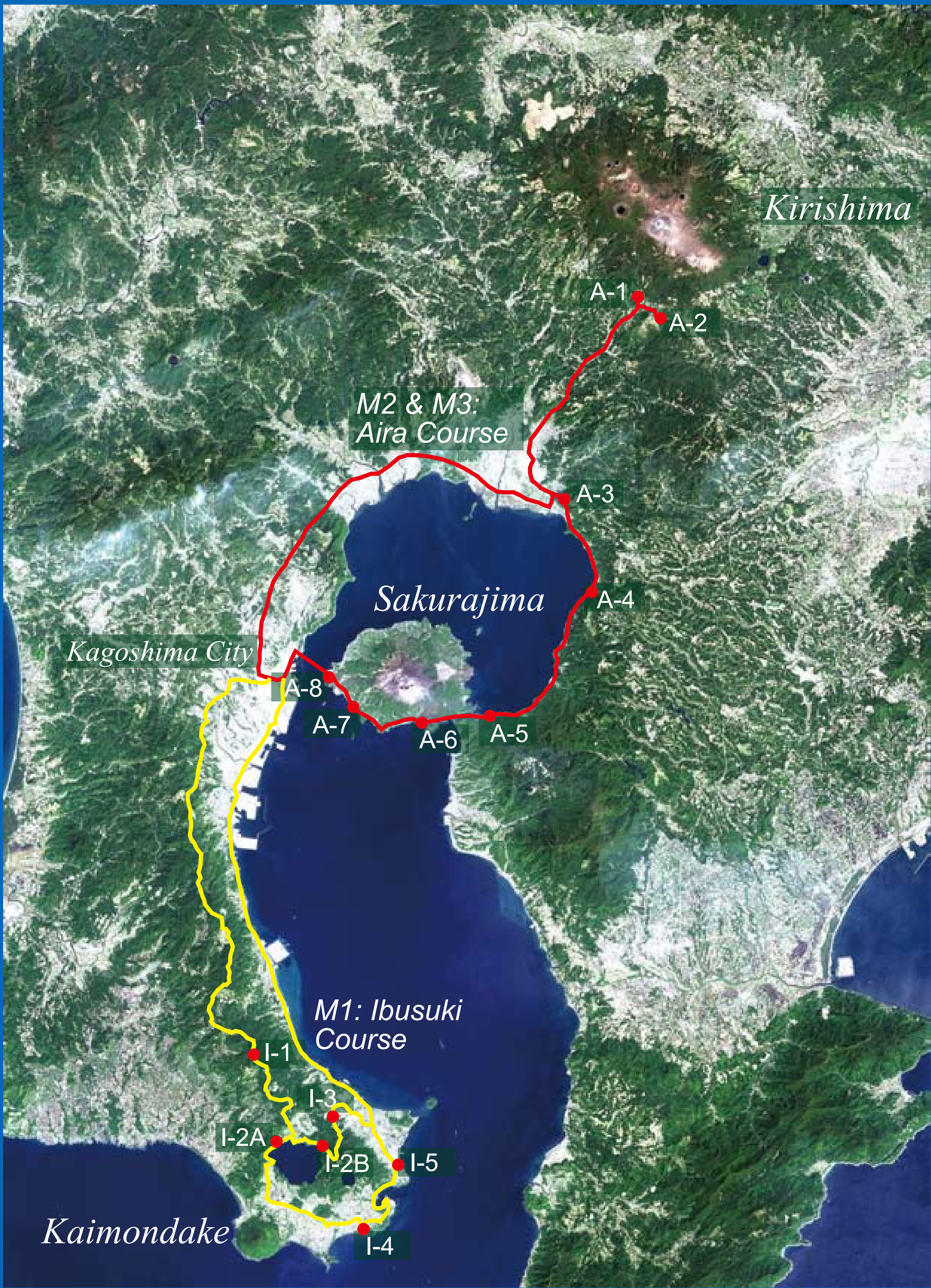
IAVCEI 2013 Scientific Assembly

A Guide for Mid-Conference Field Trip



Written by

Tetsuo Kobayashi, Ryusuke Imura and Mitsuru Okuno

CONTENTS

Cover photo: Landsat 8 image shows southern Kyushu, Japan, including Kirishima, Sakurajima and Kaimondake volcanoes. The image was taken on April 13, 2013. Image processed by M. Urai, Geological Survey of Japan, AIST. Credit: US Geological Survey.

Back cover photo: Oblique aerial view of the Sakurajima (foreground) and Kaimondake (background) volcanoes from northeast (photo by R. Imura).

Pictorial 1: Ibusuki course (M1)

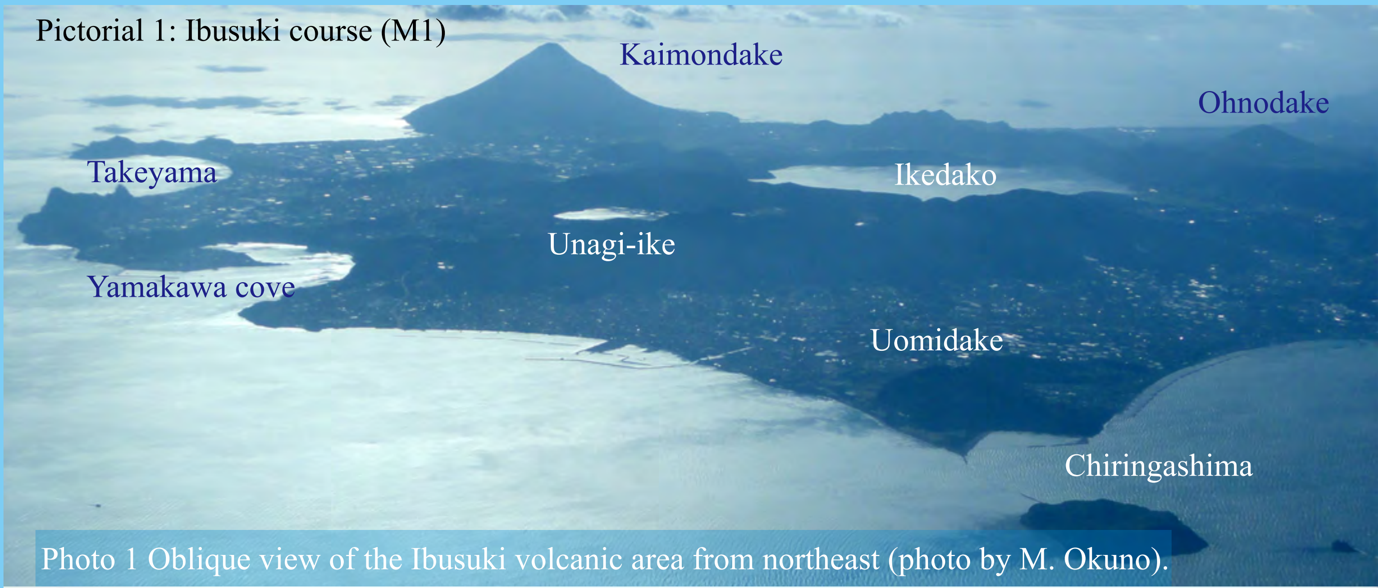


Photo 1 Oblique view of the Ibusuki volcanic area from northeast (photo by M. Okuno).

Photo 2 Ikeda caldera and Kaimondake volcano viewed from Shinageshi (Stop I-2B) located on northeastern lakeside (photo by M. Okuno).

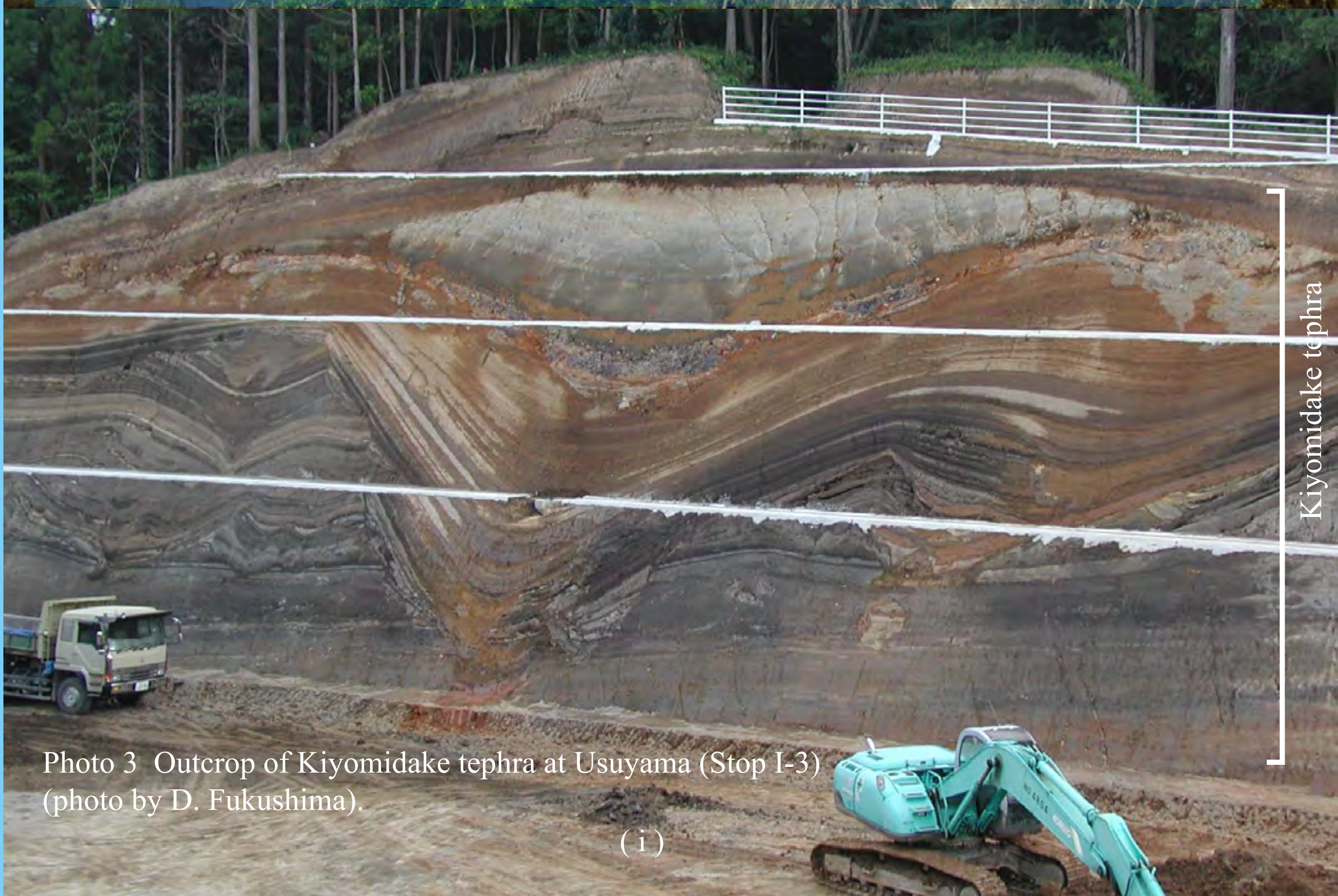


Photo 3 Outcrop of Kiyomidake tephra at Usuyama (Stop I-3) (photo by D. Fukushima).

Pictorial 2: Aira course (M2, M3)

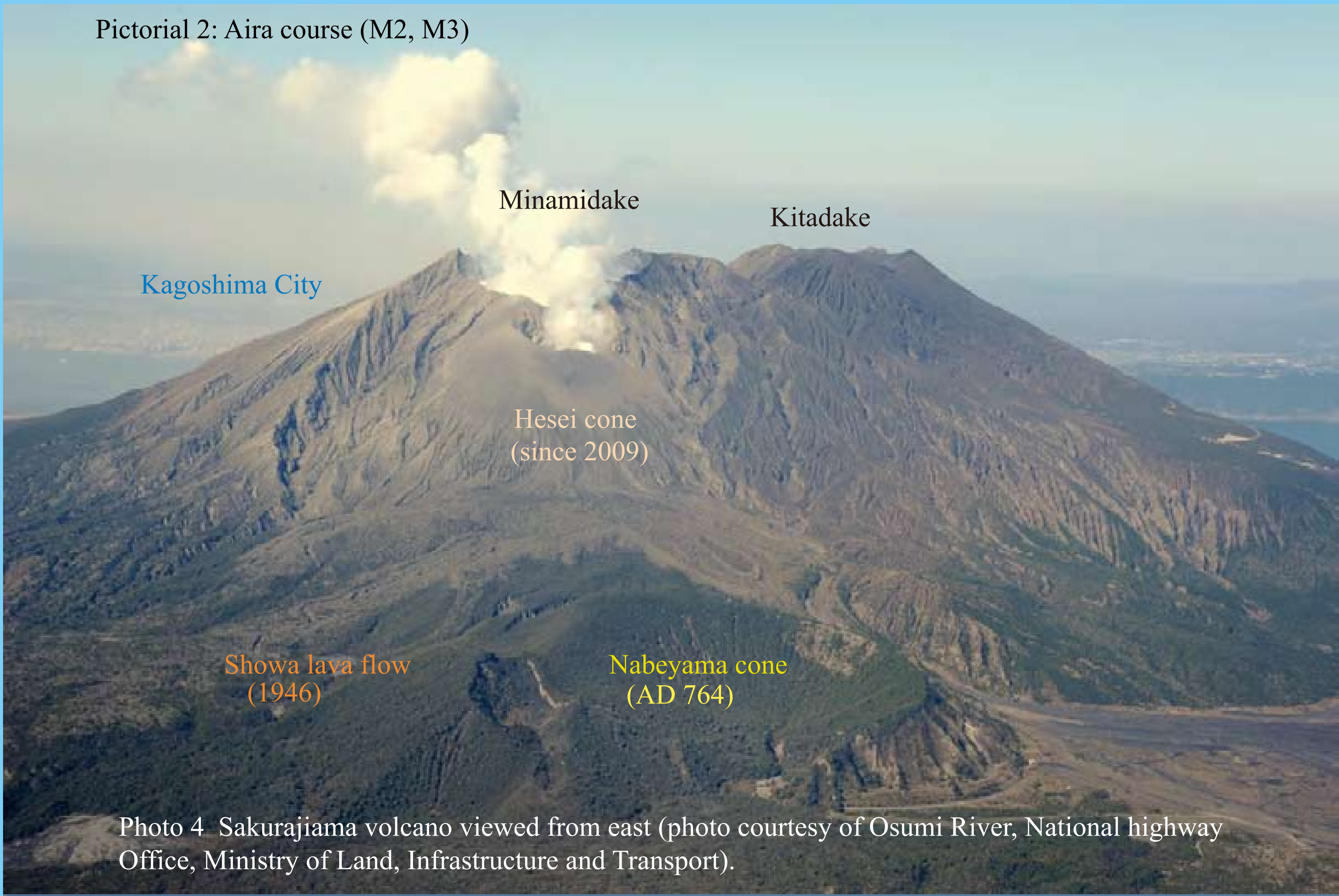


Photo 4 Sakurajiama volcano viewed from east (photo courtesy of Osumi River, National highway Office, Ministry of Land, Infrastructure and Transport).

