Aso is alive!

A journey across time and space, experiencing the land of Aso and the lives of those who live in the Gigantic Caldera.

ASO GeoPARK

Annex

Annex 2: Geological Heritage



Aso Geopark Promotion Council JAPAN



A member of Japanese Geopark Network

Geological Summary

Aso Volcano, located in central Kyushu, is one of the most beautiful Quaternary caldera volcanoes in the world.

During 270,000 to 90,000 years, gigantic pyroclastic flow eruptions of andesitic to rhyolitic magma occurred four times in the volcanic field and formed the Aso caldera, 25 km north-south and 18 km east-west.

Basement rocks of Aso volcanoes consist of Quaternary Pre-Aso volcanic rocks, Cretaceous granites and sedimentary rocks, and Paleozoic metamorphic rocks. Post-caldera central cones initiated their eruptive activity soon after the last caldera-formed eruption (90,000years) and have produced large volumes of fallout tephra layers and lava flows. The characteristic of central cones are diverse in rocks; rhyolite, dacite, andesite, and basalt. Nakadake Volcano, which is the only active central cone, is one of the most active volcanoes in Japan. Its recent activity is characterized by ash and strombolian eruptions and phreatic or phreatomagmatic explosions.



GEOLOGICAL HERITAGE

2-1 Location of the proposed Geopark

Aso Geopark is situated at 32°N, 131°E, on the island of Kyushu in the Japanese archipelago, which is located in the Circum-Pacific orogenic belt. The park is home to Aso Caldera, the most notable landform of its type in Japan. In the center of the caldera is a cone group of 18 mountains, including the active Nakadake crater, which erupts once every few years to few dozen years. The caldera measures 25 kilometres from north to south and 18 kilometres from east to west. The circumference of the somma is more than 100 kilometres, and the caldera walls have a relative elevation of between 300 and 600 meters.



E131° Oguni Town Minami-Oguni Town Ubuyama Village Aso City Nishihara Village Village Takamori Town Yamato Town

Fig. 2-1 location of Aso geopark

took place approximately 270,000 to 90,000 years ago. The fourth super eruption, 90,000 years ago, was Japan's largest in the past 100,000 years. Its eruption volume totaled 600 cubic kilometres. The volcanic ash spewed into the air and rained down over the entire Japanese archipelago. Fifteeen-centimeter-deep deposits can be observed in eastern Hokkaido, 1,700 kilometers from Aso Caldera.

Today, the region's beautiful, clearly formed caldera topography and its central cone group are important elements of Japan's geological heritage. The easily accessible Geopark offers a unique opportunity for visitors to observe the topography of a typical caldera formed by a super eruption.

2-1-1 Aso's unique location with the volcanic Japanese Islands

The Japanese archipelago is situated on mobile belt encircling the Pacific Ocean, west of the Ring of Fire.







2-1-2 Plate boundaries and motion in Japan

The Japanese archipelago consists of four main islands aligned north-to-south and surrounded by smaller islands. Kyushu, where Aso Geopark is situated, is the southernmost of the four islands. It is located on the Eurasian Plate, which is bordered to the southeast by the Philippine Sea Plate. Magma is believed to form when the Philippine Sea Plate is subducted beneath the Eurasian Plate. Fig. 2-5 shows the regional stress field, related to plate subduction, that exists between the Kii Peninsula, in the Kinki region, and Kyushu. Between the Kinki and Chugoku regions is a compressive field aligned from northwest to southeast, whereas Kyushu is situated in an extensional region coming from the north-south direction. For that reason, a rift zone related to the collapse structure and running from east to west has developed there. Most of the Japanese archipelago is believed to sit in a compression field from the Pacific, but Kyushu is an exception.

Aso Caldera is located in an area known to have a rift structure with a collapsed base that runs in an east-west direction (Matsumoto, 1974; Okada, 1993). This structure has impacted the formation of a volcanic array in the region. A number of active volcanoes on the island of Northern Kyushu are located within the rift.

Aso Caldera is situated on a geotectonic line that runs from Oita to Kumamoto and marks the southern border of the rift (Takagi et al., 2007). It has been observed that when the southern portion of Kyushu slides to the west, pull forces act in the north-south direction at the same time, creating a right-lateral fault that opens from north to south.



Fig.2-6 Central Kyushu Rift Valley and main geotectonic lines (Okada, 1993)

KYUSHU

50km

Matsuvama-

CENTRAL KYUS

Fig.2-7 Rift structure between Beppu and Shimabara, and earthquake focal mechanism (Tada, 1993)

0

13

132

RIFT

SHEAR ZONE

136

M≥4.0 ⁰ H≤30km⁰

Fig. 2-5 Regional stress field between the Kii Peninsula and Kyushu (Tsukuda, 1993)

2-1-3 Unique location of Aso caldera

Aso Caldera is situated along a volcanic front in the western Japan volcanic zone. There are two active volcanic lines in Kyushu. One runs from Yufudake, in Oita Prefecture, through the Kuju volcanoes and Aso Caldera, and on to Fugendake in the Mt. Unzen volcanic group, which is part of the Unzen Volcanic Area Global Geopark. The second active volcanic line runs from Aso Caldera to Sakurajima in the Kirishima volcanic group, and then on to the Ryukyu Islands.

