箱根火山と丹沢山地の地質と熱水系

大木靖衛編

神奈川県温泉地学研究所報告

第15巻　特集号

昭和58年

神奈川県温泉地学研究所

神奈川県箱根町湯本

GEOLOGY AND HYDROTHERMAL SYSTEM OF HAKONE VOLCANO AND TANZAWA MOUNTAINS

Y. OKI Editor

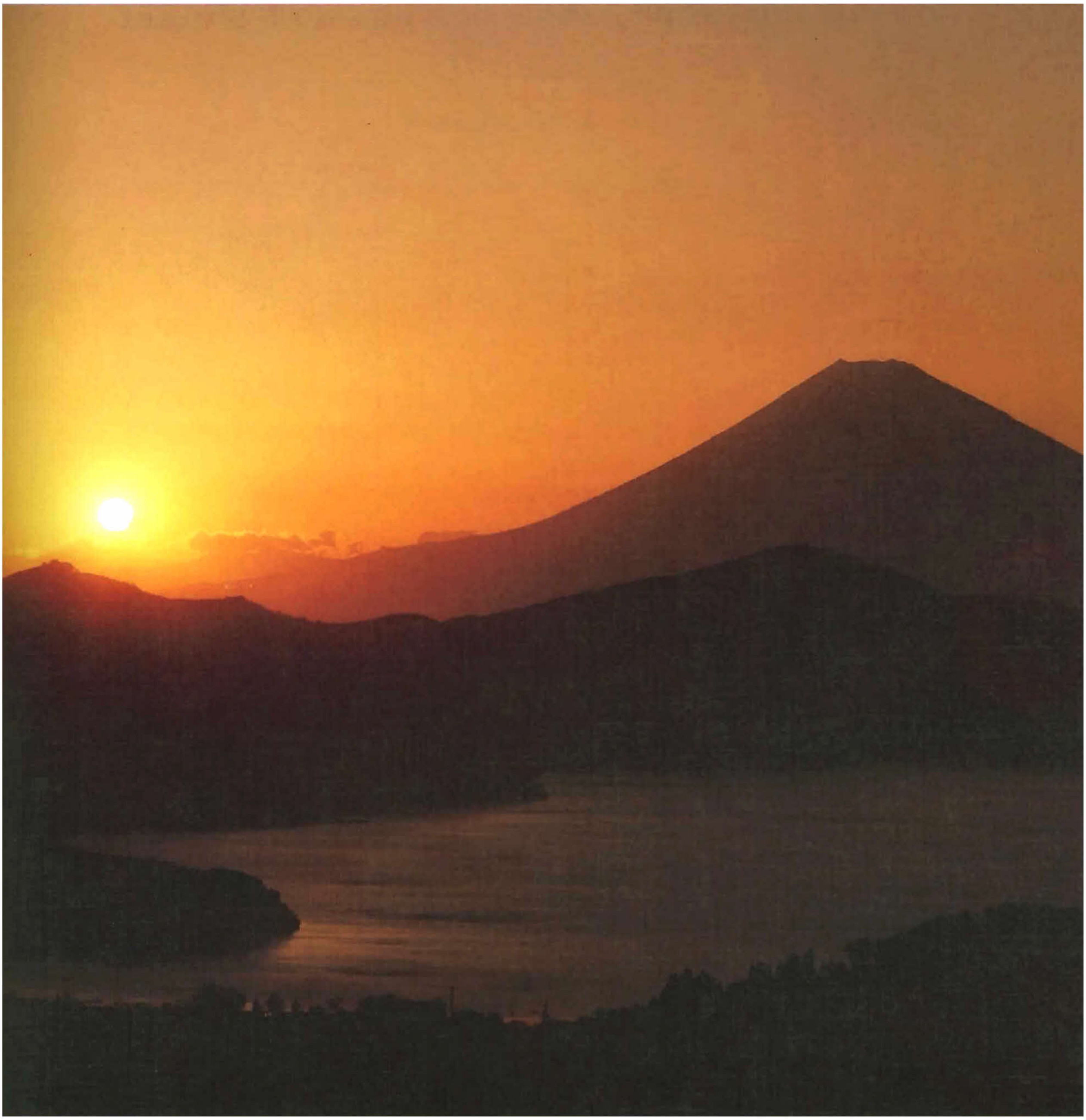
BULLETIN
OF THE
HOT SPRINGS RESEARCH INSTITUTE
KANAGAWA PREFECTURE

Vol. 15, SPECIAL ISSUE

1983

HOT SPRINGS RESEARCH INSTITUTE

KANAGAWA PREFECTURE
997 YUMOTO, HAKONE
KANAGAWA, JAPAN
250-03



Hakone caldera and Fuji volcano (Photo courtesy of Hakone Town Office).

Geology and Hydrothermal System of Hakone Volcano and Tanzawa Mountains

Yasue Oki, Editor

(Hot Springs Research Institute of Kanagawa Prefecture)

CONTENTS

Bulletin of the Hot Springs Research Institute of Kanagawa Prefecture. Vol. 15, Special Issue, 1-68 1983.

Fig. 0 Irrigation of paddy field contributes considerably to circulation of groundwater, which provide modern industries with water, in Odawara, eastern foot of Hakone.

INTRODUCTION

Japan is a country of islands which stretch in an arcuate shape along the Asian Continent. In contrast to the stable continents, Japan, a part of the fire girdle of the Pacific, is located in one of the most tectonically active sites in the world. The Japanese Archipelago consists of a series of large mountains bordered by small coastal plains. About 80 percent of the country is mountainous. Japan has a large population (112million) which ranks it seventh in the world with a population density of 306 per square kilometer. The main island of Honshu has a generally temperate climate with four distinct seasons. The backbone ranges of the Honshu Arc separate the island into two climatic regions. On the Pacific side, the summers are hot and humid due to the monsoons from the Pacific Ocean. The winters