Photo 5 Representative peaks of Kirishima volcano taked from Takachiho Bokujo (Stop A-2) (photo by R. Imura).

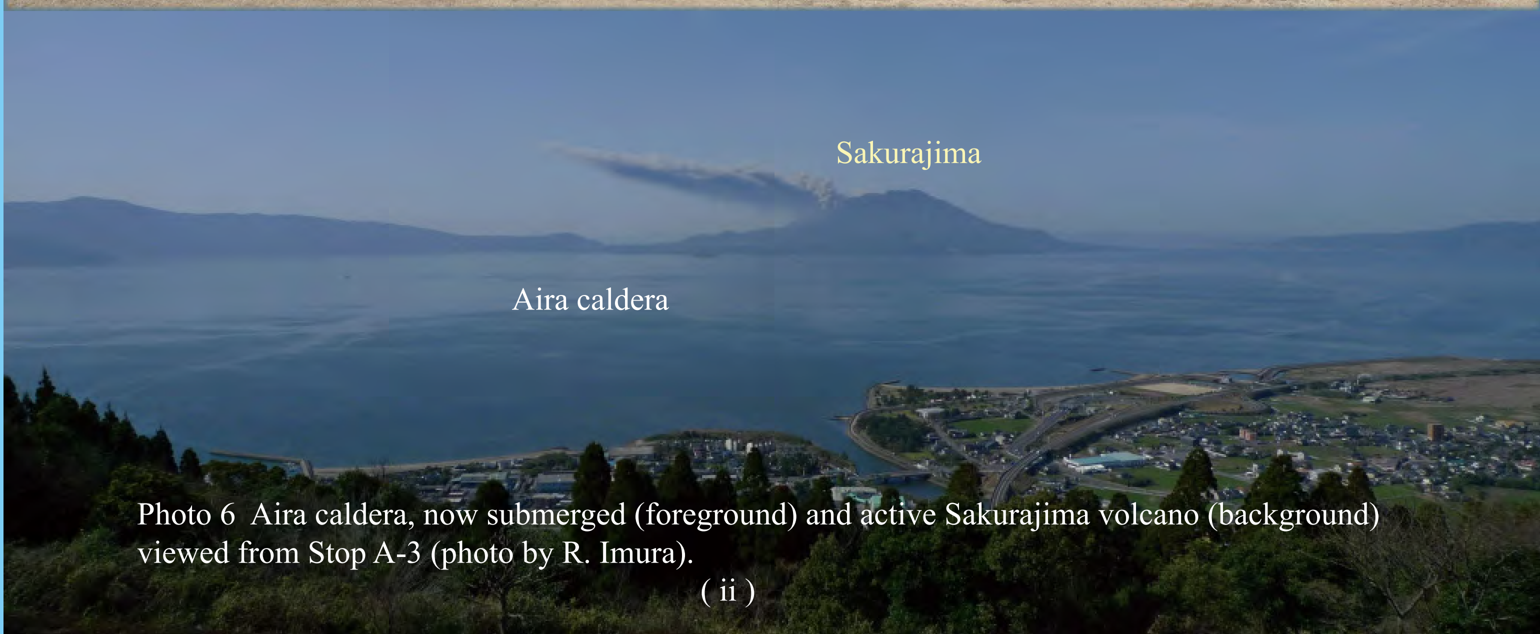


Photo 6 Aira caldera, now submerged (foreground) and active Sakurajima volcano (background) viewed from Stop A-3 (photo by R. Imura).

IAVCEI 2013 Scientific Assembly

Mid-Conference Field Trip (July 22, 2013)

M1: Ibusuki Course, M2 and M3: Aira Courses

Tetsuo Kobayashi[1)], Ryusuke Imura[1)] and Mitsuru Okuno[2)]

1) Graduate School of Science and Engineering, Kagoshima University
2) Faculty of Science; also AIG Collaborative Research Institute for International Study on Eruptive History and Informatics (ACRIFIS-EHAI), Fukuoka University

Abstract

Kagoshima graben in southern Kyushu, Japan, includes the Kakuto, Kobayashi, Aira, and Ata calderas, and extends southward to the Kikai caldera. These calderas have post-caldera volcanoes such as Kirishima, Sakurajima and Kaimondake. To enjoy the landscape and archaeology related to active volcanoes, we provide three courses for 1-day trips from Kagoshima City, where the IAVCEI 2013 Scientific Assembly is held.

Key words: Kagoshima graben, Kirishima, Sakurajima, Kaimondake, archaeological museum

INTRODUCTION

The 1000-km-long southern Kyushu-Ryukyu volcanic arc includes the active volcanoes of Kirishima, Sakurajima, and Kaimondake on Kyushu, and several volcanic islands to the southwest. The Wakamiko in the Aira caldera, and Ikeda caldera and Yamakawa maar in the Ibusuki area have also been classified as active volcanoes.

We provide three courses (M1–M3) for the mid-conference field trip on July 22, 2013. The M1 course goes to the Ibusuki area. We will see Kaimondake and other post-caldera volcanoes of Ata caldera, and visit an archaeological museum. The M2 and M3 courses proceed clockwise and anticlockwise, respectively, around the Aira caldera. Both courses include stops at the Sakurajima and Kirishima volcanoes, and at facilities such as an archaeological museum and a famous shrine. These trips cover the landscape of active volcanoes of southern Kyushu (Kirishima, Sakurajima, and Kaimondake), where the volcanic deposits and their impacts on residents can be observed.

GEOLOGY

Volcanoes in southern Kyushu

The Okinawa trough, located behind this volcanic arc, is a marginal back-arc basin that has been active since the late Miocene (Fig. 1). Simultaneous with its opening, tectonic movements associated with intense volcanism occurred and volcanism has predominated over a wide area to the west of southern Kyushu. The Kagoshima graben (Tsuyuki, 1969), which trends NNE–SSW, defines the eastern margin of the volcano-tectonic depression. Kagoshima Bay, approximately 20–30 km in width, occupies two-thirds of the southern part of the graben.

The basement complex of southern Kyushu is composed mainly of the Shimanto supergroup, Miocene silicic plutonic rocks, and Neogene–Early Pleistocene volcanic rocks. The Shimanto supergroup, which is made up of highly deformed Mesozoic–Paleogene shales, sandstones, conglomerates, and minor pillow lavas, underlies the graben. The Shimanto supergroup is broken by step faulting and overlain by a densely welded ignimbrite which has been dated to about 2.9 Ma (Shibata *et al*., 1978) and marks the beginning of formation of the volcano-tectonic depression.

The Kagoshima graben contains the Kakuto, Aira and Ata calderas and other small and unidentified depressions (Fig. 2). The Aira, Ata, and Kikai calderas, including the Aso caldera in central Kyushu, were first proposed by Matumoto (1943). The Kikai caldera, which is one of the youngest Holocene calderas in Japan, erupted 7.3 cal kBP (Kitagawa *et al*., 1995; Fukusawa, 1995). It is located about 30 km south of Kagoshima Bay. Large volumes of highly vesiculated silicic magma in the form of pyroclastic falls and flows were repeatedly erupted from these calderas and formed vast ignimbrite plateaus in the area (*e.g*., Aramaki and Ui, 1976). These calderas are now partly occupied by the active volcanoes.

Kikai caldera

More than three large-scale ignimbrites have been erupted from Kikai caldera (Fig. 3: Ono *et al*., 1982). The oldest Koabiyama ignimbrite is found only on Takeshima and Iojima islands, which represent the northern margin of the caldera. It is composed of many thin flow units and is densely welded, but its eruption age is not known. The next-youngest unwelded Nagase ignimbrite is also found only on Takeshima, but the associated co-ignimbrite ash-fall deposit (Kikai-Tozurahara ash: K-Tz) is *ca.* 90–95 ka in age and is traceable into central Japan (Machida, 1999).

The climactic Akahoya eruption produced the Koya pumice-fall deposit and Koya ignimbrite around 7.3 cal kBP. The Koya ignimbrite travelled up to 40 km across the sea and reached the Kyushu mainland where it generally consists of a single flow unit traceable up to 70 km away from the source (Fig. 4). The thickness of the deposit is generally <1 m, and decreases consistently with increasing distance from the source. The deposit generally shows semi- mantle bedding, like surge deposits, and is characterized by a dune bedding structure with a ground layer. It is the most representative low-aspect ratio ignimbrite in Japan (Ui, 1973). The Kikai Akahoya ash (K-Ah) is a co-ignimbrite ash-fall deposit that has been identified more than 1000 km away from the source (Fig. 5: Machida and Arai, 1978, 1983). K-Ah shows normal grading and has a coarse basal layer with pumice, lithics, and accretionary lapilli. In the proximal area, the partially or densely welded Funakura ignimbrite occurs within the Koya pumice-fall section on the caldera rim, suggesting that the Funakura ignimbrite is of intra-plinian type. Although a thick deposit of the Koya (also named as Takeshima) ignimbrite is observed in Takeshima, it shows no welding. Many clastic dikes associated with the K-Ah are found in southern Kyushu, suggesting that they were generated during the Akahoya eruption (Naruo and Kobayashi, 2002). Field evidence suggests that large earthquakes occurred at least twice during the eruption. Tsunamis may also have occurred at this time (*e.g*., Maeno *et al.*, 2006). Numerous wood trunks were found in pumiceous deposits of the eruption along the rivers on the northern side of Yakushima Island, 25 km south of the caldera (Okuno *et al.*, 2013). These deposits may have originated in tsunamis generated by the eruption.

Iodake and Inamuradake in Satuma-Iojima are post-caldera stratovolcanoes. Iodake is steep and rhyolitic whereas Inamuradake is small and basaltic (Ono *et al*., 1982; Kawanabe and Saito, 2002). Vigorous emission of high-temperature gas has continued at the summit of Iodake to this day. A new volcanic island was formed by the submarine eruption of rhyolite in 1934–1935 (Ono *et al*., 1982; Maeno and Taniguchi, 2006).

