Mem. Fac. Educ. Kumamoto Univ.
Nat. Sci., No. 43, 25—37, 1994

Hazard Maps of Naka-dake, Aso Volcano, Japan

Kazunori WATANABE

(Received May 23, 1994)

Abstract

Naka-dake is the only active central cone of the Aso caldera, Kyushu, Japan. About 50 thousand people make their living in the Aso caldera, and more than 5 million tourists a year visit the active crater or the tourist facilities in the area closest to the crater. There is no hazard map of Naka-dake, with the exception of restricting tourist entry to within 1 km or 2.2 km of the crater during active periods. Four scientific hazard maps of Naka-dake based on volcanological studies are prepared here. These maps show lava flow, ballistic ejecta, pyroclastic surge and ash fall for a period of several decades to several centuries in the future. These maps are of value in that they will help to forecast and reduce future volcanic disasters around Naka-dake, Aso volcano.

Key words : hazard map, eruption, Naka-dake, Aso volcano

Introduction

The Aso volcano, located in the central part of Kyushu in Japan, is a large caldera volcano (Fig. 1). The caldera, 18 km E-W and 25 km N-S in diameter, was created by the outflow of four voluminous pyroclastic flows in the late Pleistocene (ONO and WATANABE, 1985). More than seventeen central cones are clustered near the center of the caldera. Naka-dake, the central peak, is the only active central cone, of basaltic andesite to basalt in composition (ONO and WATANABE, 1985). Today, about 50 thousand people make their living in the Aso caldera, and more than 5 million tourists visit the active crater around which several tourist facilities are located within 1.2

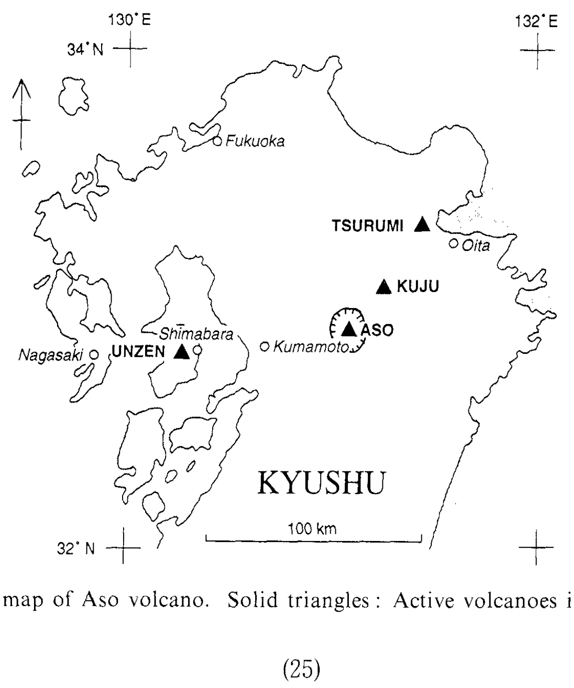

Fig. 1 Locality map of Aso volcano. Solid triangles : Active volcanoes in central Kyushou.

km of the active crater.

At present, the preparation of hazard maps of volcanic eruptions is encouraged in Japan. THE DISASTER PREVENTION BUREAU OF THE NATIONAL LAND AGENCY OF JAPAN (1993) has encouraged volcanologists to prepare the three categorical hazard maps of active volcanoes in Japan. The categories of the three types of hazard maps are scientific maps based on volcanology, practical maps for public administration purposes and simplified maps for residents and tourists.

The purpose of this paper is to suggest some scientific hazard maps based on volcanological data for the eruptions of Naka-dake, Aso volcano.

Characteristic features of eruptions and damage found around Naka-dake

The vent area of Naka-dake has a three-fold crater, which consists of an old (O), young (Y) and active (A) crater, in inward order (Fig. 2). The active crater (A) of Naka-dake is a composite of seven craterlets, Craterlets-1 to -7, aligned in a N-S direction. The northernmost craterlet, Craterlet-1, has been active in the last 60 years, although some others were also active until the eruption of 1933. Naka-dake has the longest documented volcanic history of any volcano in Japan with records going back to A. D. 553 (FUKUOKA DISTRICT METEOROLOGICAL OBSERVATORY, 1965).

Recently, Naka-dake has been active for periods of a few months to three years with intervening periods of dormancy as long as several years. In its active period, the Naka-dake crater emits almost continuously ash-laden, brown to black smoke or emits scoria intermittently of the strombolian type. In the later half of the active period, phreatic or phreatomagmatic explosions frequently occurs from the hot water pool, formed by heavy precipitation, in the active crater.

Small-scale pyroclastic surges, accompanied by sizable ballistic ejecta, are occasionally generated by large scale phreatomagmatic eruptions. The ballistic ejecta and pyroclastic surges have at

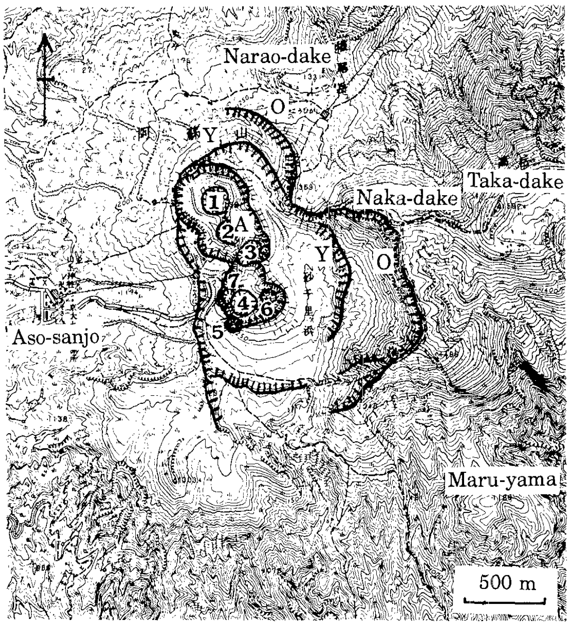

Fig. 2 Three-fold crater in the vent area of Naka-dake. Base map ; 1 : 25,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

times destroyed the tourist facilities or caused direct injuries to tourists. During the period from 1926 to 1989, 21 people were killed and 142 people were injured by eruptions in the area around the erupting crater.

