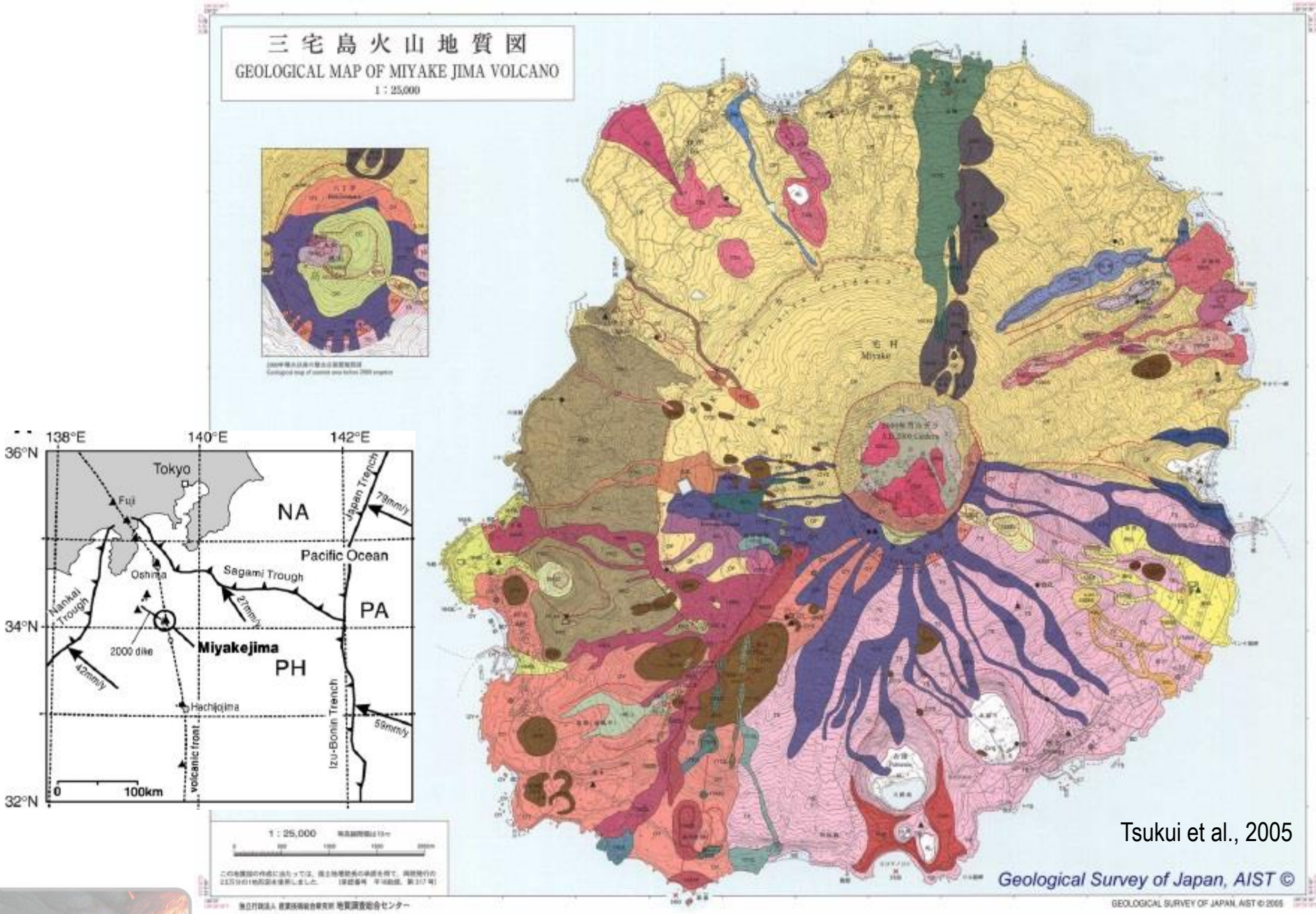
Phreatomagmatic Volcanic Hazard in Rift Edge in Coastal Regions of Volcanic Islands

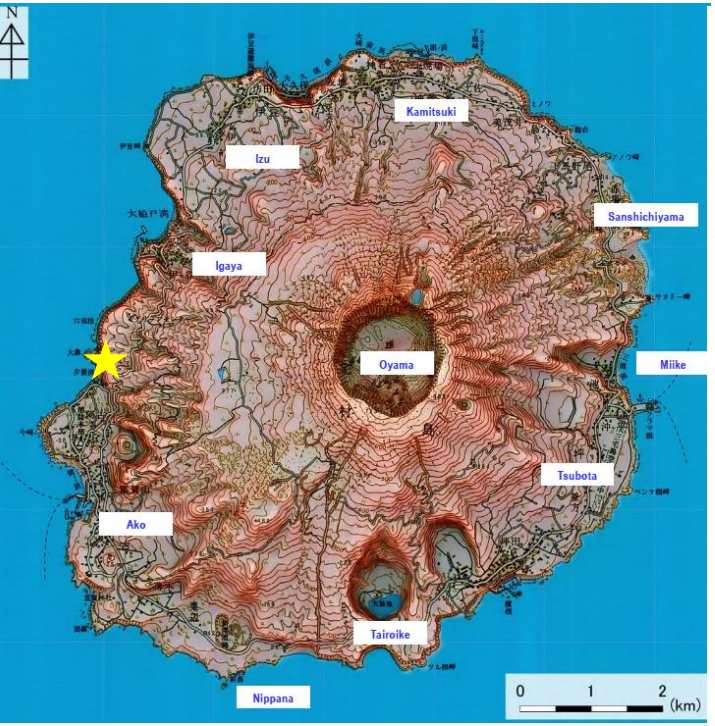
Károly Németh
IAE, Volcanic Risk Solutions,
Massey University, New Zealand

Nobuo Geshi
Geological Survey of Japan, AIST, Tsukuba

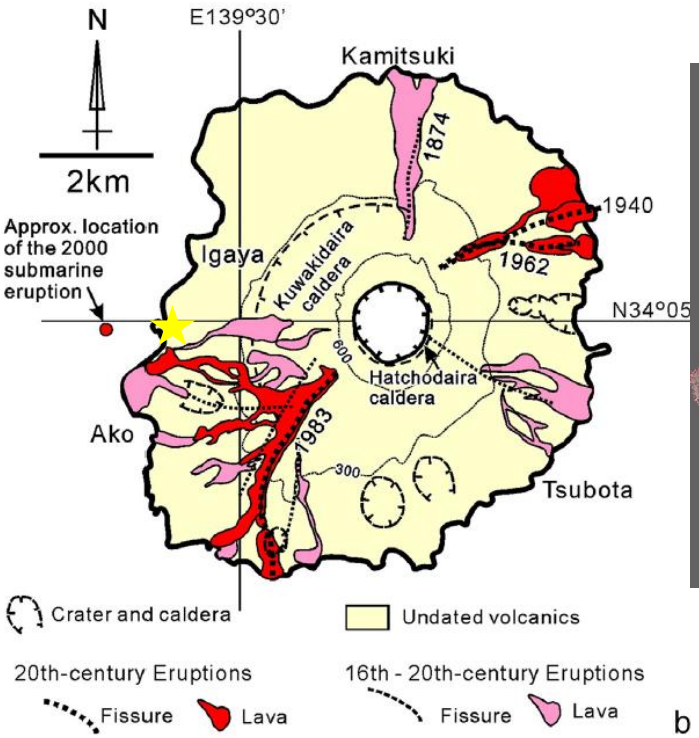
Miyakejima Volcanic Island - Geology



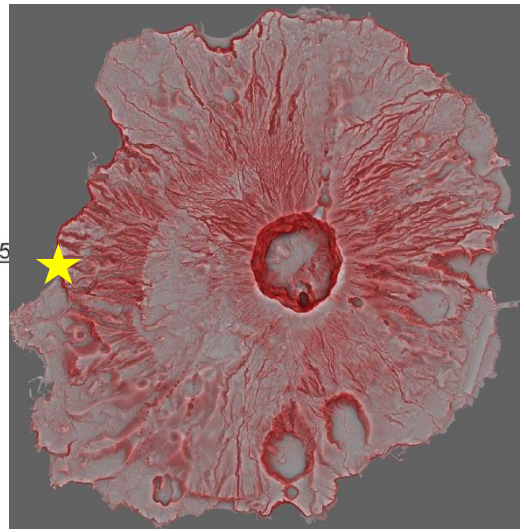
Miyakejima Volcanic Island – Facies Architecture