Ata caldera and lbusuki volcanic area

Two opinions have been expressed about the location of the source caldera for Ata ignimbrite (Figs. 4, 6–8). Matumoto (1943) thought that the Ata caldera was located at the mouth of Kagoshima Bay with its western margin defined by the steep scarps of the Onkadobira fault and its eastern margin by the steep western coast of the Osumi peninsula (Fig. 8). On the other hand, Aramaki and Ui (1966a, b), Hayasaka (1987), and Suzuki and Ui (1983) argued that the caldera depression was located north of the location proposed by Matumoto (1943), based on sea-floor sonic prospecting data and the radial pattern of depositional ramps extending outward from this source area (Fig. 7). The Ata ignimbrite is one of the largest Late Pleistocene ignimbrites in Japan, and was erupted *ca.* 110 ka (Matsumoto and Ui, 1997). The flat ignimbrite plateau is well preserved especially along the eastern coast of Kagoshima Bay. The maximum thickness of the deposit is 100 m. The

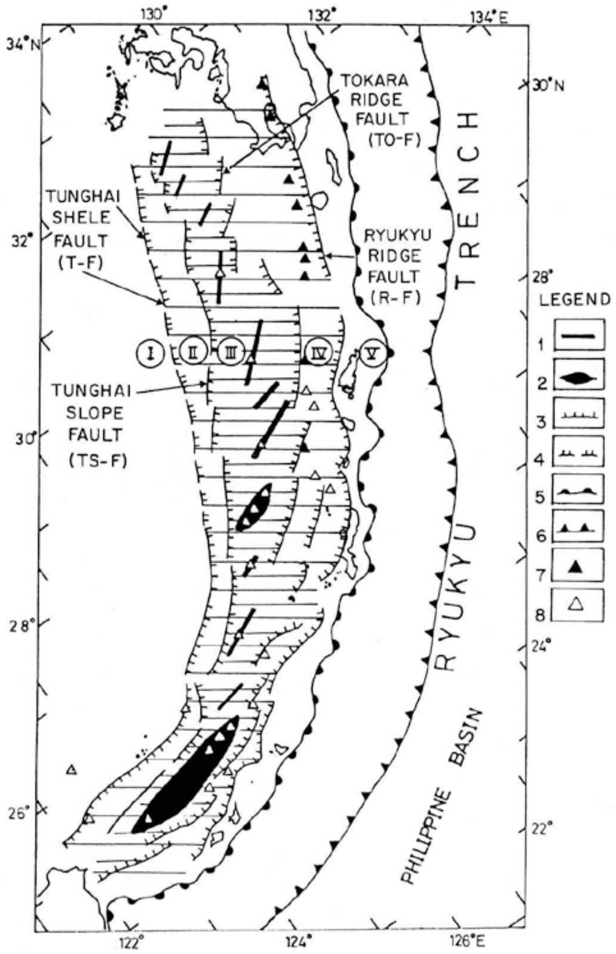


Fig. 1 Geological and structural map of the Ryukyu arc, Okinawa trough, Taiwan, and vicinity (Kimura, 1985). 1, central graben; 2, basin occupied by Pleistocene igneous intrusions; 3, major fault and fault scarp; 4, buried major fault and fault scarp; 5, eastern boundary of the Ryukyu ridge; 6, trench; 7, active volcanoes; 8, submarine intrusions or volcanoes since the late Pleistocene time.

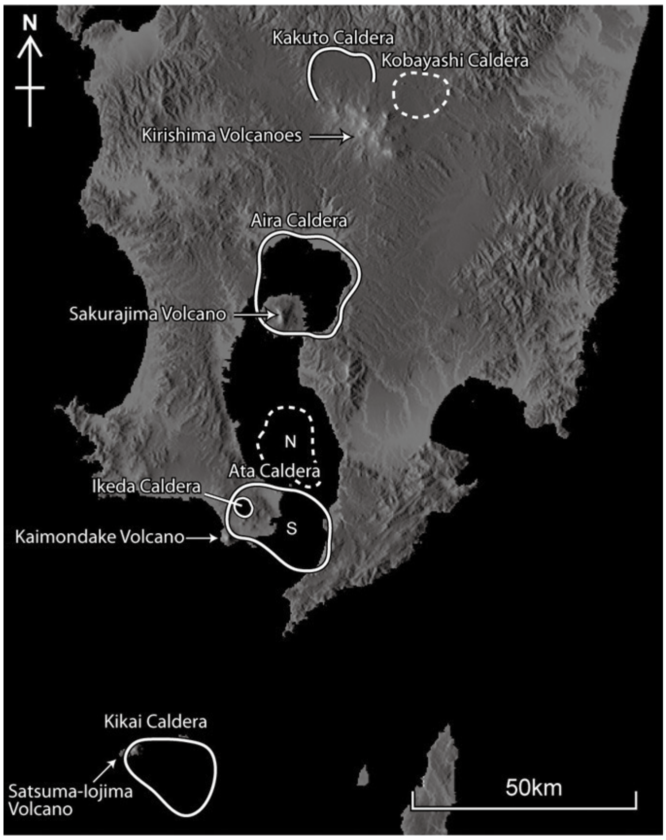


Fig. 2 Index map showing the locations of the main calderas and associated active volcanoes in southern Kyushu. The Aira, Ata, and Kikai calderas, including the Aso caldera in central Kyushu, were first proposed by Matumoto (1943).

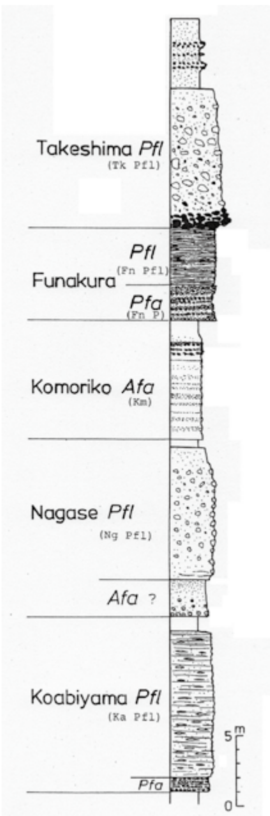


Fig. 3 Idealized columnar section for Quaternary tephra layers from the Kikai caldera on Takeshima Island (after, Nagaoka, 1988).

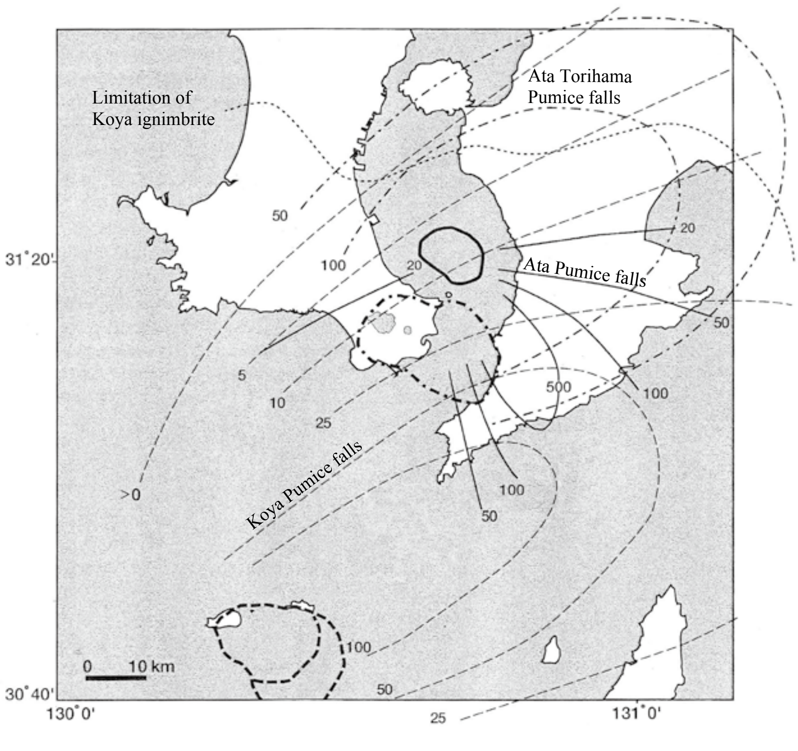


Fig. 4 Map showing the location of Kikai and Ata calderas (compiled by Kawanabe and Sakaguchi, 2005). Isopach lines for Ata and Ata Torihama (Nagaoka, 1988) and Koya pumice falls (Machida and Arai, 1978) and limitation of Koya ignimbrite (Machida and Arai, 1978) are also shown. The value is in cm.

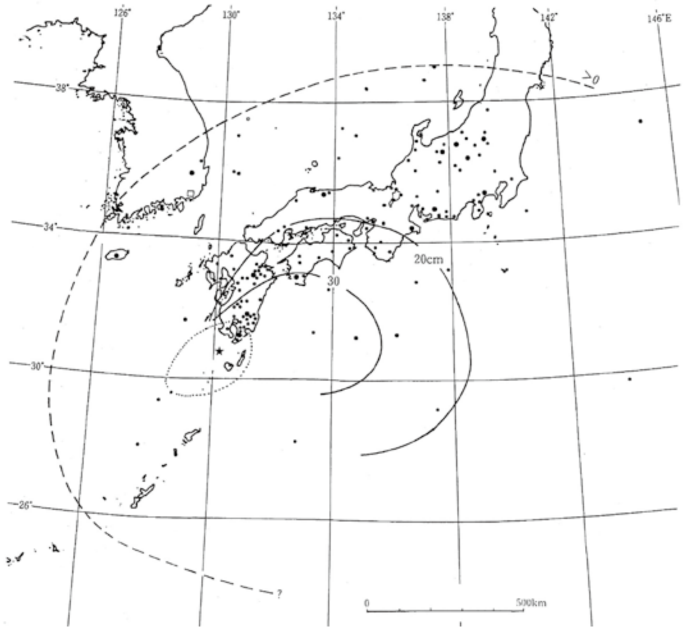


Fig. 5 Isopach map of the Kikai Akahoya ash (K-Ah) (Machida and Arai, 1978, 1983). The value is thickness (in cm).

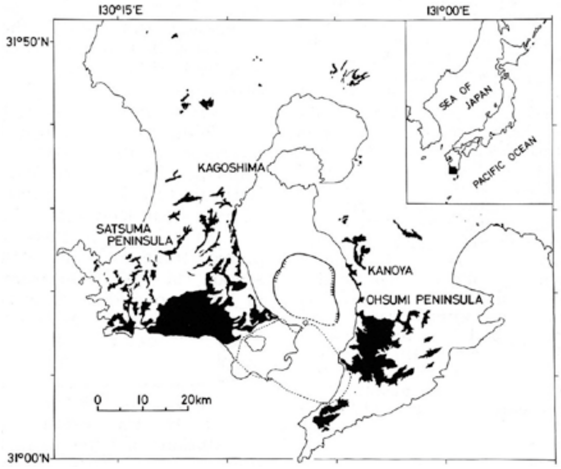


Fig. 6 Map showing the distribution of Ata ignimbrite (Suzuki and Ui, 1982, 1983). Thick and thin broken lines show the rims of the Ata caldera, as proposed by Matumoto (1943) and Hayasaka (1987), respectively.

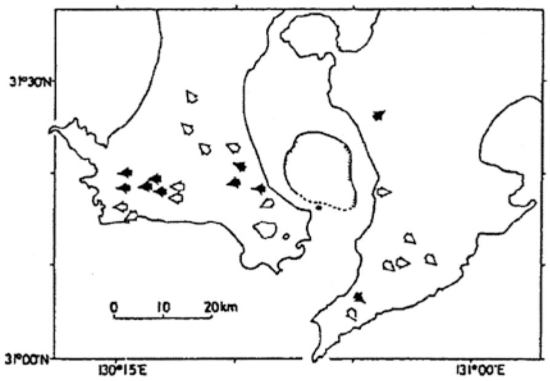


Fig. 7 Direction of depositional ramp structure of Ata ignimbrite (Suzuki-Kamata and Ui, 1988). Solid arrow: confirmed direction by field mapping and altimetry. Open arrow: estimated direction from topographic maps and photographs.

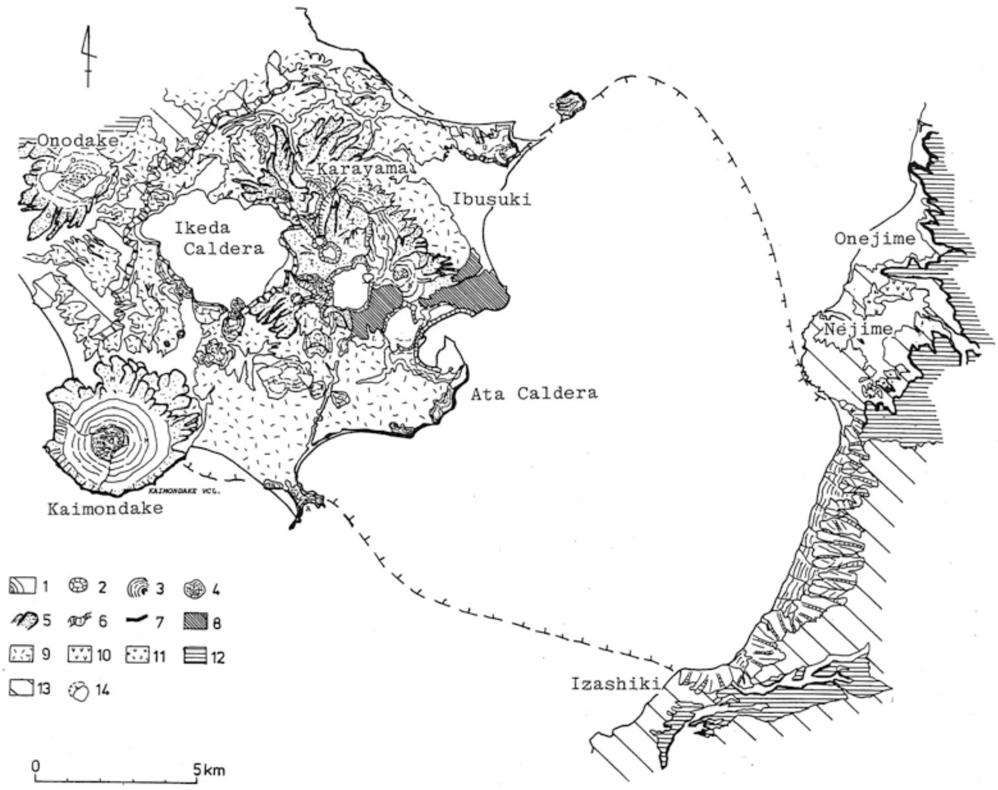


Fig. 8 Geomorphological map of the Ata caldera (Nagaoka, 1988). 1: Alluvial plain and fan, 2: Crater, 3: Conical volcano, 4: Lava dome, 5: Lava flow, 6: Caldera wall, 7: Cliff, 8: Pyroclastic surge deposit surface, 9: Ikeda ignimbrite surface, 10: Ito ignimbrite surface, 11: Tashiro ignimbrite surface, Ata ignimbrite surface, 13: Mountain and hill, 14: Landslide.