The former is characterized by dome-shaped volcanoes made of hornblende andesite, while the latter is characterized by andesite volcanoes and large calderas of felsic magma, which have very different shapes from the former. Aso Caldera sits at the



Fig.2-8 Distribution of volcanoes in Kyushu

intersection of the two volcanic lines, directly on top of the Oita-Kumamoto tectonic line, which is thought to be an extension of Kyushu's median tectonic line.

2-2 General geological description

Aso Volcano is one of the world's few great calderas, containing a volcanic group that consists of a diverse variety of volcanic topography and geology. People have been living in this volcanic area and developing a unique culture and landscape there for tens of thousands of years.

Aso Volcano is divided into four main zones based on geographical and topographical differences. The first consists of the central cones of the caldera. The second is the caldera floor. The third is the caldera wall. The fourth is the outer slope of the somma surrounding the cone group and plains.



Fig.2-9 Four geographical and geological zones of Aso volcano

Aso's volcanic history



Fig.2-10 Brief history of Aso volcano

Fig.2-10 shows the brief history of Aso Volcano. Four gigantic pyroclastic flow eruptions occurred repeatedly between 270,000 and 90,000 years ago. The current caldera was formed by the fourth super eruption 90,000 years ago. Next a caldera lake formed, and after that a complex series of volcanic events inside the caldera created the current cone group. Nakadake crater remains active and is one of the most dynamic volcanoes in Japan.

2-2-1 Central cones of the caldera

The central volcanic cone group is made up of many mountains. The five main peaks are referred to as 'Aso Gogaku': Mt. Takadake (1,592 m), Mt. Nekodake (1,433 m), Mt. Nakadake (1,506 m), Mt. Kijimadake (1,321 m) and Mt. Eboshidake (1,337 m). These mountains are varied in both shape and formation period. They include stratovolcanoes (Mt. Takadake, Mt. Nekodake, Mt. Nakadake and Mt. Eboshidake), scoria cones (Komezuka), a tuff ring (Ikenokubo marr), a lava dome (Takanoobane peak) and mud volcanoes and fumarolic areas (Yoshioka, Yunotani and Jigoku). The volcanic topography, component materials and interior structures are diverse. Mt. Nekodake is older than the other volcano groups and sits outside the gravitationally collapse structure of the caldera.

The central volcanic cones have historically been among the most active in Japan, and continue to have periodic eruptions. Fumarolic activity at the Nakadake crater has occurred repeatedly, not always in conjunction with eruption periods. This has effected the vegetation within a several kilometer radius. Only certain types of shrubs and herbaceous plants are able to grow there, creating a wild volcanic landscape. Apart from the active craters, a variety of volcanic deposits, volcanic topography, unique vegetation, and aeolian landforms can be seen at the central cones. The area is an ideal place to gain a comprehensive understanding of these volcanic features.



2-2-2 Caldera floor

The caldera floor extends to the north and south of the central cone group. The northern portion of the caldera floor is called Asodani Valley, and the southern portion is called Nangodani Valley. Both are alluvial plains formed by river basins. This flat topography is believed to have formed at the same time as the caldera lake.

The caldera floor is the centre of human life in the Aso region. Many towns and villages dot the plains, and most of the land has been converted to paddies and fields. Bountiful natural springs and hot springs flow from the floor, supporting human life and providing places for relaxation and enjoyment. Peatlands and yellow soil, called Limonite, that tell of past environmental change, lacustrine deposits that reveal the story of the ancient caldera lake, and falls over the Shirakawa and Kurokawa Rivers are among the many geological sites related to water that can be observed on the caldera floor.



2-2-3 Caldera wall

The somma is divided into the inner caldera wall and the gentle outer slopes of the caldera, which differ in terms of their topography. The walls also differ in the north and south in terms of height, slope, diss ected levels, fun, talus, and alluvial cones. The north wall is believed to be a newer formation than the south wall. Pre-Aso volcanic rocks and

pyroclastic deposits are exposed in many places on the caldera walls. They are very important geological features before the caldera formation, process of caldera formation and its period or geological changes after the caldera formation. Talus, alluvial cones and fans, which develop on the bottom of steeply- inclined caldera wall. Moreover natural springs inside the caldera wall are important geological sites for understanding topography and geological structure.

2-2-4 Outer slope of the somma

The somma is composed of gentle highlands that expand outwards from the caldera rim and include pyroclastic plateaus, hills, and undulating topography that arose primarily as a result of the formation of the caldera. The area sits in the upper reaches of the watershed of a nationally designated Class A river that runs through central Kyushu. Many exposed pyroclastic deposits can be seen in canyon walls, valley floors and riverbeds throughout the watershed. These are important sites for understanding the character of pyroclastic flows and deposits, and for studying the geological changes that took place beginning after the pyroclastic depositions and continuing up to the present day. The area also has a number of hot springs, including the so-called Jigoku or "hell" Onsen, as well as rock towers consisting of pre-Aso volcanic rocks; some of these geological sites have played an important role in people's lives for many generations.