Geospatial Information Authority of Japan



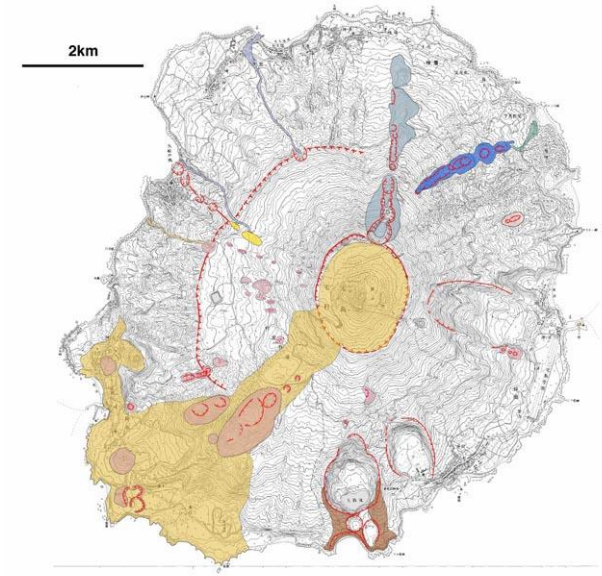
Geshi et al. 2002



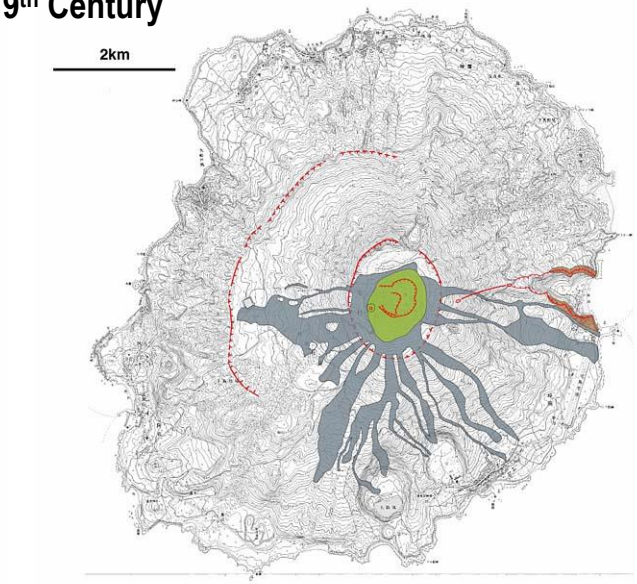
Lahar deposit: ~12 ka C14

Miyakejima Volcanic Island – summit growth

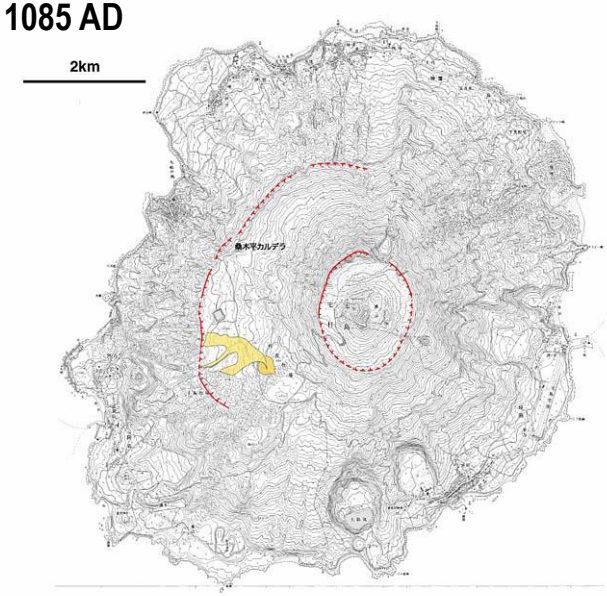
Pre-9th Century



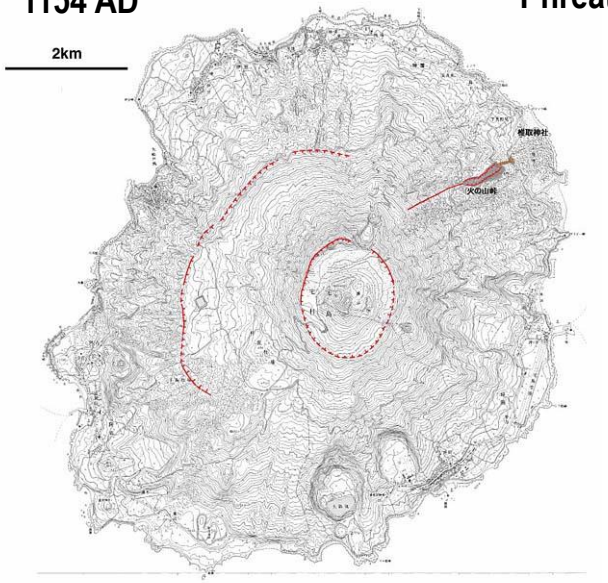
9th Century



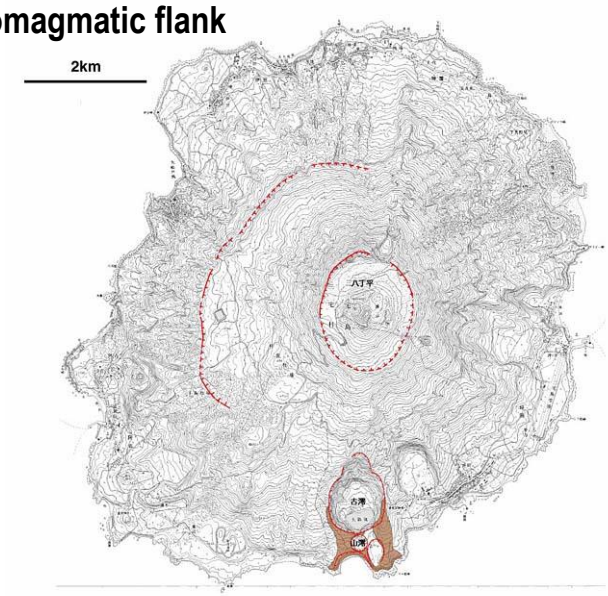
1085 AD



1154 AD



Phreatomagmatic flank

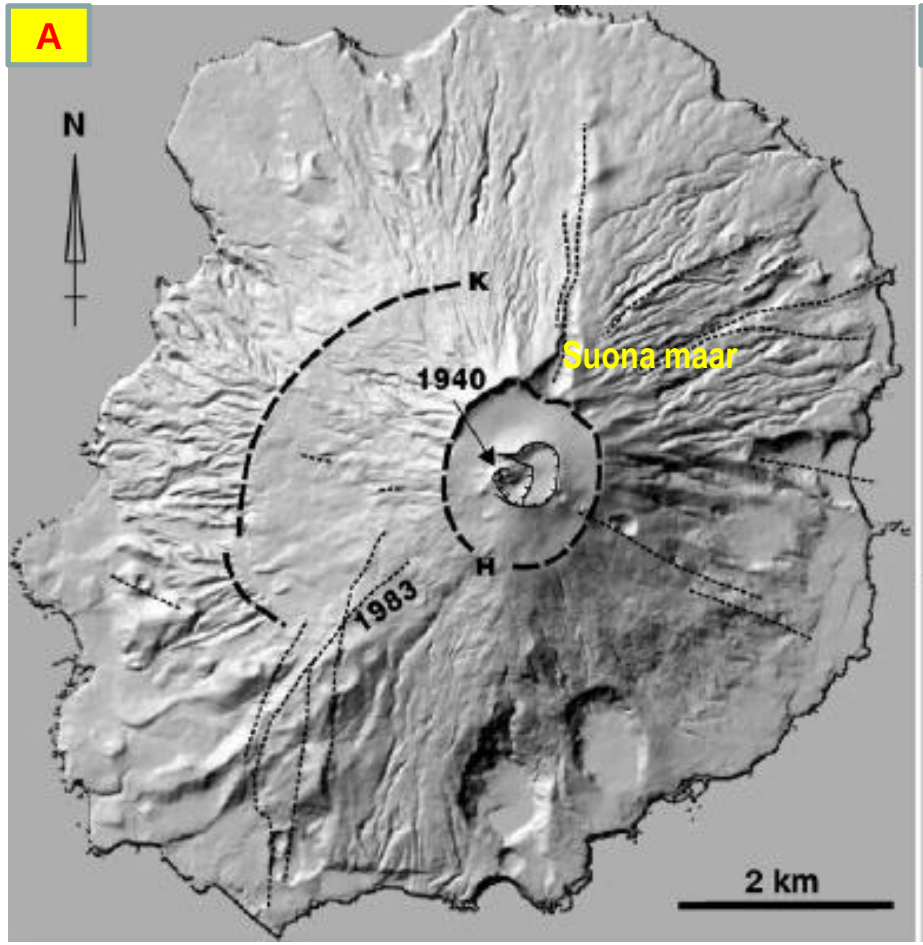


