3 Volcanic Archipelago: Volcanism as a Geoheritage Characteristic of Japan

Setsuya Nakada

Abstract

This chapter sketches an overall volcanic profile of the Japanese Islands and provides a context for the volcanic geoheritage of Japan. Mechanisms and particularities of subduction zone volcanism are discussed, and the recent volcanic history of the Japanese Islands is compared with the volcanic histories of Chile and Indonesia. It becomes clear that Japan has not experienced very large eruption activities compared to Chile and Indonesia despite having geological similarities. This quiescence possibly implies a statistical likelihood of major eruptions in the near future due to accumulation of magma. It is also shown that the actual scale of volcanic eruptions is a poor determinant of the human casualty; instead, the locations of eruptions (distance from residential areas and access) and level of preparedness or vulnerability of the affected population are important factors. The chapter argues that although it is possible to provide probable eruption scenarios, accurate detailed forecasting remains difficult, as each volcano is a different system and the eruption style is not always identical even at a single volcano. It is also argued that fundamental research on individual volcanoes is indispensable to understand this dynamic earth heritage, and reflecting on experience of geoparks in Japan, the chapter states that such heritage branding could become effective tools for promoting awareness and resilience of local societies.

Keywords

Volcanic heritage • Volcano distribution • Disaster vs. scale • Volcanic hazards and geoparks

3.1 Introduction

Volcanoes are among the most fundamental parts of the natural heritage of Planet Earth because of their beauty and elegant appearances, combination with unique ecosystems, and their dynamic behaviors. 21 of the 32 National Parks in Japan are related to active volcanoes. Volcanoes were worshipped as deities in ancient societies for their symbolic landscapes and awe-inspiring shows of force that sometimes generated disasters. The word volcano is derived from the Roman god Vulcan who is said to use a bellow in a fire workshop inside one of the Mediterranean volcanoes, sending smoke and fire from the mountain's chimney. Another famous volcano goddess is Pele of the Hawaiian mythology, who is said to live in the Halemaumau crater of Kilauea volcano, presiding over fire, thunder, dance, and violence. She is beautiful but jealous, reflecting both beautiful-spectacular and violet-destroying behaviors that can be commonly attributed to volcanoes.

In the Japanese mythology, Izanami is the goddess of volcano. She is depicted as a goddess of fertility and love, living under the ground. She bore the islands of Japan within the ocean. According to Hotate (2012), similar mythology about the origin of islands exists in the Pacific Ocean region

S. Nakada (✉)
Earthquake Research Institute, University of Tokyo, Tokyo, Japan
e-mail: nakada@eri.u-tokyo.ac.jp

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corresponding to the Circum-Pacific Volcanic Belt. The first recorded volcanic eruption of Mount Aso, found in an old Chinese document from mid-seventh Century, describes a fire pillar that stood from the crater and reached the heaven. Local people enshrined the mountain as they thought the act was divine. This shows that people's fears against unavoidable natural power had governed the society even during the eighth–ninth Century of Japan (Hotate 2012).

In modern times, we have come to possess the knowledge on the formation of volcanoes, how volcanic eruption occurs, and how we can prepare for hazards form such eruptions. In this chapter, volcanological knowledge and the difficulty of eruption forecasting is introduced to argue for informed coexistence with such dynamic earth heritage and to highlight the necessity of preparing for volcanic hazards.

3.2 Why Volcanoes Exist in Japan

The reason behind the existence of a large number of volcanoes in Japan is that the Japan Arc has geologically developed under collision of continental and oceanic plates. In the Japan Arc, oceanic plates interact with parts of continental plates and "sink" under the latter in a process called subduction. The continental plates in question are parts of the Eurasian continental plate and the North American continental plate which were separated from continental Asia by the back-arc spreading of Sea of Japan about 21–15 Ma (Otofuji et al. 1985). Due to the long history of subduction encompassing more than 400 million years (Kojima et al. 2016), the Japanese Islands have grown toward the Ocean side by accretion of sediments scraped off from the surface of the oceanic plates (Fig. 3.1). Strain that accumulates along the boundary between the continental crust and the subducting oceanic crust, or within the continental crust for a long time, can be released to generate sudden slips of the boundaries or faulting of the strata within the crust, respectively. Therefore, earthquake activity occurs so long as plate subduction continues. The surface of the oceanic plate sinking into the mantle is hydrous and becomes the site of melting due to high temperature in the mantle. Alternatively , the sinking oceanic crust squeezes out water components as its dips into the high-pressure mantle. Partial melting of the mantle due to decreasing melting temperature by the addition of water produces magma in this overlying mantle (Fig. 3.1). Magma produced in this process rises and accumulates under the crust due to the density contrast between the mantle and the crust. The magma continues to rise and accumulates in the gravitationally neutral level of the middle crust, forming a magma chamber (e.g., Grove 2000). During volcanic eruptions, this magma rises to the

