火山 第58巻（2013）
第2号，CD-BOOK

IAVCEI2013 Field Trip Guide

B03: Fuji and Hakone Volcanoes: Typical Stratovolcanoes in Japan

Akira Takada*,KazutakaMannen**andTakahiro Yamamoto*

*: *Geological Survey of Japan, AIST, Tsukuba, Japan*

**: *Hot Springs Research Institute of Kanagawa Prefecture, Odawara, Japan*

1. Introduction

Fuji and Hakone are adjoining stratovolcanoes close to Tokyo Metropolis (Fig. 1). Fuji Volcano is the highest mountainand the symbol of Japan. Three hundred years have passed since the last Hoei eruption(1707). Hakone Volcano, with its summit caldera, is famous as a hot spring resort. At present both volcanoes are superficially inactive, but they have great hazardous potential to damage the country.We describe eruptive history, geophysical monitoring and hazard mitigation of Hakone and Fuji volcanoes with explanation of field stops. We have revised the field trip guide of Fuji and Hakone Volcanoes in COV5 (Takada et al., 2007a) for IAVCEI2013.

2. Outline of tectonic setting

Hakone and Fuji are located on the zone of anarc-arc collision (Fig. 1).The Izu Peninsula, the northernmost part of the Izu-Bonin arc on the Philippine Sea plate, has been colliding with Honshu (mainland of Japan) on the Eurasian or North American Plate at a rate of about 3.5 cm/yr (Seno et al., 1993).The Sagami and Suruga Troughs (Fig. 1) are subduction boundaries between two plates. Convergence movement around the plate boundary is directly observed by GPS measurements (Fig. 2; Sagiya, 2004).

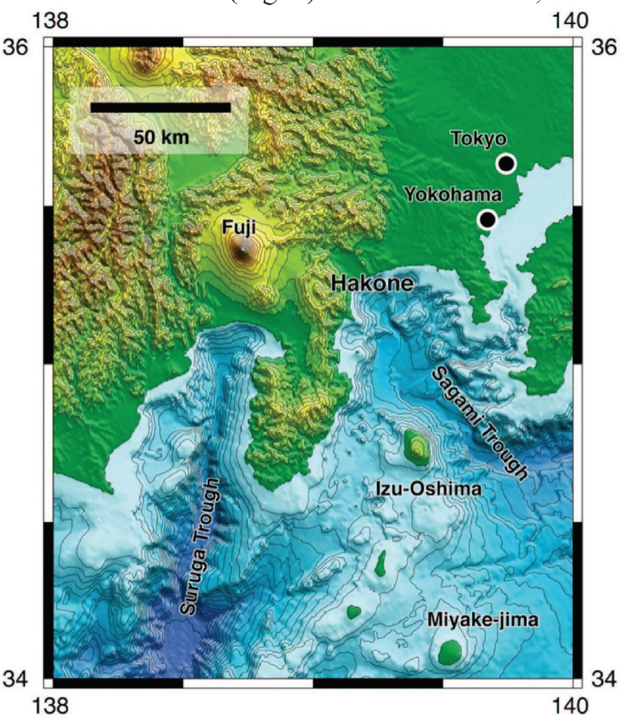


Fig. 1. Index map of Hakone and Fuji volcanoes.

3. Hakone volcano

3-1.Introduction

Hakone Volcano, located about 80 km SW of Tokyo, is one of the most famous resort areas in Japan(Fig. 1). This area attracts over 19 million tourists each year. This dissected, old, but still active volcano was designated as part of a national park in 1933 for its beautiful landscape and historic remains.

Study of this volcano as well as the introduction of geology to Japan from Europe started soon after

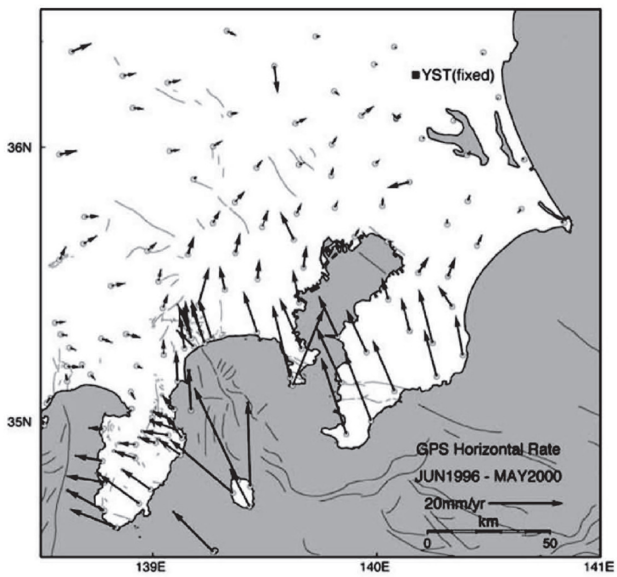


Fig. 2. Horizontal motion of Izu and Kanto Area, central Japan, observed by “GEONET”, the GPS network (Sagiya, 2004).

the MeijiRestoration (1868), and the first scientific study of the volcano was published in 1882. The most detailed geological and petrographical studies were carried out by HisashiKuno (1910-1969) immediately after the Kita-Izu earthquake (1930), which damaged this area and created abundant fresh outcrops within the volcano (Kuno, 1950a; b; 1951; 1952). For a long time, his work had never been challenged because the retrieval of vegetation made further geological surveying difficult. However, recent geological and K-Ar dating studies are revealing a more complicated history of the volcano than Kuno had proposed (e.g. Kato, 1985MS; Takahashi et al., 1999; Hirata, 1996, 1997, 1999; Hakamata et al., 2005).

Hakone has been recognized as a caldera volcano since the early stages of its study. The caldera rim is a large arcuate — nearly an oval shaped edge line, the dimension of which is 11x8 km(Figs. 3&4).The edifice composing the edge line was named Older Somma by Kuno. The highest peak of this volcano is Kamiyama (1439 m asl), one of the central cones in the caldera. Ashino-ko (Lake Ashi), located along the western margin of the caldera, is an atrio lake that is dammed up by deposit of the sector collapse of Kamiyama. Hayakawa (the Haya River) is the only drainage of Ashinoko. It runs down to the Sagami Bay through the deep valley of the northern margin of the oldercaldera floor. Since Hayakawa cuts down deeply, the Neogene basement outcrops along the valley. The most significant hot springs are located along the valley.

3-2. Eruptive history

Kuno proposed that Hakone is a triple volcano composed of two calderas, two sommas, and several post-caldera central cones. The most controversial issue before the study by Kuno was the classification of edifices inside the caldera. There are two types of edifice inside the caldera;

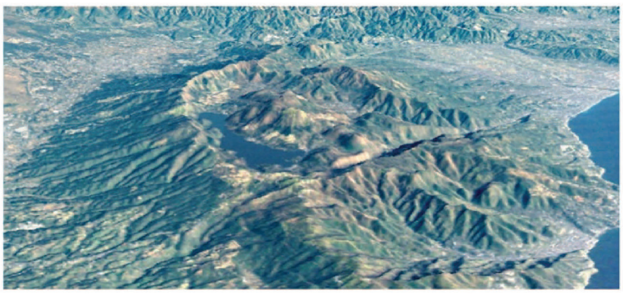


Fig. 3. Super bird's-eye of Hakone volcano. View from south. Courtesy of Kanagawa Prefectural Museum of Natural History.

flat-topped and bell-shaped. Kuno interpreted the flat-topped edifices ashe younger of the two sommas, and a remnant of the shieldvolcano which

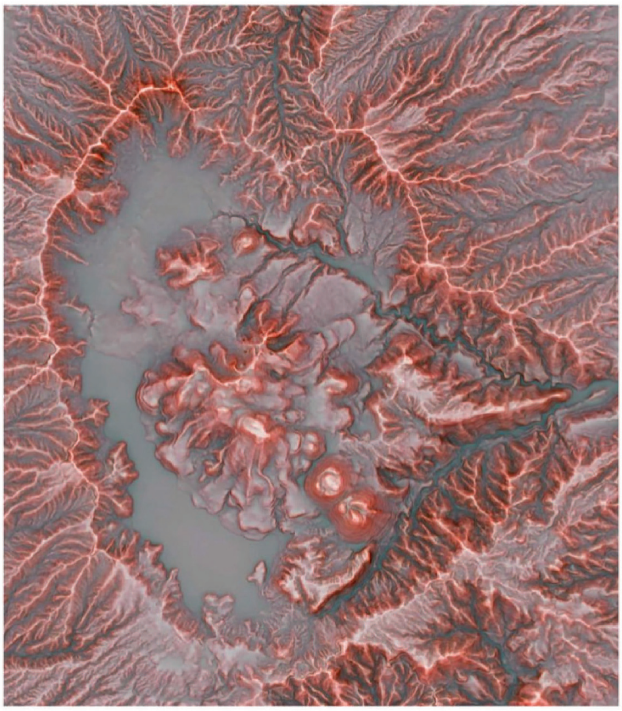


Fig. 4. Red relief topography map of main part of Hakone volcano.Courtesy of Asia Air Survey Co. Ltd.

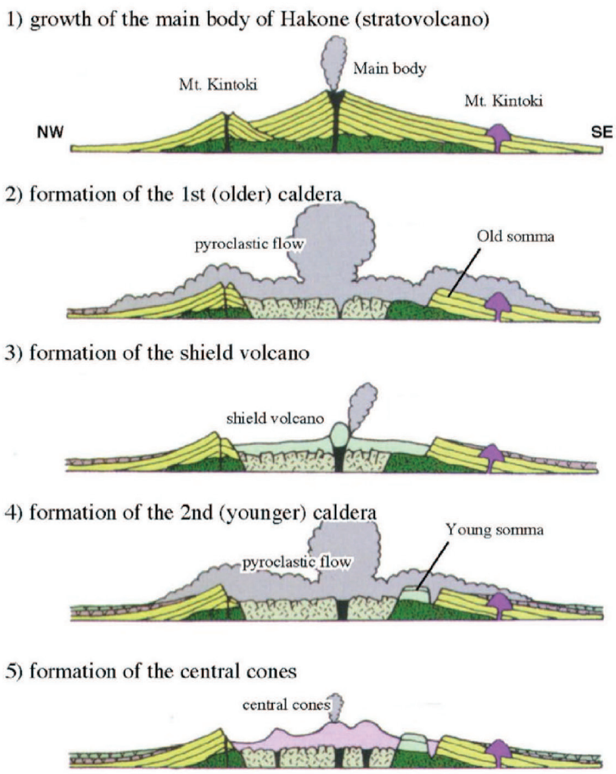


Fig. 5. Development history of Hakone volcano by Kuno (after Hakamata, 1988)

filled the first or older caldera. Kuno also proposed that the central area of the shield volcano was destroyed due to caldera subsidence—second or younger caldera—and the bell-shaped central cones were formed within the second caldera. The summary of the growth history of Hakone volcano by Kuno (1952) is shown in figure 5. Recent studies of the growth history of the volcano, however, reveal a more complicated history. The outline of the growth history of the volcano is described as follows, based on recent studies(Geological Society of Japan, 2007; Fig. 6).

Basement

Hakone Volcano lies on Neogene sub-aqueous volcaniclastics, which are divided into two groups: Yugashima Group and Hayakawa Tuff Breccia. The Yugashima Group is a widely distributed middle Miocene deposit in the northernmost part of the Izu-Bonin arc and is mainly composed of submarine volcaniclastics such as hyaloclastite and turbidite. Most parts of the Yugashima group are strongly altered by hydrothermal activity and are strongly deformed anddissected by many faults. The Hayakawa Tuff Breccia is a Pliocene and mainly composed of turbidite deposits. Mostparts of Hayakawa Tuff Breccia are fresh and horizontally stratified. The Hayakawa Tuff Breccia is correlated withShirahamaGroup which widely covers the southern half of Izu Peninsula (Otsuka, 1934; Mannen et al., 2003).The moluscan assemblages of

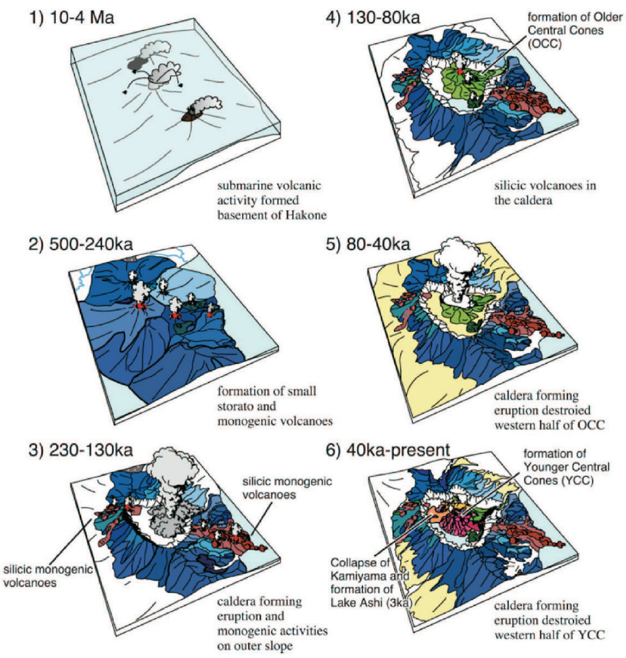


Fig. 6 Schematic development history of Hakone volcano (after Geological Society of Japan, 2007).

Hayakawa Tuff Breccia and Shirahama Group are identical. They are peculiar for their tropical elements that are absent in mainland Japan (Tomida, 1996). From paleontological and paleomagnetic studies, it is proposed that the basement of the Izu region, including Hakone, was formed in the far southern sea and moved northwards to collide with mainland Japan (Koyama, 1989; Niitsuma, 1999).

Somma

The arcuate edifice comprising the caldera rim was initially considered to be a remnant of a conical gigantic strato-volcano similar to Mt. Fuji (Kuno, 1950). The edifice is mainly composed of pyroclastic rocks such as scoria and spatter, with a relatively small amount of lava flows. The composition is mainly basaltic to basaltic andesite. However, recent systematic dip-strike measurements revealed that the eruption centers of the products were highly scattered and never concentrated on the center of the present volcano (Takahashi et al., 1999). From this investigation, Takahashi et al. (1999) proposed that the main part of the arcuate edifice is a complex of smaller sized strato-volcanoes and monogenic volcanoes. Hakamata et al. (2005) carried out extensive K-Ar dating of the volcano and revealed that the principal of the arcuate edifice was formed before 250 ka. The edifice is called somma.

Takahashi et al. (1999) revealed more detailed locations of eruption centers, and he concluded that the later part of the sommais characterized by the activities of monogenic volcanoes. Their ages are 250 ~ 120 ka (Hakamata et al., 2005). The age offormation corresponds to a period of frequent large plinianand pumice flow eruptions(Older Pumice Flows) that formed caldera.

Older Central Cones (OCC)

The flat-topped mountains within the older caldera are named Young Somma (YS) by Kuno. Takahashi et al. (1999) also studied YS in detail and the outline of the eruptive history of the volcano was established. YS lavas are thought to be supplied from multiple eruption centers and the edifice is thought to be a complex of small lava domes and thick lava flows associated with pyroclastic flows. This means that the large shield volcano proposed by Kuno as mentioned above is disputable, and YS is renamed Older Central Cones (OCC).Hakamata et al. (2005) also dated two lava flows of OCC and obtained 72 ka and 82 ka, respectively.

Younger Pumice Flows

During the period between 80 to 65 ka (MIS4), several large plinian eruptions occurredand large pumice flows were issued from Hakone Volcano (e.g. Machida, 1971).The youngest pumice flow, “Tokyo Pumice (Hk-TP)”, reached the western margin of Yokohama and its pre-culmination plinian phase covered southern part of Kanto plain including Tokyo.This period is considered to correspond to the younger caldera formation and generated ten to several tens of cubic kilometers of ignimbrite.