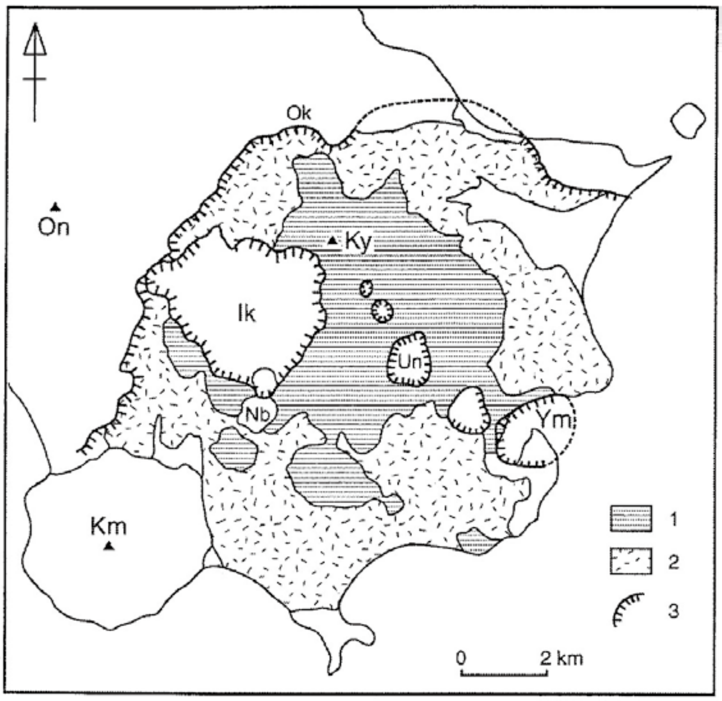


Fig. 9 Simplified geological map of the Ibusuki volcanic area (compiled by Okuno and Kobayashi, 1991). Ok: Onkadobira fault scarp, On: Ohnodake volcano, Ky: Kiyomidake volcano, Ik: Ikeda caldera, Un: Unagi-ike maar, Ym: Yamakawa maar, Nb: Nabeshimadake volcano, Km: Kaimondake volcano, 1: Post caldera volcanoes, 2: Ikeda ignimbrite and related pyroclastic surge deposit, 3: Fault scarp, caldera wall and crater rim.

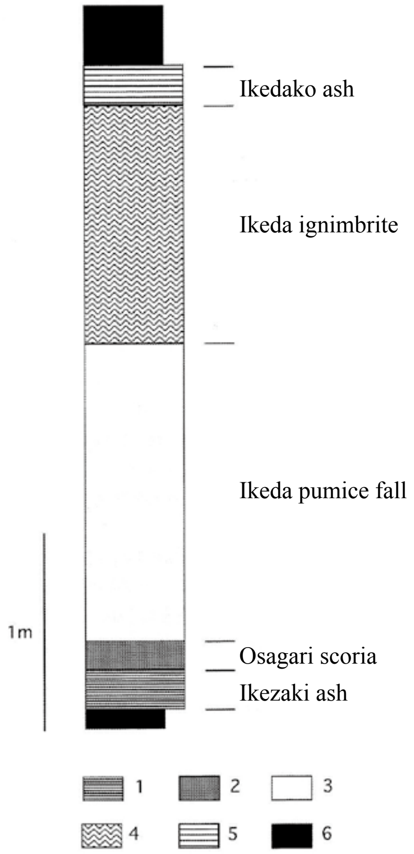


Fig. 10 Columnar section of the 6.4 cal kBP episode of the Ikeda caldera (Kawanabe and Sakaguchi, 2005). 1: Volcanic ash, 2: Scoria fall, 3: Pumice fall, 4: Ignimbrite and surge, 5: Stratified fine ash, 6: Humic soil.

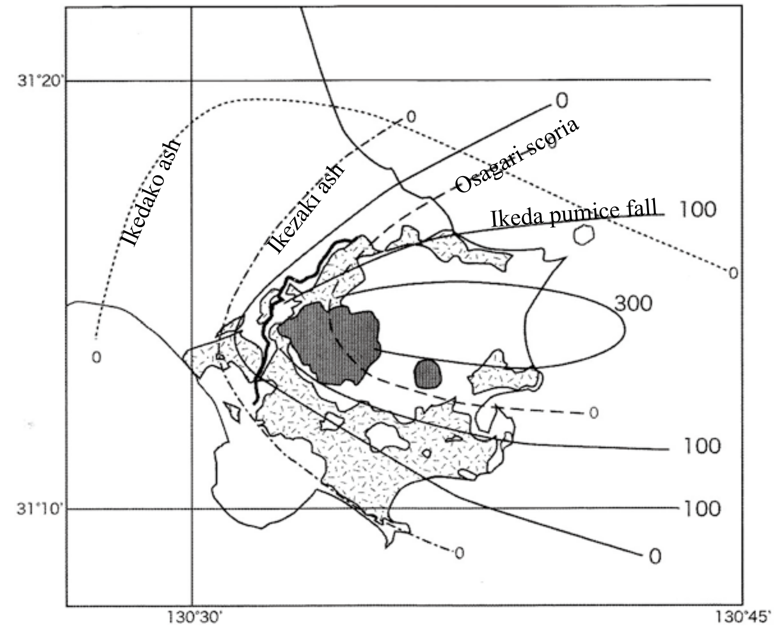


Fig. 11 Isopach map showing distribution of the 6.4 cal kBP episode of the Ikeda caldera (Kawanabe and Sakaguchi, 2005).

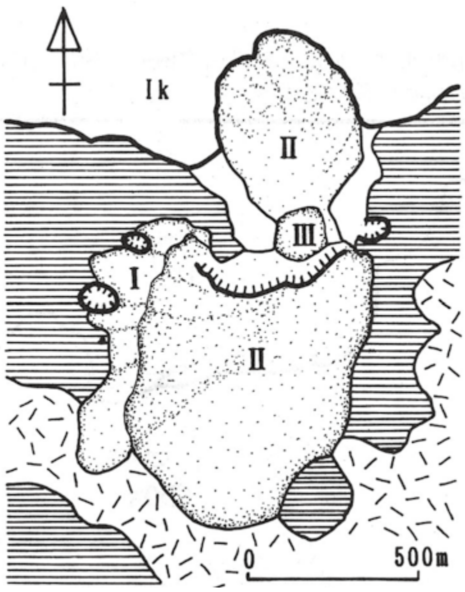


Fig. 12 Geological map of the Nabeshimadake volcano (Okuno and Kobayashi, 1991).

most distal deposits are >100 km from the caldera (Watanabe, 1985).

Post-Ata volcanism (small stratovolcanoes and lava domes) has been mainly concentrated in the Ibusuki volcanic area (Figs. 8 & 9). The Onkadobira fault is part of a large system of faults that define the western margin of the Kagoshima graben. The largest eruption on this stage is represented by the Kiyomidake tephra (7.4 km^3 in bulk; Okuno *et al.*, 1995), which reached the northern part of Tanegashima Island. The ^{14}C age for this tephra is approximately 48 kBP (Okuno *et al*., 2012). Some other tephra layers on this stage erupted from submerged vents in Kagoshima Bay (Nagaoka *et al*., 1991).

A climactic fissure occurred in the central part of the Ibusuki area *ca*. 6.4 cal kBP, resulting in the formation of the ~4-km-diameter Ikeda caldera. Sequential fissure eruptions aligned ESE formed four maars. The largest of these was the Yamakawa maar, which was formed by a base surge eruption. The caldera-forming eruption was initially phreatic, then become magmatic. The deposits thus formed were, from the bottom to top, Ikezaki ash, Osagari scoria, Ikeda plinian pumice, and Ikeda ignimbrite (Figs. 10 & 11: Ui, 1967; Kobayashi and Naruo, 1986). The Ikeda ignimbrite moved through topographic lows and reached the sea. Many littoral vents penetrating the Ikeda ignimbrite were exposed in the coastal cliff. The Osagari scoria is andesitic whereas ejecta of subsequent eruptions were all rhyolitic. Shortly after the formation of this caldera, phreatomagmatic eruptions occurred from the caldera floor and produced the Ikedako ash, which was composed mainly of an accumulation of thin ash layers with accretionary lapilli. The Ikedako ash is 10 m thick around the caldera rim. Alternating thin layers of ash gave a false impression that they were lacustrine in origin. Many clastic dikes have been found in the Ikedako ash (Naruo and Kobayashi, 1995). The total erupted volume of magma erupted is estimated to be 5 km^3. After a long period of dormancy, a small lava dome, Nabeshimadake, was formed on the southeastern caldera rim around 4.8 cal kBP (Okuno and Kobayashi, 1991; Okuno, 2002). As the dome grew, its northern half slid down into the caldera due to a sector collapse of the caldera rim (Fig. 12).

Kaimondake volcano is undissected and consists of a basal stratovolcano and a small central volcano (Fig. 13: Fujino and Kobayashi, 1997). The first eruption occurred near the coast at *ca*. 4 cal kBP, and two eruptions were documented in AD 874 and 885. The volcano was active for about 3000 years, during which time 12 major eruptions occurred. These were named Km1 to Km12 in ascending order (Fig. 14). The mode of eruption of this volcano was mainly scoriaceous subplinian type which is frequently associated with phreatomagmatic events. Lava flows were often associated with the scoria eruptions. Among the 12 major eruption deposits, Km1, Km9, Km11 and Km12 were voluminous. During the most recent eruption (Km12b), a central volcano formed in the summit crater of the basal stratovolcano. This central volcano is not a simple lava dome, but a mound of complex volcanic materials with a composite structure (Fig. 13). It consists of a basal scoria cone associated with fluid lava flows, later capped by a viscous lava dome and subsequently penetrated by a volcanic plug around the summit.

Numerous hot springs are used as spa resorts in this area. The “Suna-mushi” sand steam bath and the Yamakawa geothermal power station are located near the coastline of Fushime (see description of Stop I-4). The system in the Fushime geothermal field is characterized by a very high-temperature (>350°C) reservoir, which is located in a fractured zone that developed around a dacite intrusion (Okada *et al.*, 2000).

Aira caldera

The Aira caldera occupies the northern end of Kagoshima Bay. Because it is controlled by regional fault systems, it is rectangular, rather than circular in shape. Its northeastern portion, which has a deeper flat bottom at 200 m below sea level, is called the Wakamiko caldera (Shimomura, 1960). The southeastern rim consists of remnants of alternating ignimbrites and lava flows, ranging from 2.9 Ma to 0.2 Ma in age (Kaneoka *et al*., 1984). This sequence suggests that intense volcanism, with large-scale pyroclastic eruptions and minor lava flows, has repeatedly taken place in the caldera region.

At 29 cal kBP, a great pyroclastic eruption occurred within the Aira caldera (Aramaki, 1984). The first phase of the eruption was plinian, forming

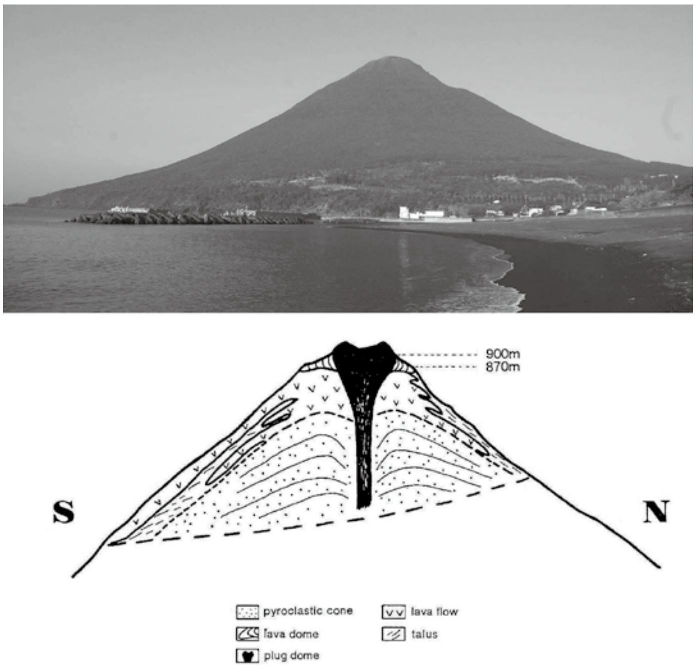


Fig. 13 Volcanic edifice of Kaimondake. (a) View from the east (photo by K. Katahira). (b) Schematic cross section of the central cone of the Kaimondake volcano (modified from Fujino and Kobayashi, 1997).