The following characteristic features of eruptions and damage caused by Naka-dake were summarized briefly by deciphering old documents and from observation of recent activities of Naka-dake.

1) *Eruption of essential material*

Ejections of essential materials from the crater of Naka-dake are mainly recognized as strombolian, vulcanian and ash eruption (Ono et al., in press).

In the strombolian eruptions, variously vesiculated scoria blocks were sometimes thrown out onto the rim of the active crater. However, in most of the strombolian eruptions, there has been no threat to human life around the crater because tourist entry is restricted to about 1 km away from the erupting crater.

The vulcanian eruptions occurred in 1932-33 and 1953. In the 1933 eruption, a mound-shaped, semisolid lava was observed on the crater bottom (Aoki et al., 1940). It is not clear if the products of the 1953 eruption are essential or not. However, this eruption is included here in vulcanian type, because that eruption took place probably from the red-hot, after drying, bottom of the crater (Fukuoka District Meteorological Observatory, 1965).

The ballistic ejecta of the 1932 eruption injured 13 people around the erupting crater. And in the 1953 eruption, the ballistic ejecta of accessory or essential materials killed 6 tourists and injured about 90 tourists within 1 km of the crater (Fukuoka District Meteorological Observatory, 1990).

The ash eruption is characterized by continuous emission of ash-laden smoke from the crater (Ono et al., in press). The ash is diffused into a very wide area, more than 10 km from the crater, and ash fall deposits, thick in the area close to the crater and thin in more distant areas, have damaged crops and farmland around Naka-dake. The ash is composed mainly of angular fragments of essential materials with a small amount of altered accessory rock fragments. In the most active period of the strombolian eruptions, Pele's hairs and glass spheres are sometimes found in the ash (Ono et al., in press).

2) *Phreatic or phreatomagmatic explosion*

Phreatic or phreatomagmatic explosions occur frequently when the hot water pool develops inside the crater during active periods. In these explosions, a large amount of ejecta composed of volcanic ash, mud and blocks are ejected in the shape of a "tephra finger jet" from the crater. A phreatomagmatic explosion is defined by the existence of essential materials in the ejecta. However, it is sometimes difficult to identify whether the ash is essential or not because the interval between the active periods is so short that the recycled fresh, nearly essential in appearance, ash fragments are found in the ejecta.

In the documents of eruption of Naka-dake, many descriptions of outflows of water with mud from the craters have been found. However, the real mode of these events is not clear because direct water or mud flow spillage from the craters has not been observed.

In the case of phreatic or phreatomagmatic explosions, a large amount of big blocks composed mainly of accessory materials is ejected ballistically to an area a small distance away from the crater. The ballistic ejecta of the accessory big blocks sometimes destroy the tourist facilities near the crater and injure or kill tourists, as mentioned before. Consequently, "The Conference for Disaster Prevention of the Aso Volcano" restricts tourist entry to within about 1 km from the erupting crater during active periods.

3) *Pyroclastic surge*

At the eruption in the shallow water, it is well known that the basal part of an eruption cloud expands of a high velocity along the surface of the ground in the lateral direction from the crater. This cloud is low particles concentration gas-solid dispersion, and is called a pyroclastic surge (CAS and WRIGHT, 1987). The small-scale pyroclastic surges are sometimes generated by explosions from the choked crater. A pyroclastic surge is powerful enough to destroy buildings and vegetation around the crater.

In the 1958 and 1979 eruptions, small scale pyroclastic surges were generated by phreatomagmatic explosions from the crater choked by mud and water. 21 and 3 persons respectively were killed in the 1958 and 1979 explosions. In 1989 and 1990, a small-scale pyroclastic surge was also generated. However, there were no casualties, fortunately, because this pyroclastic surge affected an area where are no tourist facilities.

4) *Volcanic gas*

The volcanic gas emitted from the crater of Naka-dake sometimes harms the vegetation or farmland around the crater. In the 1988-1991 eruption, thick ash fall deposit and volcanic gas damaged Miyama-kirishima, a kind of azalea, around the crater. In 1990, two tourists became ill near the active crater and then died later in the hospital. It is not clarified whether the cause of their death was volcanic gas or not. There is no public monitoring system of volcanic gas with the exception of a private observation of SO_2 in the air by the Aso Volcano Museum located about 3 km west of the crater.

Forecast of the eruptions of Naka-dake

The activity of Aso volcano started at about 0.3 Ma ago, and continued to occur with long intervening periods of dormancy. The mode of eruptions of Aso volcano varied from huge scale pyroclastic flows in the pre-caldera stage to smaller eruptions in the stage of central cones. Even the history of the central cones goes back 90 thousand years. It is not so easy to forecast all possible modes of eruption of the Aso volcano in the distant future. However, the eruption of Naka-dake have been recorded since A. D. 553 to the present. This document shows the characteristic features which we have observed in the last several ten years during the eruptive events of Naka-dake. And the ejecta around the Naka-dake suggest that the eruption modes of Naka-dake in the last 15 thousand years is very similar to those of the recent activities (WATANABE et al., 1991). Consequently, the recent activity of the Naka-dake is likely to continue in the near future, for several decades, or in the middle-term future, for several centuries.

Hazard maps of Naka-dake

According to the volcanological data described above, four scientific hazard maps of Naka-dake have been prepared in this paper. The significant eruption modes, i. e. lava flow, ballistic ejection, pyroclastic surge, and ash fall, are treated here.

