Jl geol Soc. Lond. Vol. **136**, 1979, pp. 327–329. Printed in Northern Ireland.

What is to be forecast: outbreak of eruption or possible paroxysm? The example of the Guadeloupe Soufrière

H. Tazieff

SUMMARY: Forecasting the outbreak of a volcanic eruption is superfluous, since paroxysms occur not at the start but during the development of eruptions, and very few eruptions prove dangerous for neighbouring populations. It is important to predict whether or not an eruption will culminate in a climax, and if so, of what type, when and where. Only a naturalistic approach, and not a 'modelistic' one, can allow volcanologists with experience of erupting volcanoes to predict the development of an eruption. The 1976 eruption of Soufrière, Guadeloupe, is an example of the total failure of the modelistic approach and the reliability of the naturalistic one.

It is necessary to stress once again that, from the safety standpoint, it is useless to forecast what is the usual aim of applied volcanology: the outbreak of an eruption. No volcanic catastrophes yet observed have occurred at the very start of an eruption, and this means that a certain time—days, weeks, or months—is always available in which to take necessary protective measures. Again, less than one out of several hundreds of eruptions occurring in the world proves to be dangerous for the population and this means that even if the outbreak is predicted, neither authorities nor inhabitants will take any evacuation measures before the eruption becomes alarming. This type of forecast, consequently, is rather superfluous and should an eruption be announced at Sakurajima, Mt. Rainier, or Vesuvius, even if its exact date could be accurately predicted, neither responsible authorities nor sensible people would evacuate the cities of Kagoshima, Seattle or Naples before the eruption, having broken out, became truly threatening.

On the other hand, it is of the utmost importance to predict whether or not a developing eruption will culminate in a dangerous climax and, if it does, when and how. This approach to volcanological forecasting is quite different from the classical attempts usually carried on simply to forecast an eruption's outbreak. It is different not only from an intellectual but also from a technical standpoint and it is definitely more difficult to predict the evolution of a developing eruption than to predict the initial outbreak. This is because all efforts made so far have been oriented only towards the forecast of eruptive outbreak, secondly because observations of variation of parameters related to a forthcoming climax are still extremely scarce, and thirdly because these variations are probably less drastic than those which frequently prevail between the dormant and the erupting stages of a volcano.

In all volcanological observatories the attempts to forecast eruptions are based essentially upon geophysical observations, mainly seismography, tiltmetry, and thermometry. This approach relies on the assumptions that the ascent of a magma body is preceded or accompanied by earthquakes due to the breaking of the overlying rocks, opening a way for the molten magma to inflate the volcanic pile because of the injection of supplementary volumes of this molten magma and to increase the quantity of heat evacuated through the rocky crust, both by conductivity and by ground water convection.

This approach has proved quite effective on several occasions (at Kilauea, Hawaii in 1959, at Krafla, Iceland in 1977, and in Kamchatka in 1977 for instance), but it was effective exclusively on volcanoes fed by basic magmas which are very fluid. In fact, these volcanoes are not usually dangerous. Unfortunately, as yet this approach has never worked satisfactorily on any explosive, andesitic, or dacitic volcano. This is probably because the ascent of highly viscous magmas is far too slow to engender easily-detected progressively shallower earthquake swarms, and also because the various comparatively fast tilts measured at explosive volcanoes cannot be explained by the rise of a very slow viscous magma and are not yet interpretable in any predictive way.

Furthermore, although useful to forecast the outbreak of basaltic eruptions, these geophysical methods seem to be by themselves insufficient to detect an impending climax of an eruption once started. This is due to the fact that the magma is already very close to the surface, and that consequently neither rock fracturing, volcano inflation, nor increased heat transfer act in any interpretable way at this stage. Further information is thus necessary in the case of andesitic and more acid volcanoes and we think that the information carried by the eruptive volatiles could prove valuable.

As the present theoretical models of volcanism are still very schematic and far from the actual complex reality, only an empirical approach is possible. Volcanism is a very complex natural phenomenon and it is wrong to approach it as if it were some sort of simple laboratory physical or chemical problem. It would be

0016–7649/79/0500–0327$02.00

either naive or pretentious to treat such a complex reality by means of a simplistic theoretical model. Unfortunately, this frequently happens since sophisticated instruments so easily record various geophysical parameters, supplying laboratory-based volcanologists with figures related to parameters the significance of which is often not really understood. Too many examples have shown how harmful such a simplistic, laboratory-based approach may prove.

The old, but safe, classical, naturalistic approach used in the biological sciences should be carried into the field of volcanology. This involves the empirical collecting of physical measurements, chemical analyses, geophysical data, and other observed facts, followed by critical attempts to interpret their meaning. This method has proved successful in many instances where the author has had to answer questions asked by authorities faced with eruptive problems. It cannot be attributed entirely to mere luck.

