

## Chapter 21

# Volcanic Island Chain South of Kyushu, Japan

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## 1. Introduction

The Nansei (Ryukyu) Islands south of Kyushu includes many insular volcanoes, as shown in Fig. 1, forming a volcanic island chain extending approximately 380 km from Satsuma-Iojima Is. (north) to Io-Torishima Is. (south). The northernmost volcano stands at the rim of Kikai caldera, which was the source of the most catastrophic eruption in Japan during the last 10,000 years. Each of the others has specific properties and histories almost unknown because of their geographical isolation. A brief introductory overview is given here, describing the geoscientific character of the small volcanic islands.

Let us examine the tectonic setting of these island volcanoes. They belong to the West Japan Volcanic Zone, together with Kaimondake, Sakurajima and Kirishima volcanoes in southern Kyushu and many others further north, constituting the northwest quadrant of the “Pacific Ring of Fire.”

Southwest Japan and the Ryukyu Arc are situated on the southeast rim of the Eurasian Plate, under which the Philippine Sea Plate is subducting from the eastern side. The boundary between the two plates is characterized by deep-sea trenches, the Nankai Trough in the north along Southwest Japan and the Ryukyu Trench parallel to the Ryukyu Arc. The deep Ryukyu Trench is shown in Fig. 1 as a dark zone on the eastern side of the series of islands. The volcanic island chain is located approximately 200 km from the trench axis. This is attributed to magma formation at the subduction depth of about 100 km below the sea level, as described schematically in Fig. 2, resulting in a line of volcanoes belonging to the West Japan Volcanic Zone, including mainland Kyushu. Most of the non-volcanic islands in the Ryukyu Arc consist of uplifted sediments and the remnants of coral reefs. An exception is Yakushima Is., which comprises uplifted granite cluster pen-

etrating sedimentary layers.

## 2. Satsuma-Iojima and Takeshima Islands

Now let us start our “Volcano tour,” moving north to south. Two small islands, Satsuma-Iojima Is. and Takeshima Is. (shown in Fig. 3) are located 50 km south of the mouth of Kagoshima Bay. About 7,300 years ago, the Kikai-Akahoya eruption occurred here, leaving the submerged Kikai caldera. Pyroclastic flows, composed of hot lava fragments and gases, travelled over the sea to Yakushima Is., Tanegashima Is. and other nearby islands, and covered with lithic fragments such as pumice, lapilli and ash. They further reached the Osumi and Satsuma peninsulas of mainland Kyushu, wiping out the early Jomon culture. Heavy ash-fall covered western Japan and reached northeast Honshu. The eruption was associated with tsunami and co-volcanic earthquake, as confirmed from many clastic dykes penetrating into the Kikai plinian pumice layer (NARUO and KOBAYASHI 2002). Altogether, this was the largest eruption in the last 10,000 years in Japan, and had catastrophic effects on local communities, especially in southern Kyushu and near-by islands (see MACHIDA 2010 for a recent review with calibrated chronology).

Although the main part of Kikai caldera is below sea level (seen as a basin structure of sub-marine topography), some parts of the caldera rims outcrop on Satsuma-Iojima Is. and Takeshima Is. One can observe topographies characteristic of a caldera wall passing through Satsuma-Iojima Is. and constituting the southern cliff of Takeshima Is. as shown in Fig. 3. There are two volcanoes in Satsuma-Iojima Is.: Iodake (704 m) is a steep strato-volcano formed during the last 3,000 years. The other, called Inamuradake (236 m), is a small, post-caldera scoria cone formed 3,000 years ago (KAWANABE and SAITO 2002).