- Early evolution: formation of Kuwanokidaira caldera (~ 10 ka)
- Near-complete infill of Kuwanokidaira caldera and formation of summit cones
- Growth of central volcano in Hatchodaira (post ~2.5 ka) caldera

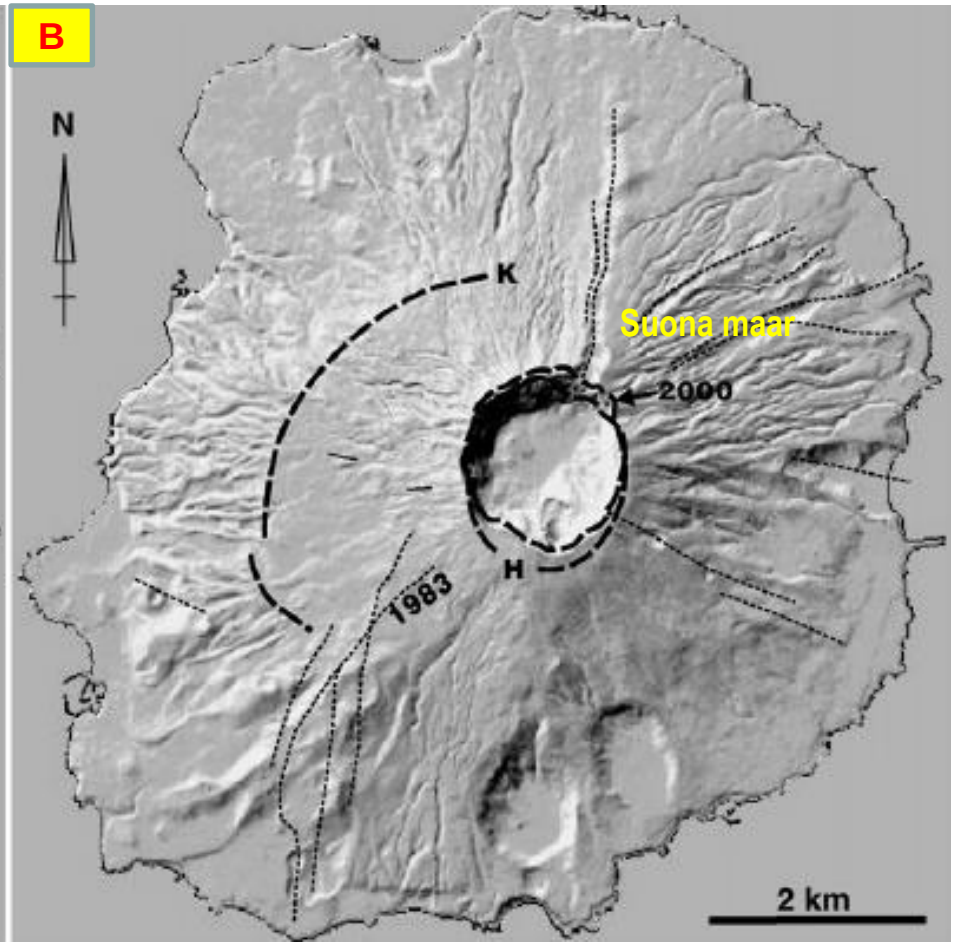
Evolution of the multiple caldera complexes

Kuwanokidaira caldera (K): at least 10 ka

Hatchodaira caldera (H): 2.5 ka



Pre-2000 AD morphology (Geshi 2009)

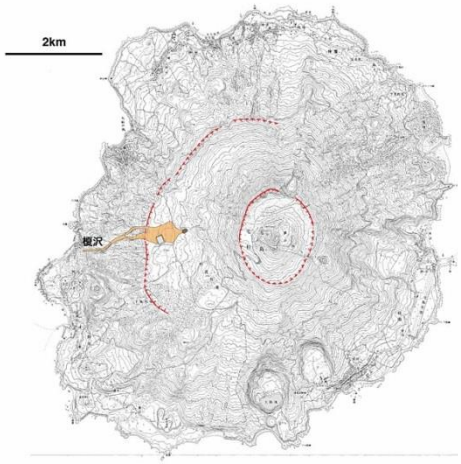


Post-2000 AD morphology (Geshi 2009)

