Radon as a Possible Criterion for Predicting Eruptions as Observed at Karymsky Volcano

A. M. CHIRKOV
Institute of Volcanology, Petropavlovsk-Kamchatskiy, USSR

Abstract

Observations carried out systematically at Karymsky volcano have shown that the Rn content in the gases from the summit crater fumaroles and from hot springs at the foot of the volcano increased before and during the 1971 activity of the volcano.

The specific place of radon as geochemical indicator of volcanic and seismic activity in the different regions is given by its chemical inertness, by its small period of semi-decay (3.8 days) and by its easy quantitative determination during field work. In recent years a number of studies have been made in the USSR on the variation of radon contents in thermal and mineral waters as possible forerunner of tectonic earthquakes, *i.e.*, Tashkent (1966), Anapka (1966) and Daghestan (1970) earthquakes. The data collected in those regions indicate that the radon concentration in waters increases 4-5 times before strong tectonic earthquakes and it decreases after them.

In 1964, the author suggested the undertaking of studies on the radioactivity of geothermal and volcanic gases with regard to predictions of volcanic eruptions. Most of the study was concentrated on Karymsky volcano.

Karymsky is one of the most active volcanoes in Kamchatka. IVANOV (1970) studied the history of the volcano and distinguished explosive and effusive-explosive stages in its activity. Each stage consists of several cycles whose duration range from several days to five years or more. Twenty-three eruptions of Karymsky volcano occurred during the last 115 years. The explosive eruptions are predominantly of Vulcanian and sometimes Vulcanian-Strombolian type. The beginning of the effusive-explosive eruption stage is characterized by the formation of intracrateric lava domes and by incandescent avalanches. The short duration of the period of quiescence of Karymsky volcano makes this area ideal for practical control of the elaborated methods of prediction of this type of eruptions.

Systematic measurements of radon concentrations in the spontaneous gas of a thermal spring near the foot of the volcano commenced in September 1966. Figure 1 shows the variations of the radon content in the spring gases from 1966 to 1971. A comparison between radon contents and character of volcanic activity during this period of time is presented below (CHIRKOV, 1970; DOUBIK *et al.*, 1972; TOKAREV

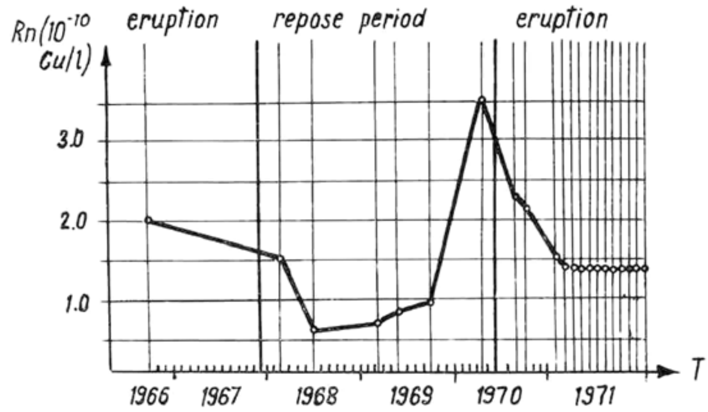

FIG. 1 - The change of radon concentration in the Karymsky thermal spring from 1966 to 1971.

et al., 1969). The effusive-explosive stage of eruption terminated in the middle of January, 1965 and the volcano entered the explosive stage characterized by rare (1-2 a day) Vulcanian explosions. In August and September 1966, the « Karymsky » seismic station, installed 3.5 km from the crater, recorded earthquakes associated with explosions in the crater. The energy of these earthquakes averaged 5.9×10^{11} erg. The last impulse of explosive activity was recorded in November 1967, after which the volcano entered a period of quiescence. No volcanic earthquakes were recorded in the summer of 1968. The temperature of fumaroles near the crater on the southern outer slope decreased from 500° C in September 1966 to 80° C in June 1968. A new eruption of Karymsky volcano commenced on May 11, 1970 with a succession of strong eruptive bursts and formation of glowing avalanches. The bursts were accompanied by earthquakes which produced soil displacements of amplitude of 0.5 μ and more at a distance of 35 km. The most strong explosions were recorded by seismic stations at a distance of 300 km. In several days a 1-kilometer long blocky flow of andesite-dacite lava poured out on the north-eastern flank of the cone. Vulcanian-Strombolian explosions occurred throughout the subsequent period of activity, decreasing gradually in frequency and strength. The growth of an intracrateric extrusive dome commenced in October 1970 and continued up to July 1971. On 16 July 1971, lava began to pour out on the western flank of the volcano. The character of explosive activity changed during the lava outflowing, *i.e.* the periods of slight gas-ash outbursts alternated with strong Vulcanian and Vulcanian-Strombolian explosions, the intervals between which varied from a few minutes to several hours.