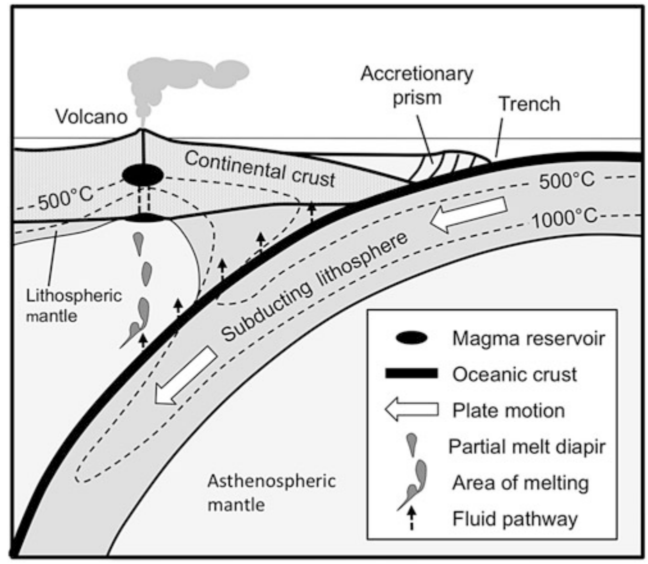

Fig. 3.1 Schematic cross section of subduction zone where the oceanic plate descends under the continental plate. The oceanic plate consists of the oceanic crust and the lithospheric mantle, while the continental plate consists of the continental crust and the lithospheric mantle. Thermal contour lines are from Wade and Wang (2009). The zone for melting in the asthenospheric mantle is defined by the combination of the pressure and temperature with the amount of water component added from beneath; inferred just above ~100 km depth of the subducting oceanic crust

surface. Basically, similar to earthquakes, so long as the oceanic plate subduction continues, magma production continues.

From this discussion, we can understand how restless seismic and volcanic activities at the plate boundaries drive land formation in the Japanese Islands. Major landforms of the Japanese Islands had been created through accretion of sediments and deposition of ejecta of volcanic eruptions, and those landforms were repeatedly deformed by dynamic movement of plates and resultant volcanism.

3.3 Volcano Distribution in the Japanese Islands

The distribution of volcanoes is controlled by the geometry of plate subduction (Fig. 3.2). In NE Japan, volcanoes are distributed nearly parallel to the Japan Trench where the Pacific Plate subsides under the NE Japan. The group of volcanoes belonging to this distribution is called the East Japan Volcanic Belt. On the other hand, in SW Japan, volcanoes are distributed nearly parallel to the Nankai Trough, and the distribution is called the West Japan Volcanic Belt. These places, where the depth of the subducting plate surfaces reaches about 100 km (Pacific Plate for the

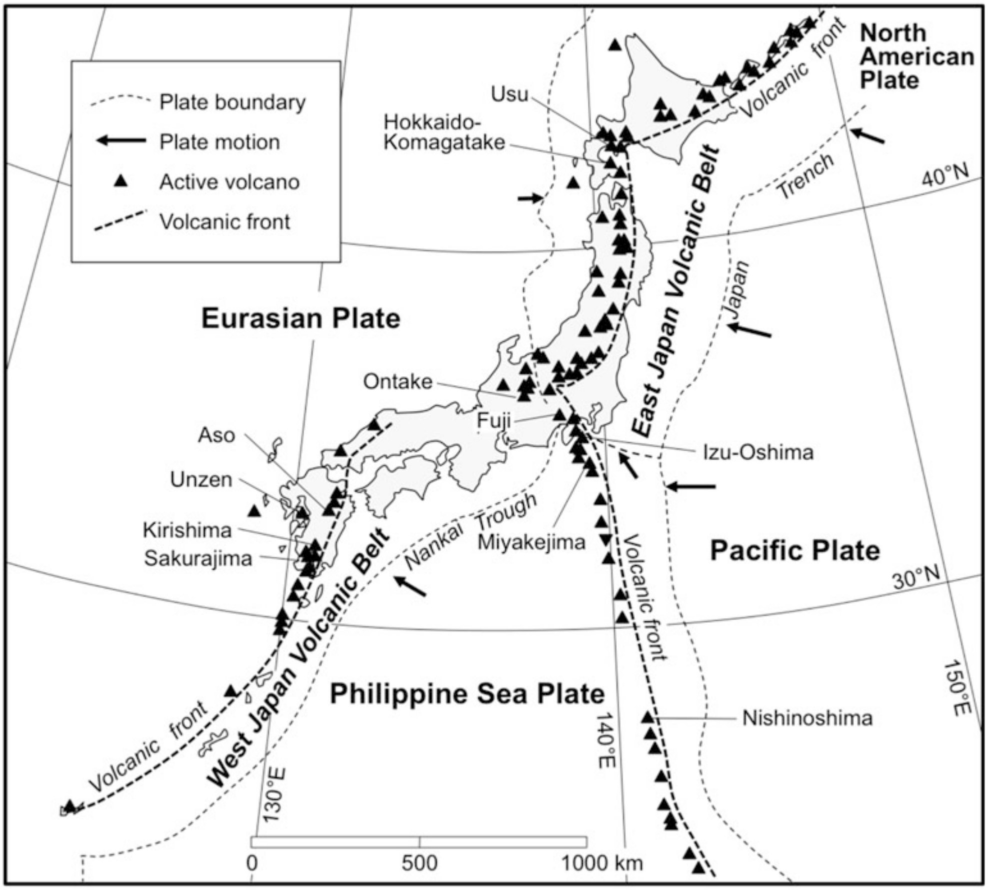

Fig. 3.2 Distribution of active volcanoes in the Japan Archipelago. The lengths of black arrows represent the relative motions of plates. Data from Nakada et al. (2016) and JMA (2013)

