; HEARLY, 1963; ZEN and HADIKUSUMO, 1965; NEUMANN VAN PADANG, 1960). This part of the volcanological science is developed sufficiently well, and by a preliminary zonation many thousand people have been saved in Japan, Indonesia and in other countries.

Seismic Methods of Location of Magmatic Chambers

Until recently, all considerations on the depth of magma chambers were purely speculative. The first experimental approach was made in Kamchatka. It was based on the screening effect of transverse seismic waves by a liquid magma chamber, discovered by the author (GORSHKOV, 1956). This result was reported at the IUGG XII General Assembly in Toronto (GORSHKOV, 1958). It was shown that transverse seismic waves of distant earthquakes when passing under the Kliuchevskaya group of volcanoes at a depth of 50-70 km, are subjected to a sharp weakening. The most probable reason of the seismic shadow is the presence at this depth, *i.e.* in the upper part of the mantle, of a vast magmatic reservoir.

This result has been for several years the only experimental proof of the existence of a magma chamber in the upper mantle. Then attenuation of transverse seismic waves was discovered on the records of nearby earthquakes in the region of the Avachinskaya group of volcanoes in Kamchatka (FEDOTOV and FARBEROV, 1966). In this case the record was made at 5 seismic stations taking into account the corrections for ground-geologic conditions of the stations. From the data on 117 earthquakes with hypocenter depth from 0 to 120 km it was shown that at a depth of 20-80 km under the Avachinskaya group of volcanoes there is a zone where transverse seismic waves are screened. The diameter of this zone reaches 25 km. The volume of liquid material in this zone is about 20 % of the total volume based on a rough estimation. The absorption coefficient of transverse seismic waves at depths of 35-80 km at the frequencies of 1-2.5 Hz has a value of 0.039 ± 0.012 km^{-1}, which is 4 times more than the normal value for the arc as a whole. The zones of anomlaous absorption of transverse seismic waves were discovered by studying records of nearby earthquakes in the Kliuchevskaya group and in certain volcanoes of eastern Kamchatka (GORELCHIK and FARBEROV; FIRSTOV and SHIROKOV, in press). These zones, located in the subcrustal parts of the mantle at depths of 30-140 km, are interpreted as zones of reduced viscosity corresponding to magmatic chambers. An extremely interesting fact is a vertical elongation of these zones somewhat tilted towards the dip of the focal zone of earthquakes.

A similar research was made in the region of the Katmai volcano in Alaska (KUBOTA and BERG, 1967). Here, on the basis of the records of local earthquakes at 3 seismic stations the screening effect of transverse seismic waves was also observed. In this way the existence of 10 small magma chambers was established at depths from 10 to 50-70 km. The chambers at depths up to 20 km correspond to specific volcanoes. Deeper chambers have not a spatial connection with particular volcanoes.

The methods of seismic prospecting were used in Kamchatka for location of the upper part of a feeding channel during the eruption of the Piip crater (BALESTA and FARBEROV, 1968).

Experiments on determining depth and form (and also the elastic properties of the material) of magmatic chambers are still a few so far. These experiments disagree sometimes in details but the existence of subcrustal magma chambers is not in doubt.

The methods of seismic location of magma chambers promises to give new important data on where the magmas originate and on the ways of their uplift to the surface. Further observations are necessary as well as experimental and theoretical works on this topic. Complex researches with application of other geophysical methods (magnetotelluric sounding, gravimetry, magnetometry) will undoubtedly improve the results.

General Conclusions

Researches on prediction of eruptions are directed towards reliable forerunners of forthcoming eruptions. Geophysical and geochemical methods of investigations are used, each of these methods having in separte cases been successful. Among. geophysical methods, recording of preliminary earthquakes is the most common. Together with observations on the deformation of the volcanic edifice (tiltmetry, in partucular) the seismic method seems to be the most trustworthty.

In those regions where a systematic control is made « unexpected eruptions » cannot occur already. However, there is no method of precise volcanic prediction so far. The place of the forthcoming eruption can be indicated easily, but the accuracy of determination of the time of eruption is still very low. In addition, any forerunner may be « false alarm » followed by no eruption at all.