1) *Lava flow*

No outflow of lava is recorded in the historic activities of Naka-dake. A little younger than

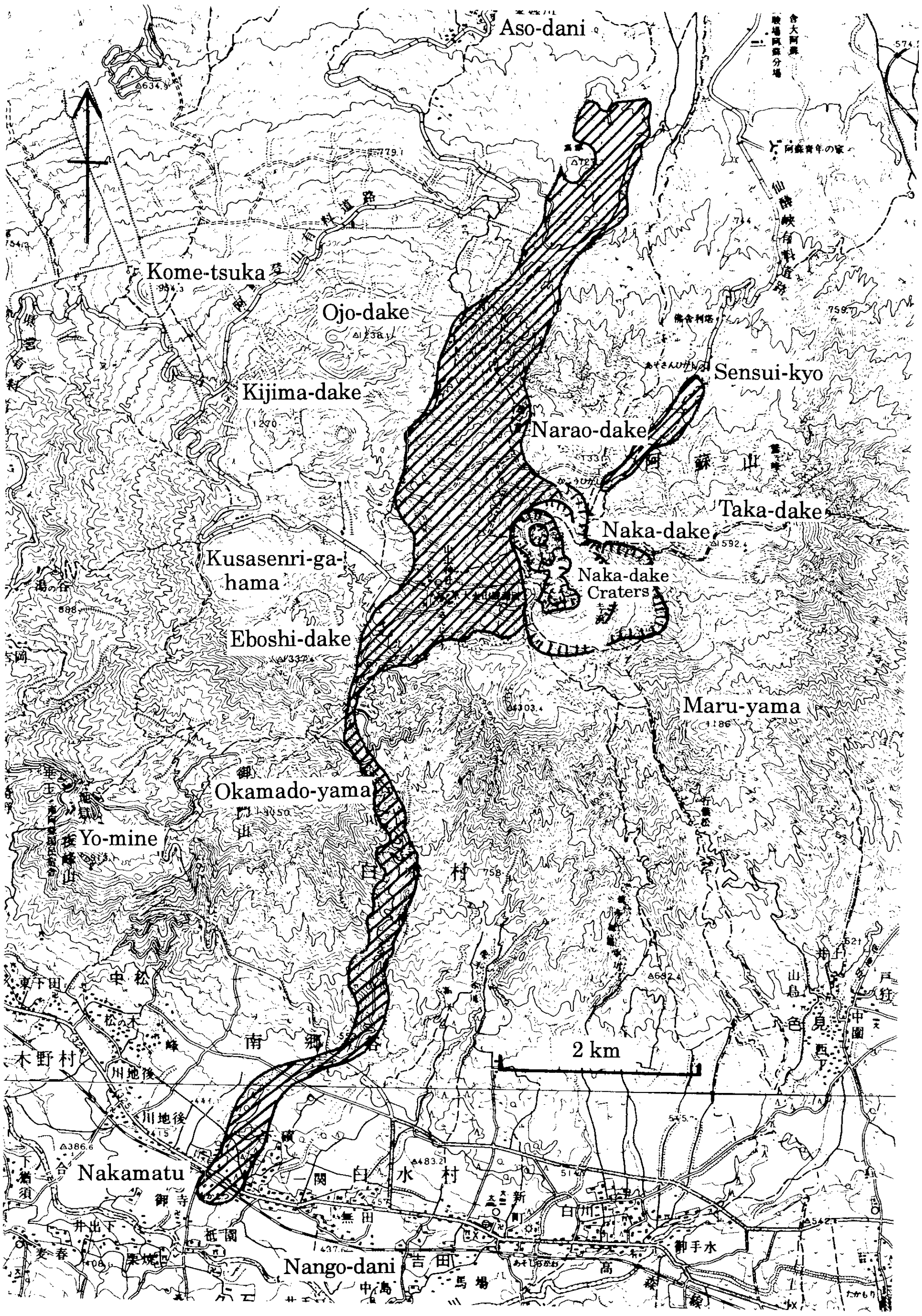

Fig. 3 Distribution map of lava flows from the vent area of Naka-dake. Age of the lavas is estimated at a little younger than 6,300 years (after ONO and WATANABE, 1985). Base map ; 1 : 50,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