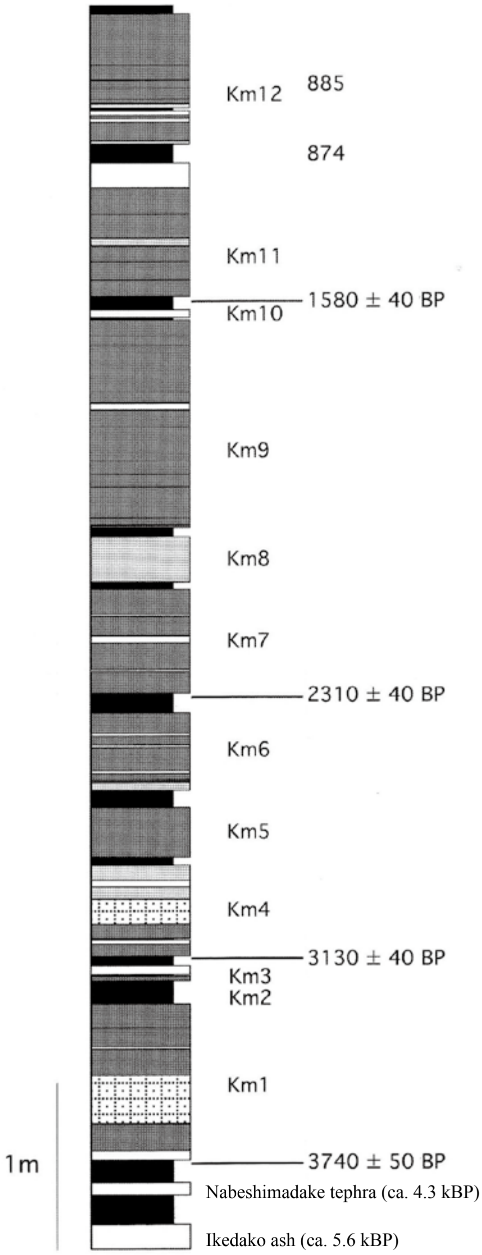


Fig. 14 Idealized columnar section of tephra layers from Kaimondake volcano (Fujino and Kobayashi, 1997; Kawanabe and Sakaguchi, 2005).

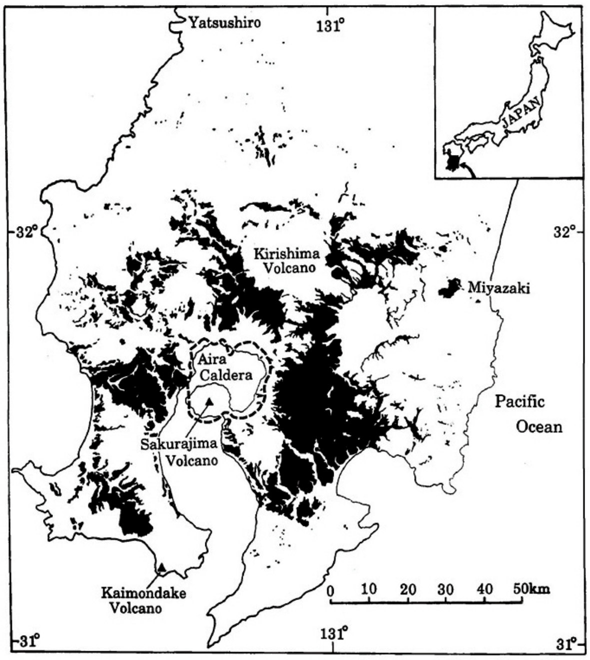


Fig. 15 Distribution of the Ito ignimbrite (Yokoyama, 2000).

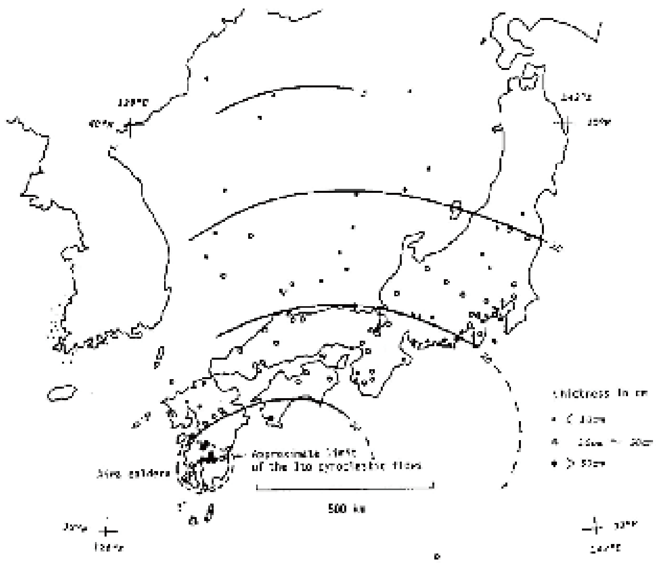


Fig. 16 Isopach map of the Aira-Tn ash (AT), with thickness in cm (Machida and Arai, 1983).

the Osumi pumice fall (Aramaki and Ui, 1966a; Kobayashi *et al*., 1983) with a dispersal axis to the southeast. This dispersal pattern indicates that the source vent is located near the present site of Sakurajima. The bulk volume of the deposit has been calculated to be about 98 km^3 (Kobayashi *et al*., 1983).

The final catastrophic eruption generated a vast ignimbrite plateau over southern Kyushu (Fig. 15). The most distal deposits are found 90 km north of the center of the caldera (Yokoyama, 2000). Aira Tn ash (AT: co-ignimbrite ash from the 29 cal kBP eruption), first described by Machida and Arai (1976, 1983), is found up to 1400 km from the vent. Indeed, it covers all of Japan and has become a good marker key bed for tephrochronology (Fig. 16). The total volume of magma erupted during the Ito eruption is about 110 km^3 (Aramaki, 1984). Vigorous submarine fumarolic activity, called "Tagiri" (Ossaka, 1991; Ishibashi *et al*., 2008), occurs on the floor of the Wakamiko caldera.

Sakurajima volcano

Sakurajima volcano (*e.g.*, Iguchi *et al.* , 2013), which began to erupt around 26 cal kBP (Okuno, 2002) on the southern rim of the Aira caldera, is composed of two adjacent stratovolcanoes, the Kitadake (1117 m) and the overlying Minamidake (1040 m), and small parasitic volcanoes (Fig. 17). Nakadake, a small peak between Kitadake and Minamidake is also thought to be a parasitic cone formed near the summit crater. A small plateau called Hakamagoshi which consists of basement deposits (remnants of the caldera rim), is located on the western coast of the volcano.

The Kitadake volcano consists largely of pyroclastic rocks, whereas the lower slope is predominantly lava flows. The western part has been thoroughly dissected by deep gorges. In contrast, some areas have flat surfaces of thick pumice deposits and are cut by deep valleys. Parasitic volcanoes of Kitadake volcano are mainly distributed on the eastern and western flanks. On the western flank of the Kitadake, three major lava domes trend in this direction. The chemical compositions of these lava domes is dacites (SiO_2=67 wt%). They probably erupted from the fissure vents almost simultaneously.

The Minamidake is an active stratovolcano that began to grow on the southern slope of Kitadake *ca.* 4.5 cal kBP. The first well-documented record of a large eruption dates to AD 764. This was a phreato-magmatic eruption occurred on the southeastern coast of the volcano. It generated the Nabeyama tuff cone, whose eastern half was eroded by sea waves soon afterward and buried by the succeeding lava flow (Kobayashi, 1982; Okuno *et al.*, 1998; Miki, 1999). The Ohira lava flowed down north from the summit crater in *ca.* AD 950 (Kobayashi *et al.*, 2009). The formation of Nakadake was estimated to occur *ca*. AD 1200 (Kobayashi, 2010).

Figure 18 shows the distribution of large-scale tephras in historical time. A series of large-scale fissure eruptions occurred in P4 (AD 764: Tenpyo-Hoji era), P3 (1471–1476: Bunmei era), P2 (1779: An-ei era) and P1 (1914: Taisho era), starting with plinian activity from newly opened fissure vents and ending with the emission of lava flow. Pyroclastic flows inevitably accompanied these eruptions. During the An-ei eruption, submarine eruptions continuously occurred in the northeastern offshore area for about 2 years. The seafloor was heaved up by the intrusion of magma beneath the submarine deposits, producing a submarine cryptodome that is 100 m high. Four islets are preserved on the surface of the cryptodome. Two of them (Shinjima and Nakanoshima islets) are composed mainly of submarine deposits with overlying blocks of giant pumice that were settled during the first phase of the An-ei submarine eruption (Kobayashi, 2009).

The Taisho eruption began on January 12, 1914, from the western and eastern fissure vents. Although activity in the western craters ceased within 2 weeks, lava emission from the eastern vents continued for more than a year. The eastern lava flow filled the Seto Strait by the end of the month, and connected the island to the Osumi peninsula.

During October 1939, small-scale pyroclastic flow eruptions occurred on the eastern slope near the summit. In 1946 (Showa era), 0.18 km^3 of lava (Ishihara *et al*., 1981) was emitted from the same parasitic crater.

A sudden explosion occurred in the summit crater of Minamidake in 1955, and summit eruption intermittently occurred thereafter. The mode of eruption was mainly vulcanian. Sometimes, however,

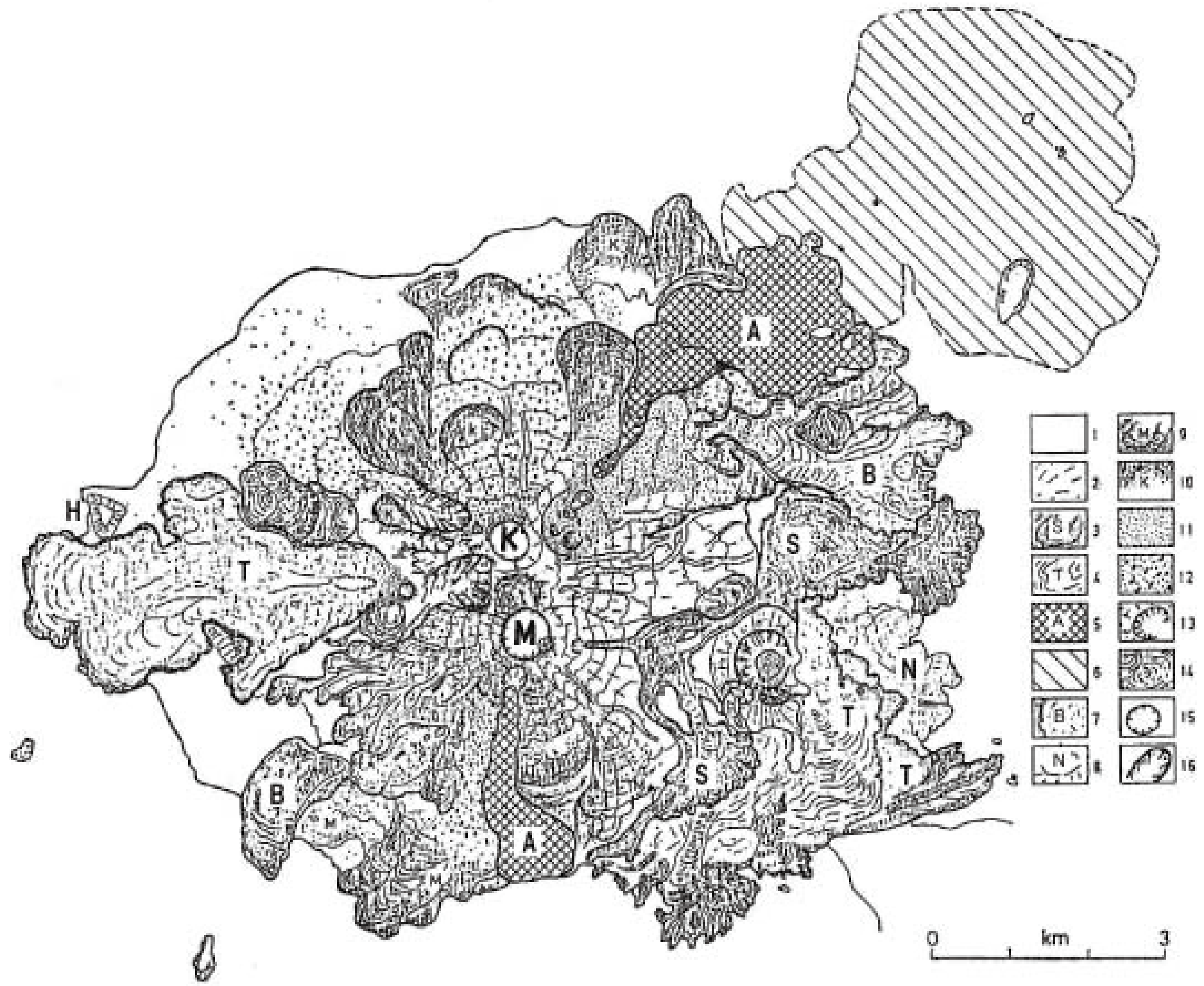


Fig. 17 Geomorphological map of Sakurajima volcano (Aramaki and Kobayashi, 1986). 1: volcanic fan, 2: recent ejecta; 3: Showa lava (S: 1946), 4: Taisho lava (T: 1914–1915), 5: An-ei lava (A: 1779), 6: submarine cryptodome formed by the intrusion of magma (1779–1781), 7: Bunmei lava (B: 1471–1476), 8: Nagasakibana lava (N: AD 764), 9: Minamidake lava, 10: Kitadake lava, 11: agglutinate, 12: pyroclastic flow deposit, 13: tuff cone, 14: lava dome, 15: crater, 16: cliff, K: Kitadake, M: Minamidake, H: Hakamagoshi

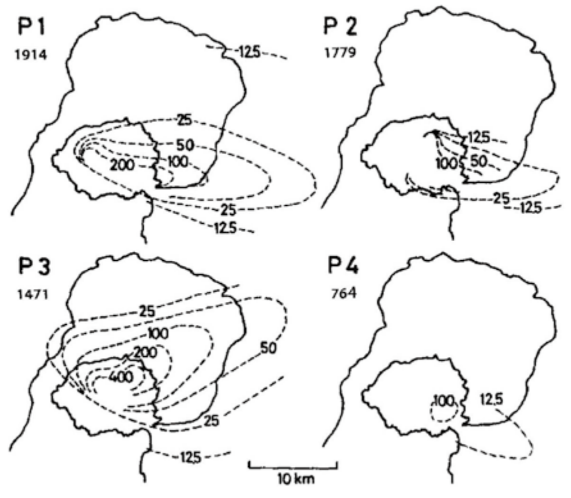


Fig. 18 Isopach maps of pumice fall deposits in historical time, with thicknesses in cm (Kobayashi and Tameike, 2002).