Younger Central Cones

The Younger Central Cones (YCC) forms a complex of bell-shaped lava domes and composite volcanoes on the central part of the caldera depression. The history of YCC is revealed by studies on the plinian tephra and dating of the block and ash flow deposits related to the lava dome or lava flow deposits (Kobayashi, 1999). The eruptive activities of the YCC were mainly small to medium-sized plinianeruptionswhich began immediately after the generation of the Younger Pumice Flow. At around 37 ka, the eruptive style changed to the formation of lava dome and lava flows. The activity of the YCC is known to be restricted within the caldera. The youngest magmaticactivity of the YCC (also themost recent

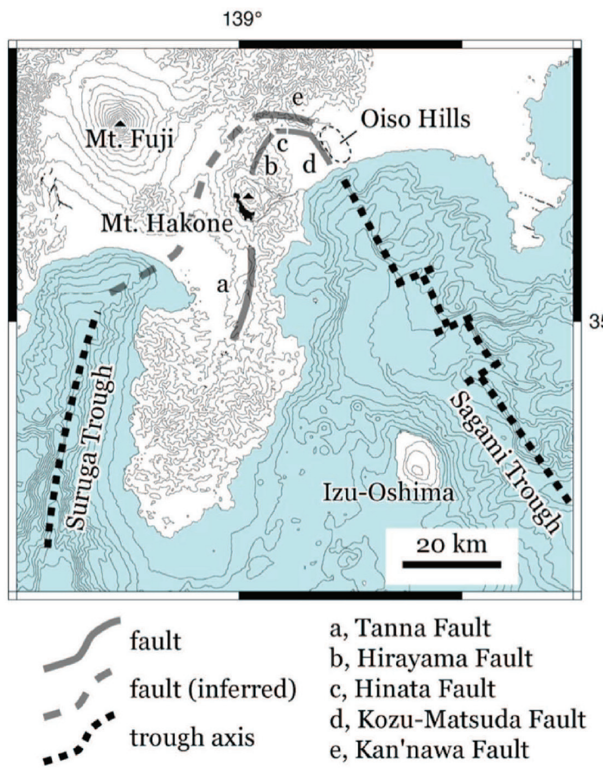


Fig. 7. Tectonic map around Hakone and Izu area.

of Hakone Volcano) formed the Kanmuriga-take lava spine within the amphitheater on the northern flank of Kamiyama (3ka, Oki and Hakamata, 1975).

Relationship with Tectonics

Hakone Volcano is traversed by a major active tectonic line named Tanna-Hirayama Tectonic Line (TTL), which is a group of left-lateral strike-slip faults (Fig. 7).Hakone is obviously deformed by the activity of TTL, having a slip rate of 0.2-0.4 cm/yr measured in the southern extension. The most recent movement of TTL is the Kita-Izu Earthquake in 1930 (e.g. Tanna Fault Trenching Research Group, 1983). Earthquake swarms, which sometimes occur in Hakone, are also associated to the TTL (Mannen, 2003).Takahashi et al. (1999) proposed that the segments of TTL make a left step-over on Hakone Volcano. Due to the step-over, a pull-apart fault system is formed beneath the volcano. In fact, the alignment of the eruption centers of the central cones is consistent with the presumed pull-apart structure (Fig. 8).

Generally, collision zones are expected to be the contraction field. However, the distribution of the eruption centers of Hakone is scattered, which is common with tensional stress. This contradiction is not well understood.However, the presence of the TTL could be a key to understanding the tectonics of the region.

This tectonic line also deforms Hakone volcano vertically.In the east of the tectonic line, the basement rocks outcrops along the valley formed by rivers while the west of it is covered by thick

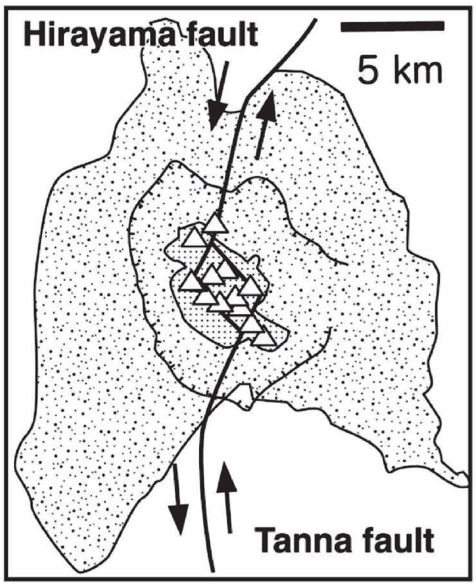


Fig. 8. Tanna and Hirayama faults and Hakone volcano. Triangles are eruptive centers of the Central Cones.

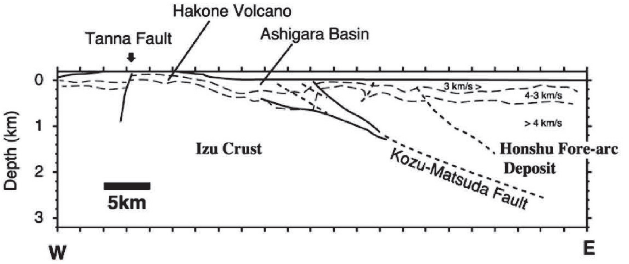


Fig. 9.Seismic velocity structure and geological interpretation of W-E section across Hakone and its eastern area (after Ministry of Education, Culture, Sports, Science and Technology, 2012).

Hakone volcano products. Recent seismic exploration revealed that western block of the tectonic line subsides up to 1 km, compared to the eastern block(Fig. 9).

Caldera

Kuno interpreted the topography of Hakone caldera as a typical "Crater Lake type" caldera. During caldera formation, a piston-shaped, coherent block fell into the magma chamber beneath it. This interpretation had been criticized even when Kuno was still alive, because no arcuate fault system was detected on the somma and other edifices. Studies conducted on the borehole samples obtained from commercial hot spring drillings showed that the head of the basement is too shallow to accommodate caldera collapse (Kuno et al., 1970). Mannen (in prep.) examined newly obtained bore hole samples and re-examined Kuno's samples and found a fresh lapilli tuff beneath the YCC (TBC), which was earlier classified as part of the basement rocks by Kuno et al. (1970). The TBC is slightly altered to smectite as compared to the Yugashima Group, which is strongly altered (epidote formation). Furthermore, the TBC is massive while the lapilli tuff of the basement rocks shows significant structure of turbidite. Petrographic and chemical analyses of lithics within the TBC reveal that some of the TBC originated from the OCC which indicate that the TBC is formed after the generation of the OCC. In some boreholes, a lacustrine deposit was found between the deposits of TBC and YCC. Pollen floras of the lacustrine deposits show that the boreal assemblage can be correlated to the MIS4 in this region (Mannen and Sugiyama, 2000; Mannen et al., 2006). From these observations, the TBC seems to have occurred within the topographic depressions of MIS4 in which a lake was formed. As mentioned above, the younger caldera was supposed to be formed during the MIS4 from the tephrochronological investigations. The distribution

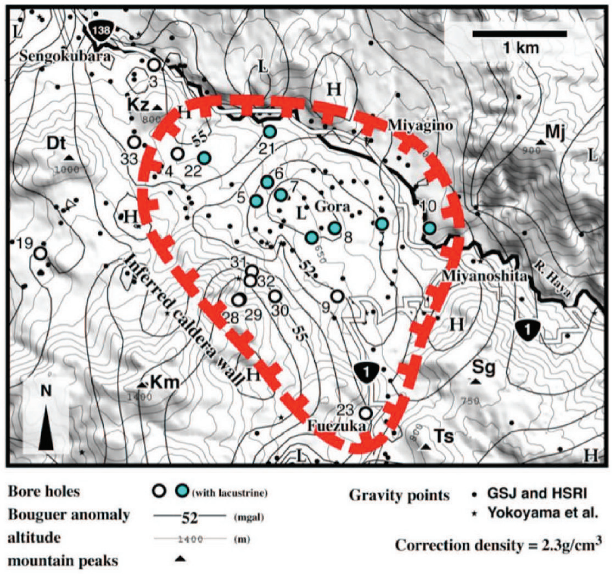


Fig. 10. Map of Topographic and gravity anomaly with hot spring well distribution (after Mannen, 2006). Caldera wall is inferred from distribution of caldera fill deposit (TBC).

of the TBC appears restricted in the region of low gravity anomaly (Fig. 10). These circumstantial pieces of evidence indicate that the TBC is a fill deposit of the younger caldera. The diameter of the uppermost caldera is less than 2 km. Calderas of such dimension which are filled with lapilli tuff and lacustrine deposits have been found in Japan since the 1980s (Mizugaki, 2003; Kurozumi and Doi, 2003; Kamata, 1989). This type of caldera, called funnel-shaped caldera or Nigorikawa type caldera (Lipman, 2000), also appears to constitute the central part of the Hakone caldera.

3-3. Major eruptions and disasters

Hakone Volcano is a caldera formed by repeated caldera-forming eruptions. The present caldera was formed during Younger Pumice Flows (80-60ka). During this stage, several plinian eruptions and two or three large pumice flowserupted. The largest eruption, the Tokyo Pumice (TP), is the last and the largest eruption of this stage, composed of an initial plinian eruption and a later ignimbrite outflow (Fig. 11). The name "Tokyo" comes from the capital Tokyo where the white pumice fall deposit is recognized in shallow horizons and often exposed at construction sites. Until late 1960s, the source of the TP was a mystery because the pumice fall deposit was not found around Hakone where it is presumed as the source. Later, it was found out that the absence of a pumice fall deposit around Hakone was due to the overlying ignimbritewhich inhibited access to the initial pumice fall deposit. The story on the quest for the source of the TP resulted in the monumental success of early stage of tephra studies in Japan.

After the outflow of TP, several plinian eruptions occurred, but the edifice formed in that period is not exposed at the present Hakone. Since 37ka, a cluster of lava domes and small composite volcanoes known as the Central Cones (CC) were formed and still exist today. During the formation of the CC, several block-and-ash flows were generated due to the collapse of lava flows and domes; some of them flowed over the caldera rim in the westward direction. All of these destructive eruptions are prehistoric (>3ka).

Documentation of the eruption of Hakone is absent. Recent studies, however, revealed that at least five phreatic eruptions took place in the last 3ky (Kobayashi et al., 2006). The latest phreatic eruption occurred during the 13th century which generated airfall, surge and mudflow deposits. Although the eruptions are small ($\leq 10^6 m^3$), such eruptions are still hazardous because the eruptive centers are located at Owaki-dani steaming area, the most popular tourist spot in Hakone.

On July 26, 1953, another large landslide took place at Soun-zan, which is the second largest steaming area of the volcano. Mudflow-induced landslide reached 2 km downslope and destroyed a dorter (accommodation of a temple) and killed thirteen people. The volume of the mudflow was as much as 0.8 million cubic meters and the velocity of the flow wasestimated to be 7m/s (25km/h). Note that both major historic landslides took place during late rainy season.

To mitigate the hazards, the local government has constructed Sabo works such as concrete dams for many years to avoid flowage of mud that covers the steaming area. Lateral bore holes have been used to drain interstitial water in order to diminish the soil load during heavy rainfalls. In Soun-zan, more challenging work was done, such as anchoring of large unstable block.

In the past, artificial degassing by boring was attempted to slow down the alteration of surface rocks. This strategy failed completely because the degassing process induced infiltration of oxygen and surface water, which increased the alteration of rocks. Rocks in steaming areas are subjected to reduction by hydrogen sulfide in volcanic gas. Due to the reduction reaction, Fe-oxides in the rocks such as magnetite or ilmenite are transformed into iron sulfides. Initially, the rocks still keep their strength, but once the rocks are exposed to air that contains oxygen, the iron sulfides in the rock swiftly break down and release sulfuric acid. The acid disintegrates the rock structure transforming them to solfataric mud.The rock alteration in steaming areas is initially due to the presence of volcanic gas. Later air inflow completes the disintegration.

Volcanic gas is also a recognized hazard at Hakone Volcano. Most of the tragedies were related to bathing in Yunohanazawa where there are a few log cabins used for bathing. In 1951 and 1952, three children were killed due to hydrogen sulfide poisoning. After the incident, all the bathing cabins in this area were removed. In Hakone, gas accidents also took place at Owaki-dani in 1933 and 1972 during construction works.

Fig. 11. Pumice flow deposit of “Tokyo Pumice” at Nakai town, 22km ENE of the center of Hakone volcano (courtesy of T. Kasama, Prefectural Museum of Natural History).

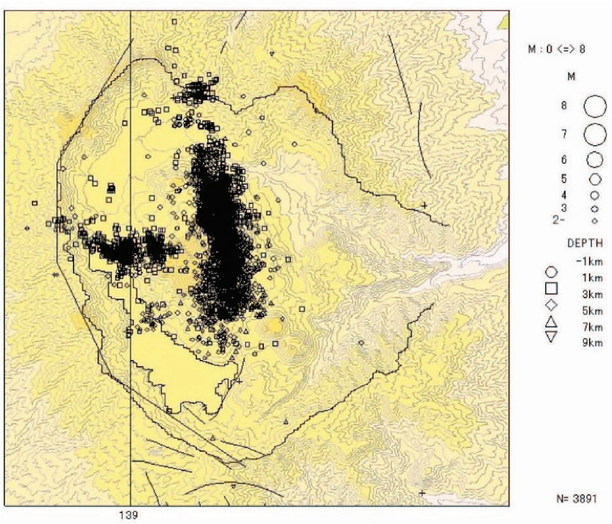


Fig. 12. Epicenter distribution in Hakone Volcano in 2001.

3-4. Geophysical monitoring and hazard mitigation

In Hakone, there have been earthquake swarms. These earthquake swarm activity was not destructive but people were sometimes anxious about volcanic activity. The first document on earthquake swarms in Hakone was written in 1786. The author lived in Edo (Tokyo), and based on hearsay, reported on earthquake swarms that took place from March 23 to 24 of that year. According to that document, over 100 earthquakes were felt and the stone fence of the checkpoint was broken.Small rock falls also took place and damaged some houses.

After the event, there were no documented earthquakes in Hakone for quite a long time. The earthquake swarm in 1917 was the first documented event after 1786 and was the first earthquake swarm described from a scientific point of view. Since 1917, at least seven major earthquake swarms were felt by local inhabitants, and hundreds of minor earthquake swarms were observed by seismic instruments (Table 1).

Seismic instruments were temporarily installed to observe earthquake swarms of 1917 and 1935. Permanent seismic observation started in 1960 due to major earthquake swarms of 1959 to 1960, which threatened local people because of long duration and intensity of the earthquakes. The network was first installed by the Earthquake Research Institute of Tokyo University, and soon transferred to the Civil Engineering Division of Kanagawa Prefectural government. Then, the network was transferred to the Hot Springs Research Institute of Kanagawa Prefecture (HSRI) in 1968. The observation network wastelemeterized in 1989 and all the data have been transferred to the Japan Meteorological Agency since 2004.

Although a few earthquake swarms accompanied the increase of fumarolic activity in 1933-35 and 2001, most of them did not. The intensity of earthquake swarms and fumarole activity seem to have no correlation; for example, the earthquakes of 1933-35 were very weak and felt only at Ubako and Owaki-dani, but increase of fumarolic activity was very significant.

From the observation by HSRI, it is clarified that the hypocenter distribution of the Hakone earthquake traverses the center of the volcano from north to south (Fig. 12). The hypocenters are on the northern extension of Kita-Izu Fault which was the source of 1930 Kita-Izu earthquake (M = 7.3). It also appears to be the southern extension of Hirayama Fault, which has no historical record but is presumed to still be active (latest activity took place about 2 ka). Thus, the hypocentral area of the earthquake swarms seems to bridge the two faults. The intense activity of the earthquake swarms without thermal manifestation in Hakone could be interpreted as fault-related activity.

Magmatic activity seems still active. In 2001, a slight inflation of the edifice was observed by tilt meters and GPS stations installed in and around the volcano (Daita et al., 2009). The source of inflation was concluded to be multiple; a single Mogi source at -7 km altitude and two open cracks at -0.2 km altitude. The inflation event lasted for more than 3months and total volumetric expansions are estimated as 7.1 $\times 10^6 m^3$ for the Mogi source and 0.15-0.51$\times 10^6 m^3$ for the open cracks.During the

earthquake swarm	January, 1917	December, 1920	1934-35	April, 1943	January, 1944	November, 1952	September, 1959- April, 1960	June to October, 2001
epicenter region	saddle of Kamiyama and Komagatake?	near Futagoyama and Moto-Hakone	Near Owakidani and the south?	norhtern part of the caldera to central cones area?	central cones area and northern part of the caldera?	Kamiyama and Owakidani	near Kamiyama	central cones
duration	1 month	1 week	1 month	2 weeks	1 month	2 weeks	8 months	4 monthes
duration of climax	2 days	12 hours	?	2 days	4 days	12 hours	10 times of 6-34 hours	
maximum intensity in JMA scale and observation point	IV~V? Ubako	V Moto-Hakone and Hakone-Machi	II~III? Ubako	IV Ashinoyu	V Ashinoyu	III central cones area	IV Gora	III Owakidani
maximum distance of perceptibility (R)	<20 km	<80 km	<3 km	<10 km	110 km	<10 km	<20km	<10km
M of maximum earthquake (*1)	<2.5	<4.1	<0.3	<1.7	4.5	<1.7	<2.5	
M of maximum earthquake (*2)					5.1		4.5	2.9
number of felt earthquake and the observation point	over 300 at Ubako	c.100? at Moto-Hakone and others	22 at Ubako	10 at Ashinoyu	12 at Hakone-yama weather st.	52 at Sengokubara	437 at Gora	more than 100 near Owakidani
earthquake number observed in Mishima				95	142	41	179	
mode of PS time in Mishima (sec)				5.2	2.1	2.8	1.8	
occurrence of the main shock	indistinct	distinct	indistinct	indistinct	distinct	indistinct?	distinct?	distinct?
rumblings	many	rare	many	?	?	many	many	many

Table 1. List of historical earthquake swarms in Hakone (after Mannen, 2003).

inflation event, more than 100 earthquakes were felt by the local people and more than 15000 earthquakes were observed by the seismological networks. In the Owaki-daniFumarolic area, two steaming wells were exploded and released gas containing SO_2, HCl, and HF, which are not common volcanic gasses in this area. This event is interpreted as magma intrusion in deep that stimulated hydrothermal system and triggered inflation and earthquakes in shallow. Similar inflation accompanying earthquakes were also observed in 2013.