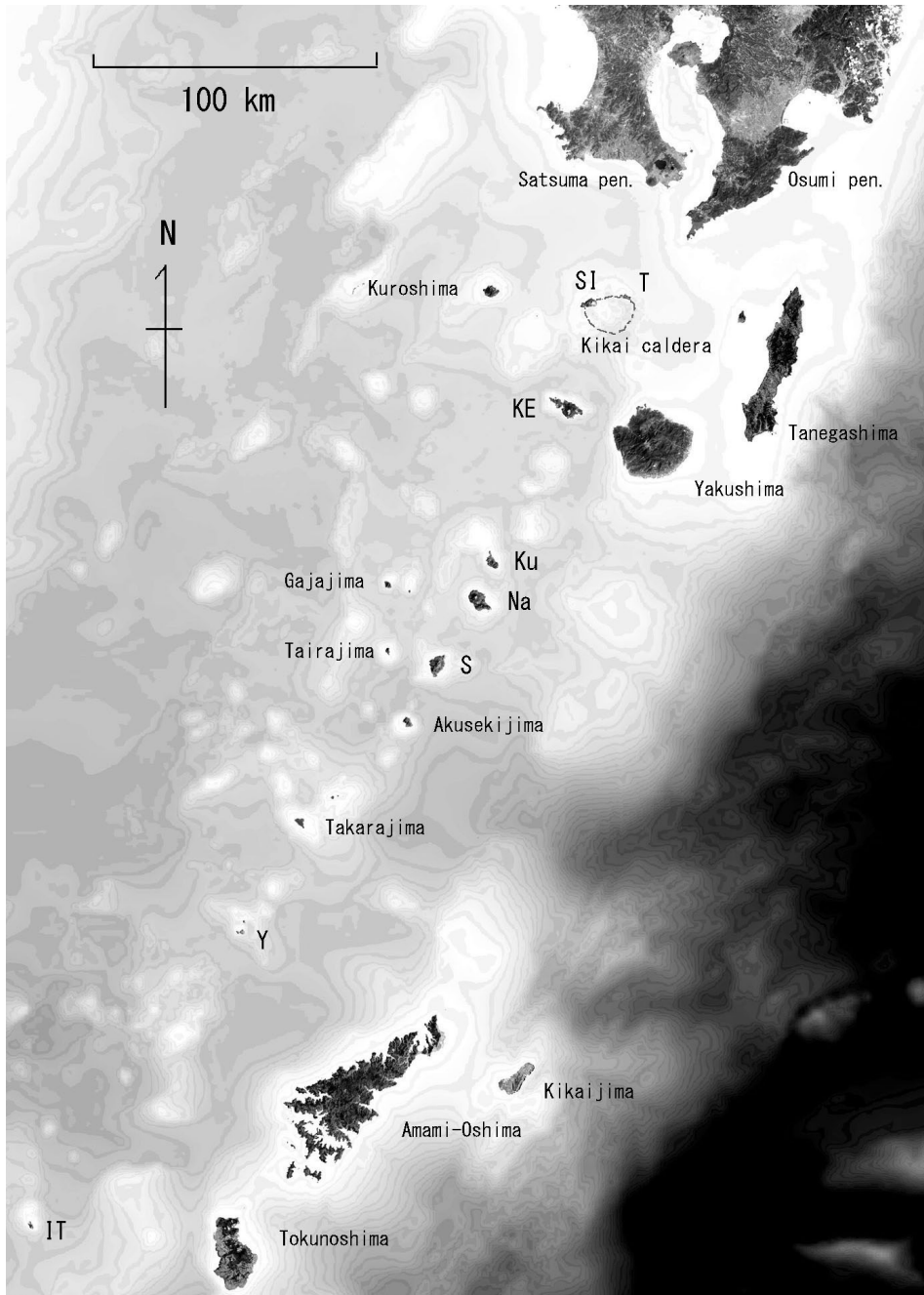


Fig. 1. Volcanic islands and others in Nansei Islands, superimposed on sea-depth chart, where the dark region on the lower-right side is the Ryukyu Trench. Initials indicate the islands with active volcanoes: SI= Satsuma-Iojima Is., T= Takeshima Is., KE= Kuchinoerabujima Is., Ku= Kuchinoshima Is., Na= Nakanoshima Is., S= Suwanosejima Is., Y= Yokoatejima Is. and IT= Io-Torishima Is. Kikai caldera is indicated by a dotted circle.

Iodake has been continuously ejecting volcanic gas and clouds for several hundred years (MATSUI *et al.* 2006). According to legend, the Buddhist monk

Shunkan, who was exiled to the island for his role in a failed coup in the 12<sup>th</sup> century, climbed the mountain to gather sulfuric stones to exchange for fish and

corn. Showa-Iojima in Fig. 3(a) is a lava flow resulting from the 1934-35 eruption.