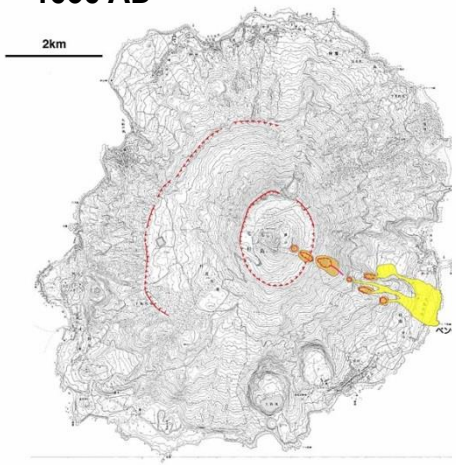
Oyama caldera: 2000 AD

Miyakejima – modern fissure eruptions

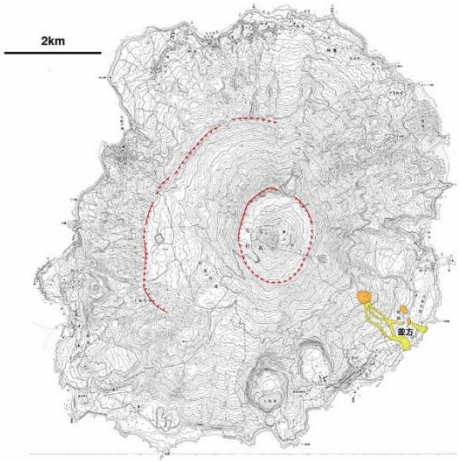
1469 AD



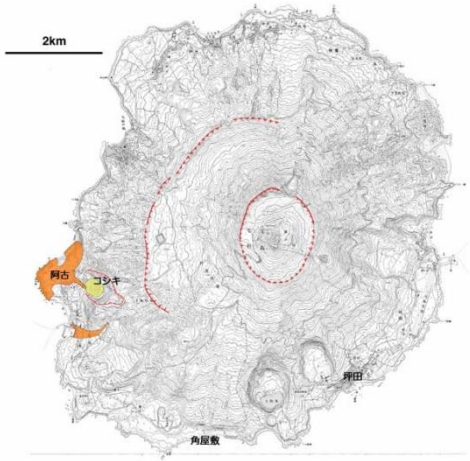
1535 AD



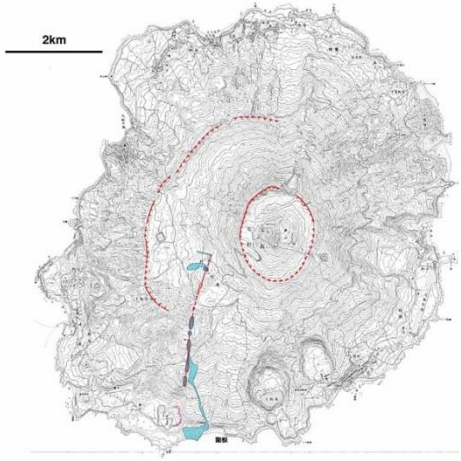
1595 AD



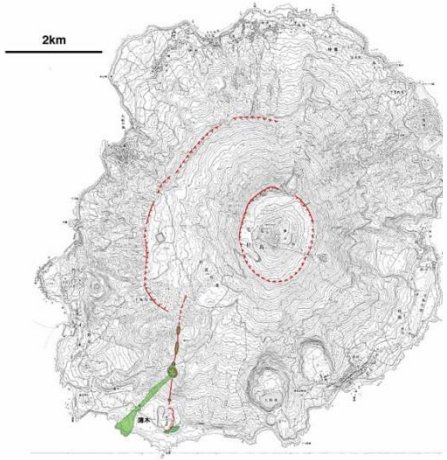
1643 AD



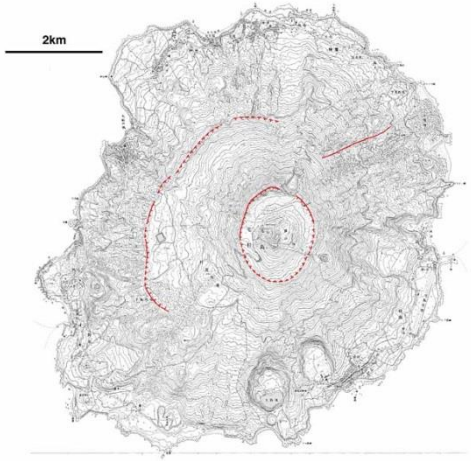
1712 AD



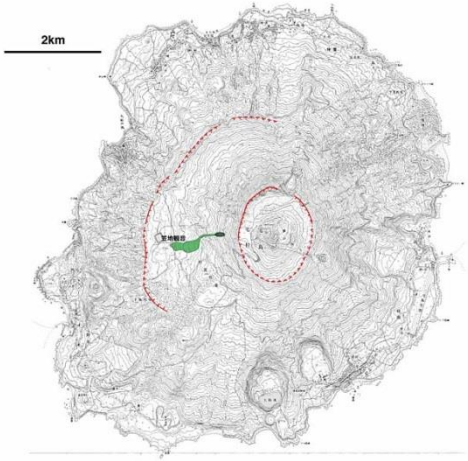
1763 AD



1811 AD

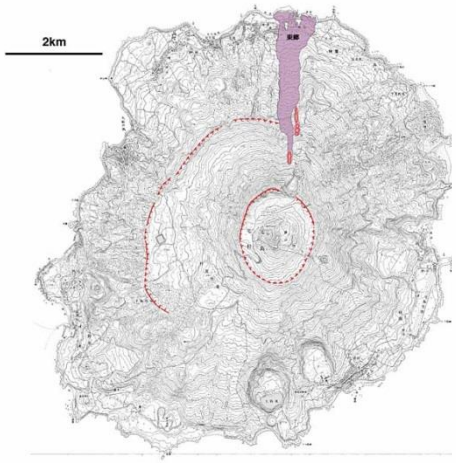


1835 AD

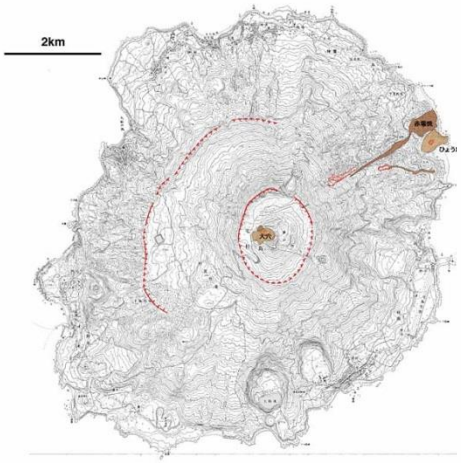


Miyakejima – role of phreatomagmatism

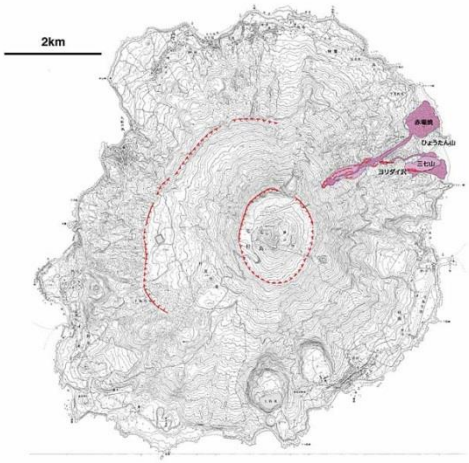
1874 AD



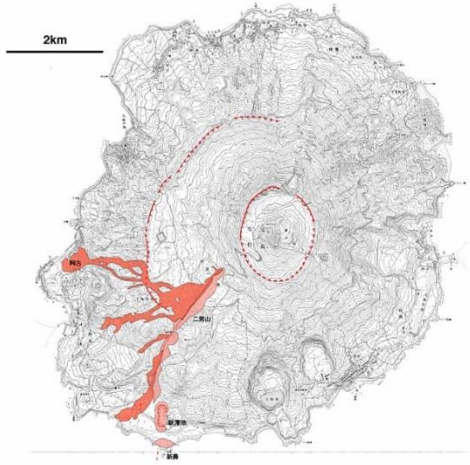
1940 AD



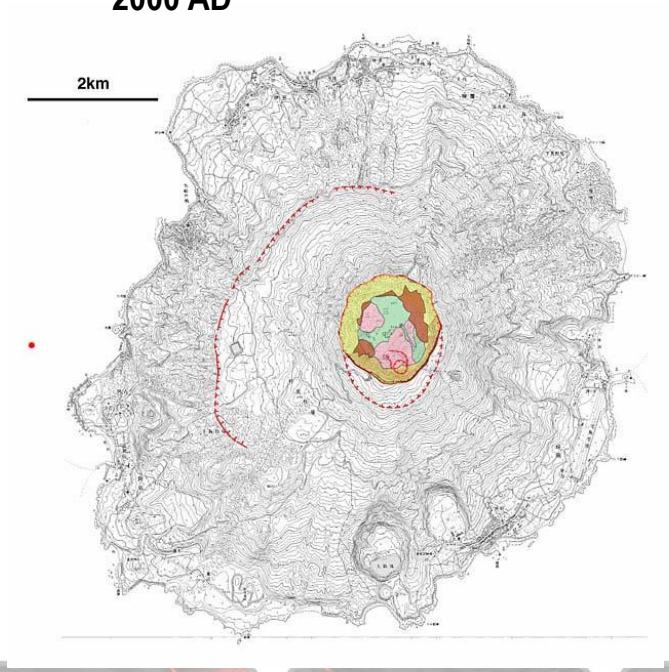
1962 AD



1983 AD



2000 AD



Role of phreatomagmatism

Suona crater (pre-9th century)