East Japan Volcanic Belt and the Philippine Sea Pate for the West Japan Volcanic Belt), correspond to the margin of the volcano distribution to the ocean side, which is also known as the "volcanic front." In each volcanic belt, the density of volcanoes grows toward the volcanic front and the magma production rate is highest just below the position of the volcanic front. Volcanoes with large-scale eruptions are located on the front (Nakada et al. 2016). Large-scale eruptions are commonly associated with the formation of caldera: a large depression resulting from the collapse of the unsupported rock body over the magma chamber. The magma chamber itself becomes nearly vacant for hours to days as a large amount of magma is taken out during the eruption. In the Japanese Islands, caldera-forming eruptions occurred in Central and Southern Kyushu, Hokkaido, and Northern Tohoku (Fig. 3.3). It is considered that the caldera nesting areas correspond to areas where the strain rate of the crust is the least; i.e., magma could steadily accumulate without interruption by frequent eruptions in these locations (Takahashi 1995). In the last 150,000 years, caldera-forming eruptions took place 14 times, and the statistical probability of VEI 7 eruptions is as low as about 0. 1/1000 year (Nakada 2015).

3.4 Characteristics of Volcanism in Japan

It can be said that in terms of volcanic activity, the Japanese Islands are currently in a quiescent phase. To understand this quiescence, it would be better to start with understanding the scale of volcanic eruptions. In volcanology, the scale of eruption is described by either the Volcanic Explosivitiy Index (VEI) or the magnitude of eruption (M). The former is based on the volume of *tephra* (a Greek word for eruption products issued from the crater into the air, including volcanic ash, block ejecta including lava fragments, pumice and scoria) from one explosive eruption, while the latter is based on the mass (weight) of all products from one eruption. Both indices range from 0 to 8. The VEI is an indicator reflecting the size of area impacted (covered) by tephra, and it can also be estimated roughly from the height of eruption column standing above the crater, which is related to the areal dimension of tephra dispersion. In case of eruptions where lava is flowing or is piled up above the crater, such as in Kilauea of Hawaii and Unzen of Japan, respectively, VEI values are small but the M values are intermediate, because only a

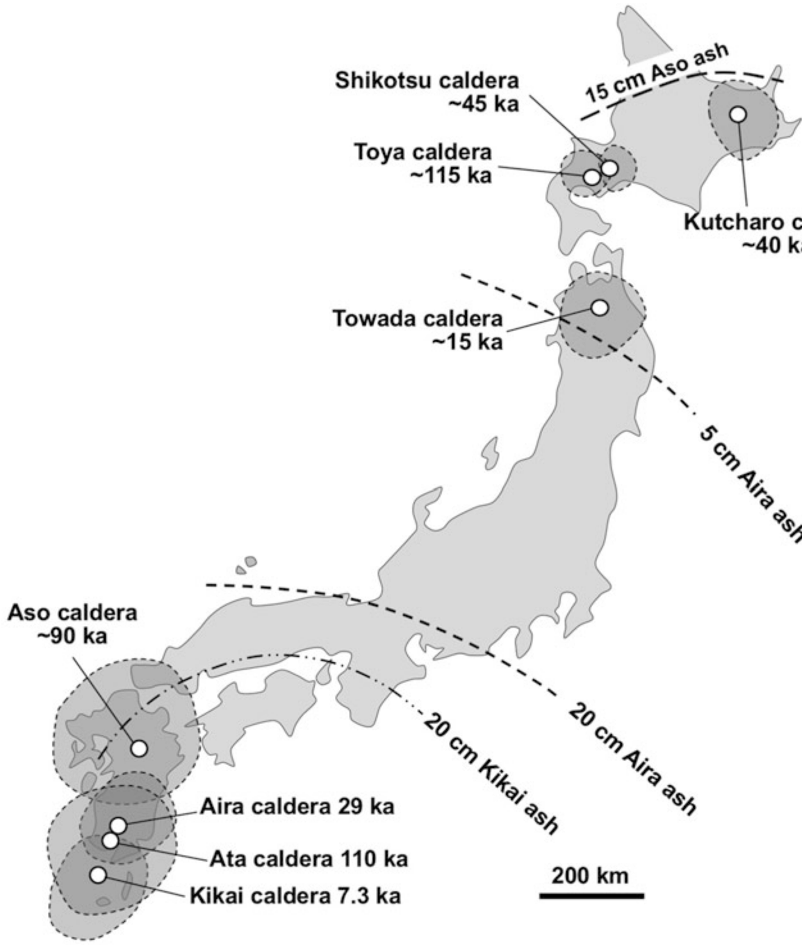

Fig. 3.3 Distribution of representative caldera volcanoes and the contours of main volcanic ash layers from caldera eruptions. "ka" means thousand years ago. Gray circular areas around caldera volcanoes are estimated as signature of pyroclastic flows associated with caldera eruptions. Modified from the National Research Institute for Earth Science and Disaster Resilience, http://dil.bosai.go.jp/workshop/02kouza_jirei/s18kasairyu/f6caldera.htm (accessed on August 30, 2016). Data from Machida and Arai (2003), JMA (2013), and Nakada et al. (2016) were referred

minor amount of tephra is ejected during those eruptions. However, when the scale of eruption is large enough, such as a caldera-forming event, both indicators show similar values.