In this report, we often use near-infrared (NIR) images from the thematic mapper sensor of the Landsat-5 satellite, their 3D views obtained from the Satellite Image Presentation System for Education (SiPSE) as described by KINOSHITA *et al.* (2006), and also NIR photographs (KINOSHITA *et al.* 2003). Although NIR light is invisible to the human eye, NIR grayscale images have the following advantages for studying volcanic phenomena (KINOSHITA *et al.*

1997, SAKAMOTO and KINOSHITA 2010), owing to the different reflectivity of materials within the 760-900 nm spectrum: (i) Water and land areas can be easily distinguished because the water surface absorbs NIR light almost completely, resulting in nearly-black images. (ii) Vegetation coverage is the dominant factor in the brightness of NIR images, because fresh plants tend to strongly reflect wavelengths that are not utilized in photosynthesis. Consequently, forests and fields covered with thick vegetation appear as bright areas, in contrast to dark areas such as bare

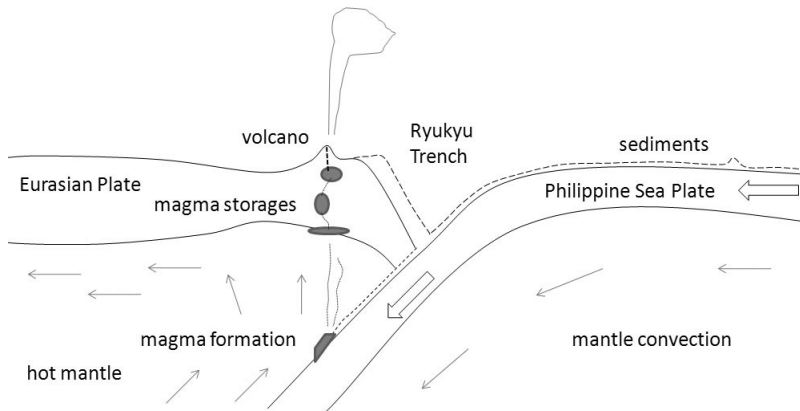


Fig. 2. Subduction of the Philippine Sea Plate under the Eurasian Plate. Volcanic islands belonging to the West Japan Volcanic Zone are formed above the magma formation zone.

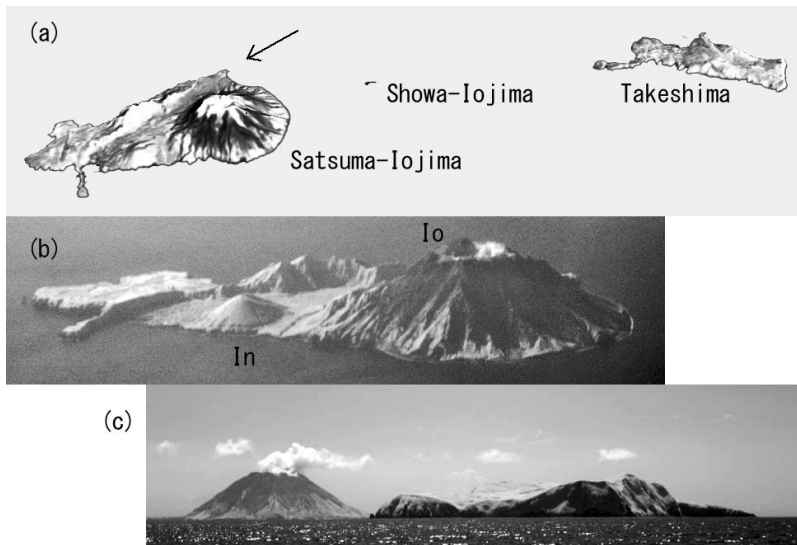


Fig. 3. Satsuma-Iojima Is. and Takeshima Is. (a) NIR 3D view from southern sky. An arrow indicates the wall of Kikai caldera. (b) Aerial NIR photograph of Satsuma-Iojima from south-eastern sky. Two volcanoes, Iodake (Io) and Inamuradake (In), are indicated. (c) Maritime NIR photograph of Satsuma-Iojima Is. and Takeshima Is. from the east.

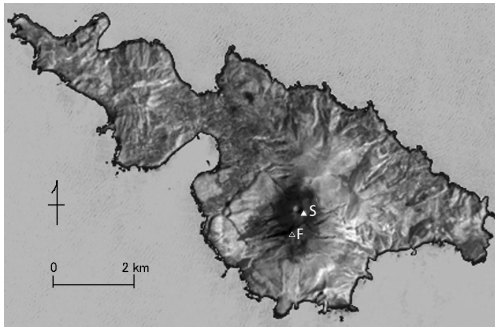


Fig. 4. Kuchinoerabujima Is. in a NIR image, indicating the locations of Furutake (F) and Shintake.