It is highly probable that complex researches including all geophysical and geochemical methods are needed, and we do believe that a continuous control at each volcano may result in a series of reliable forerunners. Researches are becoming simpler and more rapid, in part thanks to the introduction of the most recent techniques (automatization and utilization of electronic computers). In a distant future it may be possible to « exploit » the volcanic heat, if secondary magma chambers really exist at a depth of a few km, and thus to prevent all the eruptions in general, obtaining, « on the way », energy for the national economy.

As far as each volcano is concerned, a general theory of prediction of eruptions is possible only on the basis of a general theory of volcanism. At present our science is still very far from such a general theory. Fundamental studies of general regularities in volcanic activity are necessary for a scientific approach to the practical problem of the general prediction of eruptions.

References

ADAMS, R. D. and DIBBLE, R. R., 1966, *Seismological studies of the Raolt Island eruption, 1964.* Bull. Volc., T. 29, p. 5-6.

BALESTA, S. T. and FARBEROV, A. I., 1968, *Seismic studies of Piip Crater break-through.* Bull. Volc., t. 32, fasc. 2, p. 395-399.

BERG, E. et JANSSEN, Th., 1960, *Microséismes et séismes précédant l'éruption du Nyamuragira-Kitzimbanyi (Afrique Centrale) 1958.* Bull. Volc., ser. 2, t. 23, p. 63-68.

BERNSTEIN, V. A., 1960, *On magnetometric investigations in vicinity of volcanoes.* Bull. Volc., ser. 2, t. 23, p. 129-133.

BLOT, C., 1965, *Relations entre les séismes profonds et les éruptions volcaniques au Japon.* Bull. Volc., t. 28, p. 25-63.

——— et PRIAM, R., 1963, *Volcanisme et séismicité dans l'Archipel des Nouvelles-Hébrides.* Bull. Volc., t. 26, p. 167-180.

DECKER, R. W., HILL, D. P. and WRIGHT, T. L., 1966, *Deformation measurements on Kilauea Volcano, Hawaii.* Bull. Volc., t. 29, p. 721-731.

——— and PECK, D. L., 1967, *Infrared radiation from Alae lava lake, Hawaii.* U. S. Geol. Survey, Prof. Paper 575-D, p. D169-D175.

——— and WRIGHT, T. L., 1968, *Deformation measurements on Mauna Loa Volcano, Hawaii.* Bull. Volc., t. 32, fasc. 2, p. 401.

DIBBLE, R. R., 1966, *Seismic recordings of subterranean volcanic activity at Ruapehu during 1964.* Bull. Volc., t. 29, p. 761-762.

DMITRIEV, L. B., 1967, *Repeated geodesic measurements at Avacha Volcano.* Bull. Volc., St., N 43, p. 23-26. (in Russian).

EATON, J. P., 1959, *A portable water-tube tiltmeter.* Bull. Seism. Soc. Amer., Vol. 49, N 4, p. 301-316.

EIBY, G. A., 1966, *Earthquake swarms and volcanism in New Zealand.* Bull. Volc., t. 29, p. 61-73.

FARBEROV, A. I. and BALESTA, S. T., 1966, *On researches of volcanic tremor.* Bull. Volc., St., N 40, p. 45-60 (in Russian).

FEDOTOV, S. A., FARBEROV, A. I., 1966, *On screening of shear seismic waves and on magmatic chamber in the upper mantle under Avacha Volcano region.* Coll. « Volcanism and deep structure of the Earth ». Publ. « Nauka », p. 43-48 (in Russian).

FISHER, W. A., MOXHAM, R. M., POLCYN, F. and LANDIS, C. H., 1964, *Infrared survey of Hawaiian volcanoes.* Science, Vol. 146, p. 733-742.

GÈZE, B., 1960, *Compte-rendu des séances du symposium sul la surveillance des volcans actifs, la protection en cas d'éruption et l'utilisation des l'energie volcanique (avec Recommendations).* Bull. Volc., ser. 2, t. 23, p. 3-20.

GORELCHIK, V. I., 1964, *Seismological investigation of the activity of Karymsky volcano.* Bull. Volc., St. N 36, p. 17-23. (in Russian).

GORSHKOV, G. S., 1956, *On the depth of magmatic chamber of Kliuchevskiy Volcano.* C. R. (Doclady) Ac. Sc. USSR, Vol. 106, N 4, p. 703-705 (in Russian).