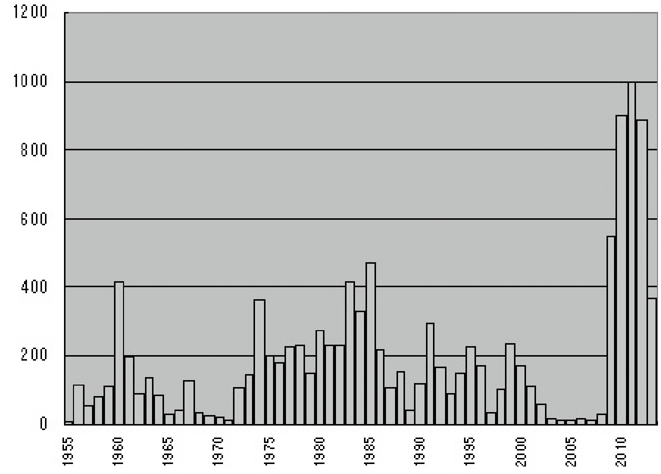


Fig. 19 Annual number of explosions from Minamidake since 1955 (data from Kagoshima Local Meteorological Observatory).

an ash-laden cloud poured out continuously with no explosive eruption for a few days, especially during active periods. Figure 19 shows the annual number of explosion of Minamidake crater since 1955. The most active period of the summit crater in the 20th century was in 1985, when 474 explosions occurred. Volcanic activity declined after 2002, but in 2006 the Showa crater resumed activity for the first time in 70 years. It became very active after 2009. The numbers of explosions in 2009, 2010, 2011, and 2012 were 548, 896, 996, and 885, respectively. In 2013, 365 explosions had occurred by the end of June. A new volcanic edifice, the Heisei pyroclastic cone, has been formed on the eastern slope of the Minamidake.

The rocks of the Sakurajima volcano are composed of olivine-bearing and/or olivine-free pyroxene andesite and pyroxene dacite, and show relatively narrow compositional variation ranging from 67 to 62 Wt% SiO_2. However, the SiO_2 content of lavas and pyroclastic rocks erupted from lateral vents has regularly decreased from 67 to 57 Wt% in the last 500 years. In 1946, the SiO_2 content suddenly increased to about 62 Wt %. It has remained almost constant with some minor fluctuation, since that time.

Kakuto and Kobayashi calderas

Two basins lie to the north of Kirishima volcano: the Kakuto basin to the west and the Kobayashi basin to the east (Fig. 2). They are interpreted to be of caldera origin on the basis of the distribution of the two great ignimbrites, *i.e.*, the Kakuto and Kobayashi ignimbrites, and the negative Bouguer anomalies. The western, northern, and eastern margins of Kakuto caldera are clear, but southern part is obscured by the overlapping younger Kirishima volcano. The Kobayashi caldera is older than the Kakuto caldera, and its rim is not as well preserved. The Kakuto ignimbrite is rhyolitic in composition, with pyroxene and hornblende. The Kobayashi ignimbrite was formed by the activity of felsic magma and is characterized by biotite phenocrysts. Co-ignimbrite ash falls of the Kakuto and Kobayashi ignimbrites have been identified in central Honshu, Japan. The stratigraphic positions of these ash falls suggest that the Kakuto and Kobayashi eruptions occurred 330–340 ka and 520–530 ka respectively (Machida and Arai, 2003). The Kakuto caldera was filled with lake water until about 29 cal kBP, and the lacustrine deposits are distributed in the basin (Aramaki, 1968).

Kirishima volcano

Kirishima volcano is a generic designation for a cluster of Quaternary volcanoes situated at the boundary of Kagoshima and Miyazaki prefectures in southern Kyushu (Fig. 2). More than 20 volcanoes and craters are concentrated in an oval-shaped area 30 × 20-km area. Kirishima is one of the active volcanoes in Japan (*e.g.*, Nagaoka and Okuno, 2011), and many records of eruptions exist in historical time.

The Kirishima volcano consists of new and old volcanic bodies; new bodies are exposed on the surface, and old bodies are slightly exposed at the base (Fig. 20). In this guidebook, the former bodies are termed the younger Kirishima volcano, and the latter are termed the older Kirishima volcano. The radiometric ages of the former are 300 ka, and those of the latter are 1.2 Ma to several hundred thousand years (Imura and Kobayashi, 2001). The Kakuto ignimbrite dates to about 340 ka, separating the younger and older Kirishima volcanoes.

The older Kirishima volcano products are now exposed only at the western foot of Kirishima. However, these volcanics predominantly underlie the present Kirishima volcano (Fig. 20). The activity of the younger Kirishima volcano began at about 300 ka. Small stratovolcanoes with poorly preserved volcanic topography, such as Kurinodake and Shishikodake, were formed in the early stage of the younger Kirishima volcano. After a few tens of thousands of years of relative dormancy, volcanic activity resumed about 100 ka and has continued until the present. This activity formed many small stratovolcanoes, pyroclastic cones, maars, and lava flows.

During the past 29,000 years, the activity of the Kirishima volcano occurred in a NW–SE-tending zone (*e.g.* Imura, 1992). In the last 10,000 years, most major eruptions have occurred in the southeastern part of the Kirishima. The Takachihonomine volcano (1574 m), which is famous for its relation to a myth, has a triangular summit. It began erupting *ca.* 8 cal kBP. The sharp peak is an exogenous lava dome that filled the summit crater. The Ohachi volcano is a small stratovolcano with a large summit crater that

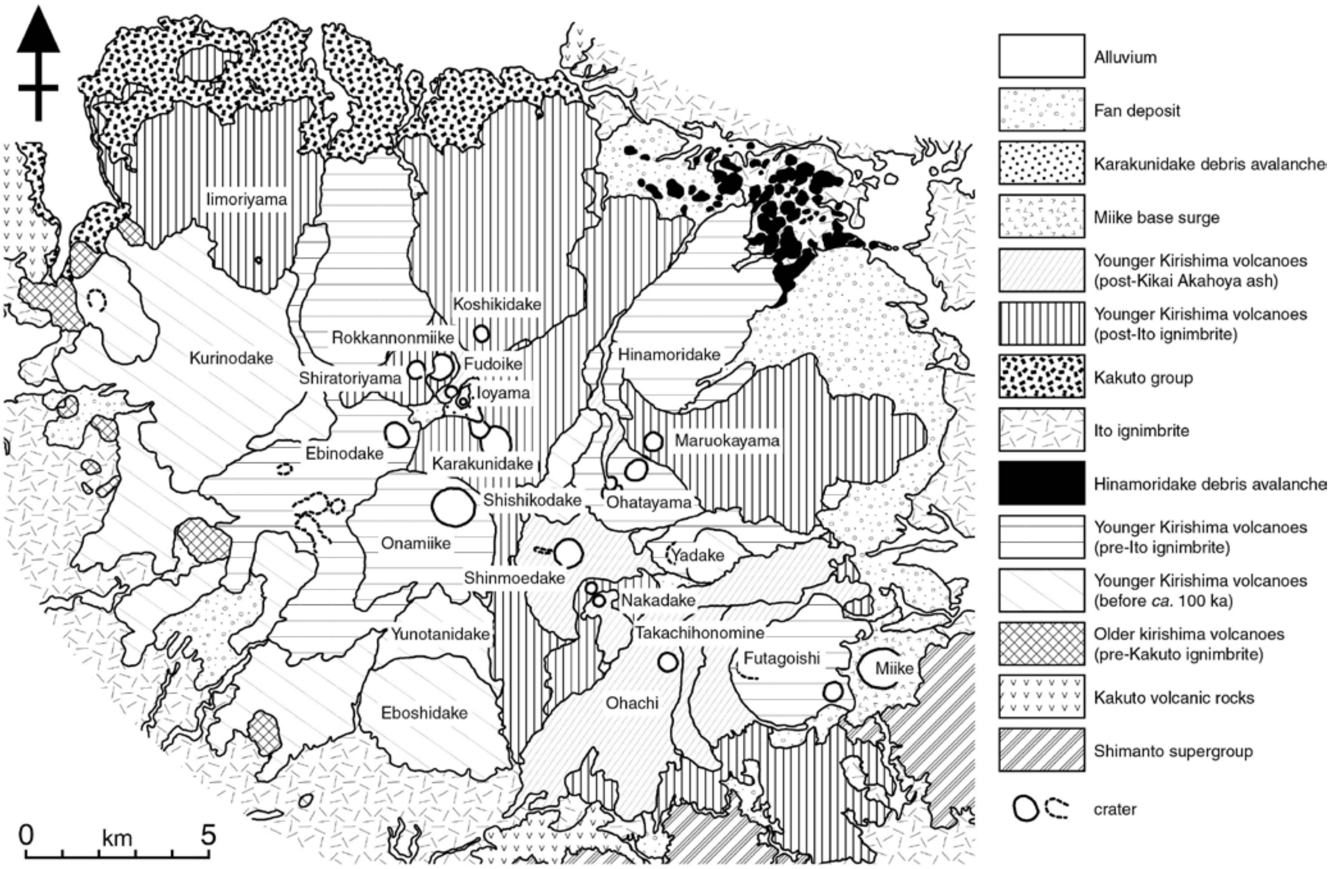


Fig. 20 Geological map of the Kirishima volcano (simplified from Imura and Kobayashi, 2001).

Fig. 21 First subplinian eruption of the Shinmoedake on the evening of 26 January, 2011 (photo by R. Imura).

Fig. 22 Lava filled the summit crater of Shinmoedake (photo by R. Imura).

was generated on the western slope of Takachihonomine. Ohachi has been the most active volcano in historical time. Another active volcano Shinmoedake (1421 m) has a large summit crater and fissure vents on its western slope. Shinmoedake resumed activity in 1716 after a long dormant period. Its most recent eruptive activity occurred in 2011.

The rocks of the older Kirishima volcano are predominantly augite-hypersthene andesites, with little or no olivine phenocrysts. The rocks of the younger Kirishima volcano, on the other hand, range from olivine basalt or pyroxene andesite with or without olivine, to hornblende-bearing pyroxene dacite (Sawamura and Matsui, 1957; Kobayashi *et al*., 1981).

More than 10 highly reliable records of eruptions since AD 742 are known to exist. The records contain information about the numbers of casualties, burnt temples, shrines, and houses, and damage to agricultural produce and livestock. Most recorded eruptions are related to Ohachi and Shinmoedake, but a small lava flow, Ioyama formed at the northwestern foot of Karakunidake in 1768. Eruptions in AD 788 and 1235 at Ohachi (Tsutsui *et al*., 2007) and in AD 1716–17 at Shinmoedake (Imura and Kobayashi, 1991) were large enough to cause complete changes in the outlines of both volcanoes. The 1235 eruption of Ohachi was the largest in historical time for the Kirishima volcano.

Eruptive activity of the Shinmoedake volcano in 2011

On the morning of January 26, 2011, an eruption occurred at the Shinmoedake volcano (*e.g.*, Nakada *et al.*, 2013; Miyabuchi *et al.*, 2013). The eruption became subplinian beginning around 16:00 (Fig. 21), with accompanying continuous air shocks. Although the eruption subsided after 18:00, violent pumice eruptions occurred from around 02:00 until dawn on the following day. Pumice eruptions occurred again in the evening of January 27. On January 26 and 27, a volume of pumice and volcanic ash fell on Miyakonojyo city and other leeward areas. Car windows were broken by volcanic ejecta at around 7–8 km distance from the crater.

On the morning of January 28, a lava dome with a diameter of tens of meters was observed in the crater (Nakada and Joint Observation Team of Kirishima Volcano, 2011). On the morning of January 31, the spreading of lava over the crater was confirmed (Fig. 22). An explosive eruption occurred on the morning of February 1, and volcanic bombs dropped in the area within 3.2 km from the crater. Furthermore, a shock wave broke windows in buildings in Kirishima city, Kagoshima prefecture, and injured a person.

During February 1–8, vulcanian eruptions repeated every few hours or days, and a volcanic ash plume was observed continuously, then gradually became intermittent. Very strong explosions occurred on February 14 and April 18. Many lapilli were ejected leeward within a broader area, causing damage such as breakage of window glass. Since then, no eruption sufficient to cause major damage has occurred.