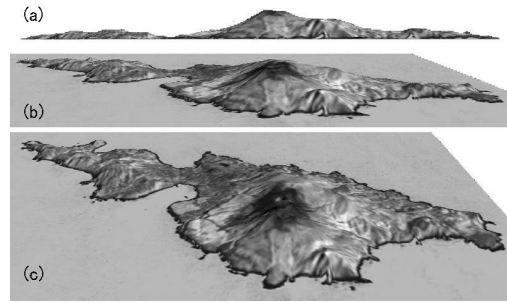


Fig. 5. Kuchinoerabujima Is. in NIR 3D views from the southern horizon (a), and skies (b, c).

fields lacking vegetation. (iii) The land topography can be seen from the strongly contrasting shading in NIR images, compared with visible-light images.

In Fig. 3, the flank of Io-dake appears very dark because sulfuric gas leads to loss of vegetation, whereas the peak area exhibits the brightness of silicate minerals. In many satellite NIR images and their 3D views, such as Fig. 3(a), sea areas, which originally appear very dark, are replaced by light-gray in order to highlight the islands.

### 3. Kuchinoerabujima Is.

Among the chain of volcanic islands in the Ryukyu Arc, the largest is Kuchinoerabujima Is., 15 km west of Yakushima Is. It comprises east and west parts in the shape of a gourd, as shown in Fig. 4, with several sites of rural hot springs worth visiting. At the southern side of the neck of the gourd-shaped island, a secret British base was once placed in order to trade with the Satsuma clan during the final stage of the isolationism of the Edo era.

In the NIR image (Fig. 4) and its 3D views (Fig. 5), one may observe a lack of vegetation around the summits of the active volcanoes Furutake (657 m) and Shintake (625 m) near the center of the eastern region, owing to the latter ejecting sulfuric gas and ash clouds. A long lava cliff bounding a plateau can be seen in Fig. 5 at the western skirt of these volcanoes (KINOSHITA 2011). All historical eruptions in this island since 1833 occurred at Shintake in the form of explosions at the summit crater. The eruption of 1933 was particularly destructive, destroying a village on the east skirt of the volcano and causing

many fatalities. There are many other volcanic edifices erupted within the last 30,000 years in the east part of the island (MORIWAKI *et al.* 2011), while the west part includes older volcanoes which formed until 200,000 years ago (GESHI and KOBAYASHI 2006).

### 4. Kuchinoshima Is.

Kuchinoshima Is. is a small volcanic island located 50 km southwest of Yakushima Is. It has mountainous topography, as shown in Fig. 6, with caldera walls and several lava domes, including the highest peak Maetake (628 m) in the center and the active dome Moetake (425 m) in the south with fumaroles (GESHI and NAKANO 2006). This island was formed over the course of several hundred thousand years, with the most recent indication of eruptive activity within the last 1,000 years. On the basis of volcanic activity during the last 10,000 years, Kuchinoshima Is. is one of 110 volcanoes in Japan that are classified as active by the Japanese Meteorological Agency, including Satsuma-Iojima Is., Kuchinoerabujima Is., Nakanoshima Is., Suwanosejima Is. and Io-Torishima Is. in the Ryukyu Arc.

After the end of the Second World War, the Ryukyu Islands south of 30° N remained under U.S. occupation, and Kuchinoshima Is. formed the northern border of the area that was isolated from Japan. The Tokara Islands were returned to Japanese control in 1952, followed by the Amami Islands in 1953. Okinawa and the remaining islands were returned to Japan in 1972.

In contrast to the NIR images in Figs 3-5, the forest areas in Fig. 6 appear dark in grayscale rep-



representations of the visible spectrum, because the absorption of visible-light is strong. A delicate adjustment of brightness is necessary to reveal mountainous topography in visible-light images.

