https://doi.org/10.20965/jdr.2020.p0070

Review:

Earthquake and Volcano Hazards Observation and Research Program: An Overview

Naoyuki Kato[*,†] **and Takeshi Nishimura**[**]

[*]Earthquake Research Institute, The University of Tokyo
1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan
[†]Corresponding author, E-mail: nkato@eri.u-tokyo.ac.jp
[**]Department of Geophysics, Graduate School of Science, Tohoku University, Miyagi, Japan
[Received October 1, 2019; accepted October 31, 2019]

The Earthquake and Volcano Hazards Observation and Research Program was from Japanese fiscal year 2014 to 2018. This national program succeeded the Research Program for Earthquake and Volcanic Eruption Prediction (2009–2013). However, mainly because of the disaster caused by the 2011 earthquake off the Pacific coast of Tohoku, known as the 2011 Tohoku Earthquake, the basic policy of the program changed drastically. It changed from research for predicting earthquakes and volcanic eruptions to comprehensive research for mitigating disasters on the basis of scientific results related to the mechanisms of earthquakes and volcanic eruptions and their forecasts. The program was planned to be multidisciplinary in nature. In addition to Earth scientists working to get a scientific understanding of earthquakes and volcanic eruptions, historians, archaeologists, human and social scientists, and engineers took part in the program aimed at collecting pre-instrumental earthquake and volcanic data, understanding earthquake and volcano disasters, risk evaluation, and research into disaster response and preparedness. In this article, we review the basic concept of the 2014–2018 program and its main achievements. In the end, we summarize the problems left for future studies.

Keywords: earthquake, volcanic eruption, hazard, national program

1. Introduction

The Pacific Plate and the Philippine Sea Plate are subducting under Japan, causing many earthquake and volcano disasters there. Consequently, national programs researching earthquakes and volcanic eruptions have been conducted in Japan for many years. Japan's national Earthquake Prediction Program and national Volcanic Eruption Prediction Program started in 1965 and 1974, respectively, on the proposals of the Geodesy Council. These programs aim to mitigate earthquake and volcano disasters by predicting their occurrence. Although the mechanisms of earthquakes and volcanic eruptions have come to be better understood through geophysical and other observations developed in the programs and through experimental and theoretical studies, the precise prediction of earthquakes and volcanic eruptions has not turned out to be as easy as we expected when the programs started.

After the 1995 Kobe earthquake, the earthquake prediction research program changed its policy from predicting earthquakes mainly based on the observation of precursory phenomena to forecasting processes of crustal activities, including large earthquakes, on the basis of observations and the physical modeling of earthquake cycles. This policy change had become possible by that time because the quantitative understanding of earthquake faulting and loading processes was obtained through the results of the programs, and mechanical models of earthquakes were developed. See [1] for more details on the early history of earthquake prediction research programs.

The deployment of observation stations on active volcanoes has enabled us to predict the occurrence of volcanic eruptions, such as the eruptions at Usu. The first dike intrusion of the Miyakejima volcano in 2000 was well monitored and predicted beforehand. However, the following caldera collapse and continuous gas emissions were not expected because such low-frequency activity had not been monitored [2]. We re-acknowledged the importance of the continuous observation of various kinds of volcanic activities and of the quantitative understanding of volcanic activities and structures.

Programs aimed at earthquake prediction and volcanic eruption prediction were merged in 2009. As both earthquakes and volcanic eruptions in the Japanese islands originate from the subduction of oceanic plates, understanding the subduction process is important for the prediction of both earthquakes and volcanic eruptions. Furthermore, some research methods, such as geophysical observations and the theory of elasticity, are commonly used in both programs.