2-3 Aso Geopark Geosite





Beitate Shrine Geosite

Fig.2-11 Location of geosite

Table 2-1 Geosite List

No.	Name of Geosite	Theme of Geosite	Brief Overview	Major Resources	Classify	Points
1	Daikanbo Caldera Geosite	Experience a world- class caldera (view from the north)	Observe and experience a world-class caldera. Appreciate the scale and impact of the eruption that formed the caldera.	caldera topography of Aso Gorge, central volcanic cone group, grasslands, kuroboku soil, pyroclastic plateau	caldera formataion	Aso Caldera
					caldera formataion	Daikanbo
					post caldera	Outcrop of Akahoya ash layer
		Sense the activity of the earth through an active volcano.	Directly experience the workings of the earth through a still-active volcano. Learn about the region's unique topography and criffs, as well as the traditional practice of worshipping the volcano. The area features both beautiful grasslands and desolate volcanic topography, as well as various volcanic formations.	crater wall, volcanic gas, wasteland flora, surge deposits, agglutinate, intrusive rocks	post caldera	Nakadake crater
2	Nakadake Geosite				post caldera	Sunasenri-ga-hama
	Kusasenri Geosite	Grazing land and volcanic activity.	Observe unique topography formed about 30,000years ago and marsh vegetation growing on the periphery of the crater pond.	Mt. Komatate, marsh vegetation	post caldera	Kusasenri-ga-hama Mt.Eboshidake
3					facilities	Aso Volcano Museum
					post caldera	Kusasenri-ga-hama lookout
		Topography and geological features formed by a relatively new volcanic group.	Komezuka is a typical scoria cone formed about 3,000 years ago, making it one of Aso's most recent volcanoes. Observe a tunnel formed by a lava flow.	Scoria, lava tunnel	post caldera	Komezuka
4	Komezuka Geosite				post caldera	Kami-Komezuka
5	Furubochu Geosite	Volcanic activity and mountain religion.	/olcanic activity andSee the remains of a center of mountain religion and reflect on the way Mt.mountain religion.Nakadake's volcanic activity shaped human culture.		Non-geological	Furubochu
6	Sensuikyo Gorge Geosite	nsuikyo Gorge Rocky peak and alpine plants. Learn about the relationship between Kyushu azalea, an alpine species, and the desolate, rocky landscape of volcanic mountains such as Mt. Nakadake, Mt. Takadake and Mt. Washigamine.		Kyushu azalea	pre/post caldera	Sensuikyo gorge Mt. Takadake, Mt.Nekodake
7	Mt. Kijimadake GeositeRecent volcanic activity dating to several thousand years ago.Like Komezuka Geosite, this is a relatively new volcano that was active 3,000~4,000 years ago. Its topographic features have not been eroded and therefore can be clearly seen.Agglutinate, Agglutinate,		Agglutinate, scoria, lava	post caldera	Mt. Kijimadake Mt. Ojyodake	
Q	Fumotobochu Geosite	One town's history and culture .	This town was revived by Kato Kiyomasa after Furubochu declined. Visit the many remaining temples, shrines and statues of Jizo, the guardian deitiy of children.	Jizo statues, townscape of Fumotobochu	Non-geological	Saigandenji temple
ð					facilities	Aso Den'en Kukan Eco museum
9	Mt. Ogidake Geosite Isolated peak on the pyroclastic flow plateau. When pyroclastic flow covered this area in ninety thousands years ago, the top part this mountain was left exposed. Enjoy excellent views of the pyroclastic plateau.		Rhyolite, isolated peak	pre caldera/caldera formataion	Mt. Ogidake Pyroclastic plateau, Kuju volcanos	
10	Koganotaki Fall Geosite	Falls on the outer rim of the caldera.	See a waterfall flowing over Sakanashi rhyolite, which forms a part of the outer rim, and its famous ice pillar in winter.	Sakanashi rhyolite	pre caldera	Koganotaki waterfall
11	The Deity of the Volcano Geosite	Seek the roots of the culture centered on Aso Volcano.	Dedicated to Takeiwatatsuno-mikoto, the pioneer deity of Aso, Aso Shrine is a spiritual center for residents of the area, as are nearby Kokuzo Shrine and the Nakadori burial mound of the Aso Family. Shimomiya Shrine, where the Hitaki shrine rituals (a sacred rite involving fire) are carried out, is also located in this site.	Myths, the pioneer deity of Aso, natural drinking water fountain, Zougahana point	Non-geological	Aso Shrine
						Kokuzo Shrine
						Kaminokokura and Shimonokokura burial mounds
						Nakadori burial mounds