As shown here, Hakone is an active volcano characterized by relatively high seismicity. Even if a large-magnitude earthquake occurs, it would not necessarily trigger an eruption in the near future. Frequent information dissemination and warning about unusual earthquake activity would be helpful for the local people in understanding the volcano. However, Hakone is one of the most popular resorts in Japan. Some announcement of earthquake activity may assure the inhabitants and tourists in the area, but broadcasting it around the country may have a negative impact on tourism. In such a situation, it is very difficult to disclose information about unusual seismic activity. The Japan Meteorological Agency, which is responsible for volcano monitoring and warning, should be careful with the distribution of information about seismic and volcanic activities to prevent unnecessary public concern.

A map with a leaflet named "Disaster Prevention Map of Hakone Volcano" was published by the Hakone Town office in 2004. This was an attempt to help inhabitants understand the seismic and volcanic nature of the volcano rather than to warn of the hazards of the volcano. In the map, the eruptive history, present situation, expected eruption style, monitoring of volcanic activity, and guide for evacuation were mentioned.Phreatic eruption, the expected eruption style,was discussed in detail, reflecting recent studies on eruptions in the last three

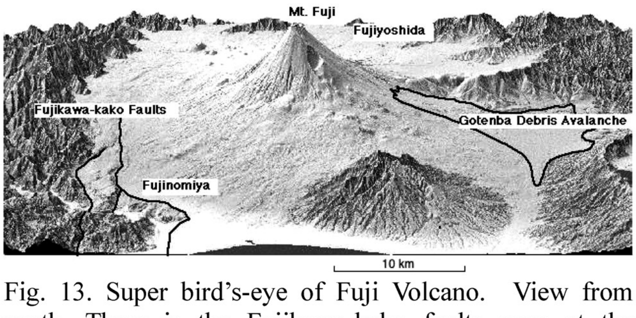


Fig. 13. Super bird's-eye of Fuji Volcano. View from south. There is the Fujikawa-kako faults zone at the southwestern foot of Fuji Volcano. After Yamamoto et al. (2002).

reflecting recent studies on eruptions in the last three thousand years.HSRI publicizes its raw data, together with some general instructions on how to read it, on their web site. The site is favored and used by local peoples, town offices, and companies, such as hotels, transportation, and hot springs businesses.

4. Fuji Volcano

4-1. Introduction

Fuji Volcano, 3776 m high, is the highest mountain in Japan. Fuji volcano has grown on the plate boundary between Eurasia Plate and Philippine Sea Plate. Its magmatic activity is caused by the subduction of Pacific Plate against Eurasian Plate. The Philippine Sea Plate beneath Fuji Volcano may split toward west and east, respectively (Takahashi, 2000). This kind of rifting between the separated plates accommodates the magma chamber beneath the volcano (Takahashi, 2000). The recent geodetic date suggests that the eastern wing of Philippine Sea Plate including Izu Peninsula may be separated into a microplate (Nishimura and Sagiya, 2007).

Basements

Fuji Volcano is surrounded by Misaka, Tenshu and Tanzawa mountains, consisting of Middle Miocene Nishiyatsushiro and TanzawaGroups and the Late Miocene to Pliocene Fujikawa Group. They are derived from the deposits in deep-sea environment including volcanic rocks. The northern part of Fuji Volcano is a submarine depositional channel connecting Tenshu Mountains and the eastern part of MisakaMountains (Matsuda, 2007). A negative Bouguer anomaly zone along the northwestern foot of Fuji Volcano suggests deep sediment-filled channel zone (Komazawa, 2000). The basement from the southwestern foot of Fuji Volcano to beneath the summit of Fuji Volcano consists probably of Tanzawa Group and quartz diorite intrusives (Matsuda, 2007). Beneath the southwestern foot of Fuji Volcano, the Pliocene Hamaishidake-Katsuragawa channel deposits and the Pleistocene Kanbara conglomerate are exposed (Matsuda, 2007).

Fujikawa-kako faults

The southeastern foot of Fuji Volcano has been deformed by the active Fujikawa-kako faults, which are northern branches of the plate boundary (Fig. 13). The long-term average slip rate is estimated to be around 10 m/ ky (Yamazaki, 1992)and six rupture events have taken place since 10 ka. The 2.9-ka event presumably triggered the Gotemba debris avalanche (Yamamoto et al., 2002).

Characteristics
Fuji Volcano is characterized by (1) size as the largest basaltic volcano in Japan, (2) the variation of erupted volume and eruption intervals, and (3) the variation of eruption style.The volume of the edifice is 400-500 km^3. Eruptions with the erupted volume of more than 1 km^3 occurred several times during the last 15,000 years; on the other hand, the quiescence period with low volcanic activity occurred for Cal BC 6,000-3600, and for the period spanning the last 900 years except the 1707 Hoei eruption. This characteristic makes it more difficult to predict future activity. There are various types of eruptions occurring in Fuji Volcano, such as Plinian eruption, lava flow, and pyroclastic flow. This characteristic also makes it more difficult to prepare the hazard map. For example, 300 years have passed since a Plinianfallout occurred at the 1707 Hoei eruption.

Geological study of Fuji Volcano
Tsuya (1940; 1968) studied the general geology and petrography of Fuji Volcano, and made the geological map of Fuji volcano (Fig. 14). Machida (1964) studied the eruptive history of Fuji Volcano,

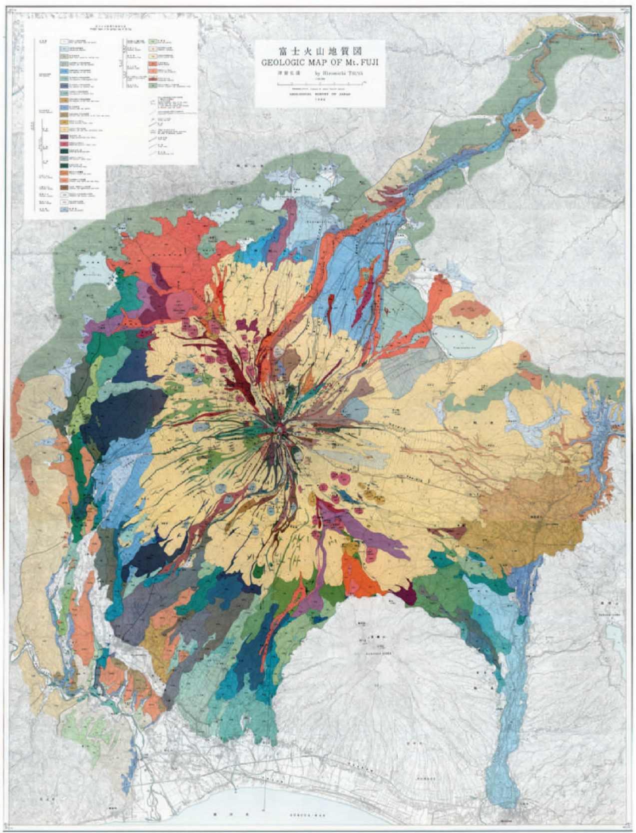


Fig. 14. Geologic map of Fuji Volcano (Tsuya, 1968).

usingtephrochronology. Uesugi (1990, 1993) and Uesugi et al. (1987)reported the detailed stratigraphy of scoria fall deposits. Miyaji (1988) studied the eruptive history of Fuji Volcano during the last 11 years. CD-ROM version of Tsuya (1968) with recent information was published by Nakano et al. (2002).

4-2. Eruptive history

Pre-Fuji volcanoes
Mt. Fuji is a composite stratovolcano consisting of Pre-Komitake, Komitake, and Fuji volcanoes: Fuji Volcano is divided into Ko-Fuji (Older Fuji) and Shin-Fuji (Younger Fuji) volcanoes (Tsuya, 1968). Pre-Komitake Volcano, older than Komitake Volcano defined by Tsuya (1968), was newly discovered as a result of chemical analysis of drilled cores on the northeastern flank of the volcano (Fig. 15; Nakada et al., 2007; Yoshimoto et al., 2010). The age of Pre-Komitake Volcano is several 100 ka. Its volcanic rocks contain basalt and hornblende-bearing andesite to dacite (50-70 % SiO_2) (Yoshimoto et al., 2010). The edifice of the volcano is concealed by Komitake and Fuji Volcanoes. On the other hand, the age of Komitake Volcano is older than 100ka. Komitake volcanic rocks contain olivine-bearing plagioclase-phyrictwo proxene basaltic andesite (51-53 % SiO_2). The volcanic edifice only crops out at the northern flank, which is easily distinguished from Fuji Volcano by its dissected topography.

Fuji Volcano
Eruption history of Fuji Volcano is summarized in Figure 16. Tephra studies suggest that the older activities of Fuji Volcano started around100 ka (Machida, 2007). Fuji Volcano is divided into Older Fuji Volcano and Younger Fuji Volcano (Tsuya, 1968; Miyaji, 1988). On the other hand, according to the study of the detailed ^{14}C datings (Yamamoto et al., 2005a), the volcanic activity of Older Fuji Volcano is known as the Hoshiyama stage (older than Cal BC 15,000); that of Younger FujiVolcano is composed of the Fujinomiya stage (Cal

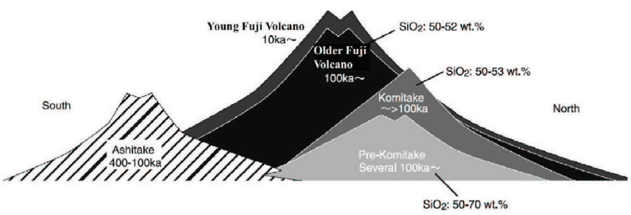


Fig. 15. Schematic north – south cross section after Nakada et al. (2007).

Volcano is composed of the Fujinomiya stage (Cal BC 15,000 - Cal BC 6,000), and the Subashiri stage (younger than Cal BC 6,000) (Yamamoto et al., 2007). The volcanic activity of Fuji Volcano became low during the period of Cal BC 6,000 – 3600 (Yamamoto et al., 2005a).

The long-term eruption rate of Fuji Volcano is around 4-5 km^3/ky for the edifice volume of 400-500 km^3 and the age of 100ka. Miyaji (2007) estimated the long-term eruption rate since the last 11 ka in detail: 17.1-3.1 km3 DRE /ky for 11-7.5 ka, 0.1 km^3 DRE /ky for 7.5-5.6 ka, 3.3-0.4 km^3 DRE /ky for 5.6-3.5 ka, 2.4 km^3 DRE /ky for 3.5-2.2 ka, 1.3 km^3 DRE /ky for 2.2-1.3 ka(Fig. 17).

100 ka – 17 ka (Cal BC 15,000)

The volcanic activity of Older Fuji Volcano (Hoshiyama stage) is characterized by sub-Plinianexplosive eruptions of basalt magma. Around 140 scoria falls were reported in this activity (Uesugi, 1990). The wide spread scoria falls are found from on the eastern flank to the Kanto plain. A lot of lahar deposits are common as distal phases to make volcanic fans at the skirt of the volcano. The volcano may have been covered with ice during the period of 100–20ka, that is correlated with the last ice age (Kaneko et al., 2004). The main part of Older Fuji volcano collapsed toward southwest at Ca BC 18,000 to shed the Tanukiko debris avalanche deposit (Fig. 18; Yamamoto et al., 2007) .

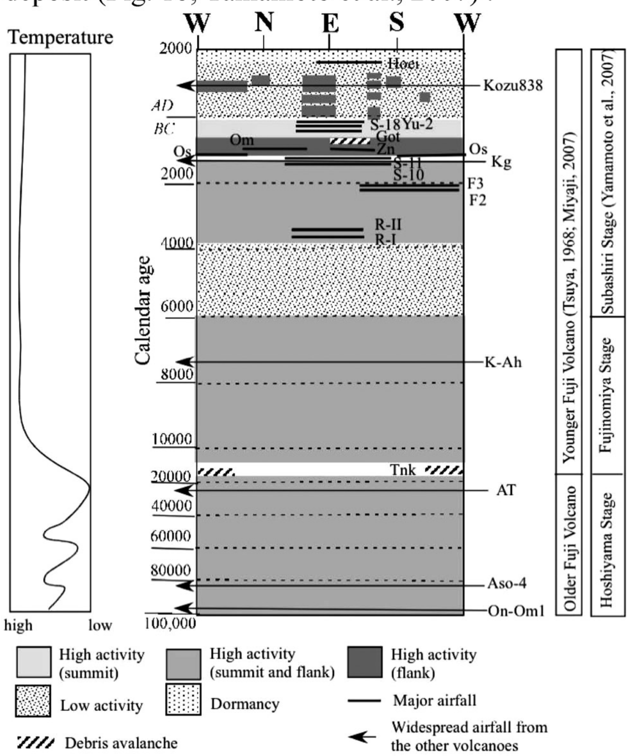


Fig. 16. Eruptive history of Fuji Volcano.

Cal BC 15,000 – BC 6,000

The volcanic edifice started to build again to construct Younger Fuji Volcano. Younger Fuji Volcano (Fujinomiya stage) eruptedvoluminous lava flowsseveral times (Fig. 19). The erupted volumes of the Mishima lava flow, the Obuchi lava flow, and the Saruhashi lava flow are estimated to be 4, 3, and 1.1 km^3, respectively (Togashi et al., 1991), and the longest runout of the lava flows is more than 40 km from the summit. Some of them are pahoehoe lava flows. A few eruptions occurred in the area of Oshino village on the northeastern foot, 13.5 km from the summit, to build scoria cones(Fig. 20). The erupted ages are estimated to be 12-9 ka, using ^{14}C datings (Nakano et al., 2007).

Cal BC 6,000 – BC 3,600

The volcanic activity became low during this period (Fig. 16), and Fuji Black Soil, which is correlated to the boundary of the two stages of Fuji Volcano proposed by Machida (1964), is accumulated on the foot of the volcano.

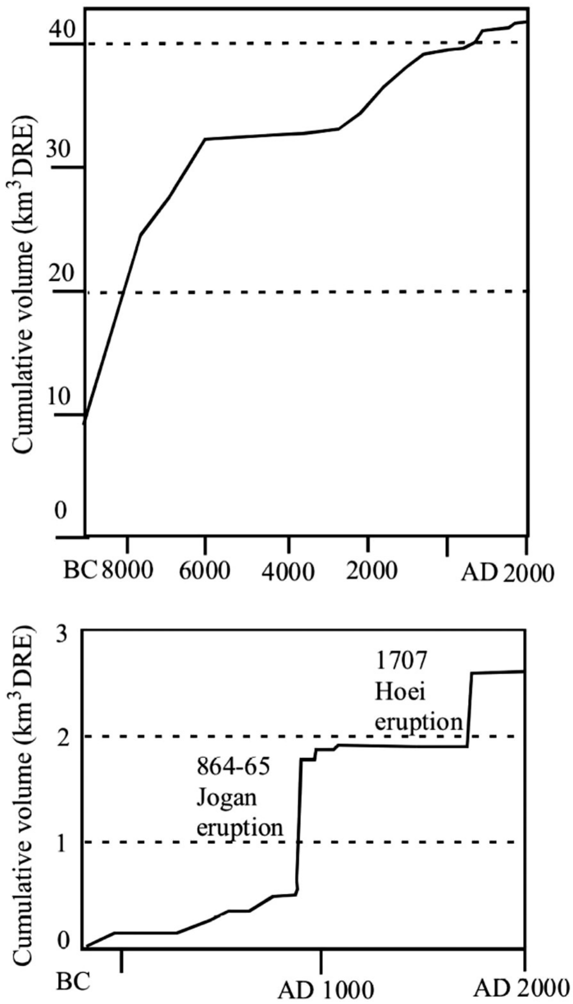


Fig. 17. Cumulative volume of erupted products after Miyaji (2007).