During the Research Program for Earthquake and Volcanic Eruption Prediction (2009–2013), the devastating 2011 Tohoku Earthquake (magnitude 9.0) occurred. The disaster caused by this great earthquake raised questions about the policies of the research program, which aims to mitigate disasters by predicting earthquakes and vol-

canic eruptions. It was felt that, in addition to prediction, other methods of disaster mitigation based on seismology and volcanology should be investigated. Moreover, research had been conducted mainly using modern geophysical data, so research on huge earthquakes and volcanic eruptions with recurrence intervals longer than several hundred years was lacking due to insufficient observation data.

We rethought the policy of the program to address the issues raised by the 2011 Tohoku Earthquake, and the Earthquake and Volcano Hazards Observation and Research Program (2014–2018) was started based of the proposal of the Geodesy subcommittee of the Council for Science and Technology. In September 2014, or about six months after the start of the program, Mt. Ontake erupted, killing more than 60 tourists. This tragedy caused a part of the program to change to promoting volcano research.

This paper is organized as follows. In Section 2, the Earthquake and Volcano Hazards Observation and Research Program (2014–2018) is outlined. In Section 3, the main results of the program are presented. In Section 4, unsolved problems in the program are discussed. In Section 5, our conclusion and the outline of the next five-year program (2019–2023) are given.

2. Purpose and Outline of the Program

Natural hazards such as strong ground motions, tsunamis, volcanic ash, and lava flows induced by earthquakes and/or volcanic eruptions interact with the vulnerability of social and geological conditions to cause natural disasters. It is therefore necessary to predict and evaluate these natural hazards to prevent disasters caused by earthquakes and volcanic eruptions. Based on this idea, the program was designed and planned by Japanese researchers nationwide from universities and institutes under the Coordinating Committee of Earthquake and Volcanic Eruption Prediction Researches (CCEVPR), established in Earthquake Research Institute of the University of Tokyo (http://www.eri.u-tokyo.ac.jp/YOTIKYO/H26-30/en/top_en.html). The program has conducted studies aimed at the comprehensive understanding of the activities of earthquakes and volcanic eruptions as well as at the development of quantitative evaluations and forecasts of the hazards, for the purpose of contributing to the mitigation of the disasters. Large earthquakes and volcanic eruptions which generally have long recurrence intervals were also studied. These natural disaster studies were conducted with the co-operation of history, archaeology, social science, and engineering departments. The program aimed to use the results of these studies for disaster mitigation by communicating them to government offices and local residents.

The program mainly consisted of three areas of study: (1) clarifying the physical processes and characteristics of the phenomena of earthquakes and volcanic eruptions, (2) developing methods for forecasting the activities of earthquakes and volcanic eruptions, and (3) forecasting the hazards caused by earthquakes and volcanic eruptions. It was expected that there would be significant collaboration among these three study areas for the improvement of methods useful to mitigation of the disasters of earthquakes and volcanic eruptions.

The first area of study, "clarifying the physical processes and characteristics of the phenomena of earthquakes and volcanic eruptions (elucidating the phenomena)," aimed to deepen our scientific knowledge of the phenomena of earthquakes and volcanic eruptions, which is the most important basis for predicting disasters caused by them. Physical and chemical processes of earthquake and/or volcanic eruption generations were investigated by conducting case studies of past earthquakes and volcanic eruptions, resolving the structures of elastic and viscoelastic properties and water distribution, and revealing stress fields where earthquakes and volcanic eruptions occur. Large earthquakes and volcanic eruptions, which may generate huge disasters, were investigated, with international cooperation, by analyzing not only recent geophysical data but also historical, archaeological, and geological data to clarify the long-term activities and their processes. Earthquake generation processes, volcanic activity and volcanic eruptions, and quantitative understanding of the structures were studied intensively.