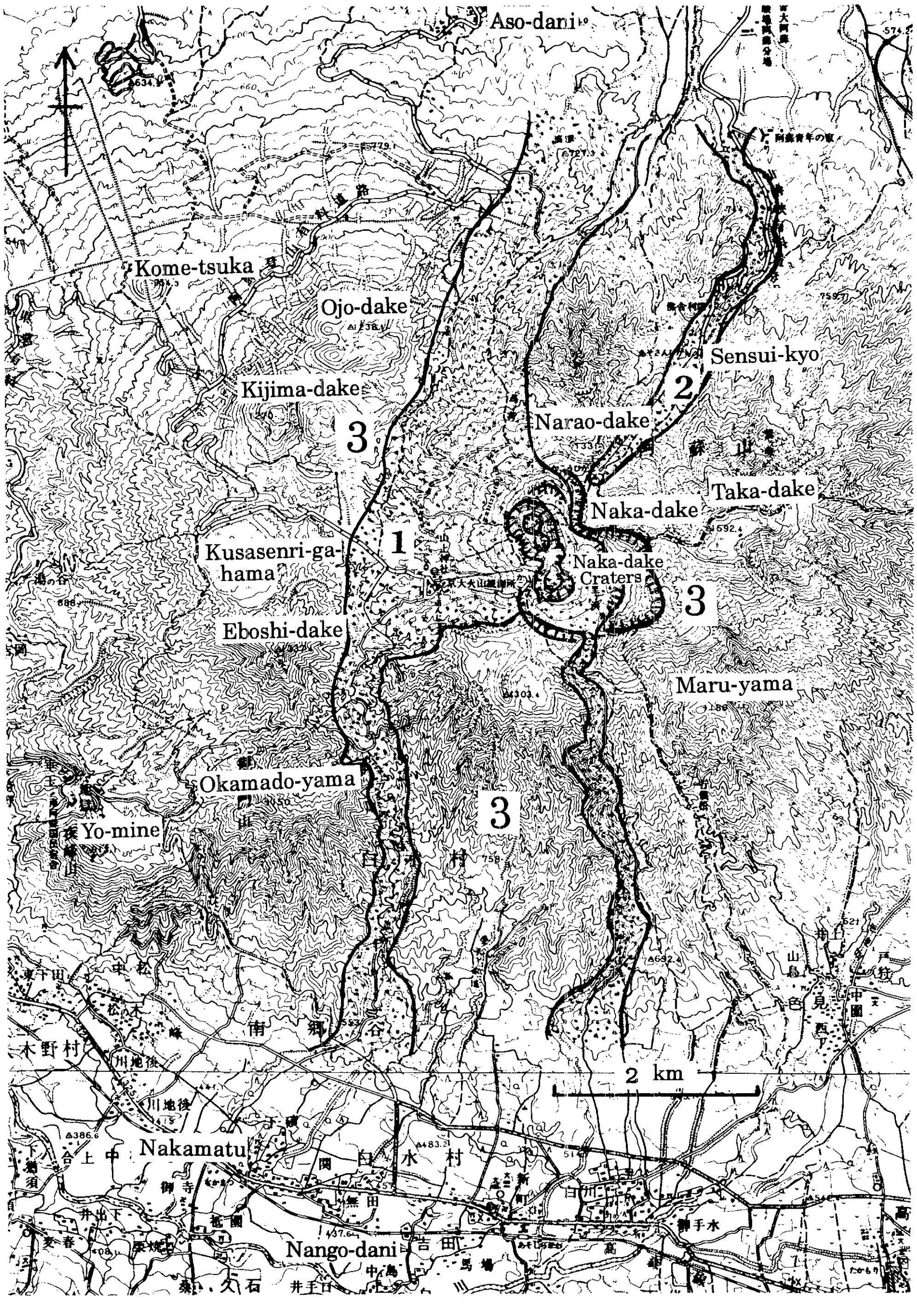

Fig. 4 The hazard map for lava flow from the vent area of Naka-dake. Level-1 : risk is reasonably high, Level-2 : risk is lower, Level-3 : risk is very low. Base map ; 1 : 50,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

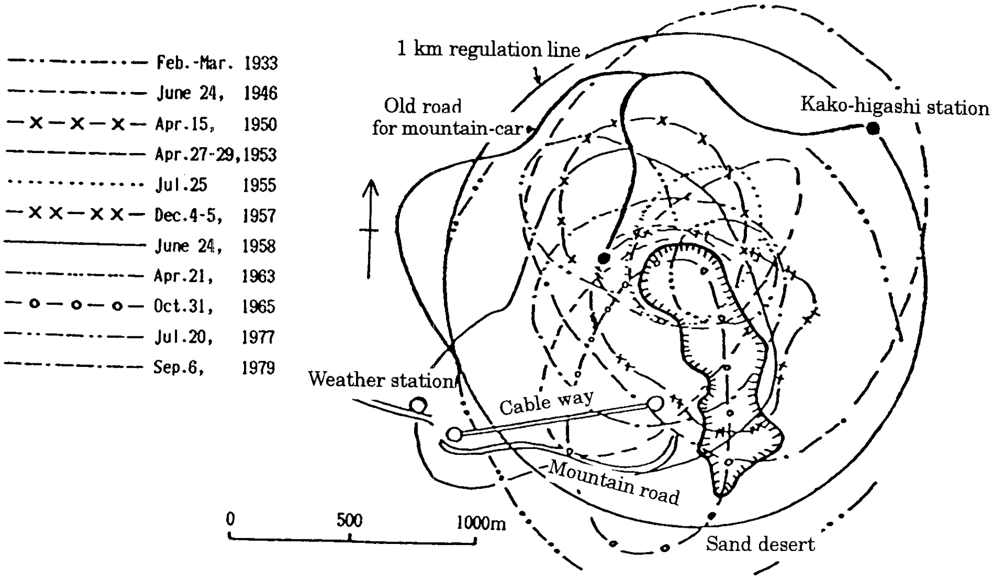

Fig. 5 Distribution of the fist-size ejecta of major recent eruptions from the Naka-dake craters (after FUKUOKA DISTRICT METEOROLOGICAL OBSERVATORY, 1990).