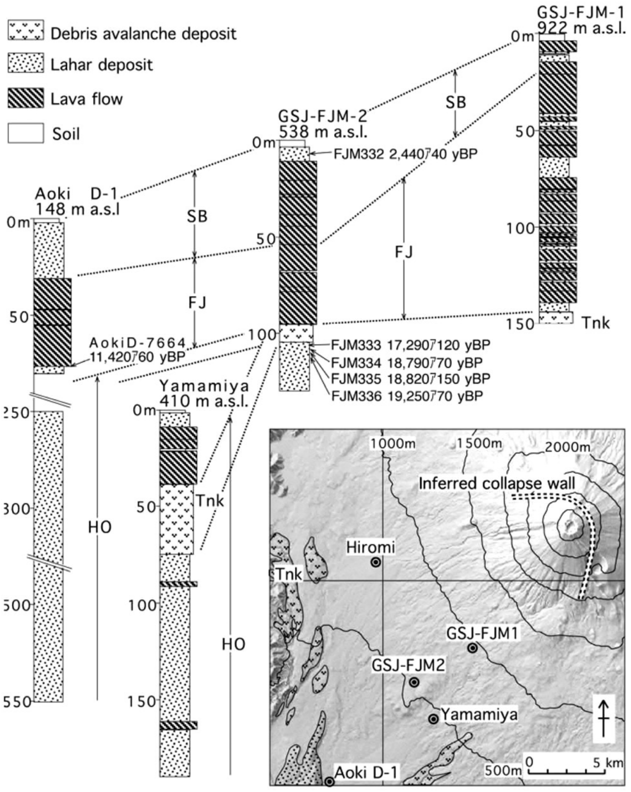


Fig. 18. Tanukiko debris abalanche (Yamamoto, 2007). SB: Subashiri stage. FJ: Fujinomiya stage. HO: Hoshiyama stage. Tnk: Tanukiko debris avalanche deposit.

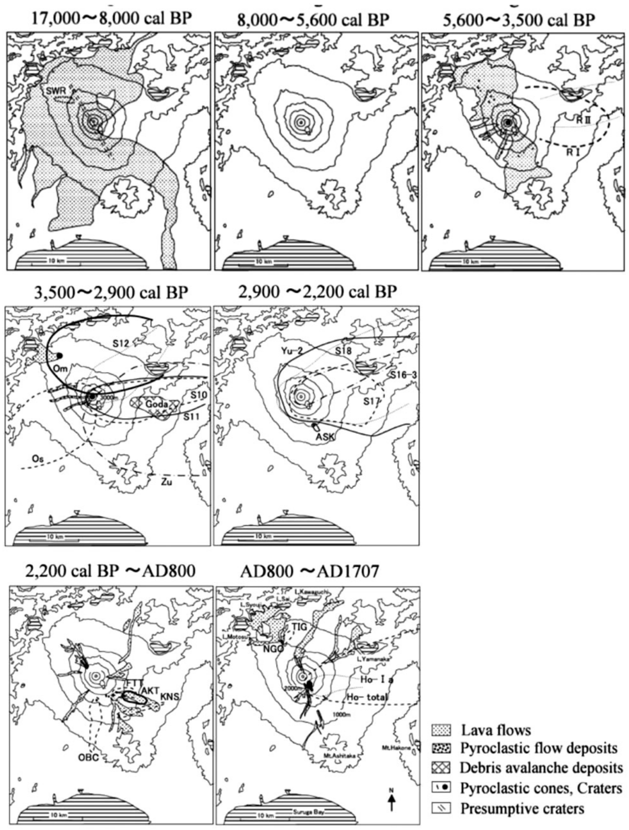


Fig. 19. Eruption products from Fuji Volcano during the last 15000 years after Miyaji (2007).

Cal BC 3,600 –BC 1,700

The eruptive activity increased again to build the present volcanic cone (Fig. 19), which is made up of many thin basalt lava flows (Takada et al., 2007b; Ishizuka et al., 2007). The summit region had been formed until Cal BC 2,100. Flank lava extrusions also occurred during this period. Some summit explosive eruption generated pyroclastic surges (Miyaji et al., 1992; b and Kobayashi, 2007).

Cal BC 1,700 – BC 300

The explosive sub-plinian or plinian eruptions at the summit (S10, S11, Os[Osawa scoria]) during Cal BC 1,700–1,300 were followed by flank explosive eruptions on the northwestern and southeastern flanks during Cal BC 1,300–1,000, such as Om (Omuro scoria) and Zn (Zunasawa scoria) (Figs. 19 & 20; Takada et al., 2007b; Ishizuka et al., 2007; Suzuki et al., 2007). The foreign tephra of Kawagadaira pumice (Kg) from Izu-Tobu Volcano Group in Izu Peninsula is found beneath S11 or Os(Fig. 16). The volcano of the eastern flank had collapsed around Cal BC 1000-900 to form Gotenba debris avalanche (Tsuya, 1968, Yamamoto et al., 2005a). The collapsed volume is estimated to be 0.1 km^3 (Yamamoto et al., 2002). The collapsed part is the edifice of Older Fuji Volcano that remained on the eastern flank (Fig. 21; Miyaji et al., 2004). After the collapse, the summit explosive eruptions became dominant (e.g. S-18, Yu-2). These eruption products cover the upper most part of the summit crater rim (Ishizuka et al., 2004). Some fall deposits emplaced on the steep western upper flank generated pyroclastic flows toward west (Fig. 22; Yamamoto et al., 2005b). On the other hand, other fall deposits emplaced on the upper flank originated the secondary lava flows.

Cal BC 300 – present

Cal BC 300 Yufune 2 scoria (Yu-2) eruption at the summit was followed only by flank eruptions. The volcanic activity on the eastern - northeastern flank was relatively higher than that on the other flanks before Cal AD 700 (Fig. 23). Pyroclastic flows originated from scoria cone collapse on steep surface during Cal AD 500-650 (Tajima et al., 2007). The frequency of flank eruption became high during Cal AD 700-1000 in any direction from the summit (Takada et al., 2007b; Yamamoto et al., 2011). The detailed stratigraphy during Cal AD 700-1000 was

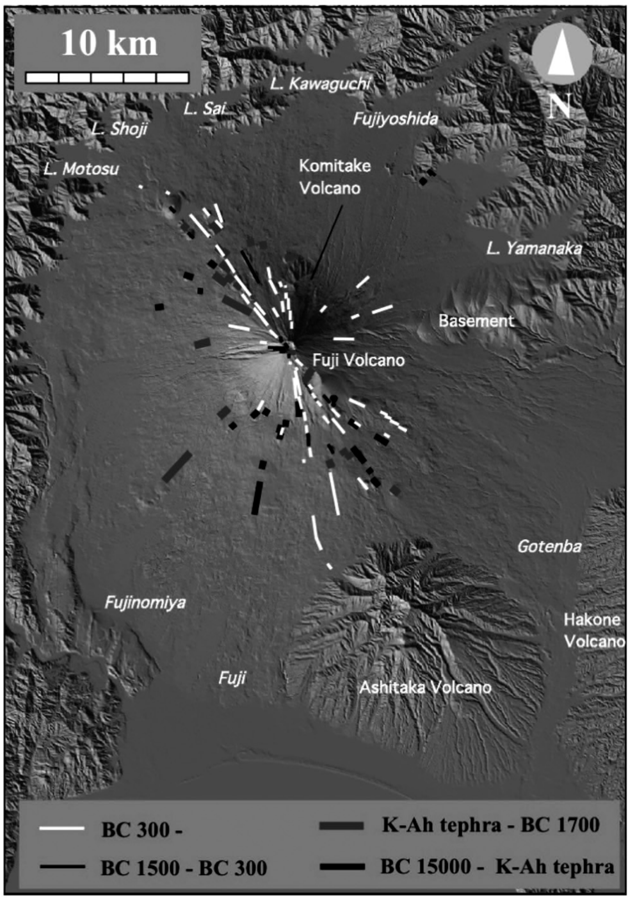


Fig. 20. Fissure eruption sites of Fuji Volcano during the period younger than BC15,000 after Takada et al. (2007b).

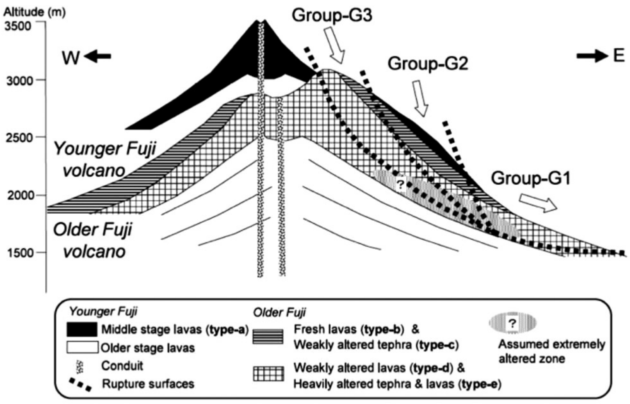


Fig. 21. Schematic section of Fuji Volcano before the Gotenba debris avalanche (Miyaji, 2007).

made clear using the widespread key tephra of the Kozushima-Tenjosan tephra (AD 838) (Kobayashi et al., 2007). Their fissure eruption sites are restricted within 13.5 km from the summit.

AD 864- 866 Joganeruption

Jogan eruption, one of the huge eruptions in Fuji Volcano, occurred on the northwestern foot in

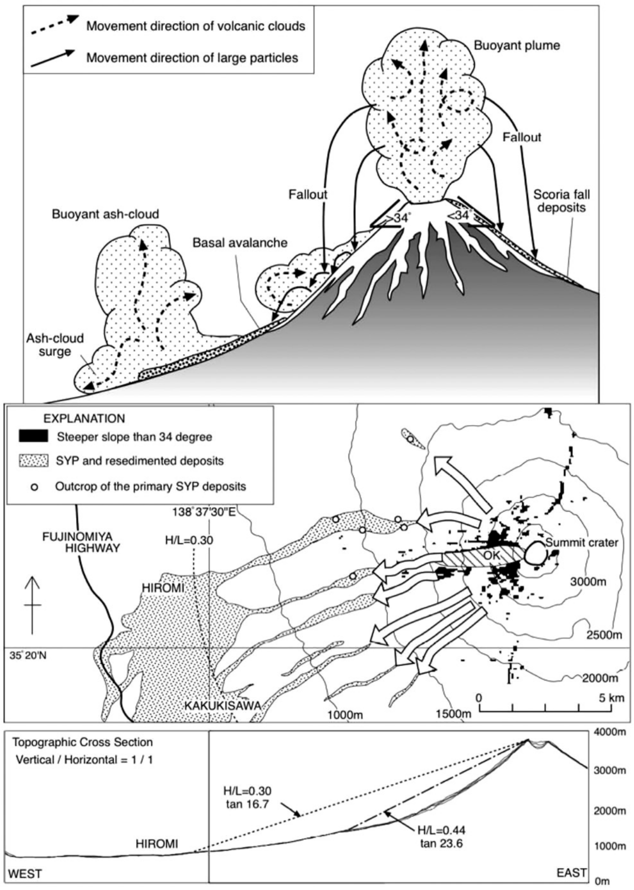


Fig. 22. Model for generation process of pyroclastic flow (upper diagram), and the moving paths on the steep western flank (white arrow) (middle diagram), and topographic cross section of Fuji Volcano in the east– west direction (Yamamoto et al., 2005b).

Cal AD 864-866 to effuse the Aokigahara lava flow (Koyama, 2007). The total erupted volume amounts to1.4 km3 (Takahashi et al., 2007). The lava flow entered into a pleo-lake, called "Seno-umi", on the northwestern foot to splitinto Lake Shoji, and Lake Sai (Miyaji et al., 1992). The split two lakes and Lake Motosu have the same water level, suggesting that they have been connecting with one another. The lava flows along the coast of the lake exhibit pillow structure (Miyaji et al., 1992), or have subaqueous flow-lobe (Obata and Umino, 1999; Umino, 2007). The eruptive fissures and lava flow topography were mapped at the northwestern foot using the light detection and ranging system (Fig. 24; Chiba et al., 2007).

Eruptions during AD 900-1000

The dominant trend of eruptive fissures is NW-SE, which is concordant to the axis of the regional maximum horizontal compressive principal stress. However, the eruptive fissures shifted its trend

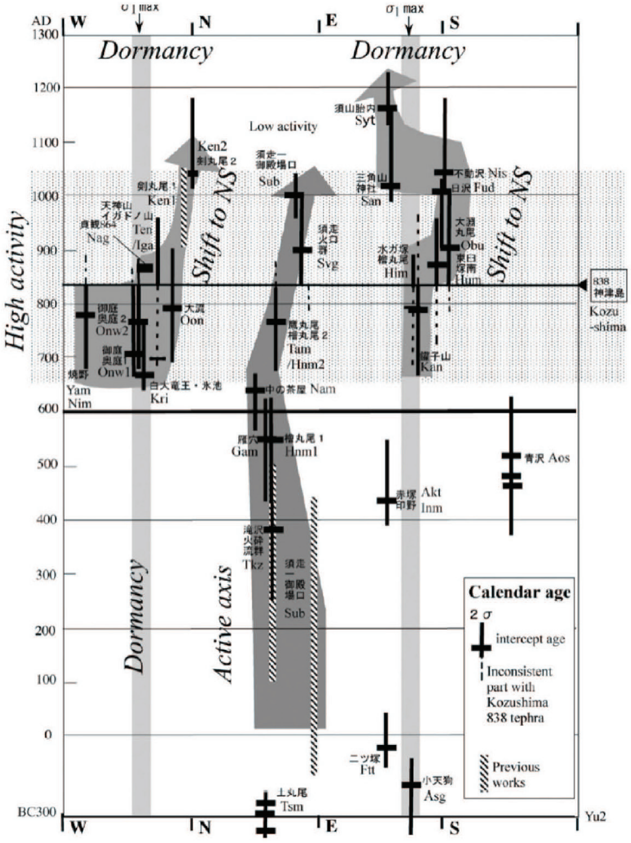


Fig. 23. Azimuth – age diagram of fissure eruption sites for Fuji volcano during the last 2000 years after Takada et al. (2007b). Only the fissure eruptions whose age were determined are plotted. Tsm: Tsuchimarubi, Asg: Kotengu, Ftt: Futatsuzuka, Sub (lw): Subashiri-Gotenbaguchi (lower), Tkz: Takizawa pyroclastic flows. Akt: Akatsuka-Innomarubi, Aos: Aozawa, Gam: Gananamaubi, Hnm1: Hinokimarubi-1, Nam: Nakanochaya, Kri: Hakudairyuo-Kooriike, Yam: Yakenomarubi, Nim: Nishinomarubi, Obs: Obuchi-scoria, Nfl; Nishi-Futatsuzuka, Onw1: Oniwa-Okuniwa-2, Onw1: Oniwa-Okuniwa-2, Oon: Onagare, Tam: Takamarubi, Hnm2: Hinokimarubi-2, Kan: Kansuyama, Ten: Tenjinyama, Iga: Igadonoyama, Nag: Jogan 864(Aokigahara), Him: Mizugatsuka-Hinokimarubi, Hum: Higashi-Usuzukaminami, Obu: Obuchimarubi, Fud: Fudosawa, Nis: Nissawa, San: Sankakuyamajinja, Svg: Subashiri vent group, Sub(up): Subashiri-Gotenbaguchi(upper),Ken1: Kenmarubi-1, Ken2: Kenmarubi-2, Syt: Suyamatainai.

from NW-SE to NS during Cal AD 900-1100. Fissure eruptions trending N-S occurred twice on both north and south flanks around AD 1000 (Yamamoto et al., 2005a; Takada et al., 2007b; Takada and Kobayashi, 2007); the paired eruptions are Kenmarubi 1st and Kenmarubi 2nd lava flows on the northern flank, and Fudosawa and Nissawa lava flows on the southern flank (Fig. 20). The explosivity decreases with time during the period of AD 700 –

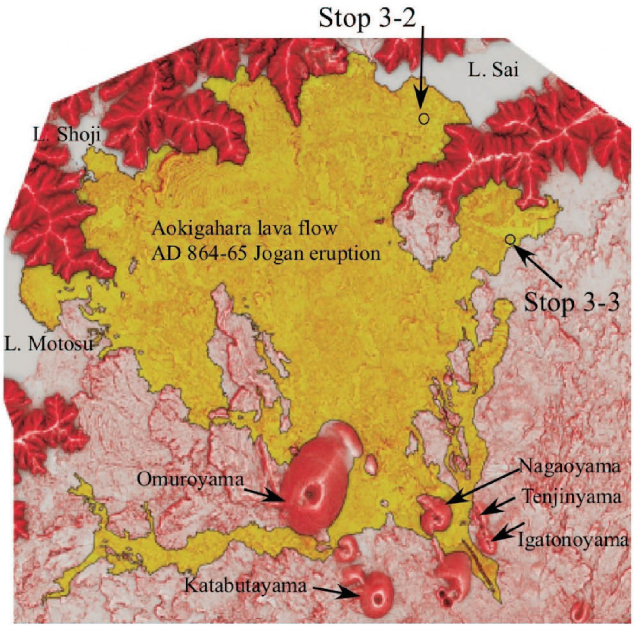
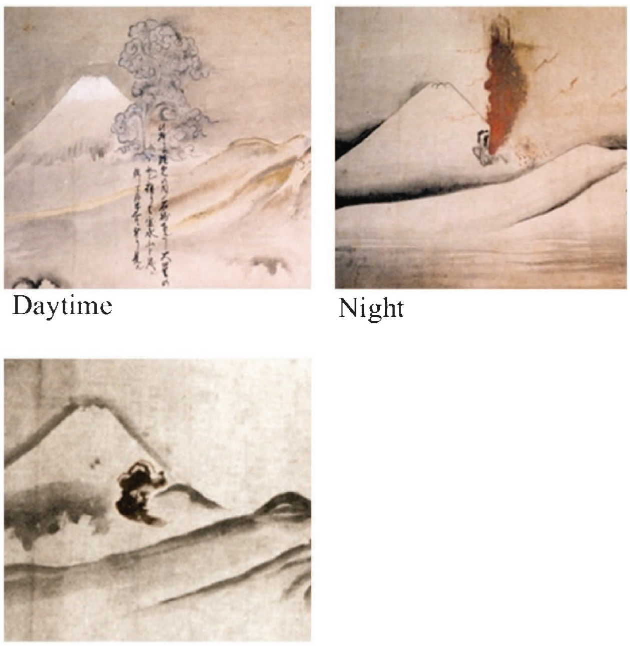


Fig. 24. Red Relief Image Map (RRIM) of Aokigahara lava flow (Chiba et al., 2007).
TheRRIM in this area is processed from 1m-DEM image which is obtained using LIDAR(LIght Detection And Ranging) system to hit the ground with the laser beam through the gap between trees.