This short description shows that during the period under investigation the activity of Karymsky volcano was characterized by the presence of all the stages of the volcanic process, namely termination of the eruption and transition to the repose stage; repose stage; and preparation and commencement of a new eruption. All of these stages are illustrated in the diagram of the variations of radon concentrations. There was noted a recession after the previous eruption. During the repose stage radon content was minimal: (0.7-1.0) 10^{-10} curie/l. Before the commencement of a new eruption, radon concentration increased 4-5 times and subsequently it decreased again. During both explosive and effusive-explosive stages of eruptions the average radon concentration amounted to approximately 1.5×10^{-10} curie/l. Sometimes there occurred short-term rises of the radon concentration. This is illustrated in Fig. 2 which shows the results of daily measurements (5 times a day) of radon contents in a spring during 1971. A comparison of the number of explosive earthquakes with variations of the radon concentration shows that the rises of the radon concentration always occurred a few days before the changes in the character of the eruption. Thus, on 11 and 12 July, before the lava outflowing (16 July, 1971), the radon concentration amounted to $(8.0\text{-}8.5) \times 10^{-10}$ curie/l; in the middle and at the end of August, 2 or 3 days before a strong increase of explosive activity, the radon content increased to 3.5×10^{-10} curie/l.

The data available imply a close connection between the activity of Karymsky volcano and the change of radon concentrations in the spontaneous gases of a thermal spring. The radiometric method allows us to forecast both a renewal of the volcanic activity and also a change of the character of the eruption. Only hypothetically one can speak at present of the mechanism of the influence of volcanic processes on radon concentrations in a surface hydrothermal spring. A connection between variations of radon contents in thermal springs of volcanic regions and seismic phenomena has been noted since long. Thus, in the gases of a spring near Hakone volcano (Japan) after the

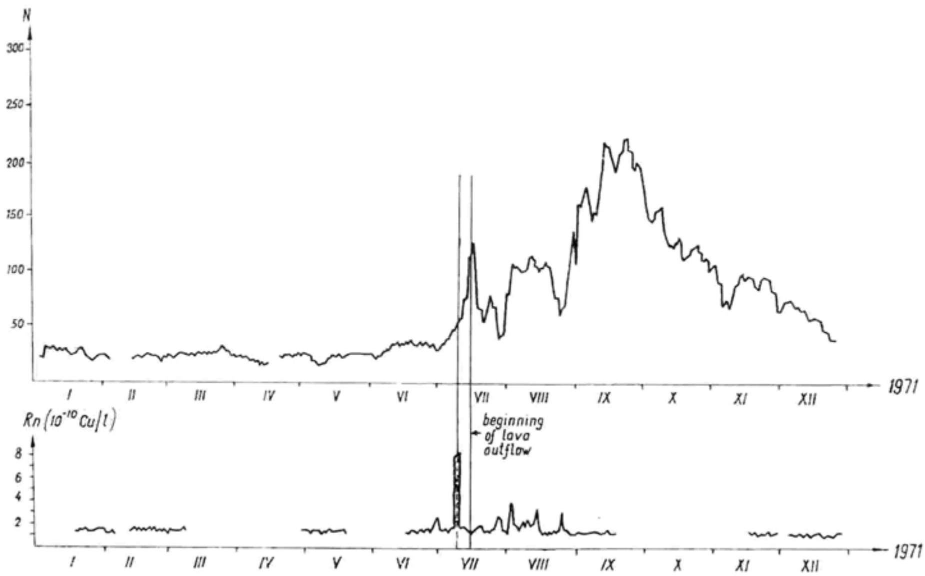

FIG. 2 - Radon concentration in the Karymsky thermal spring and the daily number of explosive earthquakes (N) recorded at the « Karymsky » seismic station in 1971 (P. P. FIRSTOV, pers. commun.).