General description and volume of tephra of eruptions can be listed below:

Non-explosive eruption	VEI 0	$<10^4$ m^3 of tephra
Small eruption	VEI 1	10^4–10^6
Moderate eruption	VEI 2	10^6–10^7
Moderate Large eruption	VEI 3	10^7–10^8
Large eruption	VEI 4	10^8–10^9
Very large eruption	VEI 5 and >5	$>10^9$

Caldera-forming eruptions normally have VEI of 6–8. The largest eruption for 150,000 years in Japan occurred at Mount Aso of 90,000 years ago, the volume of ejecta was >600 km^3, and the explosivity was rated at rank VEI 7 (Machida and Arai 2003). The latest VEI 8 eruption was recorded in Northern Sumatra of Indonesia 75,000 years ago; the Toba caldera was formed by the eruption with about 2800 km^3 (2.8×10^{12} m^3) of magma (Rose and Chesner 1987). Eruptions ranked VEI 7 and 8 are called "super eruptions."

In Fig. 3.4, the VEI values of eruptions in Japan during the past 350 years are compared with eruptions in Indonesia and Chile. Both countries have many active volcanoes like Japan. Geological backgrounds of volcanism are also similar, typified by subduction-related volcanism of the same Circum-Pacific Volcanic Zone. Figure 3.4 clearly shows that eruptions VEI 5 and more never occurred in Japan for these 300 years; in contrast, such eruptions are common in both Indonesia and Chile. In Japan, one of two last VEI 5 eruptions was the Hoei eruption at Mount Fuji in 1707. Furthermore, it becomes obvious that eruptions of VEI 4 never occurred during the last 100 years, another clear contrast to the situation in Indonesia and Chile. Geologically, there is no reason to believe that the recent geological background of recent Japan is any different from that of two countries, so the quiescence in Japan is accidental and it might suggest accumulation of magma under Japanese Islands that has not been spent by large-scale eruptions.

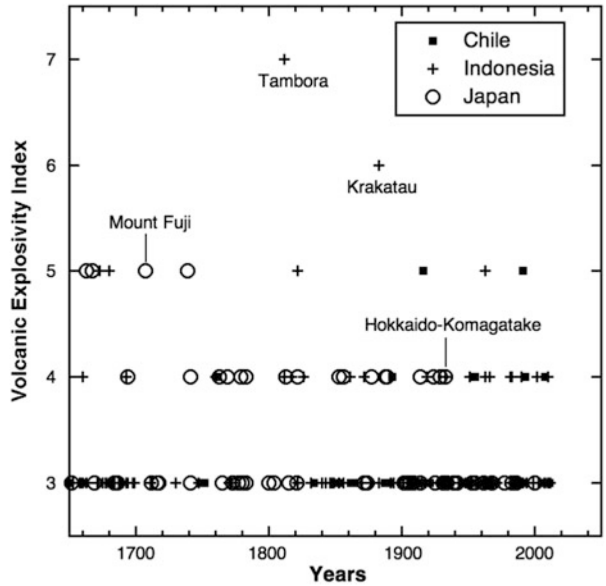

Fig. 3.4 Comparison of Volcanic Exlposivity Indices of volcanic eruptions among Japan, Indonesia, and Chile for these 350 years. Data after Nakada (2015)

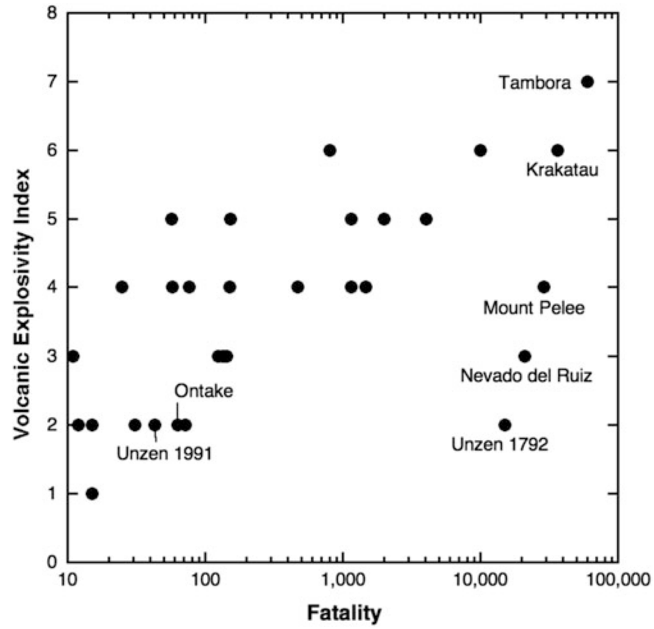

Fig. 3.5 Volcanic Explosivity Indices *vs.* numbers of fatalities for volcanic eruptions in Japan for these 300 years and for major eruptions in the world