9 July 2000 (S. Nakada)

1.0 X 0.8 km with 0.2 km depth

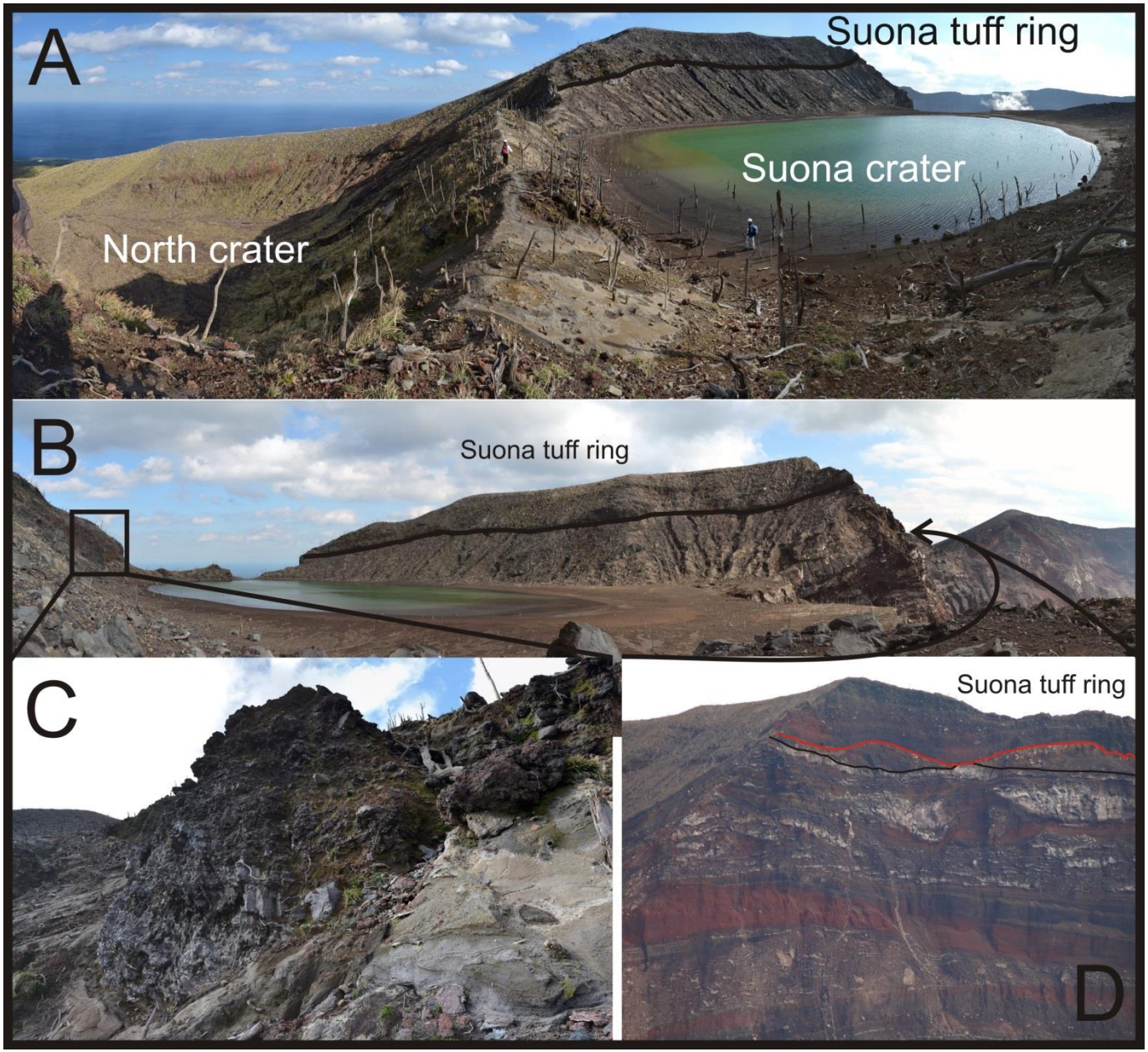
Suona crater (pre-9th century)

4 June 2001 (T. Kaneko)

1.6 km across with 0.5 km depth

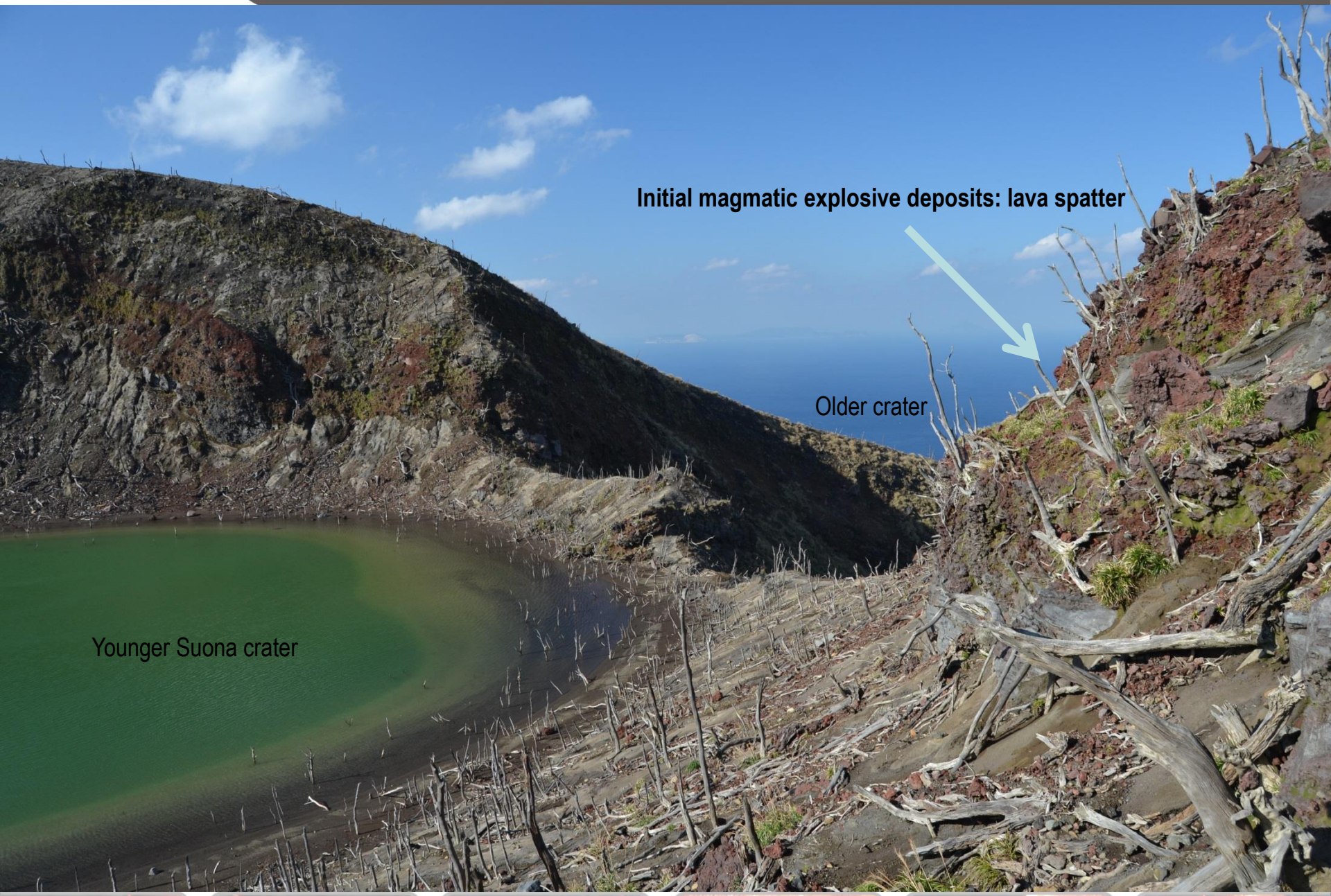
Mt Oyama – Intra-caldera compound volcanic volcano

Suona crater



- Suona crater: pre-9th century chain of craters.
- Initial eruption took place in the flak of the island (about half way to the summit.
- Initial eruptions were magmatic explosive eruptions leaving behind scoriaceous, spatter-dominated successions.
- Eruption progressed along a fissure toward the centre of the edifice.
- Eruption gradually switch to more explosive phreatomagmatic style leaving behind a pyroclastic sequence composed of less vesicular, more angular and chilled pyroclast-dominated units.
- In higher position, phreatomagmatism is more prominent eruption style along fissures.