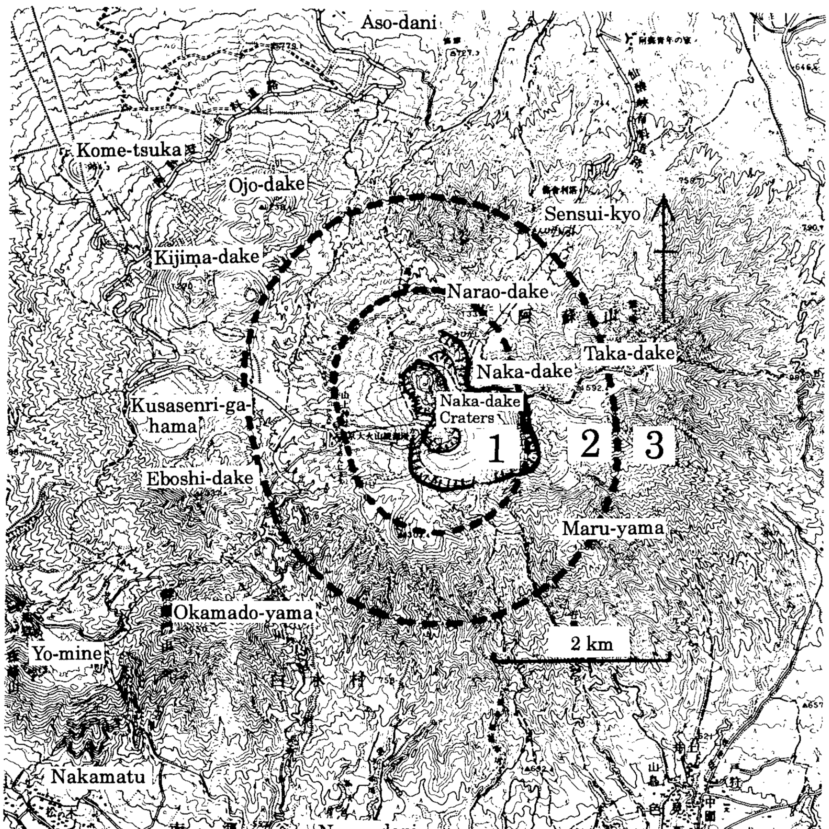

Fig. 6 The hazard map for fist-size ballistic ejecta from the Naka-dake craters. Level-1 : risk is high, Level-2 : risk is moderate, Level-3 : risk is low. Base map ; 1 : 50,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

about 6,300 Y. B. P., the lavas effused from the Y (Younger) crater of Naka-dake (Fig. 3) (ONO and WATANABE, 1985).

The hazard map for lava flow of Naka-dake is shown in Fig. 4. In the case of outflow of new lava from the composite crater (A), Crater let-1 to-7, potentially dangerous area covered by new lava is estimated from the topographic features around the craters, as the area of Level-1. In the other case, new lava will probably flow down in the area of Level-2, which contains old lava effused from the northern flank of Naka-dake (Fig. 3). The area of Level-3 has a very low risk of being covered by a new lava flow from the Naka-dake.

2) *Ballistic ejecta*

The distributions of the ballistic ejecta from the crater of Naka-dake in recent eruptions are shown in Fig. 5 (FUKUOKA METEOROLOGICAL OBSERVATORY, 1990). These data are very useful in estimating the destination of the ballistic ejecta from the craters of Naka-dake. In the three cases, 1933, 1958 and 1979, the fist-size ballistic ejecta reached an area more than 1 km from the craters. In the 1958 and 1979 eruptions, pyroclastic surges were generated at the same time as explosive

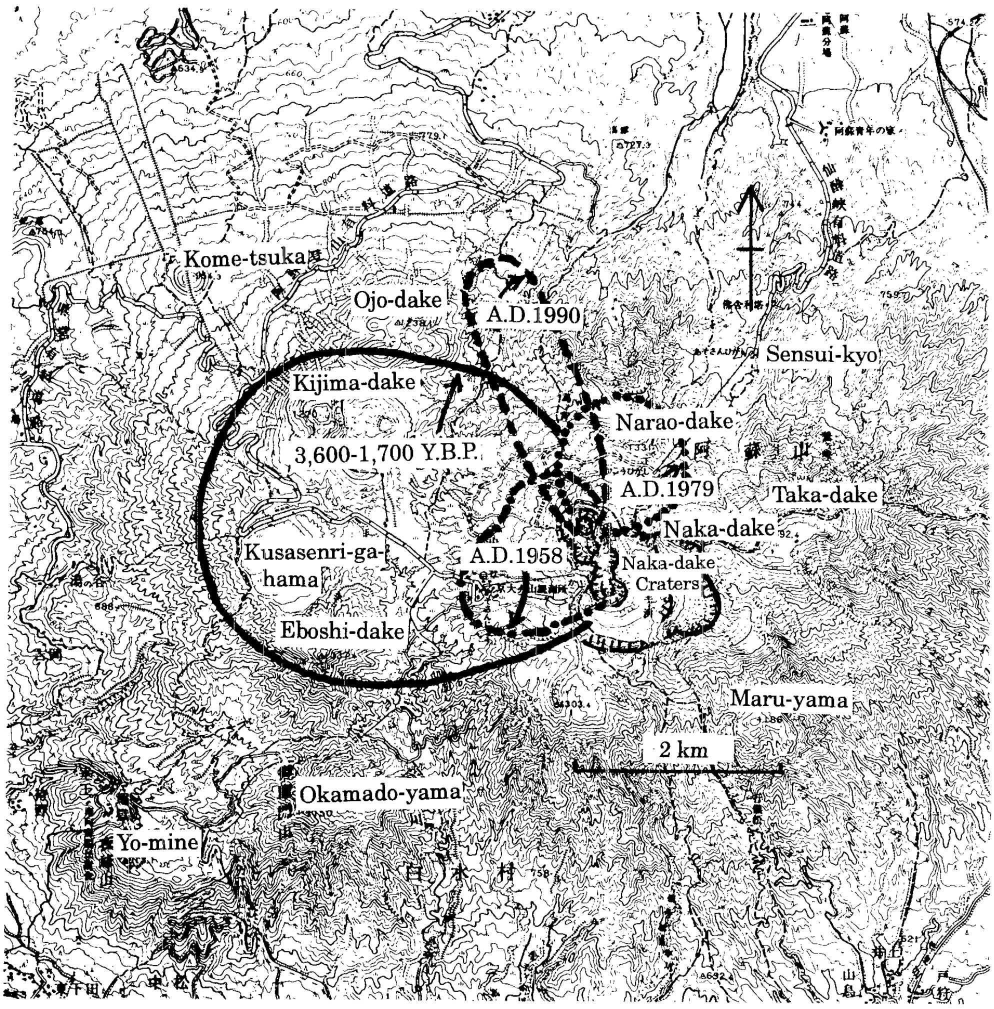

Fig. 7 Distribution of pyroclastic surge deposits around the Naka-dake craters. (Data in 1958 and 1979 are form ONO et al., 1982), Base map : 1 : 50,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

ejection. Therefore, the projectiles were probably transported by pyroclastic surge to a more distant area than in the other cases.