Scene after the eruption

Fig. 25. Drawing of Hoei eruption (by courtesy of Mr. H. Tsuchiya).

1100. The volcanic activity became low during Cal AD 1100-1700. Some historical documents reported the existence of smoking at the summit during this period (Koyama, 2007).

AD 1707 Hoei eruption

The last eruption, the AD 1707 Hoei eruption, was plinianat the three craters of the southeastern flank (Fig. 25). The erupted volume was estimated to be 0.7 DRE km^3 (Miyaji, 1988). The eruption started on Dec. 16, 1707, and finished on Jan. 1, 1708. The eruption continued for 15 days (Fig. 26).Miyaji et al. (2011) have divided the deposit into 3 stages on the basis of the patterns of the eruptive pulses. The characteristics of the three stages are described as follows. Stage 1 had two energetic eruptive pulses with at least 20 km high column, each showing an intense initial outburst, followed by a decrease in intensity. The eruption sequence indicates ruptures of highly overpressureddacite and andesite magma chambers. The initial silicic eruption was followed by basaltic magma withdrawal from a deep and voluminous magma chamber. Stage II consisted of discrete sub-plinian pulses of relatively degassed basaltic magma. Stage III was principally characterized by sustained column activity without a clear repose time. During this stage, the column height appears to have been more than 16 km.The Hoei eruption was followed by a lot of lahars (Fig. 27). About 100 years were necessary to recover from the disaster (Inoue, 2007).

4-3. Magma system

Fuji Volcano has issued mostly basaltic magmas for 100,000 years since its beginning. The general temporal change of incompatible elements in magma is caused by the original difference in primary magma (Togashi and Takahashi, 2007). The basalt of Fuji volcano has been evolved with FeO*/MgO ratio larger than 1.6, and shows large variation of incompatible elements concentration without changing in silica content (Takahashi et al., 1991, Togashi and Takahashi, 2007; Fujii, 2007). This trend is quite different from the other volcanoes of

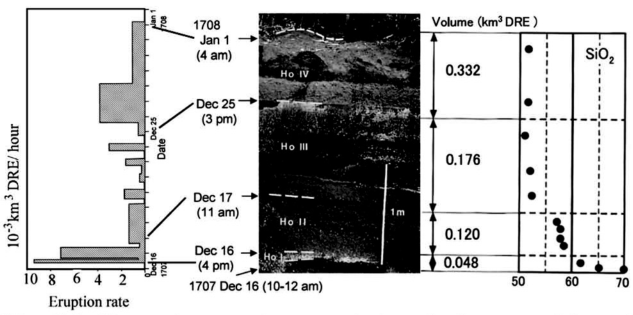


Fig. 26. Chronology, volume and chemical composition of the Hoei eruption product at Subashiri, and the estimated sequence of the eruption rate of the Hoei eruption (Miyaji, 2007). The outcrop is 12 km from the Hoei crater.

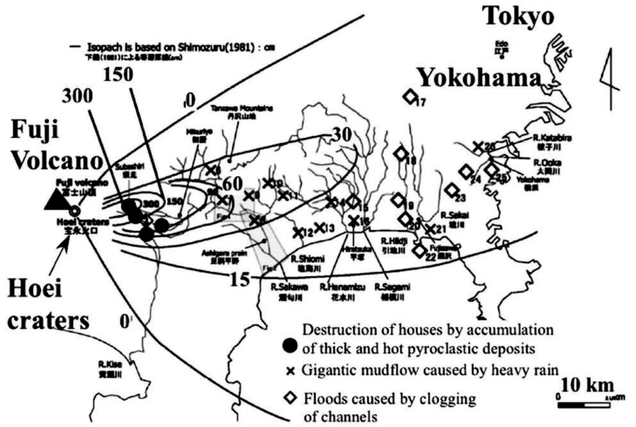


Fig. 27. Isopach of airfall of the Hoei eruption, and sediment related disasters after the eruption after Inoue (2007).

Izu arc. The magma reservoir beneath Fuji Volcano which is consistent with the geophysical observation (Fujii, 2007). The magma chamber may have been formed in the granitic middle crust of the Philippine Sea Plate beneath the Eurasian Plate.

4-4. Geophysical monitoring

Although surface volcanic activity of Fuji Volcano has been quiet in recent years, seismic observations have detected deep low frequency (DLF) earthquakes in the mid-crustal depth range beneath the summit area since the start of monitoring by using high quality seismic observations in the early 1980s.Figure 28shows typical seismograms of the DLF event in comparison with those of an ordinary tectonic earthquake in Fuji Volcano area. The predominant frequencies of most events range from 1 to 3 Hz, far lower than those of tectonic earthquakes of the same magnitude range as shown in figure 28. The DLF earthquake activity at Fuji Volcano is characterized by successive occurrence of small low frequency earthquakes during several minutes to a few tenths of minutes. Such events had occurred about 15 times in a year in average, before the year 2000.

The DLF activity extremely increased in the period from October 2000 to May 2001 as is seen in figure 29, which shows cumulative number and wave energy of the DLF events (Ukawa, 2005). The activity returned to the usual revel in June 2001. Figure 30 is a hypocenter map for the period from 2000 to 2006, in which the high activity period of the DLF events is included. The DLF earthquakes are clustered around the area centered at 2-4 km northeast from the summit. The principle depths of the DLF events are ranging from 10 to 15 km. During the high activity, no significant depth change

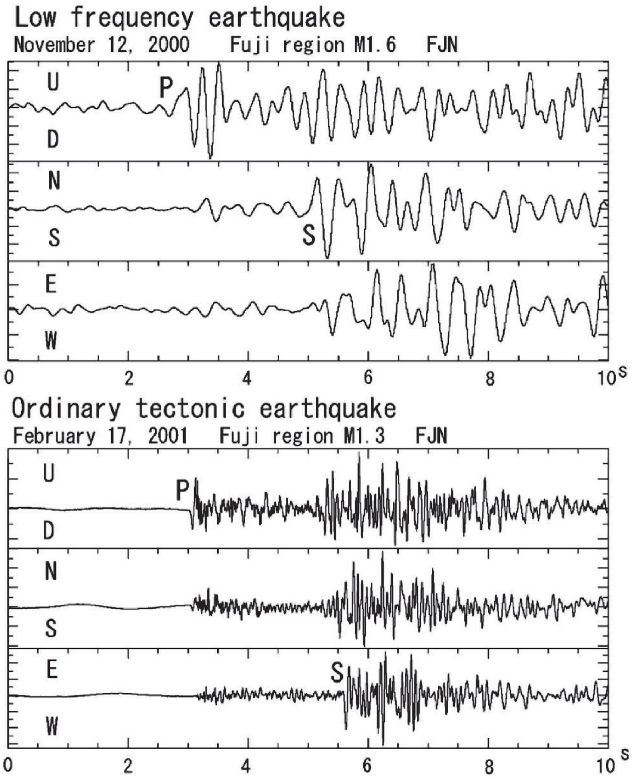


Fig. 28. An example of three component seismograms of low frequency earthquake in comparison with those of an ordinary tectonic earthquake. Both seismograms were recorded at FJN station belonging to NIED. Courtesy of National Research Institute for Earth Science and Disaster Prevention.

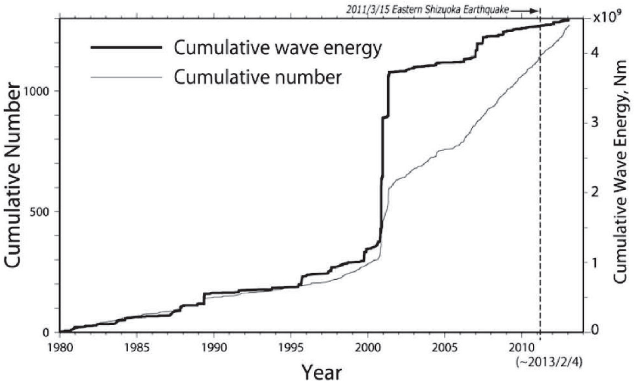


Fig. 29. Cumulative number of the DLF events (thin line) and cumulative wave energy (thick line) since 1980.Courtesy of National Research Institute for Earth Science and Disaster Prevention.

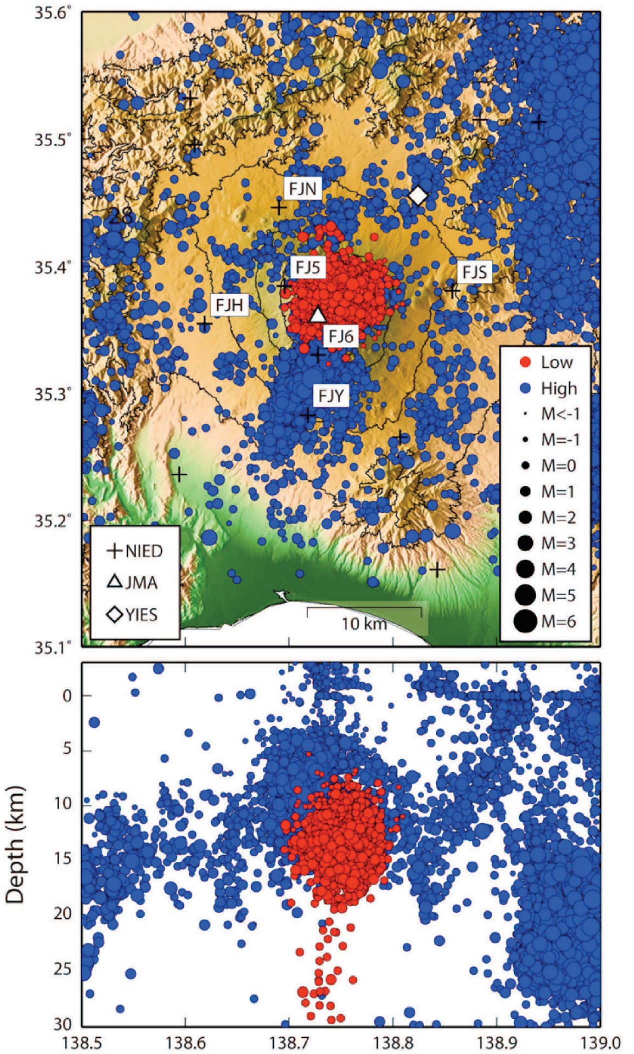


Fig. 30. Map showing hypocenters around Mount Fuji during the period from January 2000 to February 2013. Red and blue marks indicate locations of the DLF and the ordinary tectonic earthquakes, respectively. Courtesy of National Research Institute for Earth Science and Disaster Prevention.

was recognized either in epicenter or focal depth, indicating no evidence for magma ascent (Nakamichi et al, 2005, Ukawa, 2005). Ground tilt observations also indicated no abnormal changes relating to volcanic activity.

This unusual seismic activity, however, prompted thegovernment to improve seismic and crustal deformation observations, especially in the summit and in the high altitude area, partly because of the high degree of public interest in volcanic activity of Fuji Volcano. The geophysical monitoring of Fuji Volcano is performed by several institutes including National Research Institute for Earth Science and Disaster Prevention (NIED), Earthquake Research Institute of Tokyo University (ERI), Japan Meteorological Agency (JMA), Geographical Survey Institute (GSI), and Yamanashi Institute of Environmental Sciences (YIES). Most of the data are transmitted to JMA for real time monitoring of Fuji Volcano.

4-5. Hazard Mitigation

An increase in low frequency volcanic earthquake swarms during 2000-2001 beneath Fuji Volcano prompted the national government to make a hazard map of the volcano. The Review Committee for Volcanic Hazard Mitigation was established in cabinet office to prepare the feasible plans for volcanic disaster mitigation (Aramaki, 2007). The committee proposed the several examples of hazard map based on the results of numerical simulation of lava flows and pyroclastic flow, and the review of the eruptive history for the last 2000 years. The committee gave the guidelines of volcano monitoring, communication, evacuation, and other emergency plans, based on the historical record of the 1707 eruption of Fuji Volcano.

The hazard map includes the area of possible vent positions, the maximum area of ballistic fallout, the maximum possible area of ash fall in cases similar to the 1707 eruption, the maximum possible outreach of lava flow, the possible outreach of pyroclastic flow, and the possible maximum outreach of lahar.If the same type eruption as the Hoei occurs, the committee estimated that the economic loss including houses, life lines, roads, railways and airways, various manufacturing industries, tourism, etc. may amount to 200 billion US dollars. However, the number of victims will be almost nil.

If the eruptive history during the last 3000 years is reviewed, the possibility of the volcano collapse should be considered. Fuji Volcano collapsed several times (Machida, 2007). The frequency of the collapse in Fuji Volcano is larger than that of the other volcanoes in Japan, because Fuji has been deformed bythe Fujikawa-kako faultzone which is one of the most high displacement rate faults (Yamamoto et al., 2002).

Lahar in the rainy season and slush lahar in the winter season occur along the valley, and steep flank covered with thick air fall deposits (Anma, 2007).Volcano Fuji Sabo Office is monitoring debris flow form Fuji Volcano, and planning Sabo works around the Volcano. Especially, a lot of Sabo dams were contracted along Osawa valley on the western flank of the volcano (Hanaoka et al., 2007). The example of recent slush flow is shown in figure31 (Anma, 2007).

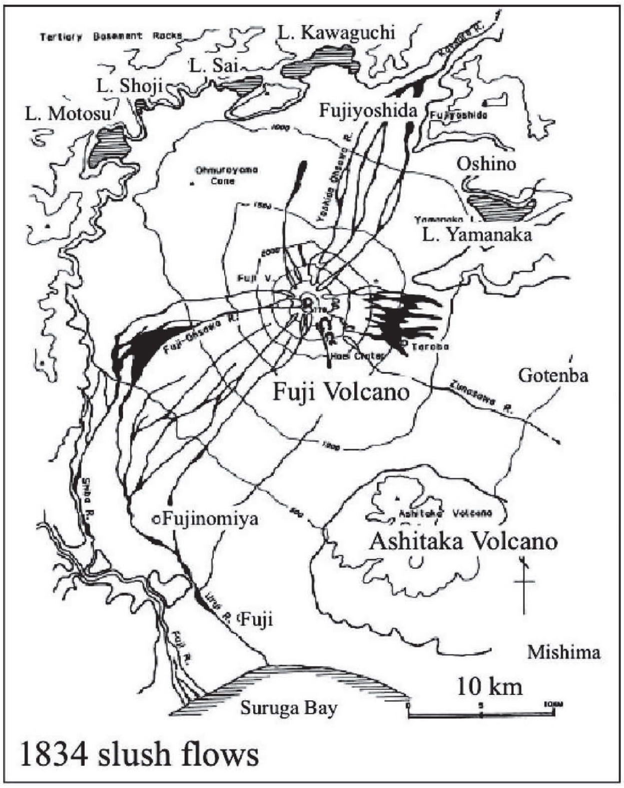


Fig. 31. The slush avalanches occurred at 1834 (Anma, 2007).