are dry and marked by many clear days. On the Japan Sea side, winter monsoons from the Asian Continent bring frequent snowstorms making the area one of the heaviest snowfall regions in the world. During the summer and autumn months, typhoons frequently hit the islands. Heavy precipitation provides Japan with enough water for agriculture and manufacturing industries, but it also causes natural disasters such as floods, landslides, etc.

The population is unevenly distributed throughout the country. Roughly 70 percent of the populace is concentrated in a belt along the Pacific coast from Kanto through the Inland Sea area to Kyushu. The heavy winter snows on the Japan Sea side may be one of the reasons that people migrate to the Pacific side of the island. Recent industrial growth along the Pacific side also serves to draw people from agricultural lands into this region. The agricultural communities are facing difficult times due to their declining population.

Acknowledgements

Paula K. Kakimoto of Geothermal Institute, University of Auckland read through the first draft of the manuscript with a lot of advice for the improvement, Tomio Hirano and Toru Awaya of Hot Springs Research Institute, Kanagawa Prefecture helped in the editorial work, to whom I am most grateful.

Y. OKI (Editor)

GEOLOGICAL SETTING

The main arc of Japan, the Honshu Arc, is divided into the Northeast Japan Arc and Southwest Japan Arc according to present volcanic and seismic activity. During the early to middle Miocene period, the Honshu Arc was split into two arcs by the development of a huge volcano-tectonic depression, the Fossa Magna. An extensive transgression of the sea onto the Northeast Japan Arc followed this event and was