earthquakes caused by volcanic activity in 1959 and 1966, the radon content suddenly decreased (IWASAKI *et al.*, 1968). An analogous phenomenon was observed during the strong tectonic earthquake in Tashkent in April 1966. ULOMOV and MAVASHOV (1967) reported a gradual increase of the radon concentration in mineral waters of the Tashkent basin for a few years before the earthquake and its strong decrease after the latter. The earthquake focus was at a depth from 3 to 8 km, and the change of radon content was noticed in a well 2 km deep in a region near the epicenter. It is noteworthy that, from geophysical data (ZUBIN *et al.*, 1971), under the present cone of Karymsky volcano at a depth of 1.5-2.0 km below sea level there is an intermediate magma chamber of isometric form 4.5-7.0 km across. The thermal spring under study is located at an absolute elevation of about 600 m immediately over this chamber. Radon surveillance in Tashkent and on Karymsky volcano was carried out in roughly the same conditions if one identifies the magma chamber with the earthquakes focus zone (formally, because before cataclysms there occurs a increase of elastic stresses to the level exceeding the medium strenght). This allows us to search for common reasons for radon content changes in springs during earthquakes and volcanic activity. As it was mentioned above, a common feature characteristic of earthquakes and eruptions is an increase of pressure in the chamber and focus zones. Under these conditions crystalline lattices of minerals commence to be destroyed favouring thus an intense release of radon from rocks. Laboratory investigations show that rock destruction is preceded by the formation of numerous small fissures which is accompanied by sonic and supersonic impulses (GOODMAN, 1963). GRATSINSKY *et al.* (1967) proved experimentally that the distribution of elastic supersonic oscillations in rocks leads to the progressive release of radioactive emanations from rocks.

Thus, it is assumed that elastic stresses in the volcano interiors before the eruption and during the emptying of the conduit during the eruption can produce an increase of the radon concentration in the thermal springs water. After the eruption, lava outflowing, destruction of extrusive domes in the crater, and elastic stresses in rocks in the chamber zone are taken off in a large measure, and the former regime of delivery of radon into water resumes. Its concentration in water and gases decreases.

It is possible that for volcanoes resembling Karymsky volcano as for lava composition, type of eruption, and existence of intermediate magma chamber, the preparation for an eruption and its course be characterized by processes analogous to the ones occurring in the interiors of Karymsky volcano. Systematic measurements of radon concentration together with other geophysical and geochemical methods can provide the principal contribution to the important national-economic problem of predicting eruptions.

Thus, the idea of a permanent « radon survey » (like the seismic survey) to be organized in Kamchatka for the prediction not only of eruptions but of earthquakes as well seems appropriate. Natural thermal springs or, that is more effective, wells located near volcanoes and pleistoseismic earthquake areas should serve as units for a systematic surveillance of radon concentrations.

It is worth noting that the present serial instruments provide only discrete measurements of the concentrations of radioactive emanations in gases. In order to render the radiometric method of prediction more effective, it is necessary to design instruments for continuous measuring, automatic recording or telemetering of radon and thoron contents.

References

CHIRKOV, A. M., 1970, *Karymsky volcano in 1967 and 1968.* Bull. Volc. St., No. 46, p. 42-45 (in Russian).

DOUBIK, Yu. M., OGORODOV, N. V., KHRENOV, A. P., ABDURAKHMANOV, A. I., TOKAREV, P. I., FIRSTOV, P. P., SHIROKOV, V. A. and LEMZIKOV, V. K., 1972, *The beginning of a new eruptive cycle of activity of Karymsky volcano.* Bull. Volc. St., No. 48, p. 21-28 (in Russian).

GOODMAN, R. E., 1963, *Subanclibe noise during compression of rocks.* Bull. Geol. Soc. America, No. 4, p. 487-490.

GRATSINSKY, V. G., GORBUSHINA, L. V. and TYMINSKY, V. G., 1967, *Supersonic release of radioactive gases from rocks.* Izd. Acad. of Sci., USSR, Fizika Zemli, No. 10, p. 91-94 (in Russian).

IVANOV, B. V., 1970, *The 1962-1965 Karymsky volcano eruption and the volcanoes of the Karymsky group.* Moscow, Nauka, 135 pp. (in Russian).

IWASAKI, I., OZAWA, T., YOSHIDA, M., KAUDA, H. and YAMAJA, K., 1968, *The change in the radon (Rn^{222}) and thoron (Rn^{220}) contents of volcanic gases in the Oowakidani district, Hakone volcano from 1960 to 1967.* Bull. Volcanol. Soc. Japan, *13, No.* 1, p. 21-31.

TOKAREV, P. I., FIRSTOV, P. P. and LEMZIKOV, V. K., 1969, *Seismic investigations on Karymsky volcano in 1966.* Bull. Volc. St., No. 45, p. 21-31 (in Russian).

ULOMOV, V. I. and MAVASHOV, B. Z., 1967, *On forerunners of strong tectonic earthquakes.* Dokl. Acad. Nauk SSSR, *176,* No. 2, p. 319-322 (in Russian).

ZUBIN, M. I., IVANOV, B. V. and STEINBERG, G. S., 1971, *Deep structure of Karymsky volcano in Kamchatka and some problems of caldera genesis.* Geol. and Geofiz., No. 1, p. 73-81 (in Russian).

Manuscript received Jan. 1975