5. Description of Field stops

Stop 1-1: Owaki-dani (Owaku-dani)

Owaki-dani ("great boiling valley") is the largest fumarolic area among the four of Hakone volcano (Figs. 32&33). This fumarolic area is developed on the foot of Kanmuriga-take, the youngest lava dome of the volcano emplaced about 3 ka. Owaki-dani is a quite famous sightseeing spot due to its excellent scenery and commanding view of Mt. Fuji. Facilities in the valley are used to make artificial hot springs. Volcanic gases obtained from steam well water are

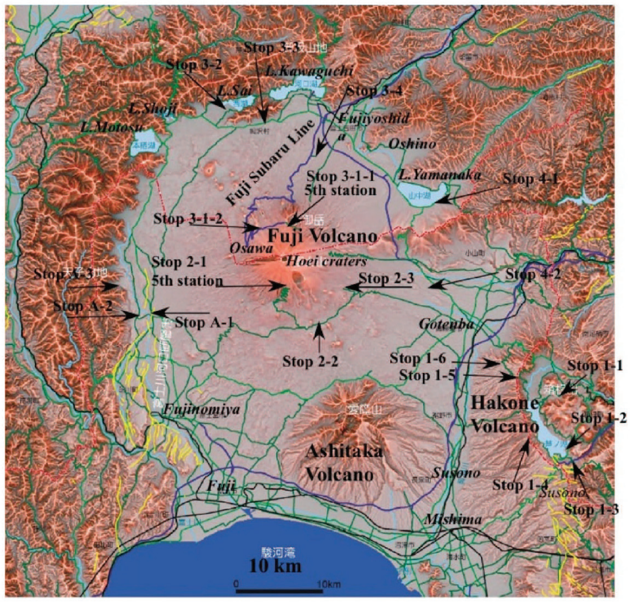


Fig. 32. Stop locality of field excursion. The Red Relief Image Map (RRIM) is after Chiba (Gijutsu-Hyohron Co., Ltd.). TheRRIM is one of the false colored image created by calculation from DEM data that issuperimposed two color gradations, reddish gradation as a steep slope portion, and brightness as aridge portion (Chiba et al., 2007).

mixed with water in the facilities. The artificial hot spring water is provided to hotels where natural hot springs are unavailable.
On the left bank of the valley, there are many Sabo (or erosion control) construction facilities works, such as sand trap dams or retaining walls (Fig. 33). In order to preserve the natural beauty of the scenery in and around the right bank of the valley, engineering intervention measures are limited to the drainage of groundwater level on the right to prevent the occurrence of landslides and mudflows of the valley.The slope is left in its natural form to preserve scenery. To prevent landslide or mudflow, groundwater level is controlled by drainage.

Stop 1-2: Hakone checkpoint
During the Edo period (1600-1867), the Shogun of the Tokugawa family ruled Japan and controlled financial and military policies, as well as international relationships. The Shogun also restricted the sovereignties of more than two hundred local feudal lords (daimyo) with overwhelming power. However, a few feudal lords remained powerful and were considered as potential threats to the shogun's hegemony. To avoid possible empowerment and alliance, the shogun forced the feudal lords to spend every other year in Edo (now known as Tokyo), and kept their family members in Edo as hostages. The Shogun installed checkpoints on major highways to control traffic. One of the most important tasks of the checkpoint was to avoid the undetected entrance of weapons (mainly rifles) into Edo or the possible escape of the family members of feudal lords. The Hakone checkpoint is the largest and most important checkpoint because it was installed on the primary highway, which links the capitals of Edo and Kyoto.

Fig. 33. View from Owaki-dani from Hakone Ropeway.

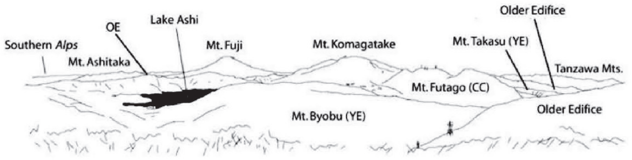


Fig. 34. View from Daikan-zan.

The original checkpoint building was destroyed after the end of the Edo period, but was later reconstructed because of its historical value to Hakone. The checkpoint has a museum, which exhibits the materials used by tourists and officers of the checkpoints.

Stop 1-3: Daikanzan
Daikanzan (Great View Mountain) is the best point to view Hakone and Mt. Fuji simultaneously (Figs. 32&34).This commanding view point is located on the southeastern part of the caldera rim of the Old edifice. However, Hirata (1996, 1997, 1999) argues that the edifice where the view point is located is younger than the rest of the Old edifice. This argument is based on detailed K-Ar dating. The southern part of the Daikanzan parking area offers a good view of the Izu islands, such as Izu-Oshima, Toshima, and Niijima.

Stop 1-4: Yamabushi-touge
From Yamabushi-touge (Yamabushi pass), the morphology of the Central Cones can be observed in detail (Figs. 32&35). The mountain on which the ropeway station building is located is named Komagatake, and is the second highest mountain of the CC. Several thick lava flows came down from Komagatake toward the lake. The lava flow fronts outline the shoreline of the lake in front of Komagatake. On the western ridge, there is a shoulder-like structure that interrupts the slope line. This structure is thought to be the remnant of an amphitheater which opened towards the south. The present summit of the mountain consists of a thick pile of lava that fills the amphitheater. Komagatake is thus considered to be a composite volcano composed of thick lava flows.

Fig. 35. View from Yamabushi-toge

Fig. 36. View from Nagao pass

Stop 1-5: View from Nagao Pass

Nagao Pass is the most famous point from which it is possible to view both Mt. Fuji and the Central Cones (YCC and OCC) of Hakone Volcano(Figs. 32&36). The highest edifice, Kamiyama,has an amphitheater on its northern flank. The sector collapse resulted from the growth of Kanmuriga-take, which is the edifice towering in the center of the amphitheater. A delta fan originating from the amphitheater toward the moat is the surface of the sector collapse deposit. Deposits from the sector collapse dammed the Hayakawa and formed the lake Ashinoko upstream of Hayakawa.

Stop 1-6: East of Nagao Pass

The outcrop here represents internal facies of LOE; abundant scoria and spatter fall and relatively small amount and thin lava flows (Figs. 32&37). The bomb sags seen here indicate that the source vent is very close, maybe within 1 or 2 km. In fact the dip of the layers here inclined roughly toward SE. This means the source is not in the present center of the volcano. Kuno also noticed the discrepancy between his model and the direction of the dip in this outcrop. He interpreted the dip observed here is formed by subsidence of caldera and initial dip was toward NW. However recent geomagnetic investigations reveal that the present dip direction is original.

Fig.37. Outcrop of “east of Nagao-toge”.

Stop 2-1: Hike to craters of AD 1707 eruption across eruptive fissures of AD 1000

The Fuji Sky Line terminates at the 5th station on the southern flank of Fuji Volcano around 2400 m above the sea level (Figs. 32 & 38). The parking area was constructed across the eruptive fissure of the Fudosawa lava flow (around Cal AD 1000). The near-vent deposits and lava flow lobes from the eruptive fissure of the Fudosawa lava flow are exposed along the cliff of the road. The near-vent scoria of the Nissawa lava flow (around Cal AD 1000) overlies those of the Fudosawa lava flow at the eastern side of the parking area. A lava flow lobe from a small scoria cone of the Nissawa lava flow, west of the 7th station, flows into the valley of the eruptive fissure of the Fudosawa lava flow, north of the 5th station parking area (Fig. 39). The trail to the 6th station crosses one of the eruptive fissures of the Nissawa lava flow, west of mountain huts (Unkaiso, and Hoeisanso) (Fig. 40).

The parallel eruptive fissures of the Fudosawa lava flow and the Nissawa lava flow, trending N-S, extend 4 km from 2850 m to 1370 m, and 2 km from 3200 m to 2250 m above the sea level, respectively. They correspond to theparallel eruptive fissures of

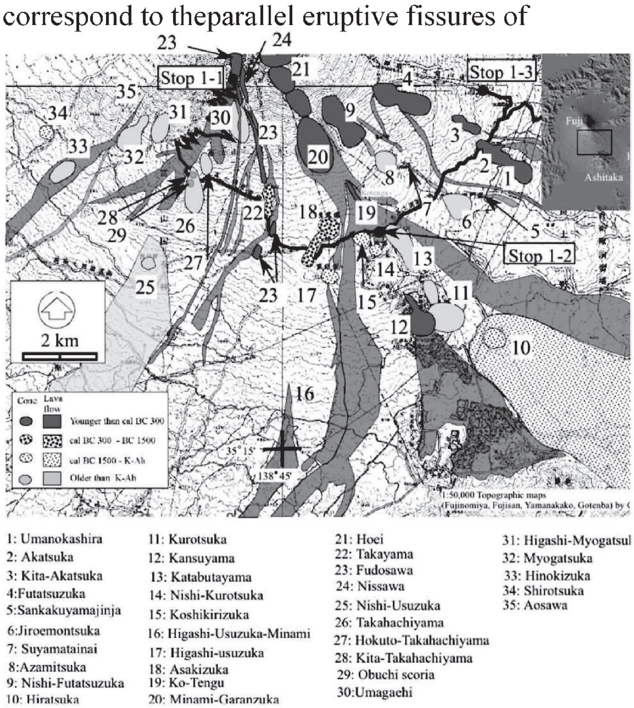


Fig. 38. Fissure eruption sites of the southern flank of Fuji Volcano after Takada and Kobayashi (2007).

theKenmarubi 1st lava flow and the Kenmarubi 2nd lava flow on the northern flank, respectively.

Departing from the main climbing trail to the summit at the mountain hut (Hoeisanso), a trail traverses the flank of the volcano for Hoei craters. Threes craters were formed on the southeastern flank at the 1707 Hoei eruption. The trail reaches the rim of Hoei crater III. Lava flows and welded scoria layers of cal BC 2500-1500 are well exposed along the crater wall (Fig. 40). Three layers of welded scoria (BC 1000-BC 200) cover them partly with unconformity. The uppermost part is a spatter rampart of the Gotenbaguchi lava flow younger than Cal BC 200. A lot of dikes crop out along the wall. The small scoria cone built at the last stage of Hoei eruption is observed at the bottom of the crater. The southeastern peak of Hoei crater III, called Hoeisan, is composed of part of the Older Fuij Volcano.

Stop 2-2: The lookout from the Mizugatsuka parking area

The Mizugatsuka parking area is a photo stop offering apicturesqueview of the southern flank of Fuji Volcano. Twin scoria cones of Futatsuzuka (~ Cal BC 50) andHoeisan (a part of Old Fuji Volcano), the craters of the 1707 Hoei eruption, can be seen on the right ridge toward the summit (Figs. 32 & 41). The parking area was constructed on the Kotengu lava flow (~ Cal BC 150), and is surround by Koshikirizuka, Katabutayama, and Nishi-Kurotsuka scoria cones clockwise from west(Fig. 38).

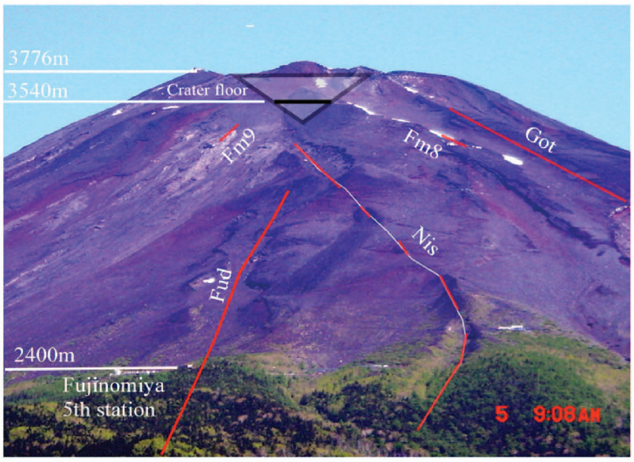
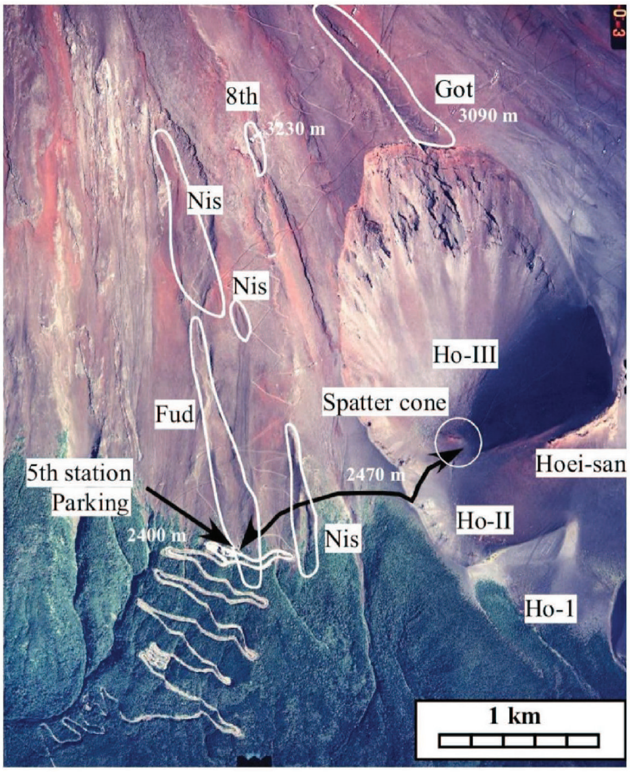


Fig. 39. Photograph of the southern flank along Fujinomiyaguchi route, Fuji volcano, showing eruptive fissures of Fudosawa (Fud), Nissawa (Nis), Gotenba-Fujinomiyaguchi (Got), Fujinomiyaguchi 8th station (Fm8), and Fujinomiyaguchi 9st station (Fm9) (Takada et al., 2007b). The floor level of the summit crater after Yubune 2 eruption is estimated from the level of the highest vent of eruptive fissure.



Nis: eruptive fissure of the Nissawa lava flow
Fud: eruptive fissure of the Fudosawa lava flow
8th: eruptive fissure of the 8th station lava flow
Got: eruptive fissure of the Gotenba lava flow
Ho: Hoei crater

⟷ Trail

Fig. 40. Airphotograph of the route from the 5th station to Hoei crater.

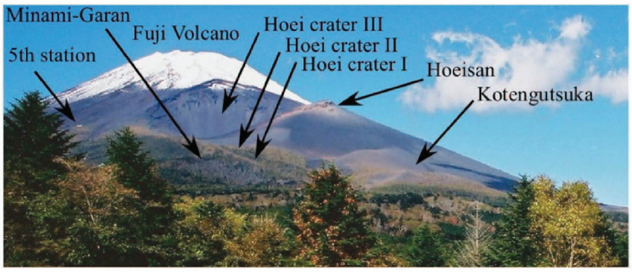


Fig. 41. Photograph of the southern flank of Fuji Volcano from Mizugatsuka paring area.