The basis of such a naturalistic approach consists in looking for possible cross-correlations between measured parameters and observed phenomena. The parameters investigated are mainly those linked with output of energy and matter. Energy, in eruptive phenomena, is principally thermal and kinetic. Matter is solid (rocks, crystals, and glass), liquid (molten glass, water, solutions of various salts), and gaseous. As the evolution of an eruption is evidently related to changes occurring in the matter and energy involved, and as the variations in the gas phase are the largest, it seems particularly important to endeavour to collect as much information as possible about the variation in the gas phase. This information can be considered to be the most significant because the gas phase is actually the active agent of the whole eruptive phenomenon. If a gas-free magma did exist, it could never erupt on to the earth's surface. The facts are, however, that these studies have hardly started, that reliable data are still extremely scarce, that the interpretation of the available information is in its infancy, and that the indispensable experience necessary to use the collected data for forecasting can be obtained only through the study of actual eruptive activity. This sounds like a self-evident truth but the fact still remains that too many volcanologists involved with the problems of civil protection possess very little experience of actual eruptions, and sometimes no experience at all. If it is admitted that the important matter is not the forecasting of an outbreak but of an eventual climax, it should also be admitted that volcanologists should not spend their time in observatories built on dormant volcanoes, but should continuously improve their knowledge of the eruptive phenomenon by studying eruptions themselves, wherever and whenever they occur. This means that volcanologists should increase their understanding of the eruptive phenomena, improve their technical equipment, and collect physical and chemical data related to eruptions on the dozen or so more or less permanently erupting volcanoes which exist in the world: Etna, Stromboli, Kilauea (at present not permanently but very frequently erupting), Santiago, Santiaguito, Erta'-Ale, Merapi, Semeru, Yahue, and Erebus. There is no doubt that experience thus obtained would prove invaluable in helping to diagnose the development of eruptions at any activated volcano.

La Soufrière, Guadeloupe

Among several, the example of the 1976 eruption of Soufrière, Guadeloupe, illustrates the necessity of a naturalistic rather than a modelistic approach in attempting to foresee the course of an eruption (Tazieff 1977). In Guadeloupe, spectacular 'ash explosions', occurring every 2 or 3 weeks, as well as variation in some measured parameters, induced some geophysicists to forecast imminent and cataclysmic glowing clouds. They relied upon seismological, tiltmetric, and petrographic parameters. 'Observations' of the last 2 parameters—extremely strong and fast tilt and presence of 60% of fresh volcanic glass in the erupted 'ash', the implication of which was that a molten body was close to the surface (Allegre 1976) were eventually proved to be fallacious. The seismological argument was that the very high number of shallow (from 2 to 6 km deep) micro-earthquakes (up to 1257 in one day) recorded over 13 months had developed a cumulative energy so high that, as one volcanologist said: 'nothing but a catastrophe could follow'.

In this case, a naturalistic approach helped, first of all, to maintain calm, because volcanologists used to working on erupting volcanoes are less easily frightened by their spectacular displays than other people. Secondly, the phenomenology of this eruption clearly suggested that it was of the phreatic and not the magmatic type. If this was actually the case then the probability of having outbreaks stronger than the first one (which occurred on 8 July 1976) was extremely small. Thirdly, the temperatures of the fumaroles were far too low ($<200°C$) for there to be any fresh magma in the vicinity. Fourthly, the chemical composition of these fumaroles (H_2O: 99%, CO_2: 0.9%, H_2S: 0.01%, H_2: 0.01%, CH_4: 0.005%) had not changed for 3 years and the eruption had not modified this composition, which is a typical feature of magmatically quiescent volcanoes. Fifthly, only old rocky fragments, exclusive of any fresh lava, had been ejected from the crater, and this was a further indication that this eruptive event was of a phreatic type. Sixthly, the focal depth of the thousands of recorded seisms was located between 2 and 6 km deep. This meant it was impossible for a molten magma body to be shallower than 6 km. A magma body could not have been located between the surface and 2 km because the temperatures and chemistry of the fumaroles showed this to be impossible, nor was it situated between 2 and 6 km depth because the earthquakes, originating there, showed that this zone was solid, and not fluid.

The conclusion was that this whole volcano-seismic crisis was of a phreatic nature and that, consequently, there was no danger that this eruption would deliver glowing clouds, incandescent avalanches, gas explosions or any other magmatic eruptive hazard of the sort which so concerns the whole Caribbean population since the dramatic 1902 eruptions of both Mt. Pelée in Martinique and St. Vincent's Soufrière.

References

ALLEGRE, C. 1976. Rapport sommaire sur la crise sismo-volcanique de la Soufrière. *INAG*, Paris, 1–10.

TAZIEFF, H. 1977. La Soufrière, volcanology and forecasting. *Nature Lond.* **269,** 96–7.

Read 7 June 1978; received 12 September 1978.

H. TAZIEFF, CNRS, CFR. 91190, Gif, France.