———, 1958, *On some theoretical problems of volcanology.* Bull. Volc., ser. 2, t. 19, p. 108-113.

GORSHKOV, G. S., 1959, *Gigantic eruption of the Volcano Bezymianny.* Bull. Volc., ser. 2, t. 20, p. 77-109.

————, 1960, *Some results of seismometric investigations at the Kamchatka Volcanological Station.* Bull. Volc., ser. 2, t. 23, p. 121-128.

————, 1961, *On the connection between volcanic and seismic phenomena during the eruption of Bezymianny Volcano (1955-1956).* Bull. Volc., St. N 31, p. 32-37. (in Russian).

————, 1963, *Directed volcanic blasts.* Bull. Volc., t. 26, p. 83-88.

———— and BOGOYAVLENSKAYA, G. E., 1965, *Bezymianny Volcano and characteristics of its last eruption, 1955-1963.* Publ. « Nauka » (in Russian).

————and DUBIK, Yu. M., 1970, *Gigantic directed blust at Shiveluch Volcano (Kamchatka).* Bull. Volc., t. 34-1, p. 261-280.

———— and KIRSANOV, I. T., 1968, *Eruption of Piip crater (Kamchatka).* Bull. Volc., t. 32, fasc. I, p. 269-282.

HEALY, J., 1963, *The broad approach to volcanic prediction.* Bull. Volc., t. 26, p. 141-151.

IMBÒ, G., CASERTANO, L. and NAPOLEONE, G., 1968, *Seismicity of Vesuvius on its present state of activity.* Bull. Volc., t. 32, fasc. 2, p. 425-435.

IWASAKI, I., OZAWA, T., YOSHIDA, M., KATSURA, T., IWASAKI, B. and KAMADA, M., 1963, *Nature of volcanic gases and volcanic eruption.* Bull. Volc., t. 26, p. 73-81.

JOLIVET, J., 1960, *Surveillance géophysique et géochimique des volcans des Antilles francaises. Possibilité de prévision et de contrôle des éruptions.* Bull. Volc., ser. 2, t. 23, p. 31-44.

KAMO, K., 1962, *Nature of the volcanic micro-tremors at the Volcano Aso.* Disaster Prevention Res. Inst., Bull. N 54-55.

KAYAMA, I., MUROZUMI, M., OKURA, T., UZUMASA, Y. and OSSAKA, T., 1963, *Volcanic sublimates and volcanic activities.* Bull. Volc., t. 26, p. 153-166.

KIZAWA, T., 1960, *A study of earthquakes in relation to volcanic activity (III).* Pap. Met. Geoph., Vol. 11, N 1, p. 30-96.

KUBOTA, S. and BERG, E., 1967, *Evidence for magma in the Katmai Volcanic Range.* Bull. Volc., t. 31, p. 175-214.

KUBOTERA, A. and YOSHIKAWA, K., 1963, *Prediction of volcanic eruption Aso and Sakurazima and some related geophysical problems.* Bull. Volc., t. 26, p. 297-317.

LO BASCIO, A., 1968, *Considerations on tilt observations at the Vesuvius Observatory.* Bull. Volc., t. 32, fasc. 2, p. 377-381.

MACDONALD, G. A., 1959, *The activity of Hawaiian volcanoes during the years 1951-1956.* Bull. Volc., ser. 2, t. 22, p. 3-70.

————, 1960, *Prediction of eruption of Hawaiian volcanoes* (abstract). Bull. Volc., ser. 2, t. 23, p. 211.

MACHADO, F., 1960, *Secular variation of seismo-volcanic phenomena in the Azores.* Bull. Volc., ser. 2, t. 23, p. 101-108.

————, 1965, *The Messina earthquake of 1908 and the magma chamber of Etna.* Bull. Volc., t. 28, p. 375-380.

MENAILOV, I. A. and NIKITINA, L. P., 1967, *The behaviour of sulfur and chlorine in fumarolic gases before intensification of activity of volcanoes.* Coll. « Volcanicity and geochemistry of its products ». p. 72-81. Publ. « Nauka » (in Russian).

MINAKAMI, T., 1959, *The study of eruptions and earthquakes originating from volcanoes. Part I - Some statistical relations between explosive eruptions and earthquakes of volcano Asama.* Bull. Volc. Soc. Japan, Vol. 7, N 2, p. 104-114.