Flank fissure toward summit

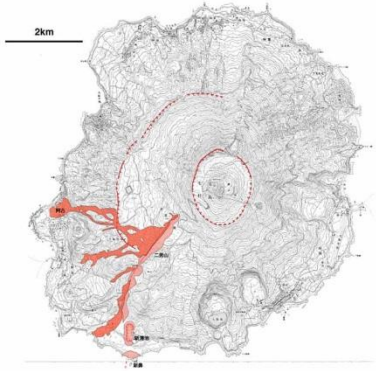


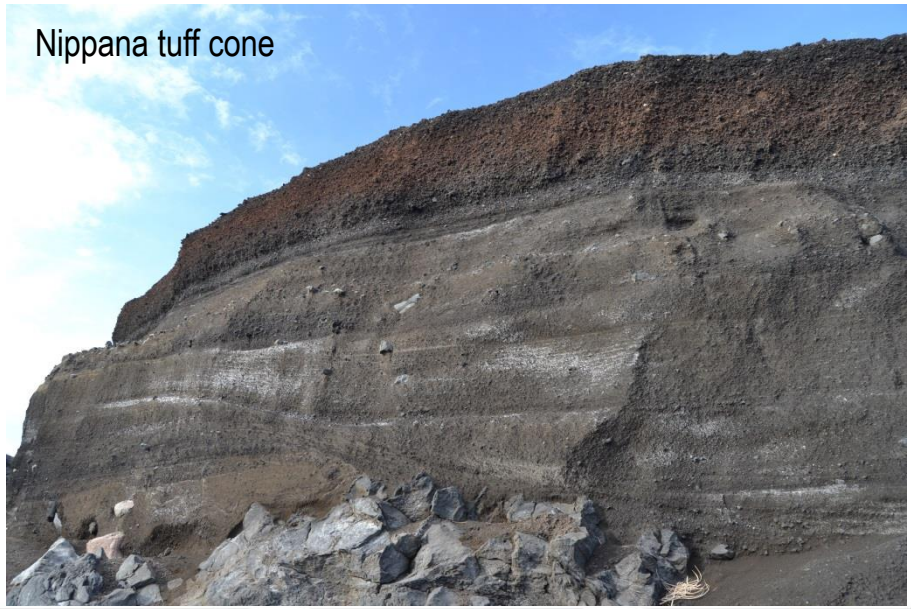
Flank fissure toward summit

Flank fissure toward summit

Flank fissure toward summit

Flank fissure toward coast - 1983 event





Flank fissure toward coast - 1983 event

Flank fissure toward coast - 1983 event

Flank fissure toward coastal plains – common case?!

Caldera infill: evidences for phreatomagmatism

Kuwanokidaria vs Hatchodaria calderas

Phreatomagmatic phase of Hatchodaira caldera formation

Confined aquifers in strato-volcanic setting

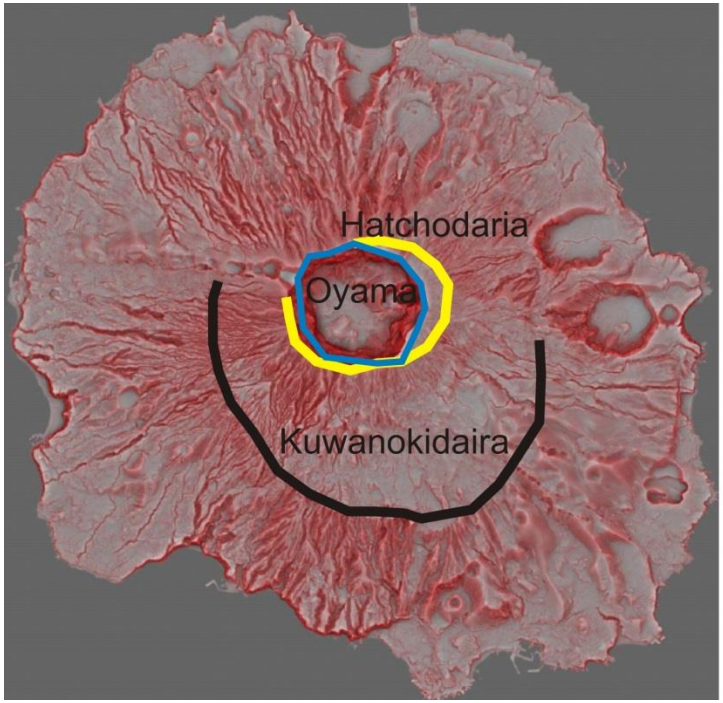
Phreatomagmatic explosive eruptions

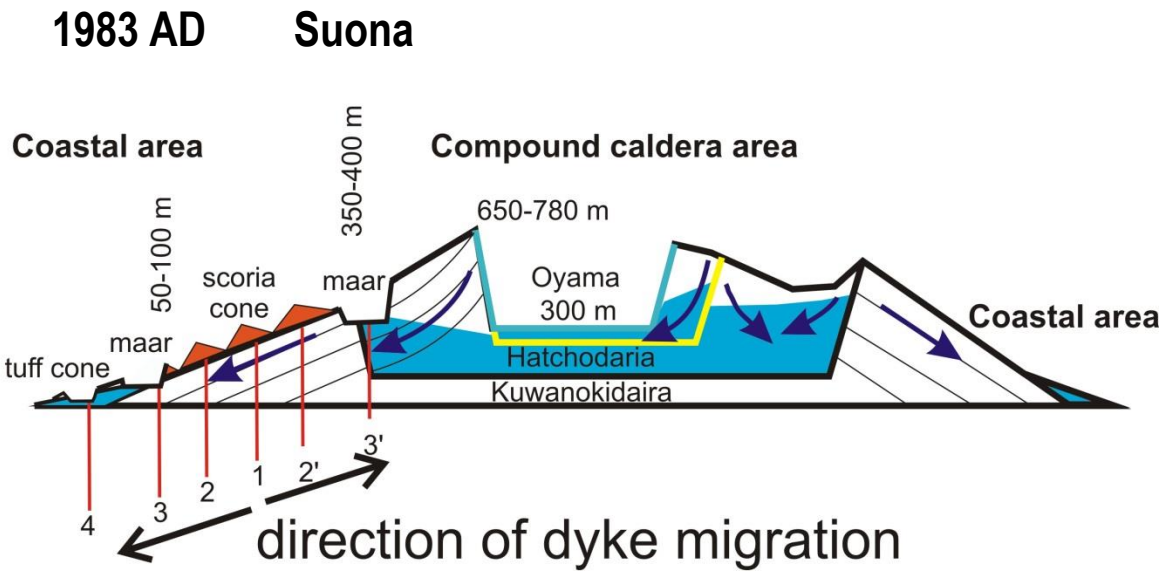
Other Pacific Islands

Ambrym

Ambae

Conclusion


Hatchodaria
Oyama
Kuwanokidaira


1983 AD
Suona
Coastal area
Compound caldera area
350-400 m
650-780 m
50-100 m
scoria cone
maar
Oyama 300 m
Coastal area
maar
tuff cone
Hatchodaria
Kuwanokidaira
4
3
2
1
2'
3'
direction of dyke migration

Historic Eruption Styles

Hatchodaira caldera, formed approximately 2,500 years ago (Tsukui et al., 2001).