3.5 Disaster vs. the Scale of Eruption

A small phreatic eruption at Mount Ontake (3067 m. asl) on September 27, 2014, caused a fatality count of 63 (including missing people). This is the largest number of casualties in a volcanic disaster after World War II. Mount Ontake is one of the famous volcanoes that have nurtured a cult of mountain worship, and the mountain is a popular destination for climbers as it is easy to climb; a cable car takes hikers to 2150 m. The day of the event (Saturday) also fell in the beginning of the fall season when the mountain slopes are covered with colorful leaves. It was a fine day with a blue sky. The eruption occurred on 11:53 a.m., just as hundreds of climbers gathered at the summit to take rest and lunch. The eruption sites were located at a hydrothermal activity site called Jigoku-dani (hell valley) on the southern slope a little below the summit (Maeno et al. 2016b). Most climbers did not initially notice the eruption, which was not accompanied by loud noises of explosions. Climbers took photos of dense cloud arising from below, forgetting to take shelter. Within 30 min, a large amount of rock fragments up to half of a meter across twice fell on the summit area. Climbers except those who had fled to mountain huts were hit by those rock fragments. Fortunately, people in the huts (about 100 of them) could escape the impact of falling stones. The VEI of this eruption was 2.

As shown in Fig. 3.5, the scale of eruption is not related to the scale of damage. The factors that amplify damages from natural hazards include the number and resilience of people who are affected and fragility/robustness of infrastructure (strength of houses and shelters, roads for evacuation, and so on). Even if large eruptions were to occur in a remote area, the human damage would not be large. However, if a large number of people are exposed to natural hazards, such as the climbers on Mount Ontake, the damage becomes large. According to the summary for recorded eruptions by Auker et al. (2013), fatal volcanic events (in terms of lives lost) are more frequent in the eruptions of VEI 2–5 rather than those of VEI >5, though fatal events with the largest total damages are also from large-scale eruptions. This result implies that fatal events occur within a moderate distance (a few to 10 km) from the source, where people can live and approach the source of the hazard. To minimize risks from volcanic hazard, the mind-set of avoiding natural hazards and preparedness for hazards based on proper knowledge on volcanic eruptions is important.

The Aso caldera eruption that occurred around Aso volcano in Kyushu about 90,000 years ago covered the whole area of Japan with fallout; the thickness of ash was >15 cm in Hokkaido (Fig. 3.3). The analysis for recorded eruptions by Auker et al. (2013) showed the fatal event from tephra (ashfall) is usually limited to <<10 km from the source. Ashfall itself is not critical, if meals and water can be prepared in shelters. The most lethal volcanic hazard is the pyroclastic flow. Pyroclastic flows are a mixture of tephra, hot gas, and ash that can travel as fast as >100 km/h. Areas attacked by pyroclastic flows are completely destroyed, burnt, and buried by thick ash and lava fragment deposits. In the case of the caldera eruption at Mount Aso 90,000 years ago, pyroclastic flows reached about 100–150 km in all directions from the source (Fig. 3.3). In the case of the Kikai caldera eruption, south of Kyushu Island, about 7000 years ago, a part of the Jomon-era habitation in the southern part of Kyushu disappeared due to pyroclastic flows crossing the sea. Tsunami generated by collapse of volcanic islands or pyroclastic flows entering the sea also causes heavy damage. The largest volcanic disaster in recorded history of Japan is a Tsunami disaster at Unzen Volcano in 1792 (Fig. 3.5) which recorded a fatality count of 15,000. This event was marked by the collapse of an old volcano triggered by a large earthquake and a large amount of collapsed debris rushed into the Ariake Bay resulting in the generation of Tsunami waves attacking both shores.

3.6 Examples of Recent Eruptions

3.6.1 Shinmoedake Volcano

The Shinmoedake volcano in the Kirishima Volcanic Group erupted magma in January 2011 after a dormancy of 300 years (Nakada et al. 2013; 2016). Columns of volcanic ash repeatedly formed up to 7 km above the crater (Fig. 3.6). Large volumes of pumice and ash from the eruption plume were carried by the northwesterly wind and covered the area near the crater and the residential area southeast of the volcano. After strong explosion events of the first 2 days, lava appeared at the summit crater, grew as a lava dome, and filled the floor. Due to sealing of the magma vent by the lava dome, another type of explosion occurred in February that shattered the lava dome. Eruptive activity continued until early September 2011 with intermittent explosions. The eruption of large quantities of pumice associated with tall plumes of volcanic ash was the first in japan in several decades, the last such event being the 1977 eruption at Usu Volcano. Again, this is another evidence for a quiet phase of volcanic activity in recent years in Japan. The total volume of tephra from this eruption was about ~ 1×10^7 m^3 and that of new lava within the crater was about 1.5×10^7 m^3). The total mass of this eruption reached about 5.5×10^7t; the scales were 3 as VEI and 3.7 as M.

Shinmoedake is in the territory of the Kirishima Japanese Geopark. A volcano hazard map was prepared under the Council of Trans-Kirishima, under the guidance of the science advisor of the geopark, and information was distributed through the geopark to all homes around the volcano before the 2011 eruption. During the eruption, up-to-date and accurate information on the eruption including a quick and efficient evacuation plan was provided to the community through the geopark. Disaster prevention education for school children was also carried out effectively and geopark people joined the volunteers to remove volcanic ash from rooftops.