MINAKAMI, T., 1960, *Fundamental research for predicting volcanic eruptions. Pt. I. Earthquakes and crustal deformations originating from volcanic activities.* Bull. Earthquake Res. Inst., Vol. 38, p. 497-544.

————, 1964, *The 1962 eruption of Miyake-sima, one of the Seven Izu Islands, Japan.* Bull. Volc., t. 27, p. 225-235.

————, HIRAGA, Sh., UCHIBORI, S. and MIYAZAKI, T., 1959, *The study of eruptions and earthquakes originating from volcanoes. Pt. 2 - Some contribution to prediction of explosive eruption of volcanoes Asama.* Bull. Volc. Soc. Japan, Vol. 4, N 2, p. 115-130.

————, SAKUMA, Sh., MOGI, K. and HIRAGA, Sh., 1960, *The study of eruptions and earthquakes originating from volcano es. Part 3-Relation between the depth of volcanic earthquakes and subsequent volcanic phenomena.* Bull. Volc. Soc. Japan, Vol. 4, N 3, p. 133-151.

MOGI, K., 1958, *Relations between the eruptions of various volcanoes and the deformations of the ground surfaces around them.* Bull. Earthquakes Res. Inst., Vol. 36, p. 99-134.

MOORE, J. G. and KRIVOY, H. L., 1964, *The 1962 flank eruption of Kilauea Volcano and structure of the East rift zone.* J. Geoph. Res., Vol. 69, N 10, p. 2033-2045.

MOXHAM, R. M., 1967, *Changes in surface temperature at Taal Volcano, Philippines 1965-1966.* Bull. Volc., t. 31, p. 215-234.

NEUMANN VAN PADANG, M., 1960, *Measures taken by the authorities of the Volcanological Survey to safeguard the population from the consequences of volcanic outburst.* Bull. Volc., ser. 2, t. 23, p. 181-192.

————, 1963, *The temperatures in the crater region of some Indonesian volcanoes before the eruption.* Bull. Volc., t. 26, p. 319-336.

NOGUCHI, K. and KAMIYA, H., 1963, *Prediction of volcanic eruption by measuring the chemical composition and amounts of gases.* Bull. Volc., t. 26, p. 367-378.

PRIAM, R., 1964, *Une nouvelle éruption du volcan de Lopevi (Nouvelles-Hébrides) et son analogie seismique avec les éruptions précédentes.* Bull. Volc., t. 27, p. 341-345.

RIKITAKE, T., YOKOYAMA, I., UYEDA, S. and YUKUTAKE, T., 1963, *Geomagnetic studies on Volcano Mihara.* Bull. Volc., t. 26, p. 49-55.

RYNDIN, E. A., 1964, *Some data on relations of volcanic activity to changing of magnetic field.* Bull. Volc. St., N 38, p. 39-40 (in Russian).

SHIMA, M., 1960, *Volcanic micro-tremors at the Volcano Aso.* Disaster Prevention Res. Inst., Bull. 34.

SHIMOZURU, D. and HORIGOME, K., 1967, *Recent seismic activity at Kozu-sima discussions on spatial relation between volcanism and seismicity at Izu-Islands.* Bull. Volc. Soc. Japan, Vol. 12, N 1, p. 11-25.

SIDOROV, S. S., 1966, *Activization of Ebeko Volcano in 1963-1964 and evolution its hydrothermal activity during the previous time.* Bull. Volc. St., N 40, p. 61-69. (in Russian).

SURNINA, L. V., VORONOVA, L. G., 1964, *Importance of researches of volcanic gases for Forcasting of eruptions.* Geology and Geophysics, N 7, p. 66-69 (in Russian).

SUWA, A., 1965, *The prediction of volcanic eruptions and prevention of eruption disasters.* Bull. Volc. Soc. Japan. Vol. 10, p. 139-144.

——— and TANAKA, Y., 1959, *The changes in the temperatures of the fumaroles in the crater of Miharayama, Oshima, in connection with the activities of the volcano.* Bull. Volc. Soc. Japan, Vol. 3, N 2, p. 107-118.