Period	Area of Activity	Eruption Type	Main Phenomena / Volume of Magma
Before 9ka?	Northern mountain slope (Myogataira crater)	Magmatic eruption	Tephra fall, lava flow.
9←→7.8ka	Ofunato Bay	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.15 km³ DRE. (VEI 4)
5.3←→4.4ka	Northwestern mountain slope	Magmatic eruption, phreatomagmatic eruption	Tephra fall, lava flow. Magma eruption volume = 0.09 km³ DRE. (VEI 4)
4.1←→3.9ka	Scoria cone at southeastern edge of reservoir in east of Igaya	Magmatic eruption	Tephra fall. Magma eruption volume = 0.01 km³ DRE. (VEI 3)
3.8←→3.7ka	Mizutamari maar	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.062 km³ DRE. (VEI 3)
3.2ka	Parasitic crater at southeastern flank	Magmatic eruption	Tephra fall. Magma eruption volume = 0.009 km³ DRE. (VEI 3)
4.1←→2.7ka	Northwestern mountain slope	Magmatic eruption	Tephra fall.
3.1←→2.7ka	Inside of Kuwanokitaira caldera to fissure crater on southern foot of volcano	Magmatic eruption → phreatomagmatic eruption → (lahar production) → phreatomagmatic eruption	Hatchodaira eruption: Tephra fall → lahar → tephra fall. Magma eruption volume = 0.37 km³ DRE. (VEI 4)
3.1←→2ka	Summit crater	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.05 km³ DRE. (VEI 3)
2.1←→2ka	Northwestern mountain slope eruption fissure	Magmatic eruption	Tephra fall, lava flow. Magma eruption volume = 0.021 km³ DRE. (VEI 3)
2.1←→1.29ka	Northwestern mountain slope	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.01 km³ DRE. (VEI 3)
2.1←→1.29ka	Southwestern volcano foot (near Toga)	Magmatic eruption	Tephra fall.
2.1←→1.29ka	Western flank crater and summit crater	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.045 km³ DRE. (VEI 4)
2.1←→1.162ka	Flank crater near Togahama	Magmatic eruption	Lava flow. Magma eruption volume = 0.0001 km³ DRE.
2.1←→1.162ka	Near coast near Kamane bus stop	Phreatomagmatic eruption	Tephra fall. Magma eruption volume = 0.01 km³ DRE. (VEI 3)
2.1←→1.162ka	North-northwestern mountain slope	Magmatic eruption	Lava flow. Magma eruption volume = 0.001 km³ DRE.
1.5←→1.4ka	Eastern flank crater	Magmatic eruption	Tephra fall. Magma eruption volume = 0.01 km³ DRE. (VEI 3)
1.3←→1.2ka	Northeastern mountain slope fissure crater	Magmatic eruption	Tephra fall, lava flow. Magma eruption volume = 0.007 km³ DRE. (VEI 3)

* Volcanic periods, areas of activity, and eruption types taken from the Active Volcano Database of Japan, AIST (Kudo and Hoshizumi, 2006). All years are noted in Western date notation. "ka" within the table indicates "1000 years ago", with the year 2000 set as 0 ka.

- **Historical Activity**

Year	Phenomenon	Activity Sequence, Damages, etc.
832 (Tencho 9)	Moderate: Phreatomagmatic eruption	June 23. Air-fall pyroclastic material. The eruption occurred on the northern slope crater chain. Magma eruption volume = 0.007 km³ DRE. (VEI 3)
850 (Kasho 3)	Large: Magmatic eruption → phreatomagmatic eruption	October 7. Lava flow → air-fall pyroclastic material. The eruption occurred in the Hatchodaira caldera and at the Miike maar. Magma eruption volume = 0.082 km³ DRE. (VEI 4)
886 ←→ 1154	Moderate: Magmatic eruption	Air-fall pyroclastic material. The eruption occurred at on the southwestern slope (southeastern Ako). Magma eruption volume = 0.012 km³ DRE. (VEI 3)
1085 (Otoku 2)	Moderate: Magmatic eruption	Air-fall pyroclastic material and lava flow. The eruption occurred on the southwestern slope (inside the Kuwanokitaira caldera). Magma eruption volume = 0.001 km³ DRE.
1154 (Kyūju 1)	Moderate: Magmatic eruption	November. Air-fall pyroclastic material and lava flow. The eruption occurred at the central crater (Oyama) and the northeastern foot of the volcano (eruption fissure from Hinoyama Pass to near Shitori shrine). Magma eruption volume = 0.05 km³ DRE. (VEI 3)
1469(Bunmei 1)	Moderate: Magmatic eruption	December 24. Air-fall pyroclastic material and lava flow. The eruption occurred on the western slope (from the water reservoir area near the west of the Kuwanokitaira caldera). Magma eruption volume = 0.002 km³ DRE.
1535 (Tenbun 4)	Moderate: Magmatic eruption	March. Air-fall pyroclastic material and lava flow. The eruption occurred between the summit and the southeastern volcano foot. Fissure eruption. Magma eruption volume = 0.003 km³ DRE.
1595 (Bunroku 4)	Moderate: Magmatic eruption	November 22. Air-fall pyroclastic material and lava flow. The eruption occurred at the southeastern volcano foot. Fissure eruption. Magma eruption volume = 0.001 km³ DRE.
1643 (Kan'ei 20)	Moderate: Magmatic eruption	Approximately 3 weeks from March 31. Air-fall pyroclastic material and lava flow. The eruption occurred on the western slope (from the Koshiki scoria cone to the Kuwanokitaira eruption fissure). A felt-earthquake at 18:00 on March 31, and an eruption at 20:00, ejecting lava which flowed approximately 1km to the sea. The entire village of Ako (which was located in a different location from the present Ako) was buried or burned down. The former Tsubota was downwind, so a large amount of volcanic ash and incandescent lapilli fall buried houses and fields. No injuries or fatalities resulted..The eruption lasted approximately 3 weeks. Magma eruption volume = 0.012 km³ DRE. (VEI 3)
1712 (Shotoku 1)	Moderate: Magmatic eruption	Approximately 2 weeks, starting February 4. Air-fall pyroclastic material and lava flow. The eruption occurred at the south-southwestern volcano foot. Fissure eruption. Felt-earthquakes frequently from approximately 18:00 on Feb. 4. An eruption on the volcano slope (?) was observed at approximately 20:00. Lava discharged from Kuwanokitaira reached the sea (near Nippana?). Muddy water buried many houses and caused livestock damage at Ako. The sound of the eruption could be heard at Kamakura. The eruption began waning after approximately 2 weeks, and ceased in the following year. Magma eruption volume = 0.001 km³ DRE.
1763 to 1769 (Horeki 13 to Meiwa 6)	Large: Magmatic eruption, phreatomagmatic eruption	The eruption began on August 17. Air-fall pyroclastic material and lava flow. The eruption occurred at the south-southwestern volcano foot. Fissure and summit eruptions. The eruption began at night at the summit of Oyama, with rumbling and earthquakes the following day. During this time, an eruption occurred at Usugi, Ako. Volcanic blocks and ash fell in both Ako and Tsubota. A deep crater formed in Usugi, retaining water (Shinmyoike Pond?). Volcanic activity continued until 1769 (Meiwa 6). Magma eruption volume = 0.066 km³ DRE. (VEI 4)
1811 (Bunka 8)	Moderate: Magmatic eruption	Approximately 1 week, beginning on January 27. Air-fall pyroclastic material and lava flow. The eruption occurred between the summit and the east-northeastern volcano foot eruption fissure. The eruption began at night near the summit and moved to the northeastern slope. The the eruption waned at approximately 06:00 on Jan. 27, but earthquake swarms lasted until February 1. Two open cracks were formed on the northwestern foot of the volcano (flow of lava is unclear). Magma eruption volume = 0.02 km³ DRE. (VEI 3)