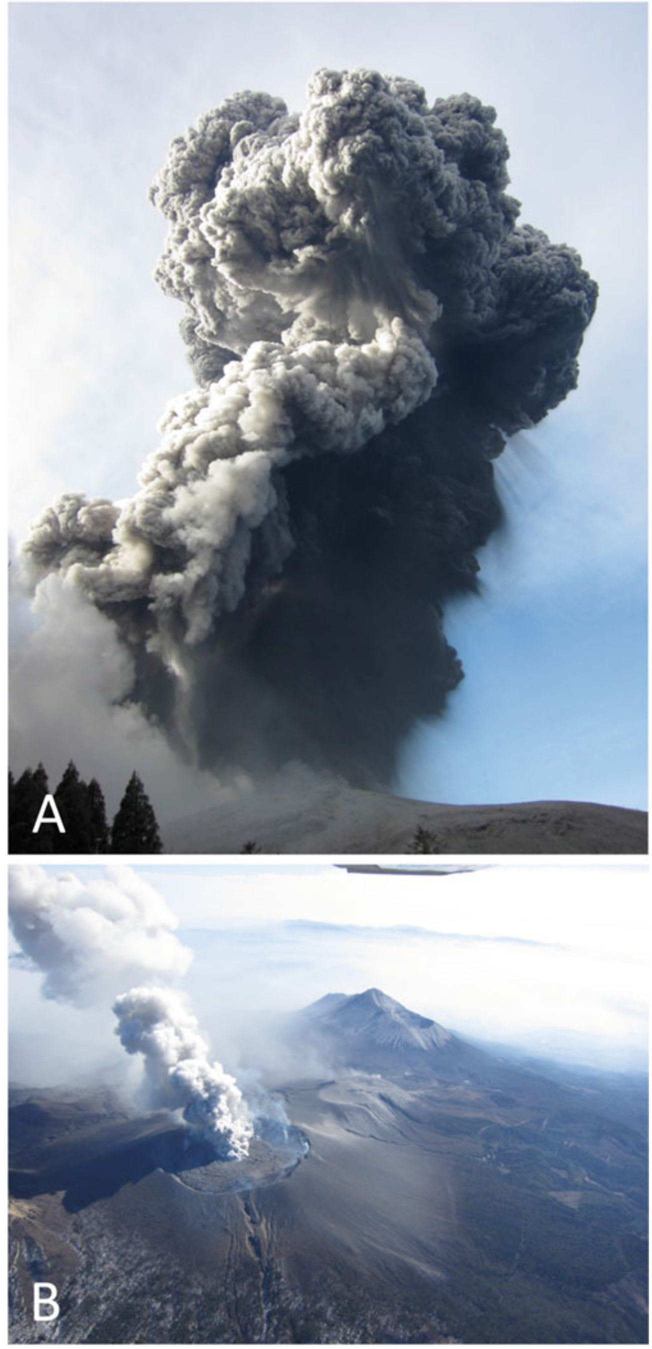

Fig. 3.6 Photos of eruptions in Shinmoedake Volcano in 2011. (**a**) A Vulcanian explosion in the afternoon of January 27, 2011. Photo taken about 3 km south of the crater. (**b**) Smoke from the center of the flattened lava dome within the crater of Shinmoedake. In the background, Takachiho and Ohachi volcanoes are visible. Photo taken on February 2, 2011

3.6.2 Nishinoshima Volcano

A volcanic eruption occurred near the Nishinoshima Island in the Pacific Ocean in 2013 (Maeno et al. 2016a). The uninhabited island is located about 1000 km south of Tokyo. In this island, an older eruption had occurred about 40 years ago, but large sections of the newly formed land were subsequently lost to wave erosion. In November 2013, eruptive activity started about 300 m southeast of the shoreline of the Nishinoshima Island with an explosive submarine eruption from the shallow sea (around the depth of a few tens of meters). Black-colored cock's tail jets were repeatedly issued from the sea surface, due to the magma's interaction with seawater (phreatomagmatic eruption). About a week after the explosion, the head of magma (lava) reached above seawater, causing the termination of phreatomagmatic activity and the eruption style changed into non-explosive lava flow with repeated bursts of lava from the central crater (Strombolian-type eruption). During the expansion of lava, the old island (Nishinoshima) was nearly swallowed by the new lava land (Fig. 3.7). Lava effusion with the Strombolian eruption continued in the summer of 2015. Late in November 2015, the eruption of Nishinoshima came to an end. The total volume of ejecta was estimated about 1.3×10^{8} m^3 including the materials erupted under the sea . This corresponds to M 4.3 (but VEI ~ 0).

3.7 Difficulty of Forecasting Volcanic Eruptions

Forecasting volcanic eruptions continues to be at the forefront of volcanological research for the last 40 years. In Japan, many scientists are involved through different national projects. As a result, we are now able to detect signals before most of the eruptions, when monitoring is carried out by multiple geophysical and geochemical methods. Especially for those volcanoes that are repeating eruptions in recent years, we can simulate the most likely scenarios of the future eruptions. However, abnormality signals are different in one volcano from the other; indeed, indicator signals are not always similar even in a single volcano. Most eruptions from recent years differed from the previous eruptions at the same volcano. Thus, it is clear that very complex mechanisms govern volcanic eruptions, and even if the approaching eruption can be detected, it is difficult to forecast the eruption scenarios (development) after the actual onset (including the manner of eruption, scale, and duration).