The second area of study, "developing methods of forecasting the activities of earthquakes and volcanic eruptions (forecasting the phenomena)," was aimed at understanding spatio-temporal changes in earthquakes and volcanic activities as well as developing methods of forecasting these activities on the basis of the scientific understanding of these phenomena. The long-term forecasting of interplate earthquakes, which are now well monitored and numerically modeled, was one of the main targets of this area of study. Short- and intermediate-term forecasting methods of seismicity were also studied and examined by statistically analyzing the seismic data and using numerical simulations. Advanced event trees of volcanic activity for eruption forecasting, which are useful not only for government offices but also for volcanologists to understand eruptive activities, were made at several active volcanoes in Japan by using historical records, geological evidence, and field observation data. Prediction methods of magnitudes and styles of volcanic eruptions were studied by investigating the relations of observational data to the eruptive activities and/or by using theoretical studies.

The third area of study, "forecasting hazards caused by earthquakes and volcanic eruptions (forecasting hazards)," comprehensively studied the relations of the hazards of earthquakes and volcanic eruptions to geological and social vulnerabilities, paying attention to the fact that natural hazards, such as strong ground motions, tsunamis, volcanic ashes and lava effusions, interact with natural and social vulnerabilities to cause disasters. Results obtained from the natural sciences, engineering, humanities, and social sciences were the subjects of multi-disciplinary discussions with a view to incorporating effective developments into disaster mitigation methods. The dissemination of information on earthquakes and volcanic erup-

Table 1. The three main areas of study and the program promotion system .

I. Studies to clarify the mechanisms and characteristics of the phenomena of earthquakes and volcanic eruptions

(a) Collection and evaluation of historical, archaeological and geological data related to earthquakes and volcanic eruptions
(b) Understanding low-frequency large earthquakes and volcanic eruptions
(c) Structure and stress field related to earthquakes and volcanic eruptions
(d) Modeling of earthquake phenomena
(e) Modeling of volcanic phenomena

II. Studies to develop methods to forecast earthquakes and volcanic eruptions.

(a) Development of advanced methods of long-term earthquake forecast
(b) Forecast of seismic activity based on monitoring data
(c) Prediction of earthquake occurrence using precursory phenomena
(d) Prediction of volcanic eruptions based on advanced volcanic event trees.

III. Studies to forecast the hazards by earthquakes and volcanic eruptions

(a) Case studies of historical disasters by earthquakes and volcanic eruptions
(b) Understanding the mechanism of disasters by interdisciplinary approaches
(c) Development of advanced methods to assess earthquake and volcano hazards
(d) Development of real-time forecasting methods for earthquake and volcano hazards
(e) Development of advanced information and announcement for mitigating the disasters by earthquakes and volcanic eruptions.

IV. Promotion system, observation technology, and database

(a) Promotion system
(b) Observation technology and database
(c) Strengthening of coordination with related research fields
(d) Human resource development for researchers, technicians, and officers on disaster preventions
(e) Development of common understanding and education for disaster mitigation
(f) International research and cooperation

tions was also studied through the cooperation of many researchers in various fields and government offices. Ways to effectively disseminate basic knowledge of seismic and volcanic activities as well as disasters caused by them were developed and carried out, and the utilization of the disaster information was discussed.

The promotion system of the program was also examined to maintain and improve cooperation between universities, national institutes, and government offices. The maintenance and deployment of observation networks were among the most important things that promoted the research into understanding and forecasting earthquakes and volcanic eruptions. The systems used for effectively and continuously recording and keeping a huge number of data were also discussed. To deal with large-scale disasters caused by large earthquakes or volcanic eruptions, the program constructed structural plans that carried multidisciplinary studies that included not only seismology and volcanology but also engineering, humanities, and social sciences. Human developments were also important targets of this program to continuously study the earthquakes and volcanic eruptions that have long-term activities. The program promoted international observations and studies to increase case studies and learn from disaster management research that had been carried out in foreign countries.