No.	Name of Geosite	Theme of Geosite	Brief Overview	Major Resources	Classify	Points
12	Cluster of springs in Aso Valley District Geosite	Alluvial fan and artesian aquifer.	An unusual area with artesian springs an alluvial fan formed by a river originating in drinking water fountain, and Teno spring water and Teno spring water found and teno		post caldera	Miyaji and Yakuinbaru destrict springs
12	Futaenotouge	Myths and history.	Learn about the formation of Aso Volcano by observing the topography of the caldera, central volcanic cone group, Kurokawa River on the caldera floor, and oxbow lake. Hear myths and folk stories related to large and unusual stones in the Aso area.	Views of the caldera, central volcanic cone group, oxbow lake, myths, stone paths made from welded tuff	post caldera	Futaenotouge mountain pass.
15	Geosite				post caldera	Matoishi(Matoishi ochaya, remain of garden pond)
14	Aso Yellow Ocher (Aso Odo) Geosite	Environmental and cultural gifts from the great volcano .	ee Aso Yellow Ocher (Limonite), distributed around Aso Gorge, and understand the elated role of geothermal water following the formation of the caldera. Ocher has been used since ancient times to make red iron oxide paint and to produce iron ore and cattle feed.		post caldera	Aso Yellow Ocher (Limonite)
15	Uchinomaki Hot Spring Geosite	Historic hot spring town.	Visit historic hot springs once frequented by writers and artists. Located in an embayment of the caldera, some believe this site was once a crater.	lacustrine deposits	post caldera	Uchinomaki hot spring
16	Milk Road Grassland Geosite	Vast grasslands cover the north somma.	Learn about the origins of Aso's grasslands by observing the grasslands in the north somma and the volcanic ash soil (kuroboku, akaboku, akahoya) visible along the road.	Kuroboku, akaboku, akahoya volcanic ash soil and Milk Road	post caldera	Grassland scenery
17	Oshito-ishi Geosite	Fusion of nature and culture.	View a group of megalithic andesite stones located on a hill 845 m above sea level. The biggest stone has a pyramid shape with a height of 5.5 m and a circumference of 15.3 m. It is said to have been a sacred place for rituals and festivals since ancient times.	Isolated peak, andesite	pre caldera/caldera formataion	Oshito-ishi
	North Outer Rim Pyroclastic Flow Geosite	Understanding the vast pyroclastic flow.	Observe the characteristics of Aso's pyroclastic flow, such as the structure of welded tuff and the unique scenery formed by erosion of the pyroclastic flow deposits.	Pyroclastic flow, welded tuff, recession of waterfall, Shiromurataki Falls	caldera formataion	Nabegataki fall
					caldera formataion	Yusuikyo gorge
18					caldera formataion	Nanataki fall
					caldera formataion	Aso pyroclastic flow deposits (on Yamanami highway)
	Oguni-go Area Hot Spring Geosite	Hot spring village formed by volcano.	Visit the abundant hot springs (onsen) in this village, believed to be heated by Kuju Volcano	Kuju volcano, Kurokawa Onsen	post caldera	Minami Oguni onsen village
19					post caldera	Tuetate onsen
					post caldera	Suzume Jigoku (Sparrow Hell)
					post caldera	Waita onsen village
20	lkeyama and Yamabuki Geosite	Sources of spring water.	Groundwater filtered through the Aso and Kuju pyroclastic flow deposits gushes from springs at this site.	Pyroclastic flow	post caldera	Ikeyama spring
-					post caldera	Yamabuki spring
21	The Sankin-kotai Road Geosite	Road utilized natural topographic features.	Bungo Highway was used by the local lord when he traveled to his alternate residence in Tokyo. The road avoids damp ground, illustrating the detailed topographic knowledge of the local people. The stone pavement along the caldera wall was made with rocks mined nearby.	Futaenotouge Mountain Pass, stone pavement, Sakanashi post town, Tenjin Bridge, Takimuro Hill, pyroclastic flow	Non-geological	Sankin-kotai road
					Non-geological	Matoishi ocyaya, remain of garden pond
22	Kusakabe Geosite	Kudarimiya Shrine, dedicated to the God of Aso.	Hikoyaimiminomikoto, the son of Emporer Jinmu, is enshrined here. The layout, which requires visitors to descend stone stairs to reach the shrine, is extremely unusual.	Myths,The pioneer god of Aso .	Non-geological	Kusakabeyoshimi shrine