TANEDA, S., 1963, *Volcanothermal investigations of active crater-temperature variation in the bottom ground of the Naka-dake crater of the Aso volcano.* Mem. Fac. Sc., Kyushi University, ser. D, Vol. 14, N 1, p. 23-38.

TARAKANOVSKY, A. A., 1967, *Some peculiarities of deep structure of South Kamchatka according gravimetric and seismological data.* Bull. Volc. St., N 43, p. 68-69 (in Russian).

TAYLOR, G. A., 1963, *Seismic and tilt phenomena preceding a Pelean type eruption from a basaltic volcano.* Bull. Volc., t. 26, p. 5-12.

TAZIEFF, H., 1967, *The menace of extinct volcanoes.* Impact, Vol. 17, N 2, p. 135-148.

———, BOULAY, J. L., GARAND, M. et MAULARD, J., 1968, *Mesure des variations rapides des parametres thermiques des gaz éruptifs.* C. R. Acad. Sc. Paris, t. 267, p. 1253-1256.

———, TONANI, Fr., 1963, *Fluctuations rapides et importantes de la phase gazeuse éruptive.* C. R. Acad. Sc. Paris, t. 257, p. 3985-3987.

THORARINSSON, S., 1960, *On the predicting of volcanic eruption in Iceland.* Bull. Volc., ser. 2, t. 23, p. 45-52.

TOKAREV, P. I., 1959, *On relations volcanic and seismic activity in Kurile-Kamchatka zone.* Trans. Labor. Vocl., N 17, p. 156-181 (in Russian).

———, 1963, *On a possibility of forecasting of Bezymianny Volcano eruptions according to seismic data.* Bull. Volc., t. 26, p. 379-386.

———, 1964*a*, *On the waves type and phase rates on spreading of the seismic waves in the time of volcanic tremor.* Coll. « Recent volcanism of the North-East Siberia » p. 103-109. Publ. « Nauka » (in Russian).

———, 1964*b*, *The swarm of earthquakes at Sheveluch Volcano in May 1964.* Bull. Volc. St., N 38, p. 41-44 (in Russian).

———, 1966, *Eruption and seismicity in Kliuchevskaya Group of Volcanoes.* Publ. « Nauka » (in Russian).

———, FIRSTOV, P. P., 1967, *Seismological researches at Karymsky Volcano.* Bull. Volc. St., N 43, p. 9-22 (in Russian).

———, SHIROKOV, V. A. and ZOBIN, V. M., 1968, *Seismic events the eruption of Piip's adventive crater in October-December 1966.* Bull. Volc., St., N 44, p. 30-41 (in Russian).

VLODAVETS, V. I., 1959, *The passive and active defence from the catastrophe eruptions of Volcanoes.* Bull. Volc. St., N 28, p. 79-91 (in Russian).

———, 1960, *Principes de la division regionale volcanique en URSS.* Bull. Volc., ser. 2, t. 23, p. 145-150.

WADA, T. and SUDO, Y., 1967, *Source mechanism of volcanic earthquake of the Volcano Aso.* Bull. Volc. Soc. Japan, Vol. 12 N 2, p. 61-69.

WARD, P. L. and MATUMOTO, T., 1967, *A summary of volcanic and seismic activity in Katmai National Monument, Alaska.* Bull. Volc., t. 31, p. 107-129.

YASUI, Y., 1963, *Summary of forecasting the explosion of Volcano Sakurajima.* Geoph. Mag. Vol. 31, N 3, p. 491-504.

YOKOYAMA, I., 1964, *Seismometrical observation of the 1962 eruption of Volcano Tokati, Hokkaido, Japan.* Bull. Volc., t. 27, p. 217-223.

YOSHIKAWA, K., 1961-62, *On the crustal movement accompanying with recent activity of the Volcano Sakurajima.* Disaster Prevention Res. Inst., Bull. N 48 and 50.

ZELENOV, K. K. and KANAKINA, M. A., 1962, *Biriuzovoe lake (Zavaritsky caldera) and changing of chemistry of its water as a result of the 1957 eruption.* Bull. Volc. St., N 32, p. 33-44 (in Russian).

ZEN, M. T. and HADIKUSUMO, D., 1965, *The future danger of Mt. Kelut (Easten Java-Indonesia).* Bull. Volc., t. 28, p. 275-282.

Manuscript received Feb., 1970