The contents of the studies done in this program are summarized in **Table 1**. The three areas of study and how they were promoted are further described by plural research items from (I) the understanding of the phenomena, (II) the forecasting of the phenomena, (III) the forecasting of the hazards, and (IV) the program promotion system. Each research item consisted of a few to tens of study subjects, each of which was proposed and planned by a few to tens of researchers from universities and institutes. These categories make the aims of this program clear. On the other hand, most of the research items include the studies of both the earthquakes and volcanic eruptions; it may be better to separate them to enhance the most advanced studies and pursue the specialty in each research field. Hence, the program set up eight Program Promotion Panels under the CCEVPR: subduction zone earthquakes, inland earthquakes, volcanoes, seismicity evaluations, pre- and real-time forecasts of the hazards, disasters caused by earthquakes and volcanic eruptions, historical materials and archaeology, and data distribution and databases. To strengthen collaboration between the eight panels and enhance the connections

between the three study areas (I–III), four additional research groups for comprehensive study were set up under CCEVPR: (1) the 2011 Tohoku Earthquake, (2) Nankai Trough earthquakes, (3) Tokyo metropolitan area earthquakes, and (4) the Sakurajima volcano. In each group, aiming to find important problems that should be solved to effectively mitigate the disasters, researchers from different scientific fields attended and discussed the state of the art of the research on the target earthquakes or volcanic eruptions at workshops to widely share the scientific results from the study areas. To effectively support and promote the three study areas and four research groups, CCEVPR newly set up Management Strategy Division in the planning section.

3. Main Achievements

In the program, about 175 research projects were carried out over the five-year period from 2014 to 2018. Every year, each research project reported its results. The program committee held a symposium at the end of the fiscal year, and about 300 researchers attended the symposium each year. All research projects presented their results on posters, and leaders of the eight panels and the four research groups summarized and presented some outstanding and important results in oral presentations. These results were summarized in an annual report by the Geodesy subcommittee. Important research results from the panels and the groups were summarized in the following review papers in this special issue.

Among many results, urgent observation and research on large earthquakes and volcanic eruptions, such as the 2014 Mount Ontake Eruption and the 2016 Kumamoto Earthquake, are important. Temporal observation and research groups were quickly organized under CCEVPR to obtain valuable observation data just after the earthquakes and volcanic eruptions. The organization of these groups was possible because CCEVPR is always active, and the research results are important to the understanding of the mechanisms of earthquakes and volcanic eruptions. Methods for rapidly evaluating earthquake source models, tsunamis, volcanic ash, etc., were developed and improved during the program. Some of them are expected to be implemented for better disaster information. Great earthquakes that were not recorded with instruments were investigated through tsunami deposits, historical documents, etc. An M9 class earthquake was estimated to have occurred off Hokkaido in northern Japan in the 17th century. Seismologists and historians started systematic collaboration to evaluate historical earthquakes by critically reviewing historical documents. New methods of making an event tree of volcanic activity for eruption forecasting were developed by using geological and geophysical data, even for volcanoes for which there were not many historical records available. Precise geodetic observations using borehole tilt meters succeeded in detecting ground deformation signals a few to tens of minutes before the occurrence of phreatic eruptions at several volcanoes, and multi-parameter observations clarified the differences in precursor signals for phreatic and magmatic eruptions at the Mt. Aso volcano. Seismologists and earthquake engineers collaborated for better risk evaluation of anticipated great earthquakes along the Nankai Trough in southwestern Japan. In the collaboration, earthquake source, seismic wave propagation, surface ground amplification, collapse of buildings, etc. were investigated to evaluate their risk and level of uncertainty. The interaction between hazards and vulnerability was investigated to gain an understanding of the mechanisms of disasters, such as the tsunami damage along the Sanriku coast caused by the 2011 Tohoku Earthquake.

See the following review papers in this special issue for details and many other results.

4. Problems to be Solved in the Next Program

As summarized in the preceding section, new efforts in the program (2014–2018) have been adequately implemented, and some initial results of multidisciplinary studies, as well as new scientific results related to the mechanisms of earthquakes and volcanic eruptions, were obtained. This may be evaluated as a good start, considering that it often takes a long time for new approaches to yield fruit. However, most initial results of new approaches are not immediately adopted for earthquake and volcano disaster mitigation. For this to happen, continuous efforts are required. These should be taken into consideration in the next program (2019–2023). The following are tasks to be carried out in the next program.