### 5. Nakanoshima Is.

The stratovolcano Otake (979 m), occupying the northern half of Nakanoshima Is. (as shown in Fig. 7) is the second-highest peak in the Ryukyu Arc after Yakushima Is., and has fresh edifice with lava flows. Mt. Nakanoshima-Otake is known locally as Tokara-Fuji, because of its symmetric conical shape

similar to Mount Fuji. Sulfuric fumes are ejected from the summit crater and a vent at eastern flank of the volcano. The last small mud eruption occurred in 1914, coinciding with the Taisho eruption of Sakurajima volcano that produced lava flows. There are dissected old volcanic mountains to the south, which were formed around 500,000 years ago.

On a flat highland in the center, there is an astronomical observatory with a 60-cm reflecting-type telescope, which was the second-largest in Kyushu when constructed in 1991. The Tokara Islands, including this site, experienced a total solar eclipse on

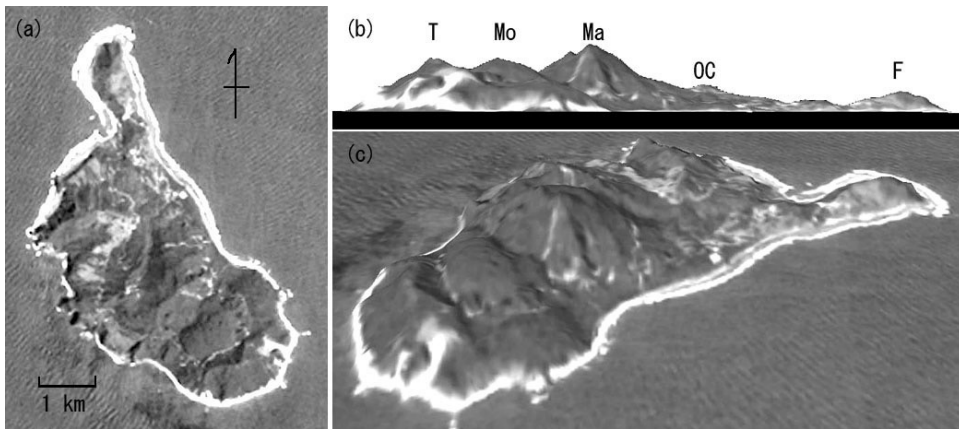


Fig. 6. Kuchinoshima in a visible-light image (a), and 3D views observed from the eastern horizon (b) and sky (c). The locations of the highest peak Maetake (Ma), the active volcano Moetake (Mo, 425 m), Ogochi caldera cliff (OC), old volcanoes Tanagiyama (T) and Furidake (F) are indicated in (b).

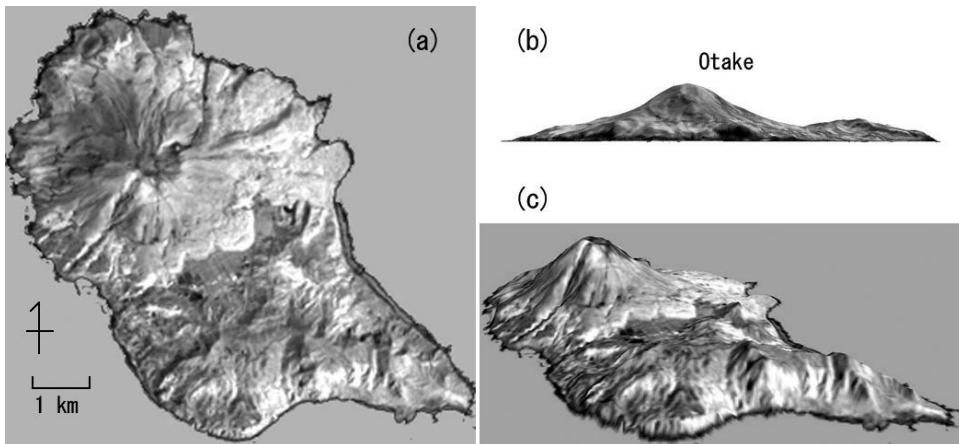


Fig. 7. Nakanoshima Is. in a NIR image (a), and 3D views observed from the western horizon (b) and southern sky (c).