No.	Name of Geosite	Theme of Geosite	Brief Overview	Major Resources	Classify	Points
23	Camel mountain (Rakuda-yama) Geosite	Scenery featuring intrusive rocks.	Observe the structure and joints of intrusive rocks to understand their development. Minami-Aso Visitor Center and wildflower garden are situated nearby. View regional vegetation.	Columnar joints, intrusive rocks	pre caldera	Camel mountain(Rakuda- yama)
					facilities	Minami-Aso visitor center Aso wild flower garden
24	Cluster of springs in Minami-Aso District	Springs created by the	Visit the well-known and abundant natural springs in the southern part of the Aso	Shirakawa spring, Terasaka spring and others, different water	post caldera	Minamiaso village spring group
24	Geosite	life of local people.	somma.	quality and amount of discharge	post caldera	Takamori spring tunnel
25	Jigoku and Tarutama Hot Springs Geosite	Geothermal area and See the hot sp hot springs, explosion region is one of crater. drawing of the		Landslide topography, crater, maar, Mt. Yomine, hydrogen sulfide, Kinryuunotaki Falls, Suzume Jigoku (Sparrow Hell), Yoshioka fumarole, Yoshioka Onsen, Yunotani Disaster, crater remains	post caldera	Jigoku and Tarutama onsens
			See the hot springs at the explosion crater and eroded area on Mt. Yomine. The entire region is one of the few fumarolic areas in the central volcanic cone group. View a drawing of the Yunotani Disaster, a hydrovolcanic explosion at the hot springs in 1816.		post caldera	Ikenokubo
26	Nango valley Geosite	Characteristic topography related to the formation of Nango Valley .	lated to Observe terraces in Nangodani Valley, in the south caldera, and learn about the of formation of lakes and rivers after the caldera was formed.		post caldera	Terraced topography in Nangodani valley
27	Mt.Rakanyama Geosite	Understand unusual formations .	View eroded or collapsed tuff breccia and, mainly at Mt. Kanmuridake, andesite consisting of huge crystals such as pyroxene and amphibole.	Tuff breccia, Osoroshiga- fuchi, Mennoishi, pyroxene at Go-Toge Peak, huge tuff breccia crystals, 16 Rakan Caves	pre caldera	Mt. Rakanyama strange spectacle
					pre caldera	Zizo-toge pass dike swarm
28	Tawarayama Mountain Pass Caldera geosite	ama Experience the grand scale of the Observe the expansive caldera topography and understand the impact of the eruptions n Pass caldera.(view from geosite the south)		caldera formation	Aso Caldera Tawarayama lookout	
	Tateno Gorge	Intersection of fault	Due to fault activity, a caldera lake is believed to have repeatedly formed and disanneared at this site. Learn about the site history and hear a related myth about	Tateno lava columnar joints, confluence of Shirakawa and Kurokawa Rivers, Kitamukouyama	post caldera	Tateno gorge
29					post caldera	Ayugaerinotaki fall
29	Geosite	activity.	Aso's pioneer deity.	forest, Kugino stratum, Kitamukouyama faults, river erosion	post caldera	Sugarugataki fall
30	Shiraitonotaki Falls GeositeWaterfall formed by lava on the somma.Visit a 20-meter-high waterfall located on rock believed to predate Aso volcanic rock. Observe clear columnar joints.		Rocks predating Aso Volcano, columnar joints	pre caldera	Shiraitonotaki fall	
31	Omine Volcano Geosite	olcano Omine Volcano was formed ust before the formation of the current caldera, and lava flows from this volcano created a vast lava plateau. Observe evidence of past movements of the plateau caused by fault activity.		Takayubaru pyroclastic flow, Aso Kumamoto airport, Futagawa faults, Futadaki Falls	pre caldera	Omine volcano, Takayubaru lava plateau
32	Soyokyo Gorge Geosite	A beautiful valley created by a volcano and springs .	View this beautiful of gorge formed by eroded Aso pyroclastic flow deposits	Pyroclastic flow, columnar joints, Funanokuchi Spring	caldera formataion	Soyokyo Gorge
33	Heitate Shrine GeositeConnect with the world of the gods.Surrounded by a rich natural environment, this shrine is said to be the birthplace of Takama-ga-hara mythology.		Myths	Non-geological	Heitate Shrine	

2-4 Characteristics of Aso

2-4-1 Characteristics of Aso caldera

Aso Caldera measures about 25 kilometres north-south and about 18 kilometres east-west, with a perimeter of over 100 kilometres. The total inner area is about 380 square kilometres. Two caldera floors, Asodani Valley and Nangodani Valley, occupy the north and south portions of the caldera interior. Nangodani Valley is 300 to 600 meters above sea level; the outer rim is 600 to 1,200 meters above sea level. Between the caldera rim and the caldera floor stand steep caldera walls. The central cones are aligned from east to west in the center of the caldera. Giant calderas like Aso are formed when a super eruption is followed by a collapse. The present giant caldera was formed mainly by a super eruption about 90,000years ago (Aso-4), but three other super eruptions also took place starting 270,000 years ago.

Fig2-13 shows the Volcanic Explosive Index based on volume of volcanic products. Volcanic products from Aso-4 comprised over 80 cubic kilometres of pyroclastic flow and 600 cubic kilometres of total deposits, including tephra blown across a wide area. Aso-4 is believed to have been a super eruption bigger than VEI 7.

VEI	Ejected magma	Examples			
	3000km ³	The youngest Toba-Tuff (74,000 years ago)			
8 (mega-colossal)	2000km³	Yellowstone Huckleberry Ridge Tuff (2,000,000 years ago			
	1000km³	Yellowstone Lava Creek Tuff (600,000 years ago)			
7 (super-colossal)					
6 (solossal)	— 100km³				
		Tambora (1815)			
5 (paroxysmal)		Pinatubo (1991) 			
A () , , , , , , , , , , , , , , , , , ,	— 1km³				
4 (cataclysmic)	0.1km ³	Mount. Unzen (1990-95)			
3 (severe)					
	0.01km ³				
2 (explosive)	0.001km ³				
1 (gentle)	0.001km				
	0.00001km ³				
0 (non-explosive)					

Fig.2-13 Volume of volcanic products based on Volcanic Explosive Index (VEI)



Fig.2-12 Amount of volcanic products of super-eruption (modified from Takahashi, 2008)



Fig.2-14 Schematic diagram of pyroclastic flow (Machida and Arai, 1992)

The biggest caldera in the world is Toba Caldera in the north of the Indonesian island of Sumatra. It is 100 kilometers long and about 30 kilometers wide, with a water depth of up to 530 meters and a total area of 1,000 square kilometres. The caldera has become a lake, and is the largest of its type in the world today. It was formed by the biggest super eruption in the past two million years, on the same level as the Huckleberry Ridge eruption, which had an erupted magma volume of 2,500 cubic kilometres and created a tuff in Yellowstone. The Aso-4 eruption was just one level below these two events.