Stop 2-3: Air fall sequence at Tarobo

A series of continuous air-fall deposits of Younger Fuji Volcano is observed along a valley close to parking area of Gotenbaguchi 5th station (1440 m above the sea level), located at the southeastern foot of Fuji Volcano (Figs. 32 &42). The upper part of the cliff is a series of scoria falls: for example,Futatsuzuka scoria (FTT; ca. BC50), Subashiriguchi-Umagaeshi 1 scoria (SU1; ca. AD150), Akatsuka scoria (AKT; ca. AD450),Nishifutatsuzuka scoria (NFT; ca. AD550), and the

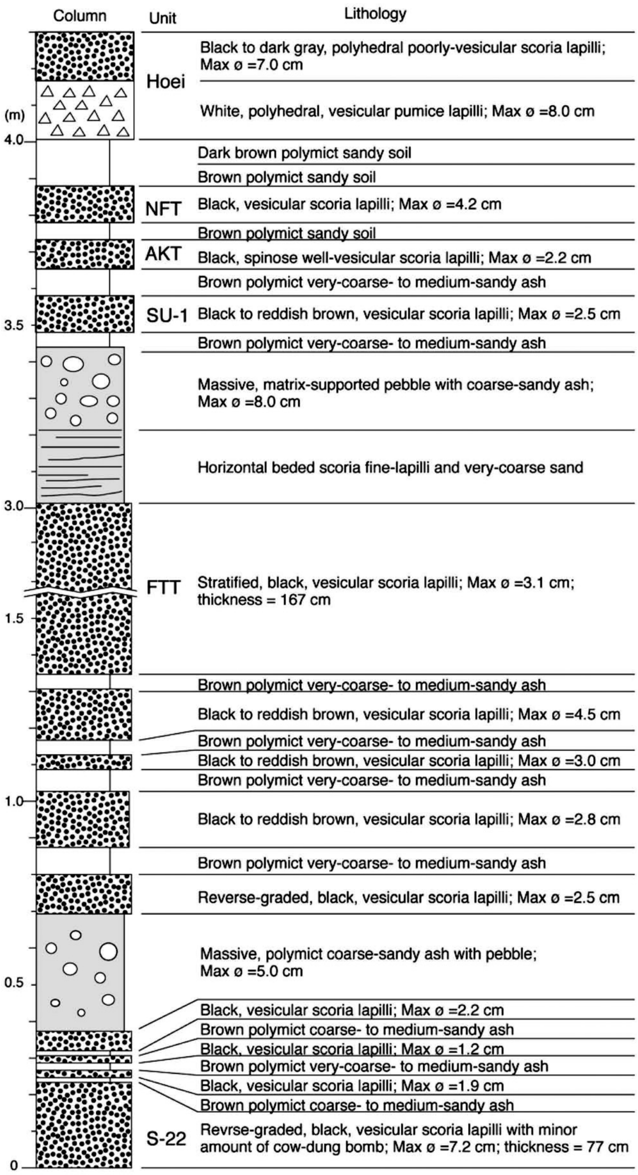


Fig. 42. Stratigraphic section through the recent tephra units and their characteristics at Taroubou (Yamamoto et al., 2011).AKT = Akatsuka scoria; FTT = Futatsutsuka scoria; NFT = Nishifutatsutsuka scoria; SU-1 = Subashiriguchi-Umagaeshi 1 scorias; S-22 = S-22 scoria.

1707 Hoei tephra, in ascending order.Volcanic glasses with low refractive indices were detected betweenHoei and NFT. They are derived from widespread tephra of the Kozushima-Tenjosan eruption (AD 838) (Kobayashi et al., 2007).

Hoei eruption product is classified into Ho-Ia, Ho-Ib, Ho-II, Ho-III, and Ho-IV (Miyaji et al., 1992)(Fig. 26). Ho-1a is a coarse-grained, dacitic pumice fall; Ho-Ib is a fine-grained, andesitic pumice fall including banded pumice; Ho-II is a coarse-grained, dense basaltic scoria fall; Ho-III is a fine grained, less-dense basaltic scoria fall; Ho-IV is a fine-grained, vesicular basaltic scoria fall. A lot of gabbroic fragments are included in the Hoei eruption products. Olivine-pyroxene gabbro, and plagiophyric pyroxene gabbro are originated from the accumulated part of magma body, and the wall and inside of magma body, respectively (Yasui et al., 1998).

Stop 3-1: Eruptive fissures along Fuji Subaru Line

The 30 km long toll road, the Fuji Subaru Line, leads to the 5th station of Mt. Fuji (2305 m above sea level) on the northern flank (Fig. 43). The road traces on the Kenmarubi 1st lava flow (AD ~1000), and the Kenmarubi 2nd lava flow (AD 1000-1100) to the parking area of the 1st station. A lot of scoria cones are observed part of the way along and around the road for the 5th station (Ishizuka et al., 2007; Suzuki et al., 2007): for example, Maruyama (BC~2700) (No. 25 in Fig. 43), Higashiken(BC~1500) (No.27),

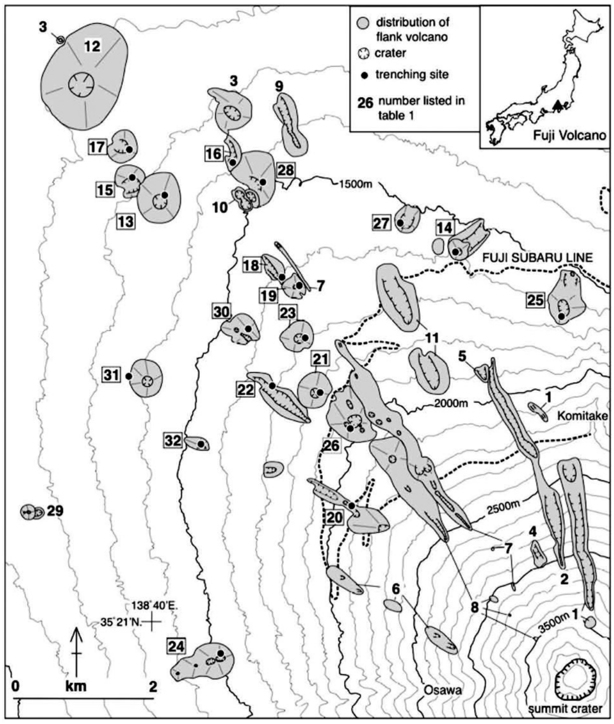


Fig. 43. Fissure eruption sites along the Fuji Subaru Line (Ishizuka et al., 2007). Contour interval is 100 m. 1: Kenmarubi-1, 2: Kenmarubi-2, 3: Jogan, 4: Onagare, 5: Garan, 6: Yakeno-Nishimarubi, 7: Oniwa-Okuniwa-2, 8: Oniwa-Okuniwa-1, 9: Tenjinyama-Igatonoyama, 10: Hakudairyuo-Koriike, 11: Ohirayama-Sajikiyama, 12: Omuroyama, 13: Katabutayama, 14: Higashiken, 15: Shikanokashira: 16: Hokuseiyumiizuka, 17: Tsugaoyama, 18: Hokuseiusuyama, 19: Usuyama, 20: Tomine, 21: Kosukemaru, 22: Nishikosukemaru, 23: Hachikenyama, 24: Toyazuka, 25: Maruyama, 26: Hokuseiokuniwa, 27: Nishiken, 28: Yomiizuka, 29: Inusuzumiyama, 30:

Sawarayama, 31: Futatsuyama, 31: Nagayama.
Nishiken (BC~4200) (No.27), Ohirayama-Sajikiyama(BC~1000) (No. 11), Kosukemaru (BC~2000) (No. 21), Hokusei-Okuniwa (BC~3200) (No. 26), the cater row of Tomine (No.20), the spatter cone of the Yakeno-Nishimarubi lava flow (AD 680-890) (No. 6), the crater row of the Oniwa-Okuniwa 1st lava flow (AD 660-860) (No. 8), the crater row of Oniwa-Okuniwa 2nd lava flow (AD 620-880) (No. 7), the Kenmarubi 1st lava flow (Cal AD ~1000) (No. 2), the Kenmarubi 2nd lava flow (AD 1000-1100) (No. 1).
Eruptive fissure of the Oniwa-Okuniwa 1st lava flow continued 3.5 km long in en echelon arrangement from 3400 m to 2100 m. Eruptive fissure of the Oniwa-Okuniwa 2nd lava flow continued 5.5 km long in en echelon arrangement from 3000 m to 1570 m. Scoria fall of the Oniwa-Okuniwa 1st lava flow is overlaid by that of the Oniwa-Okuniwa 2nd lava flow. The crater row of the Oniwa-Okuniwa 2nd lava flow is observed along the trail from the Okuniwa parking area (2227m above sea level) (Stop 3-1-1). The ridge of the 5th station consists of Komitake Volcano older than Fuji Volcano (Fig. 15).Part of the lavas poured into an old lake, which is called Lake Senoumi in historical documents, and divided it into two lakes (Lakes Shojiko and Saiko).

Stop 3-2: Lava tunnel of the Aokigahara lava flow (Komoriana)

Fig. 44. Red Relief Image Map around Senoumi (Chiba et al., 2007), and the trail map to Bad cave (Komoriana).

The 864-866 Joganeruption is one of the most voluminous eruptions of Fuji Volcano during the past 15000 years. Part of the Aokigahara lava flow poured into an old lake, which is called Lake Senoumi in historical documents, and divided it into two lakes, Lakes Shoji and Sai(Fig. 24 &32). The maximum thickness of the lava flow is estimated to around 135m by the observation of loc.1 bore hole.
Komoriana means bad cave in Japanese. A lot of lava tunnels have been discovered in the Aokigahara lava flow. They can provide wonderful sightseeing sites with forests on the lava flow. Inflating flow lobes with tensile axial crack and collapsed lava tunnels are observed along the trail to Komoriana (Fig. 44). The lava terraces caused by lava level change, and ropy lava surface are well preserved in the tunnel.

Stop 3-3: Cross section of the Aokigahara lava flow at a quarry in Narusawa

The Aokigahara lava flow of the Jogan eruption, and the air fall deposit of Omuro scoria (Cal BC 1200-1300) are exposed along the wall of the abandoned quarry. The volcanic glass fragments originated from the Kozushima-Tenjosan tephra (AD 838) concentrate just below the Aokigahara lava flow (Kobayashi et al., 2007)(Fig. 45). The Omuro scoria erupted from, at least, two eruption sites, Omuroyama and Katabutayama at the northwest foot of the volcano (Suzuki et al., 2007) (Fig. 43). The eruption was explosive, compared with that of the Jagan eruption. The Aokigahara lava flow is composed mainly of pahoehoe lavas. The outcrop is

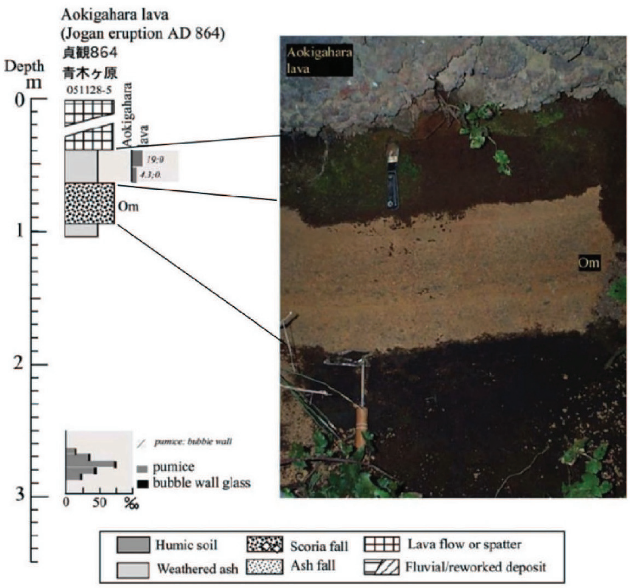


Fig. 45. Columner section and photograph of the Narusawa quarry. Om: Omuroyma scoria fall.

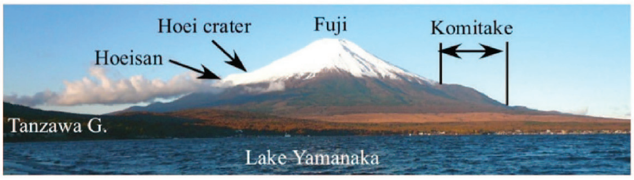


Fig. 46. Photograph of the eastern flank of Fuji Volcano from Lake Yamanaka.

located near the termination of the lava flow, and separated into several lobes with finger-like structure. Each lobe shows a tube-like structure with radialinflation (Takahashi et al., 2007). A tree mold is found in some lava lobes.

Stop 4-1: The view of Fuji Volcano from Lake Yamanaka

Thelodge is located along the southern lake side of Lake Yamanaka (Fig. 32). The lake was dammed by the Takamarubi lava flow, which is correlated to the historical eruption of AD 800-802 (Nakano et al., 2007). The Takamarubi lave flow is just below the soil including volcanic ash from widespread tephra of the Kozushima-Tenjosan eruption (AD 838) (Kobayashi et al., 2007).

The view from Lake Yamanaka suggests that Mt. Fuji is a composite volcano (Fig. 46). The mountain on the left side consists of the Miocene Tanzawa group of volcanic rocks, quartz diorite, and sedimentary rocks (Matsuda, 2007). The slope of the volcano does not become continuously gentle toward the skirt. The edifice of Komitake Volcano changes the northern slope discontinuously. The Hoeisan peak of the Older Fuji volcano and Hoei crater change the southern slope discontinuously. The boring cores on the eastern and northeastern flanks indicate that Pre-Komitake Volcano concealedunder Komitake Volcano (Yoshimoto et al., 2010).

Stop 4-2: Hummock hills in Gotenba city

The eastern flank collapsed three times after AT tephra of 29 ka; the last one is the Gtenba debris avalanche (Machida, 2007). The Gotenba debris avalanche deposit is widely distributed, and exhibits hummocky surface. Its flow units assume a finger-like distribution; Hummock hill is 5-10 m high at the main depositional area (Miyaji et al., 1992) (Fig. 47). The Gotenba debris avalanche deposit varies its faces from the original avalanche deposit to lahar at the foot, and to fluvial deposit along valleys (Miyaji et al., 2007). Almost all fragments in the Gotenba debris avalanche deposit are derived from the edifice of Older Fuji Volcano (Miyaji et al., 2004).

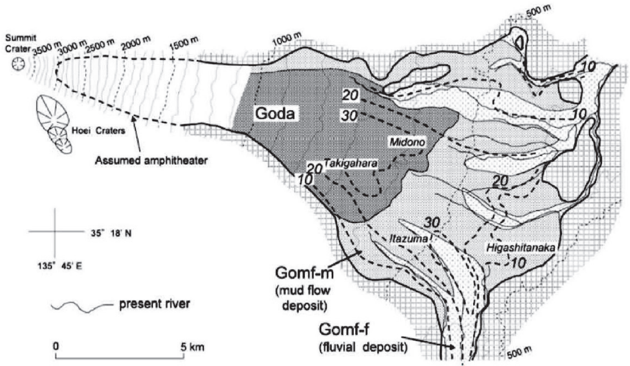


Fig. 47. Gotenba debris avalanche deposit (Goda), Gotenba mudflow (Gomf-m), and its fluvial deposit (Gomf-f) at eastern foot of Fuji Volcano, with isopachmap of these deposits (m) (Miyaji, 2007).

Additional stops for bad weather condition

Stop A-1: Osawa

Osawa is a huge deeply dissected valley from the western crater rim of the summit (Fig. 32). It is one of largest failure sites in Japan. The valley feeds an alluvial fan deposit at the foot of the volcano (Miyaji et al., 1992). Debris flow is taking place along the valley. Volcano Fuji Sabo Office is monitoring the failure along the wall of the valley, and its debris flow in the valley (Hanaoka et al., 2007).

Stop A-2: Shiraito Falls

Shiraito Falls is a well-known tourism site at Fuji Volcano (Fig. 32). Shiraito means white strings. The falls is about 20 m high and 120 m wide. Water comes from a surface stream and flowsfrom the boundary between the Shiraito lava flow of Younger Fuji Volcano and underlying lahar deposit of Older Fuji (Fig. 18). Charcoal just beneath the Shiraito lava flow yields ^{14}C age of Cal BC 12,000 (Yamamoto et al, 2007).

Stop A-3: Tanukiko debris avalanche deposit

The Tanukiko debris avalanche deposit crops out near the Tanukiko dam (Fig. 32). According to ^{14}C dating of wood in the deposit, Older Fuji Volcano collapsed toward southwest at Ca BC 18,000 (Fig. 18). Mega blocks with jigsaw cracks are included in the debris avalanche deposit.

Reference

Anma, S. (2007) Lahars and slush lahars on the slopes of Fuji Volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 285-301, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Aramaki, S. (2007) Volcanic disaster mitigation maps of Fuji volcano and overview of mitigation programs. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 451-475, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Chiba, T., Tomita, Y., Suzuki, Y., Arai, K., Fujii, N., Miyaji, N., Koizumi, S. and Nakashima, K. (2007) Analysis of micro topography of the Aokigahara lava flows, Fuji volcano, by the light detection and ranging system. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 349-363, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Daita, T., Tanada, T., Tanbo, T., Ito, H., Harada, M., Mannen, K. (2009) Temporal change of the pressure source estimated by tilt records during the 2001 Hakone swarm activity.*Bull. Volcanol. Soc. Japan*, **54**, 223-234.

Fujii, T. (2007) Magmatology of Fuji Volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 233-244, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Geological Society of Japan (2007) *Hakone Volcano* (geological leaflet with geological map).

Hakamata, K., Sugiyama, S., Imanaga, I., Mannen, K., and Oki, Y. (2005) K-Ar ages of Hakone Volcano, Japan, *Bull.Volcanol. Soc. Japan*.,**50**, 285-299.