One suggestive example can be seen in the Mount Ontake eruption that was discussed earlier (Maeno et al. 2016b). The last eruption before 2014 occurred in 2007; the inflation of the summit area was observed with the escalation of seismicity during that event. During September 10–11 in 2014, a seismic swarm occurred under Mount Ontake, and the Japan Meteorological Agency (JMA) issued the Volcanic Information that indicated a possibility of a small phreatic eruption. However, seismicity declined in the following days, leaving only a few low-frequency seismic events, and no detectable inflation of the summit was observed except for the last few minutes prior to the eruption. The initial information on the seismic swarm itself was not accepted by the local administrative units as the danger sign, and consequently, no information was given to the climbers on that day. Thus, this event marked an instance where forecasting failed to generate adequate response, and this failure effected the reconsideration of volcanic disaster-related information and its handling by administrators and scientists.

Volcanoes commonly repeat similar phenomena from the past. Furthermore, eruptions do not occur randomly; instead, they follow a crude statistical rule whereby larger eruptions are less frequent than smaller eruptions, and the magma release rate for a volcano or a volcanic region is roughly constant over long temporal scale (Nakada 2015). Based on these facts, we may be able to ascertain the probability of future eruptions for a volcanic region. As every volcano is a distinct system, continuation of scientific research on every active volcano to understand these relationships and patterns is vital.

3.8 Preparing for Volcanic Hazards and Geoparks

From the foregoing discussion, it is clear that nearly all regions of the Japanese Islands are likely to be affected by a major volcanic eruption at some point, and many locations continually experience small- to moderate-scale volcanism. Therefore, volcanoes and their dynamics are fundamental aspects of the geological heritage of this archipelago. In this sense, Japanese volcanologists and science educators have a unique responsibility not only to continue research at the forefront of volcanic eruption forecasting, hazard mitigation, and monitoring of volcanoes but also to reach out to people and disseminate information in an effective manner. As the majority of Japanese geoparks feature volcanic themes, geoparks have emerged as a key tool for disseminating volcano-related information. However at the same time, volcanoes are complex systems and no two eruptions are completely the same. This necessitates more fundamental level research on each volcano and understanding the diversity of volcanic mechanisms. It also requires a change in the mind-set and risk awareness level of the local administrators and residents. Geoparks can play effective roles in achieving such aims.

Due to the natural variation of volcanoes and the socio-economic differences of concerned areas, preparing for volcanic eruptions varies from administrative to local resident levels. Monitoring with the help of the newest technology in