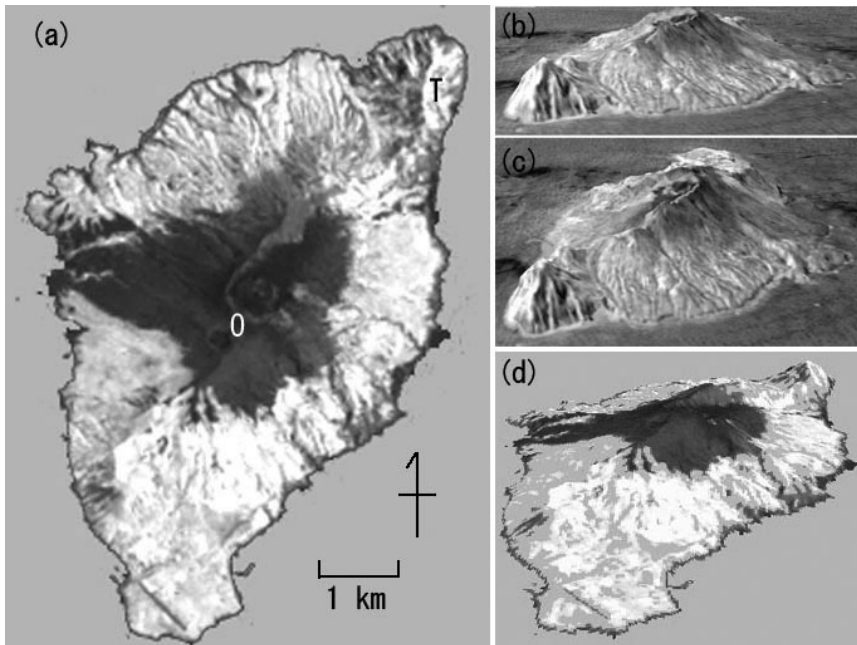


Fig. 8. Suwanosejima Is. in a NIR image (a), and 3D views observed from the northern (b, c) and southern (d) skies. Otake (O) and Tondachidake (T) peaks are indicated in (a).

22 July 2009, but the opportunity for observations was spoiled by bad weather.

## 6. Suwanosejima Is.

In the early years of this century, Suwanosejima volcano was the most eruptive in Japan, with explosive activities from the crater inside Sakuchi caldera on the east side of Otake (799 m), as shown in Fig. 8. The horseshoe-shaped caldera was formed by the sector collapse of the summit crater to the east, forming a large debris avalanche during the last stage of the 1813 eruption, which was the largest in the history of this island. The island subsequently remained uninhabited for the 70 years. The caldera was partially filled with lava flows to the east coast in the 1884 eruption (SHIMANO and KOBAYACHI 2001). In the NIR images shown in Fig. 8, the lack of vegetation is apparent around the summit and a belt zone on western slope, owing to present activities and the lava flow of the 1813 eruption to the west. The caldera structure is clearly visible, especially in Fig. 8 (b, c), where brightness is strongly enhanced.

Historically, sailors often used the small islands of the Ryukyu Arc as navigation markers. Similarly



Fig. 9. Suwanosejima Is. and its volcanic cloud from the crater of Mt. Otake, recorded by a NIR web camera at Nakanoshima Is., 25 km northeast of the volcano (12:00 JST; April 29, 2004).

to Stromboli volcano in the Mediterranean Sea, Suwanosejima-Otake was particularly famous in East China Sea as the “lighthouse,” owing to its continual eruptive activities. In recent years, Suwanosejima and Sakurajima have received much attention from the international aviation safety community, because volcanic ash presents a hazard to aircraft (KINOSHITA *et al.* 2004). The NIR photograph of ash clouds in Fig. 9 was recorded by a web-camera at a school in Nakanoshima Is. 25 km northeast of the volcano (KINOSHITA *et al.* 2008). Fig. 10 is a composite image of visible and NIR bands from the ASTER sensor onboard the Terra satellite.

## 7. Akusekijima Is. and other old volcanic islands

Akusekijima Is. in Fig. 10 is located along the ASSW extension of the volcanic archipelago that we have discussed. Akusekijima Is. was dormant for a few tens-of-thousands of years following the formation of the double calderas and a central cone.

There are other small volcanic islands somewhat west of the active ones shown in Fig. 1, such as Kuroshima Is. (west of Satsuma-Iojima Is.), Gajajima Is. (west of Nakanoshima Is.) and Tairajima Is. (west of Suwanosejima Is.; see Fig. 10). These were formed more than 100,000 years ago, and are classified as the older series (MATSUMOTO 1983), indicating that the volcanic front-line had shifted from west to east over time, as a result of the shift of the subduction line described in Fig. 2. Takarajima Is., 60 km southwest of Akusekijima Is., is a very old member of this series, with coral sediments on the volcanic rocks.