The hazard map for the fist-size ballistic ejecta around the crater is shown in Fig. 6. From the data shown in Fig. 5, the area of highest risk in terms of ballistic ejecta is estimated ordinarily as the area of Level-1, about 1 km from the craters. In the pre-historic age, a little less than 6,300 years ago, ballistic blocks more than several cm in diameters were found in the area about 1.7 km from the craters. Consequently, the area of Level-2, less than 2 km from the crater, may be classed as low risk in terms of being hit by ballistic ejecta. The area of Level-3 has the lowest risk of being hit by ballistic ejecta.

3) *Pyroclastic surge*

Small-scale pyroclastic surges occurred in 1958, 1979 and 1990 eruptions, as mentioned before

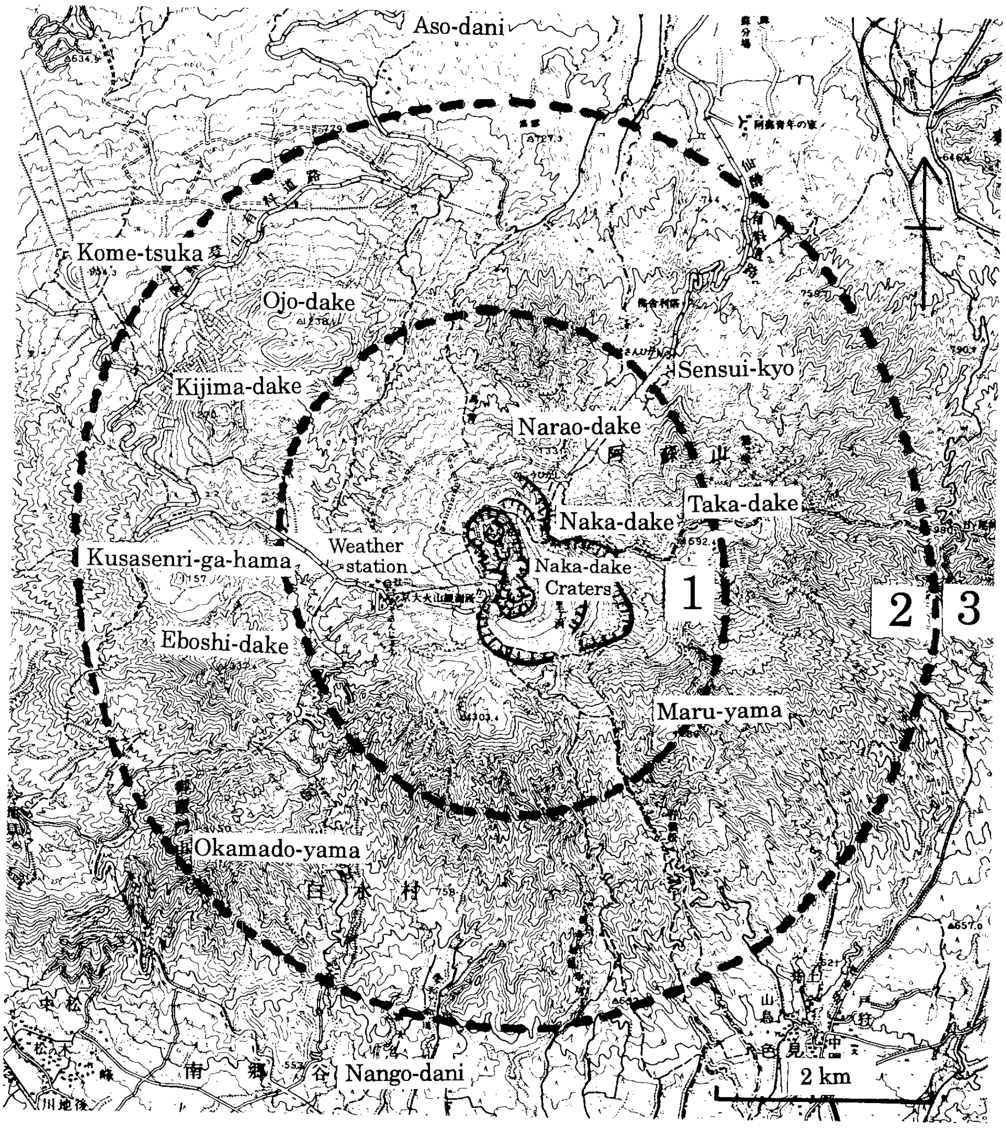

Fig. 8 The hazard map for pyroclastic surge from Naka-dake craters. Level-1 : risk is high, Level-2 : risk is moderate and Level-3 ; risk is low. Base map ; 1 : 50,000 "Asosan" published by GEOGRAPHICAL SURVEY INSTITUTE.

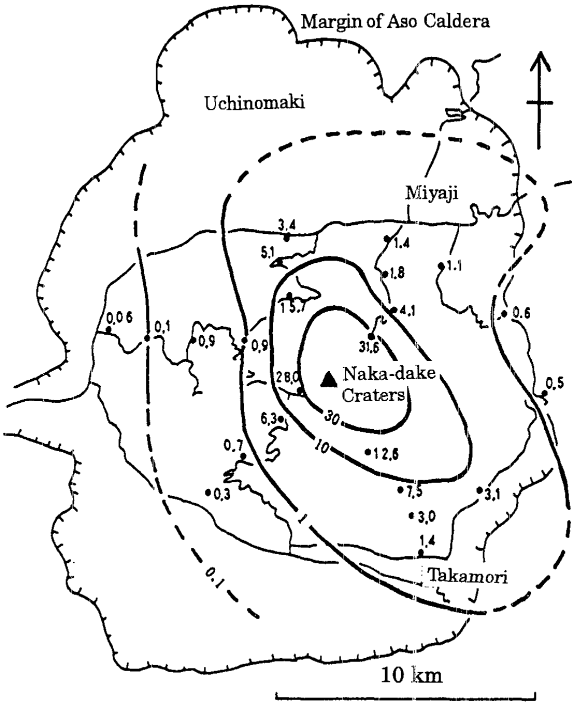

Fig. 9 Isopleth map of ash fall deposits from the Naka-dake crater for about 1 year, from November 1989 to October 1990. Numbers represent in kg/m^2 (WATANABE, 1991).