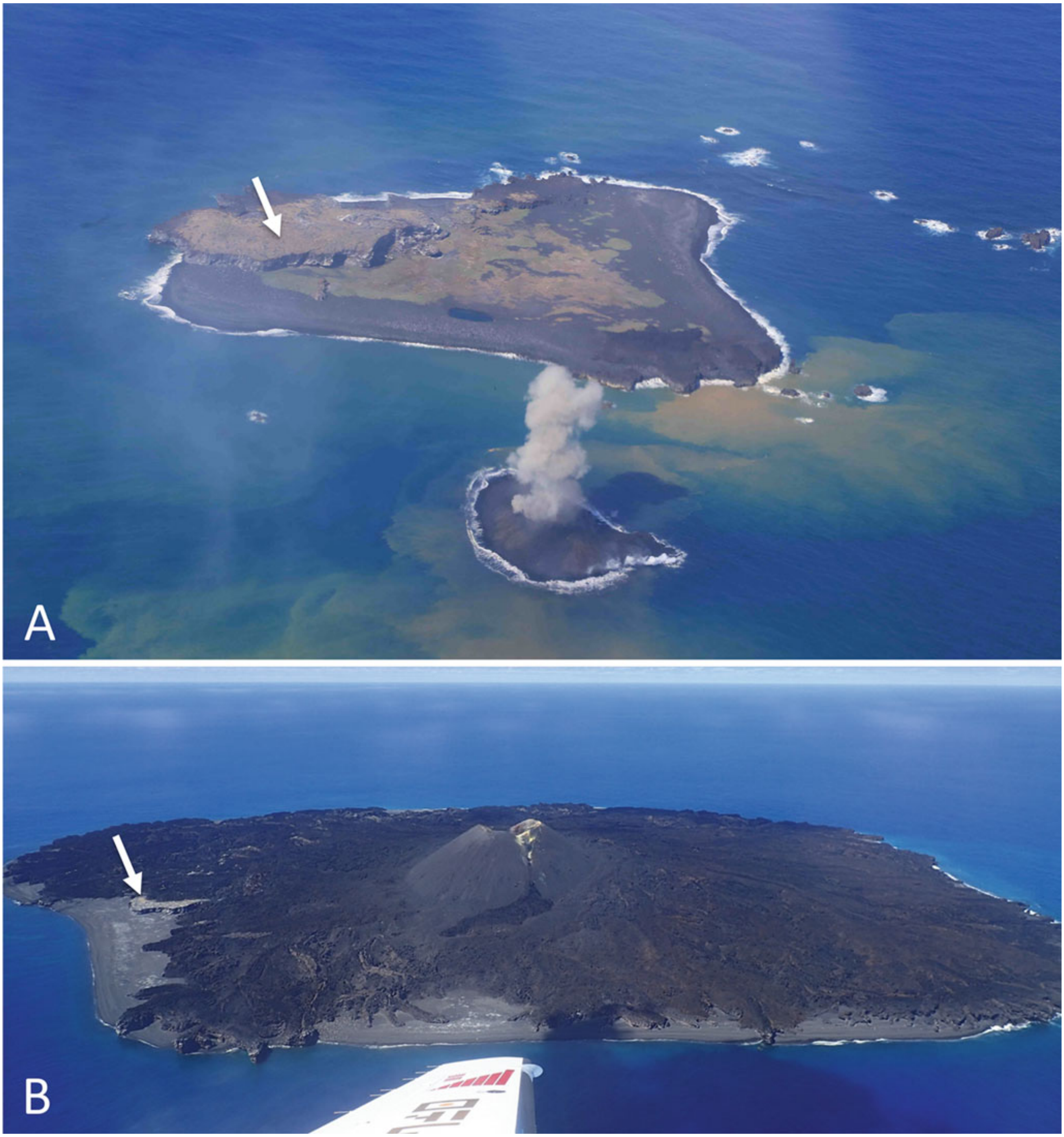

Fig. 3.7 Photos of eruptions in Nishinoshima volcano. (**a**) Eruption that commenced offshore of Nishinoshima started creating new volcano island. Photo November 24, 2013. (**b**) After the end of eruption, a new volcanic island grew and covered the older island with lava flows. Photo July 2, 2016. White arrows indicate the same cliff of the older Nishinoshima Island in the beginning of and after the 2013 eruption. The eruption center is represented by a scoria cone taller than the surrounding lava flows. Both photos were taken from aircrafts of the Asahi and Yomiuri Shimbuns, respectively

multiple ways and at multiple places is important for active volcanoes. Establishing information systems on and around volcanoes is important as well. This in turn will facilitate providing information to local people and climbers. Geoparks can be a medium where monitoring data released by the JMA are transferred and explained in easy-to-understand terms; this will increase the potential of swift response in case an emergency occurs. Planning resilient infrastructure for volcanic disasters is also important; this includes setting of shelters and signboards to show routes for evacuation near craters and availability of disaster (or hazard) maps. Exercises (drills) for evacuation can involve the local people and can raise awareness of volcanic phenomena and the role of hazard maps. Administrators can also realize weaknesses of planning and receive guidance on volcanic crisis management in the process. As the community becomes an important unit in case of volcanic crisis, role plays of both community leaders and members should be discussed before and during exercises. Elevating the knowledge of people including climbers is another *must* when coexisting with volcanoes. Such knowledge is critical for saving lives on the mountains. In a natural disaster, the extent of the damage depends on the resilience or vulnerability of the people. The points mentioned above can raise the resilience of local people and tourists, effecting an increase of resilience in societies, communities, and individuals in the face of volcanic hazards, and can foster the potential to recover quickly from damage.

There are two excellent UNESCO Global Geoparks: the Unzen Volcanic Area and Toya Caldera-Usu Volcano, which contain highly active volcanoes of Unzen and Usu, respectively. The last eruption at Unzen (1990–1995) was a lava dome-forming eruption that lasted for four and half years. Principal casualties were due to pyroclastic flows generated by partial collapse of the lava dome. On Unzen volcano, a lava dome that formed in the last eruption has become an excellent natural monument of the volcanic landscape and a memorial for volcanic disasters. This is also an interesting case where a new geological heritage was formed by a very recent eruption. The community that experienced this volcanic disaster increased their resilience, and currently, geopark guides in this area showcase the potential of the community to respond to future volcanic disasters. The Usu volcano repeats eruptions every 20–50 years within the Toya Caldera that formed about 110,000 years ago (Fig. 3.3). The last eruption in 2000 was started by a small pumice eruption, and the event was followed by phreatic (water-laden) eruptions. Soon after the eruption, the "Volcano Meister" system was introduced in the geopark; this program has trained guides to convey knowledge to visitors and to the next generations on the history and the hazards of the volcano, based on their experience of disaster and recovery.

3.9 Conclusions

In ancient societies, volcanoes inspired awe as gods or goddesses, and people could do little except praying when faced with volcanic disasters. Today, modern technology enables us to diagnose volcanoes and understand anomalies before eruption events. Although eruption mechanisms have been studied by scientists, understanding such mechanisms is not always enough for forecasting eruption onset and scale. Timely forecasting remains difficult and predicting detailed scenarios (development of eruption) is even more difficult. However, probable scenarios of the future eruptions can be provided based on geological research on the eruption history of individual volcanoes. Such research also has the additional important function of improving hazard maps that can be utilized for city planning and evacuation during crises. As this chapter argued, the scale of volcanic disasters is not directly dependent on the scale of eruptions. The exposure of people and their properties is more important as a factor. Although recently Japan is abnormally quiet in terms of volcanic activity, large eruptions are a constant possibility. It is in this sense that more fundamental research on each active volcano is required, especially for a land that has been borne directly out of subduction and volcanism in an active plate margin . Not only does such research help us understand the beauty of volcanoes, the complexity of their behavior, and the diversity of the heritage they engender, but such efforts can also be effectively translated to a more resilient and better informed society through tools such as geoparks and other heritage labels.

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