The difference between these calderas and Aso is their present condition. Other calderas are either so huge that viewing their topography as a whole is impossible, their walls have dissected out, or they have becomes caldera lakes. What's unique about Aso Caldera is that despite its enormous scale, it remains a nearly intact circle and can be seen clearly with the naked eye. Due to earthquakes and the erosive action of rivers, part of the caldera wall has collapsed, drying out the floor and allowing easy observation of the central cone group. An excellent network of roads means that visitors can view the caldera's beautiful form from many different angles. In addition, the region's 70,000 residents have evolved a unique culture that takes advantage of the geographical conditions, making the caldera an excellent site for learning about how humans live in volcanic areas.



Fig.2-15 Distributions of Aso1-4 pyroclastic flow depositions (Ono and Watanabe, 1983)

2-4-2 Impact of super eruptions

Impact of pyroclastic flow

Following the super eruptions that formed Aso Caldera, pyroclastic flow spread over the surrounding land. Depositions from Aso-4 pyroclastic flows covered an area with a 160-kilometre radius to the north and a 100-kilometre radius to the south. A portion of the materials extended across the sea to Honshu, the main island in the Japanese archipelago. The area around Aso was completely covered by the pyroclastic flow, and nearly all the plants and animals there are believed to have died. If the total eruption volume of 600 cubic kilometres had settled evenly over Kyushu, it would have covered the entire island with a layer 17 meters thick.

Many geological sites on the somma offer an opportunity for visitors to sense the enormity and impact of the ancient super eruption. The magnificent caldera landscape, the central volcanic cones, and the rim of the caldera can be viewed in their entirety from numerous points on the surrounding peaks. Looking in the other direction, a gentle pyroclastic plateau and hills formed by volcanic deposits are visible. A diversity of unique landscapes, structures, and rock faces formed by the pyroclastic flow may also be observed.

Fig.2-15 shows the current distribution of depositions on all sides of the caldera. The deposits are especially well preserved and easy to see on the north and southeast sides of the caldera. These sites offer an excellent opportunity to study the deposition process as well as the subsequent processes of cooling and erosion.

Widespread impact of volcanic ash

During super eruptions such as Aso-4, volcanic ash consisting of light-weight volcanic glass separates from ash columns and pyroclastic flows. These clouds of ash are spread by the eruption as well as by wind, leading to fallout and deposition of volcanic ash over a wide area.

In Japan, westerly winds typically blow over the archipelago at a speed of 25 to 50 m/s and a height of 5,000 to 10,000 m. For that reason, when a super eruption in the region sends ash columns high into the air, volcanic ash is carried east. In the case of large eruptions from Aso Volcano, volcanic ash spreads northeast from Aso's location in the southwest of the Japanese archipelago. Fifteen-centimetre-thick ash sediment from the Aso-4 super eruption has been found in eastern Hokkaido, 1,700 kilometres north, attesting to the massive scale of the event. Assuming an average wind speed of 30 m/s, ash likely began to fall over Hokkaido a mere 16 hours after the eruption began. Ash from Aso-4 also turned into aerosol and covered the entire globe, causing climate change. This is believed to have happened in a relatively short period of time.



Examples of volcanic impact in other areas, And the significance of Aso geopark

Super eruptions have a huge impact on both environments and people's lives. Volcanic ash from the Akahoya super eruption of the Kikai Caldera, which took place about 7,300 years ago in southern Kyushu and formed a 20-by-17-kilometer submarine caldera, had a total eruptive volume of 170 cubic kilometres. The twenty-centimetre-thick deposits at the Daikanbo Caldera Geological Site in Aso Geopark originate from this eruption. The Takeshima pyroclastic flow produced by the Akahoya eruption is also believed to have had a massive impact on the surrounding area. Laurel forests in the flow area died and were replaced by Japanese silver grass (*susuki*) and other grassland vegetation. The impact of the flow has also been observed in the region's earthenware culture, with the eruption marking a clear disconnect in the style of pottery produced.

Ex.1) Impact of 1628 BC Minoan Eruption

In 1628 BC, a caldera was formed by the Minoan Eruption, a huge eruption of a submarine volcano. The explosive event caused disasters all over the Aegean Sea.

EX.2) Impact of 535 eruption of Krakatoa

A volcanic winter was caused by the destructive eruption in 535. Trees around the world stopped growing for several years after the eruption.

EX.3) Impact of 1815 eruption of Tambora

The 1815 eruption was the largest recorded in the past two centuries. Abnormal sunsets were observed globally for several years following the event. This led to global cooling known as the 'year without a summer' that caused 10,000 deaths. In total 50,000~90,000 people died as a result of the eruption, including deaths caused by famine and plague.

The eruption that formed the Aso caldera was bigger than these eruptions, and its impact is believed to have been massive and widespread. However, its exact impacts remain unclear.

As noted above, the world's most recent super eruption occurred at Mt. Tambora in 1815. However, no super eruptions have occurred in Japan since the Kikai Caldera eruption 7,300 years ago. As a result most people today spend little time thinking about such events. Yet without a doubt future caldera eruptions will occur on the world's tectonic belts. One of Aso Geopark's most important and meaningful roles is to communicate the processes and impacts of super eruptions to visitors from Japan and the world.