Historic Eruption Styles

Year	Phenomenon	Activity Sequence, Damages, etc.
1835 (Tenpo 6)	Moderate: Magmatic eruption	10 days, starting on November 10. Air-fall pyroclastic material and lava flow. The eruption occurred on the western slope (inside the Kuwanokitaira caldera). Rumbling was frequent and an eruption occurred near Kasaji, on the western slope. Volcanic blocks and lava flow. The eruption calmed in the middle of the night. Even after the eruption ended, earthquake swarms occurred, and landslides and fissures in both Igaya and Ako. A hot spring appeared in Ako as a result of the eruption. Magma eruption volume = 0.0004 km^3 DRE.
1874 (Meiji 7)	Moderate: Magmatic eruption	Approximately 2 weeks, beginning on July 3. Air-fall pyroclastic material → lava flow. The eruption occurred on the northern slope. Occasional earthquakes began at approximately 08:00 on Jul. 3. At roughly noon, an eruption occurred in the mountains to the south of Kamitsuki. Lava flowed to the north, reaching Togo and creating 5,000 m^2 of new land on the coast. 45 houses were buried by lava. The eruption and rumbling ended 4 days later, but activity continued for approximately 2 weeks. 1 person was killed. Total ejecta: 1.6×10^7 m^3. Magma eruption volume = 0.016 km^3 DRE.
1900 (Meiji 33)	Earthquake	November. Houses were damaged in Miyakejima, Mikurajima, and Kozushima, and many aftershocks occurred (the largest being M6.6).
1935 (Showa 10)	Earthquake	From August 27 to mid-September earthquake swarms occurred (maximum magnitude of M5.1).
1940 (Showa 15)	Moderate: Magmatic eruption	July 12. Air-fall pyroclastic material and lava flow. The eruption occurred at the northeastern slope eruption fissure and summit crater. It began from the pyroclastic cone near Akabakkyo at the end of the previous year. In May phreatic eruptions occurred on the coast of Akabakkyo and from the northeastern volcano slope. Earthquakes occurred for several days before the eruption. Divers heard rumbling underwater in Akabakkyo Bay for 2 or 3 days before the eruption. On July 12 at approximately 19:30 an eruption from the northeastern slope began. Lava flowed down and covered villages on the island, reaching Akabakkyo. The eruption on the slope was mostly over by July 13. A summit eruption began on the morning of July 14, producing a large amount of volcanic ash and volcanic projectiles. This eruption ended by approximately August 8. The eruption killed 11 people, injured 20, killed 35 cattle, completely destroyed or burned down 24 houses, and caused extensive additional damage. Total ejecta: 1.9×10^7 m^3. Magma eruption volume = 0.012 km^3 DRE. (VEI 3)
1943 (Showa 18)	Earthquake	Earthquake swarms between December 9 and 31 (maximum magnitude of M5.3).
1953 (Showa 28)	Rumbling, hot spring anomaly	August. Rumbling occurred on Oyama. Saplings wilted and died on the slopes, and the sea temperature rose.
1956 (Showa 31)	Hot spring anomaly	August 13. Hot water was emitted on the coast of Onoharajima, approximately 9 km west-southwest of Miyakejima, and the temperature of the sea in the area rose.
1959 (Showa 34)	Earthquake	Earthquake swarms from late April to early August (maximum magnitude of M4.6).
1962 (Showa 37)	Moderate: Magmatic eruption	August 24. Air-fall pyroclastic material and lava flow. The eruption occurred at the northeastern slope eruption fissure. After earthquake swarms in May (which continued intermittently until September), an eruption occurred after 22:00 on August 24 at an elevation of between 200 m and 400 m on the northeastern slope (near the site of the 1940 eruption). Fissure eruption, lava fountain. Lava flowed from many craters into the sea. The eruption ended in 30 hours, but many felt-earthquakes occurred from the middle of the eruption, with the number of earthquakes affecting Izu villages surpassing 2,000 by August 30. Children were evacuated from the island, and island residents were extremely nervous about the situation, but the number of earthquakes gradually tailed off by the end of the year. The earthquake hypocenters were not in the same area as the eruptions, but instead were in the northwest of the island. The largest earthquake had a magnitude of M5.9 (August 26). 5 houses were burned down, and roads, mountain forests, and agricultural land were damaged. The Sanshichipyroclastic cone (meaning a cone formed in thirtyseventh year of the Showa Era, 1962AD) was formed. Total ejecta: 1×10^7 m^3 (approximately 20 million tons). Magma eruption volume = 0.007 km^3 DRE. (VEI 2)
1963 (Showa 38)	Fumarole	A new fumarolic area appeared near the summit of Oyama.
1974 (Showa 49)	Earthquake	Earthquake swarm from June 27 to 30 (maximum magnitude of M6.1)..
1982 to 1983 (Showa 57 to 58)	Earthquake	December to January, 1983. Earthquake swarm (several km to approximately 20 km at sea, to the southeast, maximum magnitude of M6.4).
1983 (Showa 58)	Moderate: Magmatic eruption, phreatomagmatic eruption	October 3 to 4. Air fall pyroclastic material, lava flow, pyroclastic surge. The eruption occurred at the south-southwestern volcano foot eruption fissure. 1983 (Showa 58) Miyakejima eruption. On October 3 at approximately 15:23, an eruption began from a fissure which appeared on the southwestern slope. Lava fountain. The lava flow went in three main directions. The lava which flowed to the south-southwest passed through Awabe and reached the sea. The lava which flowed to the west buried houses in the Ako area, and stopped short of the coast. Phreatomagmatic explosions occurred at the coast near Shinmyoike and Nippana, to the south. A large amount of blocks fell on the surrounding area, and a large volume of volcanic ash covered near Tsubota, to the east. The lava flow had mostly stopped by the early morning of the following day. Approximately 400 houses were buried or burned down. Mountain forest and agricultural land was damaged. No injuries or fatalities resulted. The total amount of ejecta was 5 to 7×10^6 m^3 of lava flow (measured by the Geospatial Information Authority of Japan), and 6×10^6 m^3 of volcanic ash, etc., for a total of 20 million tons. 101 felt-earthquakes occurred before and after the eruption, The largest being the earthquake at 22:33 on October 3, which had a magnitude of M6.2 and a JMA scale seismic intensity of 5. Magma eruption volume = 0.012 km^3 DRE. (VEI 3)
1990 (Heisei 2)	Earthquake	October. Earthquake swarm at sea, approximately 30 km south-southwest (Mikura Seamount), with a maximum magnitude of M4.6).
2000 to 2002 (Heisei 12 to 14)	Moderate: Phreatic eruption, phreatomagmatic eruption, (sea discoloration)	From June. Air fall pyroclastic material, lava flow, pyroclastic surge. The eruptions occurred at the summit caldera, and in the sea approximately 1 km west of Miyakejima. On June 26 earthquake activity began on Miyakejima, accompanied by crustal deformation. The hypocenters moved gradually towards to the sea west of Miyakejima. A submarine eruption occurred in the sea to the west of Miyakejima in the morning on June 27. The hypocenters moved even further to the west, and earthquake swarm activity continued in the seas near Niijima and Kozushima (maximum magnitude of M6.5, maximum JMA scale seismic intensity of 6-lower). From July 4, earthquake activity with hypocenters directly below the summit of Oyama began. On July 8 an eruption began at the summit. The summit subsided, followed by repeated intermittent eruptions. The eruptive activity created a caldera for the first time in approximately 2,500 years. On August 10, August 18, and August 29 large eruptions occurred. The eruption on August 18 caused volcanic blocks to fall as far as the volcano foot. On August 29, low temperature pyroclastic flow reached the sea, and rain caused frequent lahars. The entire island was evacuated at the start of September. The eruptions continued until September, followed by large discharges of volcanic gas from the summit crater. For some time, over 50,000 tons per day of sulfur dioxide were emitted. Volcanic activity slowed after that, and the amount of volcanic gas being emitted decreased. During this period small eruptions occurred occasionally, with tephar fall at the volcano foot. (June 27, July 8, July 14, 15, and August 10 to September 28, 2000. January 11, March 19, May 27, June 3, 10, 13, 24, July 10, 18, September 26, 27, 28, October 11, 16, and November 1, 2001. January 23, February 21, March 2, 31, April 2, 3, 16, June 15, August 1, September 16, October 8, and November 24, 2002) Magma eruption volume = 0.0026 km^3 DRE. (VEI 3)
2004 to 2005 (Heisei 16 to 17)	Eruption	November 30, December 2, 7 to 8, and 9, 2004. April 12 and May 18, 2005. Air-fall pyroclastic material. The eruptions occurred at the summit caldera. Very small eruptions occurred in April and May.
2006 (Heisei 18)	Eruption	February 17. Air-fall pyroclastic material. The eruption occurred at the summit caldera. Very small eruptions occurred in February.
2006 (Heisei 18)	Eruption	August 23. Air-fall pyroclastic material. The eruption occurred at the summit caldera. Very small eruptions occurred in August.
2008 (Heisei 20)	Eruption	Very small eruptions occurred in January and May. The eruptions occurred at the summit caldera.
2009 (Heisei 21)	Eruption	Very small eruptions occurred in April, May, and November. The eruptions occurred at the summit caldera.
2010 (Heisei 22)	Eruption	Very small eruptions occurred in April and July. The eruptions occurred at the summit caldera.

* Reference documents have been appended with reference to the Active Volcano Database of Japan, AIST (Kudo and , 2006) for volcanic periods, areas of activity, eruption types, and eruption events.