1. The 2014 Mount Ontake eruption has indicated that even phreatic eruptions of small magnitude may cause severe disasters. Seismic activity for about one month and accelerating volcano deformation just before the eruption indicate that precursory phenomena may be detected even for phreatic eruptions. Similar deformations have been observed at several other volcanoes. It is important that methods for evaluating the small precursory phenomena of phreatic eruptions be developed. Moreover, the problem of how to best issue information about phreatic eruptions should be tackled by volcanologists and social scientists.
2. The 2016 Kumamoto earthquake has indicated that large earthquakes may occur successively in a complex fault system. The successive occurrence of great earthquakes is also expected along the Nankai Trough in southwestern Japan. Intermediate- and short-term earthquake forecasts, including forecasts of successive earthquakes, are important for disaster mitigation. Moreover, a social survey on the 2016 Kumamoto Earthquake has revealed that earthquake risk evaluated as high by the Earthquake Research Committee was not widely recognized by residents of Kumamoto [3]. This suggests that disaster information based on earthquake science has not

been used effectively to mitigate disasters. The effective use of disaster information must be investigated.

3. Historical and archeological data related to earthquakes and volcanic eruptions in periods before mechanical measurements have been collected and later evaluated by historians and archeologists. These activities have increased the available data on pre-instrumentally recorded earthquakes and volcanic eruptions as well as improved the reliability of the data. Long-term forecasts of great earthquakes and volcanic eruptions can be steadily improved by analyzing historical and archeological data. As it is important to develop more effective uses for historical and archeological data in long-term forecasts, continuous work must be done on databases of ancient earthquakes and volcanic eruptions.
4. Observation data of preseismic phenomena, such as foreshocks and slow slip events, have been accumulated and partially statistically evaluated. However, the physical mechanisms of preseismic phenomena are not sufficiently understood. Observational and theoretical studies of these phenomena are important for intermediate- and short-term earthquake forecasts. Moreover, it is important to build mechanical models of preseismic phenomena for quantitative comparisons of theoretical predictions and observations.
5. Theoretical models of volcanic processes and the evaluation of data from continuous monitoring should be taken in the development of event trees of volcanic activity for eruption forecasting. For this purpose, cooperative studies between experimental and theoretical studies, geophysical observation and data analyses, geological studies, and eruptive histories must be carried out. The prediction and evaluation of mid-term (a few months to several years) volcanic activities are especially important.
6. Better evaluation of earthquake ground motions and tsunamis is important for effective preparation for earthquake disasters from an engineering standpoint. For better evaluation of earthquake risk, seismologists and engineers must be involved in collaborative research on the total process of earthquake sources, seismic wave propagation, amplification at the Earth's surface, and damage to buildings. Better evaluation of tsunamis is important for evacuation plans, where traffic problems should be taken into consideration.
7. The development of way to rapidly evaluate and forecast volcanic ash falls is important. The monitoring and modeling of both underground magmatic processes and volcanic ash behaviors in the atmosphere are required for volcanic hazards to be quantitatively evaluated and predicted. The effects of ground accumulations of volcanic ash on human activities is another important issue that must be studied for the mitigation of volcanic disasters.
8. Although the forecasting of earthquakes and volcanic eruptions includes large uncertainties both in time and magnitude, forecast information is useful for mitigating disasters. Research aimed at determining the most effective use of forecast information, especially research focusing on the uncertainty of the information, is important. In addition, a series of disaster processes, from the occurrence of an earthquake or volcanic eruption, through the occurrence of disaster, to recovery, including interaction between hazards and human and social factors, should be investigated. Such investigations are necessary for the development of methods of mitigating disasters through the use of information about earthquakes and volcanic eruptions.