2-4-3 Central volcanic cone group

The active Nakadake Volcano has erupted on average once every 10 years for the past 1,500 years, which is as far back as records exist. The present characteristics of the volcano's magma have been studied through its deposits. The magma is primarily basaltic andesite, with a high volume of potassium relative to other volcanoes. This differentiates Aso from other active volcanoes on Kyushu, and has characterized it since the Aso-1 super eruption occurred about 270,000 years ago.

Many sites in Aso Geopark provide opportunities to understand volcanic activity after the formation of the caldera. At the Nakadake Geological Site, layers of volcanic ash, volcanic bombs, agglutinate and other materials formed from magma can be seen. At other sites, visitors can experience the activity of the Earth through hot springs, geothermal areas, and other features unique to active volcanic regions.

Nakadake Crater

Aso's Nakadake Crater is distinguished by its well-maintained access routes. Visitors can reach the crater by car, ropeway or footpath and peer inside. For Japanese tourists, a trip to Aso is synonymous with a visit to the mouth of the active Nakadake Crater. Nakadake is composed of multiple craters aligned from north to south in an area measuring 400 meters east-to-west and 900 meters north-to-south. The four clearest craters are numbered 1-4.

Volcanic activity at Nakadake has been frequent and has shifted between craters. The regular cycle of activity is as follows: a crater lake or "yudamari" is formed in the basin during the inactive period \rightarrow gravel spouts from the basin, drying it out \rightarrow red heat phenomenon occurs \rightarrow volcanic ash



Fig.2-17 Strombolian Eruption at Nakadake Crater

erupts \rightarrow rumbling and eruption of volcanic rock occurs (Stromboli eruptions). After

the Stromboli eruptions have continued for a period, a phreatomagmatic eruption suddenly takes place. When activity subsides, a "yudamari" lake once again forms in the crater bottom.

Even during its calm periods, Nakadake Crater emits several hundred tons of volcanic gas daily on average. The strongly acidic water in the yudamari remains at about 50 to 60 degrees Celsius, and is colored a beautiful emerald green by iron ions.



Fig.2-18 Nakadake geosite



Fig.2-19 crater lake "yudamari"

Fig.2-20 red heat phenomenon

Volcanic cone group and surroundings

The central volcanic cone group consists of many mountains in addition to Mt. Nakadake. The five main mountains (Aso Gogaku) are Mt. Takadake (1,592 m), Mt. Nekodake (1,433 m), Mt. Nakadake (1,506 m), Mt. Kijimadake (1,321 m) and Mt. Eboshidake (1,337 m). These mountains vary both in shape and formation period. They include stratovolcanoes (Mt. Takadake, Mt. Nekodake, Mt. Nakadake and Mt. Eboshidake), scoria hills (Komezuka), a tuff ring (Ikenokubo), a lava dome (on the crater floor of eastern Mt. Kijimadake) and mud volcanoes and fumarolic areas (Yoshioka, Yunotani and Jigoku). The volcanic topography, component materials and interior structures are widely varied. Although, All the mountains in the group except Mt. Nekodake were formed after the caldera.

Each mountain provides insight into how geographical features vary according to formation period, as well as a sense of the Earth's dynamic activity. Komezuka is a very well balanced scoria hill, whose faults can be observed at Kamikomezuka. Kusasenri-ga-hama crater is the remains of a 30,000-year-old crater, measuring about 1,000 across and now covered with low grass. The site is representative of many landscapes at Aso Geopark. To the north of Kusasenri-ga-hama crater lie Mt Kijima and Mt.Ojodake, scoria dating back several thousand years. The grassy landscapes here contrast with the wild and rocky scenery of Mt. Takadake and Mt. Nekodake, which consist of intrusive rocks, agglutinate and lava.



Fig.2-21 Komezuka

Fig.2-22 Kusasenri-ga-hama

Aso Volcano Museum is located near Kusasenri-ga-hama crater. The museum functions as a visitor centre and an optional site for geo tours when the weather is bad.

CENTRAL VOLCANIC CONE GROUP FOOTHILLS AND CALDERA FLOOR

The foothills of the central volcanic cone group and the caldera lowlands are divided into two main areas, Asodani Valley in the north and Nangodani Valley in the south. These valleys are made up of alluvial fans and plains. A number of geological sites here are ideal for observing volcanic formations, lava flows and other features formed by sedimentation.

The main geological sites in these areas are the Jigoku-Tarutama Onsen (hot springs), Ayugaerinotaki Falls, Sugarugataki Falls, Kugino Geological Layers, Tateno Lava Columnar Joint, Aso Yellow Ochre and Nangodani Valley River Terrace.

Each of these sites consists of various geological elements, making them essential places for learning about the diversity and complexity of Aso Volcano.

Geological sites around the somma

Many geological sites around the somma illustrate the repeated dynamic volcanic activity that occurred before the caldera formed, not only in the central volcanic cone group, but also at Tateno Gorge, Omine Volcano, Futagawa Faults and Rakuda (camel) Mountain.

Tateno Gorge is the only gap in the somma, and was formed by an active fault group that fans out from it. After formation of the original V-shaped gorge, the area was repeatedly reshaped by lava from Tateno, Akase and other volcanoes in the central cone group, which dammed the river. Fault activity and further changes followed; the river is currently in the process of deepening once again.