DESCRIPTION OF FIELD STOPS

M1: Ibusuki Course

The Ibusuki volcanic area (Photo 1) occupies the western half of Ata caldera, as proposed by Matumoto (1943). This course provides special views of Lake Ikeda, Kaimondake, and other post-caldera volcanoes within the caldera. At Usuyama, which is located on the northern foot of Kiyomidake volcano, we can observe thick tephra layers in a roadside outcrop. We will also visit the COCCO Hashimure Archaeological Museum which is exhibiting archaeological materials with special reference to the Kaimondake volcano disaster.

ACRIFIS-EHAI provides a photo sharing site (http://ehai-app.rd.fukuoka-u.ac.jp/IAVCEI2013/) for IAVCEI 2013. Geological map by GSJ is also available on this site.

Stop I-1: Senganbira Lookout

On the way to Ibusuki, we have a panoramic view of the Sakurajima volcano and Kagoshima City from Senganbira Lookout, along the Ibusuki Skyline mountain road (http://www.kagoshimaken-dourokousha.or.jp/). Along the trail to the viewpoint from the parking lot, we can observe the Kikai Akahoya and Ikedako tephras in small outcrops. The Akahoya tephra consists of ignimbrite and overlying co-ignimbrite ash-falls. Small charcoal fragments and accretionary lapilli can be found in this tephra.

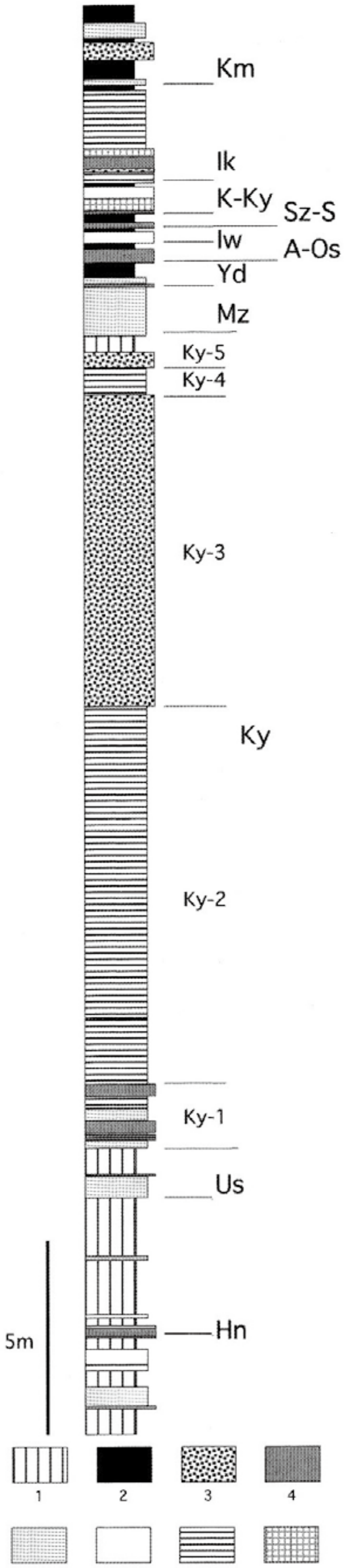


Fig. 24 Photograph of the view from the Fushime coast (Stop I-4)(photo by M. Okuno).

Fig. 25 Photograph of the volcanic neck Takeyama (background) and the Yamakawa geothermal power plant (foreground) viewed from northwest near Stop I-4 (photo by M. Okuno).

Fig. 23. Columnar section of tephra layers at Usuyama (Stop I-3)(modified from Kawanabe and Sakaguchi, 2005). Hn: Hananoki tephra, Us: Usuyama tephra, Ky: Kiyomidake tephra, Mz: Mizusako tephra, Yd: Yadoribai tephra, A-Os: Osumi pumice fall, Iw: Iwamoto tephra, Sz-S: Sakurajima-Satsuma (P14) tephra, K-Ky: Kikai Koya tephra (=K-Ah), Ik: Ikedako tephra, Km: Kaimondake tephra. 1: Loam, 2: Humic soil, 3: Scoria, 4: Pumice, 5: Sandy ash and lapilli, 6: fine ash, 7: stratified ash (including accretionary lapilli), 8: ignimbrite.

Stop I-2: View from the Ikedako lakeside

We can see the topographies of Nabeshimadake (Fig. 12) and Kaimondake (Fig. 13) volcanoes from the lookout on the Ikedako lakeside (Photo 2). We can use the rest room and shop at Stop I-2A the Ikedako Paradise Lakeside Station (http://www3.synapse.ne.jp/ikepara/).

Stop I-3: Roadside outcrop at Usuyama

An agricultural roadcut provides an impressive tephra section on the northern slope of Kiyomidake volcano (Photo 3). Lava and overlying Kiyomidake – Ikedako tephras can be observed (Fig. 23). We can determine the detailed depositional structure (*e.g.*, slumping) of the thick Kiyomidake tephra, the largest tephra that formed during post-caldera volcanism.

Stop I-4: Fushime geothermal field

Here, we can enjoy wonderful views of the cliffs of Ikeda ignimbrite, the sandsteam bath "Suna-mushi" (http://www.seika-spc.co.jp/sayuri/), the Yamakawa geothermal power station (http://www.kyuden.co.jp/effort_geothermal_t_yamagawa.html) and Takeyama (Figs. 24 and 25). Takeyama is a pyroxene dacite volcanic neck with a fission track age of 60±30 ka (Kawanabe and Sakaguchi, 2005).

Stop I-5: COCCO Hashimure Archaeological Museum

This museum (http://www.minc.ne.jp/cocco/) exhibits archaeological information including that related to the Kaimondake volcanic disaster. It provides foreign-language (English, Chinese and Korean languages) explanation on paper and on iPad devices. You can also obtain this information on your own device by downloading the application.

M2 and M3: Aira Courses

M2 proceeds clockwise around the Aira caldera, and **M3** proceeds counterclockwise. We list here the representative stops of **M2**, which first ascends to the Kirishima area. After lunch, we will descend south along the eastern side of the Aira caldera, and finally enter the Sakurajima area. **M3** goes first to Sakurajima, and then proceeds counterclockwise around the Aira caldera. We must travel in many buses simultaneously, so all buses may not visit all stops.

Stop A-1: Kirishima Shrine "Kirishima Jingu"

Kirishima Jingu (http://www.kirishimajingu.or.jp/index.html) is a Shinto shrine located at the southern foot of Kirishima volcano (Fig. 26). The Kirishima area plays an important role in Japanese mythology. Here, the god Ninigi-no-Mikoto, grandson of the sun goddess Amaterasu, is said to have descended from heaven to rule over the earth. Devoted to Ninigi-no-Mikoto, Kirishima Shrine was built during the 6th century on a different site from where it stands today. It has been destroyed numerous times by volcanic eruptions, but it has always been rebuilt. The current red-painted main building of the shrine was constructed in 1715, and survives to this day.

Stop A-2: Takachiho Bokujo (Takachiho Farm)

This location provides an excellent overview of the Kirishima volcano (Photo 5). It is like a museum of volcanology because we can observe many types of volcanoes, volcanic products and associated landforms. The ejecta of the 2011 Shinmoedake eruptions covered not only Shinmoedake but also other leeward volcanoes. Takachiho Farm (http://www.takachiho-bokujou.co. jp/) is 35 hectares of green land, where you can try milking a cow and touching animals. The farm also produces original dairy products including bread, ice cream, yogurt, and meat.

Stop A-3: Uenohara Jomon-no-mori Archeological Site

The Uenohara Jomon-no-mori Archaeological Museum (http://www.jomon-no-mori.jp/) on the Aira caldera rim is the remains of a 9500 BP (corresponding to 10.6 cal kBP) settlement. We can learn the history of the Sakurajima eruptions and human occupation for about 10,000 years at this site. We will visit the reconstructed ancient dwelling cluster, the tephra sequence observatory, and the relic preservation dome, where pit dwellings (Fig. 27), stone formations, earthen pit ovens, and other parts of the village dating to 10.6 cal kBP have been excavated and can be observed in their original state. If the weather is good, we will have a wonderful view

Fig. 26 Kirishima Jingu (photo by R. Imura).

Fig. 27 Reproduction of the settlement at Uenohara Jomon-no-mori (photo by R. Imura).

Fig. 28 Minamidake viewed from Arimura lookout (photo by T. Kobayashi). The Showa crater is behind the right shoulder of Minamidake. A growing slope of the Heisei pyroclastic cone can also be seen.

of the Kirishima volcano to the north, and Sakurajima volcano and Aira caldera to the south (Photo 6).

Stop A-4: Traditional Vinegar Factory

A traditional vinegar factory is located on the gentle slope of the eastern caldera wall (http://kurozurestaurant. com/). The moderate climate and large quantities of clear water render this area suitable for the brewing of Kurozu, high-quality vinegar, Kurozu is a trademark meaning black vinegar, although the product is not black, but a dense brownish yellow, just like amber. Kurozu is brewed for about 2–3 years in a large pot designed especially for this purpose. We can see how the vinegar is made and taste it. If you wish, you can also buy some as a gift. Kurozu vinegar contains large quantities of amino acids, so it is believed to be very good for health.

Stop A-5: Tarumizu Michi-no-eki Roadside Station

The Tarumizu Michi-no-Eki Station (http://eki-tarumizu. com/index.php) is located on the east coast of Kagoshima Bay. We can see the east side of Sakurajima volcano with Showa crater (Photo 4), and also see the An-ei islets, which were generated offshore to the northeast of Sakurajima during the An-ei eruption (1779–1782). This station boasts a hot foot bath for travelers to rest their feet while enjoying the view of the Sakurajima and Kirishima volcanoes and the Kagoshima Bay. We can see many rafts floating on the sea, where yellowtails are cultivated.

Between **Stops A-5 and A-6**, we pass the junction between Sakurajima and Osumi peninsula. This area was once a 400-m-wide strait, but it was buried by lava flows from the eastern fissure vents during the Taisho eruption (1914–1915).

Stop A-6: Arimura Lookout: Historical Lava Flows

This stop is located on the Taisho lava flow, which erupted in 1914. We can see Minamidake, where the Showa lava flow erupted from a parasitic vent in 1946, directly in front of us. You may be able to see eruption plumes from the Showa crater (Fig. 28). Extensive ramp structures are present in the block lava around the lookout site. A concrete facility at the parking lot is a shelter against projectiles. On clear days, the Kaimondake volcano can be seen to the south.

Stop A-7: Sakurajima International Volcanic Sabo Center

The establishment of an international comprehensive information/ research/ training center was first proposed at the Kagoshima International Volcanoes Conference in 1988. The resulting Sakurajima International Volcanic Sabo Center (http: //www.qsr.mlit.go.jp/osumi/kyoutsuu/sabocente) opened in 1999. The sabo facilities and lahars in Sakurajima are displayed on the exhibition floor. There, we can experience the horror of lahar and learn what to do in the case of a disaster.

Stop A-8: Sakurajima Visitor Center

Sakurajima Visitor Center (http://www.sakurajima. gr.jp/svc/english/) located next to the Sakurajima ferry terminal, is a small museum where you can learn about Sakurajima. Travelers visiting Sakurajima see this first. The center simply exhibits and explains history and nature to allow a deep understanding of Sakurajima. In the nine-part pavilion, the history of Sakurajima and the transitions of plants, sightseeing information and disaster- prevention activities are available. You can experience the active volcano Sakurajima through the hi-vision theater, the diorama and our computer programs. A corner shop offers goods that you can buy only there.

REFERENCES

Aramaki, S. (1968) Geology of the Kakuto Basin, southern Kyushu, and the earthquake swarm from February, 1968. *Bull. Earthq. Res. Inst. Univ. Tokyo*, **46**, 1325–1343. **

Aramaki, S. (1984) Formation of the Aira caldera, southern Kyushu, -22,000 years ago. *J. Geophys. Res.*, **89**, 8485–8501.

Aramaki, S. and Ui, T. (1966a) Aira and Ata pyroclastic flows and related caldera depressions in southern Kyushu, Japan. *Bull. Volcanol.*, **29**, 29–48.

Aramaki, S. and Ui, T. (1966b) Ata pyroclastic flows and Ata caldera in southern Kyushu, Japan. *J. Geol. Soc. Japan*, **72**, 337–349. **

Aramaki, S. and Ui, T. (1976) Pyroclastic deposits in southern Kyushu : A correlation by the Ca-Mg-Fe ratios of the phenocrystic minerals. *Bull. Earthq. Res. Inst. Univ. Tokyo*, **51**, 151–182. **

Fujino, N. and Kobayashi, T. (1997) Eruptive history of Kaimondake volcano, southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **42**, 195–211. **

Fukusawa, H. (1995) Non-glacial varved lake sediment as a natural timekeeper and detector on environmental change. *The Quat. Res. (Daiyonki-Kenkyu)*, **34**, 135–149. **

Hayasaka, S. (1987) Geologic structure of Kagoshima Bay, South Kyushu, Japan. *In*: Matsumoto, Y. , Hase, Y., Takeshita, H., Hayasaka, S. and Furukawa, H. (ed.) *Various Topics of the Late Cenozoic Volcanism in Kyushu, Japan*, Monograph **33**, The Association for the Geological Collaboration in Japan, 225–233.**

Iguchi, M. *et al.* (eds.) (2013) Sakurajima special Issue. *Bull. Volcanol. Soc. Japan*, **58**, 1-306.