Hanaoka, M., Tomita, Y., and Ito, M. (2007) OsawaKuzure (failure) and debris flows in Mt. Fuji.In, *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 407-425,Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Hirata, Y. (1996) Geology and Volcanic Activity of Hakone Volcano, Japan. *IBM arc system symposium - program with abstracts*. 103-106.

Hirata, Y. (1997) Hakone Volcano: Time depending tectonic stress orientation indicator of the Phillipine Sea Plate. *IAVCEI, Puerto Vallarta, Mexico, 1997 General Assembly, Abstract*, 71p.

Hirata, Y. (1999) Developmental History of Hakone volcano, Japan. *Res. Rep. Kanagawa Pref. Mus. Nat. Hist*. **9**, 153-178.

Inoue, K (2007) Distribution of sediment-related disasters after the Hoei Eruption of Fuji Volcano in 1707, based on historical documents. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 427-439, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Ishizuka, Y., Yamamoto, T., Takada, A., and Nakano, S. (2004) Characteristics of basaltic ejecta about the summit area of Fuji Volcano, Japan.*IAVCEI meeting, Abstract*.

Ishizuka, Y., Takada, A., Suzuki, Y., Kobayashi, M., and Nakano, S. (2007) Eruption ages and whole-rock chemistries of scoria cones on the northern to western slope of Fuji Volcano based on trenching surveys. *Bull. Geol. Surv. Japan*, **57**, 357-376 (in Japanese with English abstract).

Kamata, H. (1989) Shishimuta caldera, the buried source of the Yabakei pyroclastic flow in Hohi volcanic zone, Japan. *Bull. Volcanol*.,**51**, 41-50.

Kaneko, T., Yoshimoto, M., Shimano. T., Yasuda, A., Fujii, T., Nakada, S., and Uesugi, Y. (2004) Stratigraphic study of tephra deposits on the eastern slop of Mt. Fuji: Results of scientific drilling and the volcano development history. *Chikyu monthly*, **48**, 101-107 (in Japanese).

Kato, T. (1985MS) Geology and petrology of the north and west old somma of Hakone volcano, Japan.*Master thesis, Univ. Tokyo*. 106p.

Kobayashi, M. (1999) Tephrochronology and eruptive activity on Hakone volcano in tha past 50 ka.*Quaternary Res*., **38**, 327-343.

Kobayashi, M., Mannen, K., Okuno, M., Nakamura, T. and Hakamata, K. (2006) The Owakidani Tephra group: A newly discovered post-magmatic eruption product of Hakone Volcano, Japan. *Bull. Volcanol. Soc. Japan,* **51**, 245-256 (in Japanese with English abstract).

Kobayashi, M., Takada, A., and Nakano, S. (2007) Eruptive history of Fuji Volcano from AD 700 to AD 1,000 using stratigraphic correlation of the Kozushima-Tenjosan Tephra. *Bull. Geol. Surv. Japan*, **57**, 409-430 (in Japanese with English abstract).

Komazawa, M. (2000) The gravity anomaly of Fuji Volcano and the estimated density structure of its edifice. *Chikyu monthly*, **22**, 539-543 (in Japanese).

Koyama, M. (1989) Paleomagnetic studies in the south Fossa Magna and adjacent areas, Japan.*Modern Geol*., **14**, 69-84.

Koyama, M. (2007) Database of eruptions and other activities of Fuji Volcano, Japan, based on historical records since AD 781,Fuji volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 119-136, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Kuno, H. (1950a) Petrology of Hakone volcano and adjacent areas, Japan. *Bull. Geol. Soc. Am.* ,**61**, 957-1020.

Kuno, H. (1950b) Geology of Hakone volcano and adjacent areas, Part I. *J. Fac. Sci., Univ. Tokyo,*

Sec.2, **7**, 257-279.
Kuno, H., (1951) Geology of Hakkonevolcanoand adjacent areas. Part II. *J. Fac. Sci., Univ. Tokyo*, Sec.2, **7**, 351-402.
Kuno, H., (1952) Explanatory text of the geological map of Japan "Atami". *Geol. Surv. Japan*, 141pp.
Kuno, H., Oki, Y., Ogino, K., and Hirota, S. (1970) Structure of Hakone Caldera as revealed by drilling.*Bull. Volcanol*.,**71**, 713-725.
Kurozumi, H., and Doi, N. (2003) Inner structure of the Nigorikawa caldera, Hokkaido, Japan.*Bull. Volcanol. Soc. Japan*, **48**, 259-274.
Lipman, P.W., 2000. Calderas. In: Sigurdsson, H. (Ed.), Encyclopedia of Volcanoes. Academic Press, San Francisco, 643–662.
Machida, H. (1964) Tephrochronological study of Volcano Fuji and adjacent areas. J .Geography, **73**, 293-308, 337-350 (in Japanese with English abstract).
Machida, H. (1971) Tephrochronogical study in south Kanto part I stratigraphy of tephra and its relation to the history of volcano,.*Quaternary Res*., **10**, 1-20.
Machida, H. (2007) Development of Fuji volcano: A review from Quaternary tephrochronology. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 29-44, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Mannen, K. (2003) A re-examination of Hakone Earthquake Swamrs by literature (1917-60): implication for the regional tectonics. *Bull. Volcanol. Soc. Japan*, **48**, 425-443.
Mannen, K., Mizuno, K., Itoh, J., and Yamashita, H. (2006) Subsurface geology of Gora region, Hakone Volcano, Japan, with special reference to the buried lacustrine and its depositional environment, *Bull. Hot Springs Res. Inst*., **38**, 11-26.
Mannen, K., Horiuchi, S., Taguchi, K., Yamashita, H., Hirata, D., Kawate, S., Ebiko, T., and Taniguchi, H. (2003) Microfossil age of Hayakawa Tuff Breccia in the Hakone area, Japan and its significance, *J. Geol. Soc. Japan*, **109**, 661-664.
Mannen, K., and Sugiyama, S. (2000) Geology of Drilling Cores and Hotsprings of Motohakone-36. *Bull. Hot Springs Res. Inst*. **31**, 77-90.
Matsuda, T. (2007) Geology and geohistory of the Tertiary basement of Mt. Fuji. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 45-57, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Ministry of Education, Culture, Sports, Science and Technology (2012) Report on intensive research observation of Kan'nawa – Kozu – Matsuda Fault (FY2008-2011).
http://www.jishin.go.jp/main/chousakenkyuu/kannawa_juten/h23/index.htm
Miyaji, N. (1988) History of younger Fuji Volcano.*J. Geol. Soc. Japan*, **94**, 433-452 (in Japanese with English abstract).
Miyaji, N. (2007) Eruptive history, eruption rate and scale of eruptions for the Fuji Volcano during the last 11,000 years, Fuji volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 79-95, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Miyaji, N., Kan'no, A., Kanamaru, T., Mannen, K., (2011) High-resolution reconstruction of the Hoei eruption (AD 1707) of Fuji volcano, Japan. *J. Volcanol. Geotherm. Res.*, **207**, 113-129.
Miyaji, M., Eendo, K., Togashi, S., and Uesugi, Y. (1992) Tephrochronological History of Mt. Fuji(C12), IGC Field Trip Guide Book, 29th, *Volcanoes and Geothermal Fields of Japan*, **4**, 75-109.
Miyaji, N., Togashi, S., and Chiba, T. (2004) A Large-scale collapse event at the eastern slope of Fuji Volcano about 2900 years ago.*Bull. Volcanol. Soc. Japan*, **49**, 237-248 (in Japanese with English abstract).
Mizugaki, K. (2003) Geologic structure and volcanic history of the Yanaizu-Nishiyama (Okuaizu) geothermal field, Northeast Japan.*Geothermics*, **29**, 233-256.
Nakada, S., Yoshimoto, M., and Fujii, T. (2007) Pre-Fuji Volcanoes, Fuji volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 69-77, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Nakamichi, H., Ukawa, M. and Sakai, S. (2005) Precise hypocenter locations of midcrustal low-frequency earthquakes beneath Mt. Fuji, Japan. *Earth Planets and Space*, **56**, e37-e40.
Nakano, S., Ishizuka, Y., Yamamoto, T., Nakajima, K., Iwaya, T., Takada, A., Shirao, M., and Itoh, J. (2002) Geological Map of Fuji Volcano (CD-ROM Version). Digital Geoscience Map, G-9,1 CD-ROM, Geological Survey of Japan, AIST.
Nakano, S., Takada, A., Ishizuka, Y., Suzuki, Y., Chiba, T., Arai, K., Kobayashi, M., and Tajima, Y. (2007) Eruption ages of younger-stage lava

flows and older-stage pyroclastic cones on the northeastern foot of Fuji Volcano, Japan.*Bull. Geol. Surv. Japan*, **57**, 387-407 (in Japanese with English abstract).

Niitsuma, N. (1999) Rupture and delamitnation of arc crust rupture and delamination of island arc crust due to the arc-arc collision in the South Fossa Magna, central Japan. *Island Arc*, **8**, 441-458.

Nishimura, T., and Sagiya, T. (2007) Regional tectonics around Mt. Fuji Volcano - Crustal block kinematics of the Kanto and Tokai regions induced from crustal deformation data - . In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 203-217, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Obata, S., and Umino, S. (1999) Morphology of A.D. 864 Aokigahara lava flow exposed on the coast of Motosuko Lake, Fuji Volcano.*Bull. Volcanol. Soc. Japan,***44**, 201-216 (in Japanese with English abstract).

Oki Y. and Hakamata (1975) Mystery of birth of Lake Ashi, Hakone volcano. *National Land and Education*, **30** , 2-9 (in Japanese).

Otsuka, Y. (1934) Fossils in northern flank of Mt. Minobu and molluscan fossils in Hayakawa Tuff.*J. Geol. Soc. Japan*, **41**, 562-568.

Sagiya, T. (2004) Interplate coupling in the Kanto district, central Japan, and the Boso peninsula silent earthquake in May 1996.*Pure Appl. Geophys*.,**161**, 2327-2342.

Seno, T., Stein, S., and Gripp, A. E. (1993) A model for the motion of the Philippine Sea plate consistent with Nuvel-1 and geological data. *J. Geophys. Res*., **98**, 17941-17948.

Suzuki, Y., Takada, A., Ishizuka, Y. and Kobayashi, M. (2007) Reexamination of the eruptive history of scoria cones on the northwestern foot of Fuji Volcano, Japan.*Bull. Geol. Surv. Japan*, **57,** 377-385 (in Japanese with English abstract).

Tajima, Y., Miyaji, N., Yoshimoto, M., Abe, N., and Chiba, T. (2007) Pyroclastic flows originated from the collapse of scoria cones for the last 2,000 years on the north eastern slope of Fuji volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 255-267, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Takada, A., and Kobayashi, M. (2007) Eruptive history of flank eruptions by the trench survey on scoria cones on the southern flank of Fuji Volcano. Japan. *Bull. Geol. Surv. Japan*, **57**, 329-356 (in Japanese with English abstract).

Takada, A., Mannen, K., Ukawa, M. and Chiba, T. (2007a). Fuji and Hakone Volcanoes. *Cities on Volcanoes 5 Field Excursion A3*.

Takada, A., Ishizuka, Y., Nakano, S., Yamamoto, T., Kobayashi, M., and Suzuki, Y. (2007b) Characteristic and evolution inferred from eruptive fissures of Fuji volcano, Japan. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 183-202, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Takahashi, M. (2000) Magma system and tectonics of Fuji Volcano. –mini-oceanic ridge model-. *Chikyu monthly*, **22**, 516-523 (in Japanese).

Takahashi, M., Hasegawa, H., Tsukui, M., and Nemoto, Y. (1991) Evolution of magma-plumbing system beneath Fuji Volcano: On the view point of whole-rock chemistry. *Bull. Volcanol. Soc. Japan*, **36**, 281-296 (in Japanese with English abstract).

Takahashi, M., Nagai, M., Naito, S. and Nakamura, N. (1999) Development history of Hakone volcano and its regional stress field.*Chikyu Monthly*, **21**, 437-455.

Takahashi, M., Matsuda, F., Yasui, M., Chiba, T., and Miyaji, N. (2007) Geology of the Aokigahara lava flow field in Fuji Volcano and its implications in the process of Jogan Eruption. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 303-338, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Tanna Fault Trenching Research Group (1983) Trenching study for Tanna fault, Izu, at Myoga, Shizuoka prefecture, Japan. *Bull. Earthquake Res. Inst., Univ. Tokyo*. **58**, 797-830.

Togashi, S., and Takahashi, M. (2007) Geochemistry of rocks from the Fuji volcano, Japan; constraints for evolution of magmas. . In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 219-231, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).

Togashi, S., Miyaji, N., and Yamazaki, H. (1991) Fractional crystallization in a largetholeiitic magma chamber during the early stage of the Younger Fuji Volcano, Japan. *Bull. Volcanol. Soc. Japan*, **36**, 269-280 (in Japanese with English abstract).

Tomida, S. (1996) Late neogenetoropical and subtropical molluscan faunas from the south

Fossa-Magna region, central Japan.*Bull. Mizunami Fossil Mus*., **23**, 89-140.
Tsuya, H. (1940) Geological and petrological studies of Volcano Huzi (Fuji), III.Geology of the southern foot of Volcano Huzi.*Bull. Earthq. Res. Inst., Univ. Tokyo*, **18**, 419-445.
Tsuya, H. (1968) *Geology of Volcano Mt.Fuji*. Explanatory text of geological map 1:50, 000 scale, Geological survey of Japan.
Uesugi, Y. (1990) Standard tephra columns for the eastward area of Volcano Fuji. Part 1: S-25 ～ Y-141. *Bull. Assoc. Kanto Quat. Res*., **16**, 3-28(in Japanese).
Uesugi, Y. (1993) Tephrostratigraphic eruption forecasts of Fuji Volcano, Central Japan.*Quaternary Research*, **32**, 271-282 (in Japanese with English abstract).
Uesugi, Y., Horiuchi, M., Miyaji, N. and Furuta, T. (1987) Recent tephras of the younger Fuji Volcano - Classification and age -.*Quaternary Research*, **26**, 59-68 (in Japanese with English abstract).
Ukawa, M. (2005) Deep low-frequency earthquake swarm in the mid-crust beneath Mount Fuji (Japan) in 2000 and 2001. *Bull. Volcanol.*,**68**, 47-56.
Umino, S. (2007) Characteristics of lava flows of Fuji volcano. In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 269-283, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Yamamoto, T., Takada, A., and Shimokawa, K. (2002) Debris avalanche deposits of Fuji Voclano.*Chikyu monthly*, **24**, 640-644 (in Japanese).
Yamamoto, T., Takada, A., Ishizuka, Y. and Nakano, S. (2005a) Chronology of the products of Fuji volcano based on new radiometric carbon ages. *Bull. Volcanol. Soc. Japan*, **50**, 53-70 (in Japanese with English abstract).
Yamamoto, T., Takada, A., Ishizuka, Y., Miyaji, N., and Tajima, Y. (2005b) Basaltic pyroclastic flows of Fuji volcano, Japan: characteristics of the deposits and their origin. *Bull. Volcanol.*,**67**, 622-633.
Yamamoto, T., Ishizuka, Y., and Takada, A. (2007) Surface and subsurface geology at the southwestern foot of Fuji volcano, Japan: New stratigraphy and chemical variations of the products. . In *Fuji volcano* (Aramaki, S., Fujii, T., Nakada, S. and Miyaji, N. eds,), 97-118, Yamanashi Institute of Environmental Sciences (in Japanese with English abstract).
Yamamoto, T., Nakano, S., Takada, A. and Kobayashi, M. (2011) New stratigraphy of the recent ejecta on the eastern flank of Fuji volcano, Japan. *Bull. Geol. Surv. Japan*, **62**, 405-424(in Japanese with English abstract).
Yamazaki, H. (1992) Tectonics of a plate collision along the northern margin of Izu peninsula, central Japan.*Bull. Geol. Surv. Japan*, **43**, 603-657.
Yasui, M., Togashi, S., Shimomura, Y., Sakamoto, S., Miyaji, N., and Endo, K. (1998) Petrological features and origin of the gabbroic fragments contained in the 1707 pyroclastic fall deposits, Fuji Volcano. *Bull. Volcanol. Soc. Japan*, **43**,2, 43-59 (in Japanese with English abstract).
Yoshimoto, M., Fujii, T., Kaneko, T., Yasuda, A., Nakada, S., Matsumoto, A. (2010) Evolution of Mount Fuji, Japan: Inference from drilling into the subaerial oldest volcano, pre-Komitake. *Island Arc,* **19**, 470-488.