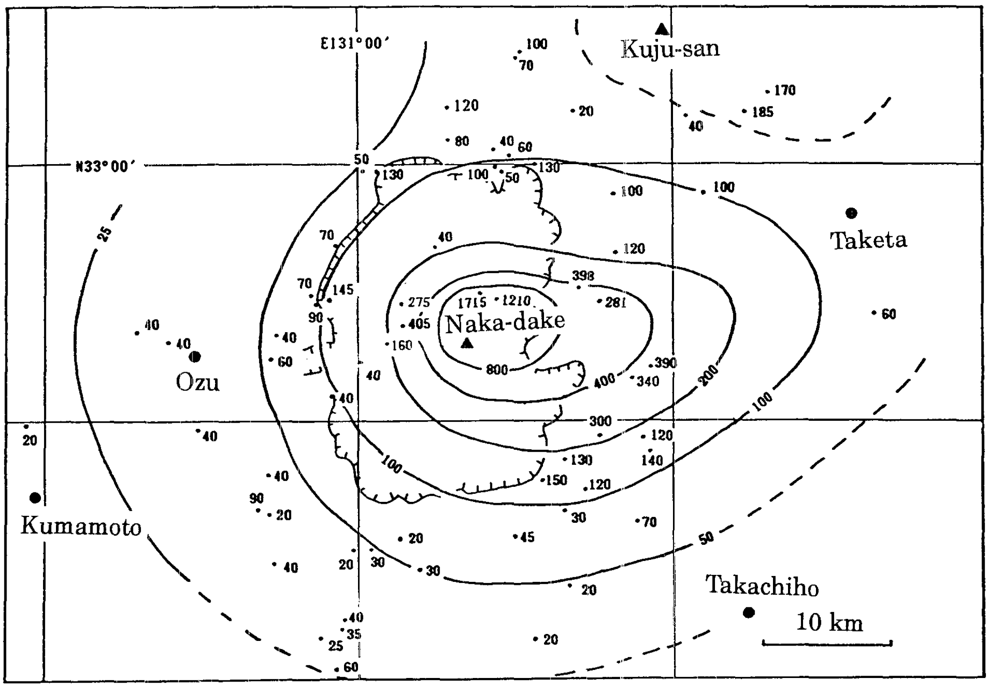

Fig. 10 Isopach map of pyroclastic fall deposits, mainly ash, from the Naka-dake craters in the recent about 6,300 years. Numbers represent in cm (WATANABE and TAKADA, 1990).

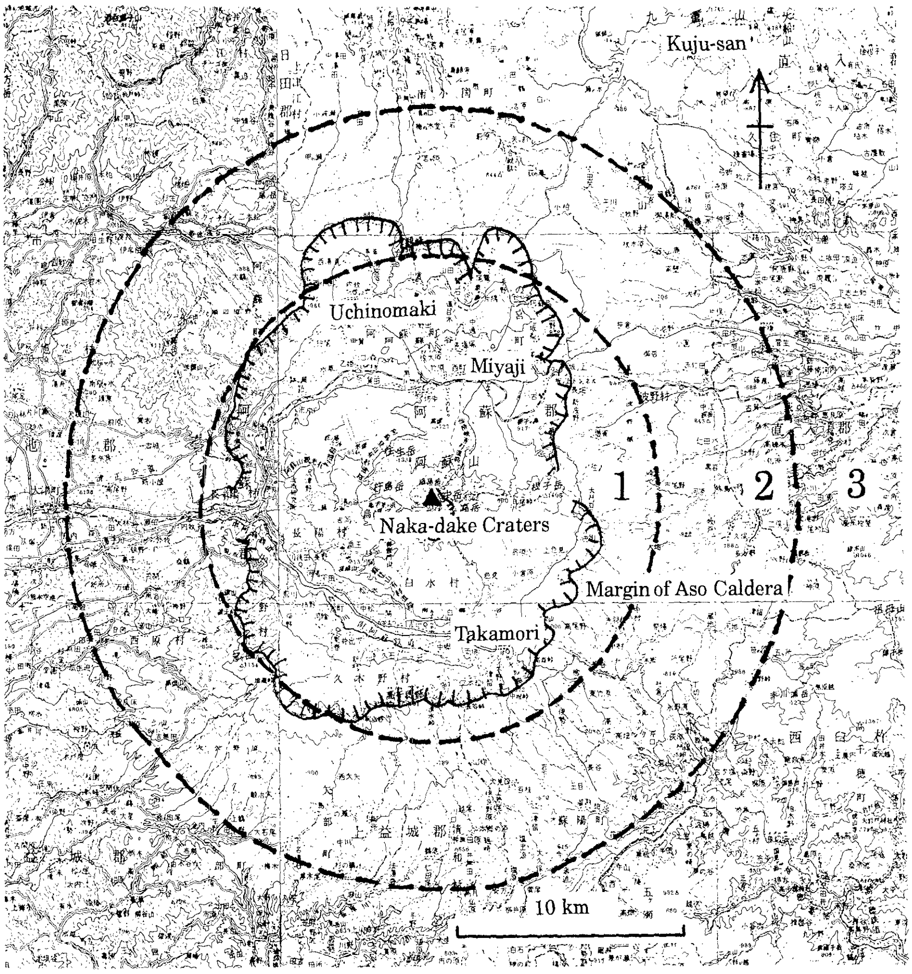

Fig. 11 The hazard map for the quantity of ash fall deposits around the Naka-dake craters. Level-1 ; thick, Level-2 ; moderate, Level-3 ; thin. Base map ; 1 : 200,000 "Kumamoto and Ōita" published by GEOGRAPHICAL SURVEY INSTITUTE.