2-4-4 Preserved grassland

Aso Geopark's grasslands are the largest in Japan and a magnificent symbol of the park. In the somma, they cover a landscape formed by pyroclastic plateaus and volcanic ash, and are composed of unique plant communities of miscanthus (*susuki*) and dwarf bamboo (*nezasa*). A similar landscape can be seen near the central cone group.

Although the details of the grassland's formation are not entirely clear, researchers have confirmed that sasa grasslands (primarily miyako zaza dwarf bamboo) existed in the area between 32,000 and 30,000 years ago by studying phytoliths in the volcanic ash layers east of Aso Volcano. However, the grasslands deteriorated during the most recent glacial cooling period between about 30,000 and 13,500 years ago, in part due to volcanic activity. About 13,500 years ago, miscanthus-dominated grasslands began to spread, and



Fig.2-23 Grassland burning

continue to thrive today. It is unlikely that the miscanthus grasslands would have existed for such a long period without some form of human interference to forestall succession; researchers believe humans have been maintaining them from the time of their formation.

The 10th century Chronicles of Japan includes a description of "grassy fields extending far and wide" in the region, indicating that grasslands have without doubt existed for at least a millennia. The space remained open and treeless not only because of repeated volcanic activity and ash fallout, but also most likely because of grazing, grass harvesting, and burning carried out by humans.

The annual burning takes place to clear out dead plant matter and suppress the growth of bushes and trees. The ultimate goals of this activity are to encourage the growth of plants suitable for feeding to livestock, prevent flooding and landslides caused by the accumulation of dead grass in rivers, and prevent wildfires. Grassland management has been crucial to maintaining healthy animal and plant communities, water resources, and land, as well as ensuring the livelihood of cattle farmers and the health of the regional economy.

This system of land maintenance and cattle farming was registered as a Globally Important Agriculture Heritage System (GIAHS) by FAO in 2013. An important role of GIAHS in developed countries is to advance global agricultural technology. In Aso, the agricultural system is deeply related to the volcanic geography, and has potential for application in other volcanic regions. Aso Geopark would be the first site in the world to be registered as both a Global Geopark and a GIAHS.



Fig.2-24 GIAHS Logo

2-4-5 Aso yellow ocher "LIMONITE"

Aso Geopark contains iron and lacustrine deposits that yield limonite, called 'Aso odo' or Aso yellow ochre because of its colour. These ochers are believed to have been formed by the accumulation of geothermal water and organic matter during the caldera lake period. According to current research, limonite continues to be produced by gushing geothermal water.

The yellow ochre is an ancient regional resource that scholars believe was the foundation of a local trading culture. It was likely used to produce a type of red oxide baked paint used in ancient burial mounds, and as a raw material for making iron tools. Today the soil is valued for its usefulness in desulfurization, odour absorption, and water purification, as well as for its high mineral content. It is used as a desulfurizing agent and an animal feed stock. Pioneering projects in resource circulation that focus on reusing desulfurizing agents are currently being implemented, and represent an important field of sustainable technology.



Fig.2-25 Aso yellow ocher"LIMONITE"

2-4-6 Natural springs and onsen (hot springs)

Aso Geopark has many magma-heated onsen (hot springs) and natural springs fed by catchments in the somma and central cones. These are attractive elements for many visitors. Over 1,500 springs exist, but their complex structure means that some are not fully understood. Many springs gush from the northern part of the caldera floor. They supply abundant water for domestic and agricultural use, and are recharged mainly in the slopes of the eastern central cones. The southern portion of the caldera also has abundant water resources, located mainly near the bottom edges and erosion valleys of the central cone group's alluvial fans. These are believed to be recharged mainly on the southern slopes of the central cone group. One of the most important springs is Shirakawa Spring, which gushes 60 tons of water per minute and was selected as one of Japan's 100 Best Water Environments by the Environment Ministry.

Springs in the somma are believed to be related both to the nature of the soil and to pyroclastic deposits. The sloped lower portions the caldera walls are comprised of pre-Aso volcanic rocks, alluvial cones and talus. Thick pyroclastic sediments can also be observed at the top of the caldera walls and all around the plateau on the outer slope of the caldera. Some springs gush from the cracks in welded tuffs or from non-welded sediments.

Onsens in Aso Geopark are heated by Aso Volcano and Kuju Volcano. The percentage of magma in these springs is small because of the abundant ground water, but quality varies with the heat source. For example, Kurokawa and Tuetate Onsens in the north somma, whose heat source is Kuju Volcano, are highly carbonated. Jigoku and Tarutama Onsens, located at the foot of the central cones, have acidic springs heated by Aso Volcano. In contrast, granite distributed underground in the vicinity of Uchinomaki Onsen, in the north caldera floor, gives the springs a high sodium bicarbonate content.



Fig.2-27 Gush of spring in Asodani valley

Many accommodations in Aso Geopark are located near onsens, allowing guests to experience the earth's energy as they relax with delicious food and hot springs.



Fig.2-26 Jigoku and Tarutama Onsen



Annex 2: Geological Heritage



Aso Geopark Promotion Council, JAPAN



A member of Japanese Geopark Network