5. Conclusion

The Earthquake and Volcano Hazards Observation and Research Program (2014–2018) was significantly remodeled from previous earthquake and volcano observation and research programs to contribute to disaster mitigation based on earthquake and volcano sciences. Generally speaking, the objectives, such as multidisciplinary research for disaster mitigation, were successfully met. To strengthen this line of research and to address the problems found during the program, the Geodesy subcommittee of the Council for Science and Technology proposed a new program for 2019–2023, the Second Earthquake and Volcano Hazards Observation and Research Program, after recommendation from external review. In the new program, mechanisms and forecasts of earthquakes and volcanic eruptions are continuously investigated and new subjects of research are introduced. (1) To improve the use of disaster information, better earthquake and volcanic disaster literacy is vitally important. Effective methods for raising the level of literacy are investigated to produce a training program. (2) The following three targets of priority research are set: long-term earthquake forecasts using geophysical observation data, intermediate-term earthquake forecasts on the basis of crustal activity monitoring, and volcanic eruption forecasts on the basis of models of volcanic activity. These are expected to be helpful for future implementation by the government. (3) The following five targets of comprehensive research are set: great earthquakes along the Nankai Trough, earthquakes in the Tokyo metropolitan area, great earthquakes along the Kuril Trench, significant eruptions of the Sakurajima Volcano, and small yet high-risk volcanic eruptions, such as the 2014 Mount Ontake eruption. Multidisciplinary study is conducted for each target, and the results are expected to be useful for disaster mitigation in the event of other earthquakes and volcanic eruptions.

References:
[1] N. Hirata, "Past, current and future of Japanese national program for earthquake prediction research," Earth Planet. Space, Vol.56, pp. xliii-1, doi: 10.1186/BF03353075, 2004.
[2] S. Nakada, M. Nagai, T. Kaneko, A. Nozawa, and K. Suzuki-Kamata, "Chronology and products of the 2000 eruption of Miyakejima Volcano, Japan," Bull. Volcanology, Vol.67, pp. 205-218, doi: 10.1007/s00445-004-0404-4, 2005.
[3] R. Kimura, S. Ohtomo, and N. Hirata, "A Study on the 2016 Kumamoto Earthquake: Citizen's Evaluation of Earthquake Information and Their Evacuation and Sheltering Behaviors," J. Disaster Res., Vol.12, No.6, pp. 1117-1138, doi: 10.20965/jdr.2017.p1117, 2017.

Name:
Naoyuki Kato

Affiliation:
Professor, Earthquake Research Institute, The University of Tokyo

Address:
1-1-1 Yayoi, Bunkyo-ku, Tokyo 113-0032, Japan

Brief Career:
1990 Assistant Professor, Tohoku University
1997 Researcher, Geological Survey of Japan
2001 Associate Professor, The University of Tokyo
2013 Professor, The University of Tokyo

Selected Publications:
• "Dependence of earthquake stress drop on critical slip-weakening distance," J. of Geophysical Research, Vol.117, doi: 10.1029/2011JB008359, 2012.

Academic Societies & Scientific Organizations:
• Seismological Society of Japan (SSJ)
• Japan Geoscience Union (JpGU)
• American Geophysical Union (AGU)

Name:
Takeshi Nishimura

Affiliation:
Professor, Department of Geophysics, Graduate School of Science, Tohoku University

Address:
6-3 Aramaki-aza Aoba, Aoba-ku, Sendai, Miyagi 980-8578, Japan

Brief Career:
1994 Assistant Professor, Tohoku University
1996 Visiting Scientist, Los Alamos National Laboratory
1997 Vising Scientist, United State Geological Survey
2000 Associate Professor, Tohoku University
2012 Professor, Tohoku University

Selected Publications:
• T. Nishimura and M. Iguchi, "Volcanic Earthquakes and Tremor in Japan," Kyoto University Press, 2006.

Academic Societies & Scientific Organizations:
• Volcanological Society of Japan (VSJ)
• Seismological Society of Japan (SSJ)
• Japan Geoscience Union (JpGU)