(Fig. 7). A bigger-scale pyroclastic surge deposit, of 25 cm in thickness at 3 km west from the crater, is intercalated in the scoria fall deposits produced by eruptions from the Kishima-dake (Fig. 7). The age of the surge deposit is estimated at about 1,700 to 3,600 years old.

The hazard map for pyroclastic surges is shown in Fig. 8. The risk of destination of pyroclastic surges is very high in the area of Level-1, which is less than 2 km from the crater. The area of Level -2, between 2 km and 4 km from the crater, has a moderate risk of being affected by a pyroclastic surge. The area of Level-3, farther than 4 km from the crater, has a lower risk than that of Level -2.

4) *Ash fall*

A large amount of volcanic ash is emitted from the crater during active periods. The ash is dispersed to very wide area around the Naka-dake. In the 1988 to 1990 eruptions, which was a very active period, many quantitative data of ash fall deposit were obtained around the crater (Fig. 9). An isopach map of the ash fall deposits in the period from about 6,300 Y. B. P. to the present is shown in Fig. 10. Both of the contour lines in Figs. 9 and 10 show an almost concentric pattern.

This pattern means that the column of ash eruption is not so high and affected by the various wind directions at a low altitude (WATANABE and TAKADA, 1990).

The hazard map for fall ash from the Naka-dake is shown in Fig. 11. As shown in Fig. 9, the area of about 1 kg/m^2 of ash fall deposit in active periods for one year is estimated within about 10 km from the crater. These data are considered to be a basis of heavy ash fall. Consequently, the area of Level-1, heavy ash fall area, is estimated as shown in Fig. 11. The boundary between the area of Level-2 and Level-3 is estimated by the existence of minor damage of cultivated fields and vegetation.

Conclusion

No example of the hazard map for the eruptions of Naka-dake has been published. At present, about 50 thousand people make their living in the Aso caldera, and more than 5 million tourists a year visit the active crater. Consequently, hazard maps for this volcano are required. Four scientific hazard maps based on volcanological data for the eruptions of Naka-dake are suggested here. The eruptions of lava flow, ballistic ejecta, pyroclastic surge, and ash fall around the active crater are discussed in this paper. In these hazard maps, three levels of risk, from Level-1 to Level-3, have been identified around the area of the active crater. While there is room for improvement in the criteria of discrimination of the boundaries between each area, these maps are considered to be of value in the forecasting and reduction of future volcanic disasters around the Naka-dake, Aso volcano.

Acknowledgments

The author wishes to thank the following people and institutions for helpful information and discussion in the course of this work: K. ONO of the OYO Corporation; S. YOKOYAMA of Kumamoto University; H. HOSIZUMI of the Geological Survey of Japan; S. IKEBE of the Aso Volcano Museum; R. YOSHIMURA of the Continent Consultants; Asosan Weather Station of Japan Meteorological Agency; Aso Volcanological Laboratory of Kyoto University; Office of Aso District of Kumamoto Prefecture; Office of Aso Kuju National Park of Environment Agency.

References

AOKI, S., HONDA, T. and HAYAMIZU, I. (1940) Report on the activity of Aso volcano, February, 1933. Kenshinjihou, 11, 133-163 (in Japanese).

CAS, R. A. F. and WRIGHT, J. V. (1987) Volcanic successions, modern and ancient. Allen & Unwin (Publishers) Ltd., pp. 548.

DISASTER PREVENTION BUREAU, NATIONAL LAND AGENCE, JAPAN (1993) A manual to makeup the hazard maps of volcanic eruption. pp. 153, with pp. 49 collect materials. (in Japanese).

FUKUOKA DISTRICT METEOROLOGICAL OBSERVATORY (1965) Aso-san in the activity history of volcanoes in Kyushu district. Mem. Fukuoka Meteorological Observatory, 20, 15-46. (in Japanese).

------ (1990) The active volcanoes in Kyushu district. Mem. Fukuoka District Meteorological Observatory, 45, 1-46 (in Japanese).

IKEBE, S. and WATANABE, K. (1989) The 1989 eruption of Naka-dake, Aso volcano. J. Volcanol. Soc. Japan, 34, 389-390 (in Japanese).

------ (1990) Recent activity of Naka-dake, Aso volcano ; March 1988-November, 1989. Chishitsu News, no. 426, 6-14 (in Japanese).

ONO, K. and WATANABE, K. (1985) Geological Map of Aso Volcano. Geological Map of Volcanoes 4. Geol. Surv. of Japan (in Japanese with English abstract).

------ and SHIMOKAWA, K., SOYA, T. and WATANABE, K. (1982) Geological and petrologic study on the ejecta of 1979 eruption of Naka-dake, Aso volcano Japan. Report on an urgent study of 1979 eruption of Ontake and Aso volcano, Agency of Science and Technology, 167-189 (in Japanese).

------, WATANABE, K., HOSHIZUMI, H. and IKEBE, S. (In press). Ash eruption of Naka-dake erater, Aso volcano, western Japan. Jour. Volcanol. Geothem. Res., Special Issue.

WATANABE, K. (1991) On the ejecta of Aso volcano. Proceedings on the 23rd symposium of "Sabo Gakkai", 1-9 (in Japanese).

------- and TAKADA, H. (1990) Nonparallel relation between volcanic ash beds and "Kuro-boku" soil around the Aso caldera, Japan. Mem. Fac. Educ. Kumamoto Univ., Nat. Sci., 39, 21-27 (in Japanese with English abstract).

------, KAWANO, T., TANOUE, T., HIRASE, M., and TAKADA, S. (1991) Activity history of Naka-dake in recent 15 kilo-years, Aso volcano. Abstracts of Spring meeting of Volcanol. Soc. Japan, 1991, 39 (in Japanese).