An important historical incident at Takarajima Is. is the contact between islanders and a British whaling ship in 1824. The British sailors requested food and cattle from the inhabitants. Under the poli-

cy of isolationism at that time, their requests were refused. The sailors then staged an armed landing, but were defeated after an intense battle. This incident was taken as a strong warning to the Satsuma clan and TOKUGAWA shogunate prior to the visit of Commodore Perry's fleet to Uruga near Edo in 1853.

Takarajima Is. was rumored to be the "Treasure Island" mentioned in the legend of William Kidd, one of the most notorious pirates in history, who was said to have hidden his treasure in one of the caves there.

## 8. Yokoatejima Is.

The southernmost island of the Tokara chain is the desert island, Yokoatejima (Y in Fig. 1), composed of two small stratovolcanoes, called the east and west peaks, with the connecting saddle barely above sea-level. The 3D images of the east peak (495 m) with the summit crater surrounded by sharp and smooth slopes strongly suggest it to be a young volcano. Historical documents also suggest ash plumes during the late Edo period, but geochronological studies are still to be done. The west peak (259 m) and the nearby Kaminonejima Is. (280 m) 2.4 km north of the east peak have somewhat older edifices that have been subjected to wave erosion.

## 9. Io-Torishima Is.

The southernmost island of the volcanic chain is Io-Torishima Is. (IT in Fig. 1). The southern half of the island is occupied by a caldera with doubled walls, surrounding a lava dome of Gusuku volcano (129 m) (KOBAYASHI and NAKANO 2008). The vertical structure of the island can be seen in visible and NIR photographs (KINOSHITA 2011).

For several hundred years, there was a sulfur mine at the crater on the west side of Iodake (212 m). The mine was often destroyed by phreatomagmatic eruptions at the crater and was finally abandoned in 1967, since when the island has remained deserted. During the Middle Ages, the mine was a very important asset of the Ryukyu Dynasty for the export of sulfur. Sulfur mines were previously important industries on many of the volcanic islands we have discussed, such as Satsuma-Iojima, Kuchinoerabujima, Kuchinoshima and Nakanoshima Islands. However, all of them closed by the 1960s, when large-scale

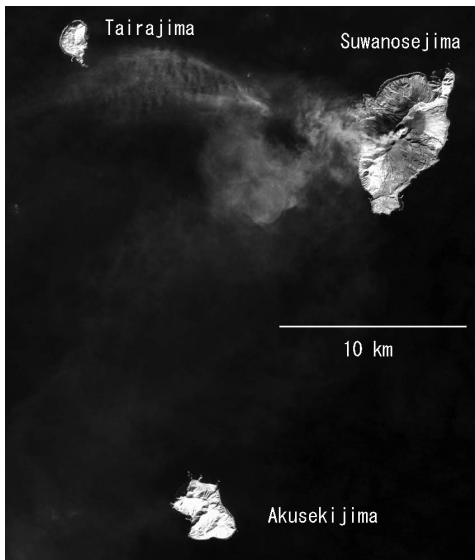


Fig. 10. ASTER VNIR image of Suwanosejima Is. with an eruption cloud (11:04 JST; January 28, 2006), and nearby islands Tairajima and Akusekijima Is.

sulfur production quickly emerged as a by-product of processes to reduce sulfuric air pollution caused by burning coal or oil.

## 10. Remarks

Access to the small volcanic islands we have discussed is limited to ferry routes, as there are no flight routes. Three islands in the north - Takeshima Is., Satsuma-Iojima Is. and Kuroshima Is. - can be reached via the Mishima line from Kagoshima city three times a week, while inhabited Tokara islands south of Yakushima Is. can be accessed by the Toshi-ma ferry twice a week. Kuchinoerabujima Is. can only be accessed from Yakushima Is. Ferry schedules are heavily affected by weather conditions, and are subject to change in the case of strong wind and high waves.

Recent reports of volcanic clouds in southwest Japan and related works may be accessed from the website of the Kagoshima University - Kumamoto University group (<http://wwwkav.udo.jp/volc/index-e.html>), where the links to the volcanic topographies of some of the islands may be found. The SiPSE website (<http://wwwkav.udo.jp/sipse3d/sipse-e/>) for the 3D view construction includes links to 3D product images. A specific website about the chain of volcanic islands is under construction.

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