Imura, R. (1992) Eruptive history of the Kirishima volcano during the past 22,000 years. *Geogr. Rep. Tokyo Metropolitan Univ.*, **27**, 71–89.

Imura, R. and Kobayashi, T. (1991) Eruptions of Shinmoedake volcano, Kirishima Volcano Group, in the last 300 years. *Bull.Volcanol.Soc.Japan,* **36**, 135–148. **

Imura, R. and Kobayashi, T. (2001) Geological map of Kirishima Volcano (1:50,000). Geological Map of Volcanoes **11**, Geological Survey of Japan.**

Ishibashi, J., Nakaseama, M., Seguchi, M., Yamashita, T., Doi, S., Sakamoto, T., Shimada, K., Shimada, N., Noguchi, T., Oomori, T., Kusakabe, M., Yamanaka, T. (2008) Marine shallow-water hydrothermal activity and mineralization at the Wakamiko crater in Kagoshima bay, south Kyushu, Japan. *J. Volcanol. Geotherm. Res.*, **173**, 84–98.

Ishihara, K., Takayama, T., Tanaka, Y. and Hirabayashi, J. (1981) Lava flows at Sakurajima volcano (I) - Volume of the historic lava flows -. *Ann. Disast. Prevent. Res. Inst. Kyoto Univ.*, **24B-1**, 1–10. **

Kaneoka, I., Aramaki, S., Kobayashi, T. and Oki, K. (1984) Pliocene and Pleistocene volcanism in southern Kyushu : K-Ar ages of Fumoto and Isaku pyroclastic flows and related rocks. *Bull. Volcanol. Soc. Japan*, **29**, 59–62.

Kawanabe, Y. and Saito, G. (2002) Volcanic activity of the Satsuma-Iwojima area during the past 6500 years. *Earth Planets Space*, **54**, 295–301.

Kawanabe, Y. and Sakaguchi, K. (2005) Geology of the Kaimon Dake district. Quadrangle Series, 1:50,000, Geological Survey of Japan, AIST, 82pp.**

Kimura, M. (1985) Back-arc rifting in the Okinawa Trough. *Marine and Petroleum Geol.*, 2, 222–240.

Kitagawa, H., Fukusawa, H., Nakamura, T., Okamura, M., Takemura, K., Hayashida, A. and Yasuda, Y. (1995) AMS ^{14}C dating of varved dediments from Lake Suigetsu, central Japan and atmospheric ^{14}C change during the late Pleistocene. *Radiocarbon*, **37**, 371–378.

Kobayashi, T. (1982) Geology of Sakurajima volcano: A review. *Bull. Volcanol. Soc. Japan*, **27**, 277–292.**

Kobayashi, T. (2009) Origin of new islets (An-ei islets) formed during the An-ei eruption (1779-1782) of Sakurajima volcano, southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **54**, 1–13.**

Kobayashi, T. (2010) Formation age of Nakadake of Sakurajima volcano: was it formed in historical time? *Programme and abstracts of 2010 Fall meeting, Volcanol. Soc. Japan*, 33.*

Kobayashi, T. and Naruo, H. (1986) Phreatomagmatic deposits erupted from Ibusuki volcanic center, Japan. *Intern. Volcanol. Cong. New Zealand, Abstract*, 108.

Kobayashi, T. and Tameike, T. (2002) History of eruptions and volcanic damage from Sakurajima volcano, southern Kyushu, Japan. *The Quat. Res. (Daiyonki-Kenkyu)*, **41**, 269–278.**

Kobayashi, T., Aramaki, S., Watanabe, T. and Kamada, M, (1981) Part II Kirishima Volcano. *Field Excursion Guide to Sakurajima, Kirishima and Aso volcanoes, Symposium on Arc Volcanism, Tokyo and Hakone, Japan*, Volcanol. Soc. Japan and IAVCEI, 19–32.

Kobayashi, T., Hayakawa, Y. and Aramaki, S. (1983) Thickness and grain-size distribution of Osumi pumice fall deposit from the Aira caldera. *Bull. Volcanol. Soc. Japan*, **28**, 129–139.

Kobayashi, T., Ishihara, K., Hirabayashi, J. and Osumi Work Office of Ministry of Construction (1988) A guide book for Sakurajima Volcano. Kagoshima Prefectural Government, 73pp, Kagoshima International Conference on Volcanoes (ed).

Kobayashi, T., Okuno, M., Nakamura, T., and Fukushima, D. (2009) Newly discovered historic lava flow from Minamidake, Sakurajima volcano. *Programme and abstracts of 2009 Fall meeting, Volcanol. Soc. Japan*, 164.*

Machida, H. (1999) The stratigraphy, chronology and distribution of distal marker-tephras in and around Japan. *Global Planetary Change*, **21**, 71–94.

Machida, H. and Arai, F. (1976) A widespread volcanic ash: Discovery of Aira-Tn ash and its significance. *Science J. (Kagaku)*, **46**, 339–347.*

Machida, H. and Arai, F. (1978) Akahoya ash**:** a Holocene widespread tephra erupted from the Kikai caldera, south Kyushu, Japan. *The Quat. Res. (Daiyonki-Kenkyu)*, **17**, 143–163.**

Machida, H. and Arai, F. (1983) Extensive ash fall in and around the Sea of Japan from large late Quaternary eruptions. *J. Volcanol. Geotherm. Res.*, **18**, 151–164.

Machida, H. and Arai, F. (2003) Atlas of Tephra in and around Japan (Revised Edition). University of Tokyo Press, Tokyo, 336pp.*

Maeno, F. and Taniguchi, H. (2006) Silicic lava dome growth in the 1934-1935 Showa Iwo-jima eruption, Kikai caldera, south of Kyushu, Japan. *Bull. Volcanol.*, **68**, 673–688.

Maeno, F., Imamura, F. and Taniguchi, H. (2006) Numerical simulation of tsunami generated by caldera collapse during the 7.3 ka Kikai eruption, Japan. *Earth Planets Space*, **58**, 1013–1024.

Matsumoto, A. and Ui, T. (1997) K-Ar age of Ata pyroclastic flow deposit, southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **42**, 223–225. *

Matumoto, T. (1943) The four gigantic caldera volcanoes of Kyushu. *Japanese J. Geol. Geogr.*, **19**, special number, 1–57.

Miyabuchi, Y. Hanada, D., Niimi, H. Kobayashi, T. (2013) Stratigraphy, grain-size and component characteristics of the 2011 Shinmoedake eruption deposits, Kirishima volcano, Japan. *J. Volcanol. Geotherm. Res.*, **258**, 31–46.

Miki, D. (1999) Estimate of the age of lava flows at Sakurajima volcano, Kyushu, Japan; Inferred from paleomagnetic directions and paleointensities. *Bull. Volcanol. Soc. Japan*, **44**, 111–122.**

Nagaoka, S. (1988) Late Quaternary tephra layers from the caldera volcanoes in and around Kagoshima Bay, southern Kyushu, Japan. *Geogr. Rep. Tokyo Metropolitan Univ.*, **23**, 49–122.

Nagaoka, S. and Okuno, M. (2011) Tephro-chronology and eruptive history of Kirishima volcano in southern Japan. *Quat. Intern.*, **246**, 260–269.

Nagaoka, S., Kokuta, S., Okubo, S., Fukae, K. and Yatsuda, H. (1991) Explosive volcanism during late Quaternary and submarine topography of Kagoshima Bay. *The Earth Monthly (Gekkan Chikyu)*, **13**, 209-217. *

Nakada, S. and Joint Observation Team of Kirishima Volcano (2011) Outline and eruption scenario of the 2011 eruption of Kirishima Volcano. *Japan Geoscience Union Meeting 2011 Abstracts*, SVC050-01.

Nakada, S., Nagai, M., Kaneko, T., Suzuki, Y., Maeno, F. (2013) The outline of the 2011 eruption at Shinmoe-dake (Kirishima), Japan. *Earth Planets Space*, **65**, 475–488.

Naruo, H. and Kobayashi, T. (1995) Clastic dykes formed during the eruption. *Rep. Fac. Sci. Kagoshima Univ. (Earth Sci. and Biol.)*, **28**, 111–122.**

Naruo, H. and Kobayashi, T. (2002) Two large-scale earthquakes triggered by a 6.5 ka BP eruption from Kikai caldera, southern Kyushu, Japan. *The Quatern. Res. (Daiyonki-Kenkyu)*, **41**, 287–299.**

Okada, H., Yasuda, Y., Yagi, M. and Kai, K. (2000) Geology and fluid chemistry of the Fushine geothermal field, Kyushu, Japan. *Geothermics*, **29**, 279–311.

Okuno, M. (2002) Chronology of tephra layers in southern Kyushu, SW Japan, for the last 30,000 years. *The Quatern. Res. (Daiyonki-Kenkyu)*, **41**, 225–236.**

Okuno, M. and Kobayashi, T. (1991) Geology of Nabeshima-dake volcano, southern Kyushu, Japan. *Rep. Fac. Sci. Kagoshima Univ. (Earth Sci. and Biol.)*, **24**, 11–23.**

Okuno, M., Nakamura, T. and Kobayashi, T. (1998) AMS ^{14}C dating of historic eruptions of the Kirishima, Sakurajima and Kaimondake volcanoes, southern Kyushu, Japan. *Radiocarbon*, **40**, 825–832.

Okuno, M., Naruo, H., Arai, F. and Kobayashi, T. (1995) Late Pleistocene tephra layers distributed on southern part of Osumi Peninsula, southwest Japan. *Rep. Fac. Sci. Kagoshima Univ. (Earth Sci. and Biol.)*, **28**, 101–110.**

Okuno, M., Torii, M., Naruo, H., Saito-Kokubu, Y. and Kobayashi, T. (2012) AMS radiocarbon dates and major element composition of glass shards of late Pleistocene tephras on Tanegashima Island, southern Japan. *Radiocarbon*, **54**, 351–358.

Okuno, M., Nakamura, T., Geshi, N., Kimura, K., Saito-Kokubu, Y. and Kobayashi, T. (2013) AMS radiocarbon dating of wood trunks in the pumiceous deposits of the Kikai-Akahoya eruption in Yakushima Island, SW Japan. *Nucl. Instr. Meth. Phys. Res.*, Sec. B, **294**, 602–605.

Ono, K., Soya, T. and Hosono, T. (1982) Geology of the Satsuma-Io-Jima district. Quadrangle Series, 1:50,000, Geological Survey of Japan, 80p.**

Ossaka, J., 1991. Eruption of submarine volcanoes around Japan. Tokai University Press, Tokyo. 280 pp.*

Sawamura, K. and Matsui, K. (1957) Explanatory text of the geological map of Japan, "Kirishimayama", Scale 1:50,000. *Geol. Surv. Japan*.**

Shibata, K., Ono, K., Hayasaka, S., Oki, K and Yamamoto, M. (1978) K-Ar age of the Terukuni pyroclastic flow underlying Kagoshima city, southern Kyushu. *J. Geol. Soc. Japan*, **84**, 551–553.*

Shimomura, H. (1960) The physiographic divisions of the Aira submerged caldera. *The Hiroshima Univ. studies, Literature Dept.*, **18**, 308-331.

Suzuki, K. and Ui, T. (1982) Grain orientation and depositional ramps as flow direction indicators of a large-scale pyroclastic flow deposit in Japan. *Geology*, **10**, 429–432.

Suzuki, K. and Ui, T. (1983) Factors governing the flow lineation of a large-scale pyroclastic flow — An example in the Ata pyroclastic flow deposit, Japan. *Bull. Volcanol.*, **46**, 71–81.

Suzuki-Kamata, K. and Ui, T. (1988) Depositional ramp: asymmetric distribution structure in the Ata pyroclastic flow deposit, Japan. *Bull. Volcanol.*, **50**, 26–34.

Tsutsui, M., Okuno, M. and Kobayashi, T. (2007) Eruptive History of Ohachi Volcano, Kirishima Volcano Group, Southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **52**, 1–21.**

Tsuyuki, T. (1969) Geological study of hot springs in Kyushu, Japan: (5) Some hot springs in the Kagoshima Graben, with special reference to thermal water reservoir. *Rep. Fac. Sci. Kagoshima Univ. (Earth Sci. and Biol.)*, **2**, 85–101.**

Ui, T. (1967) Geology of Ibusuki area, southern Kyushu, Japan. *J. Geol. Soc. Japan*., **73**, 477-490.*

Ui, T. (1973) Exceptionally far-reaching, thin pyroclastic flow in southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **18**, 153–168.**

Watanabe, K. (1985) Ata pyroclastic flow deposit in the Hitoyoshi Basin, Kumamoto Prefecture. *Mem. Fac. Educ. Kumamoto Univ. (Natural Sci.)*, **34**, 55–62.**

Yokoyama, S. (2000) The northern limits of the distribution of the Ito ignimbrite, southern Kyushu, Japan. *Bull. Volcanol. Soc. Japan*, **45**, 209–216.**

(* In Japanese. ** In Japanese with English abstract.)

IAVCEI 2013 Scientific Assembly