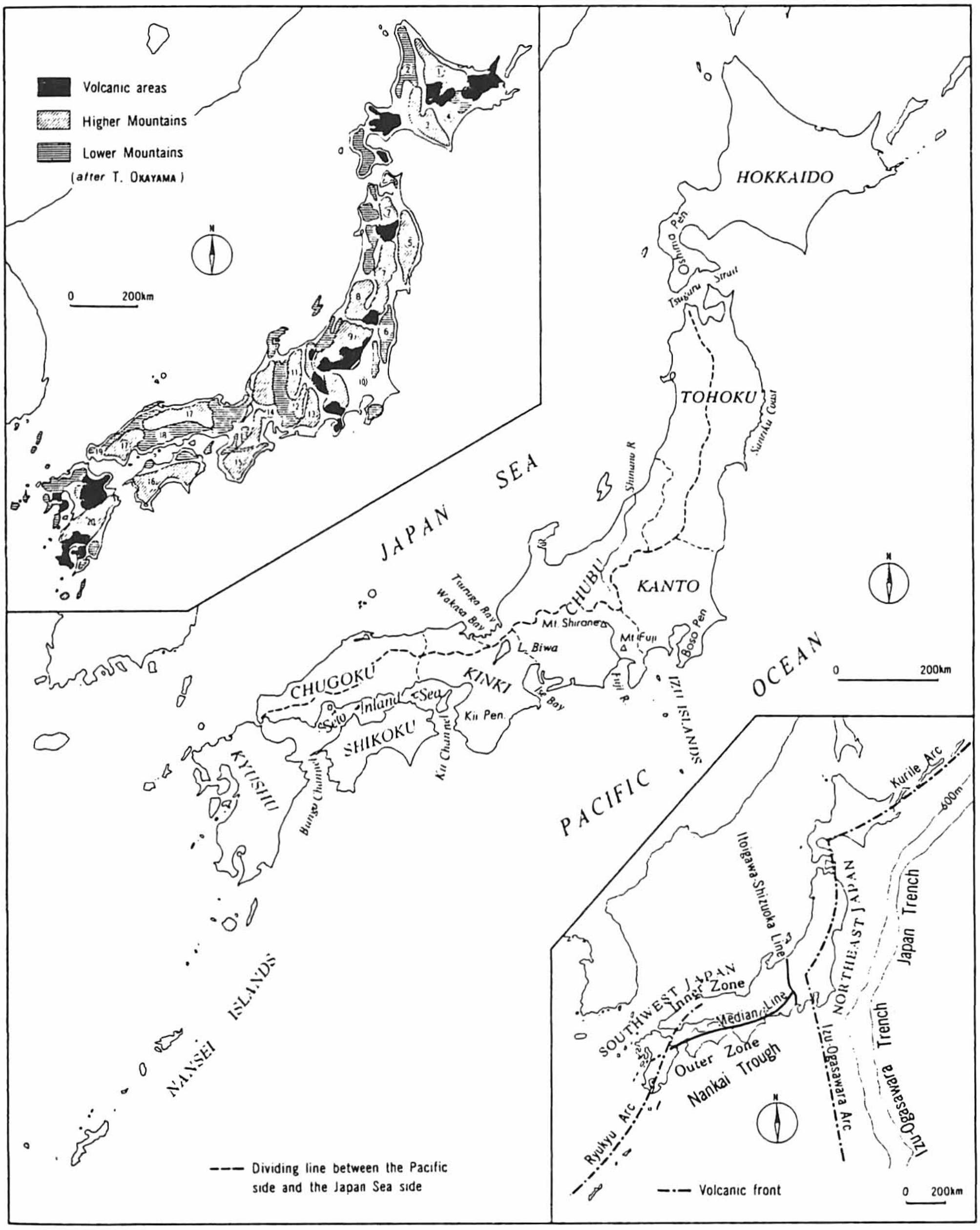


Fig. 1 Physical Geographic Regionalization of Japan (Y. Sakaguchi, 1980).
① Kitami Mountains ② Teshio Mountains ③ Hidaka Mountains ④ Tokachi Mountains ⑤ Kitakami Mountains ⑥ Abukuma Mountains ⑦ Ou Mountain Range ⑧ Asahi-Iide Mountains ⑨ Echigo Mountains ⑩ Kanto Plain ⑪ Hida Mountain Range ⑫ Kiso Mountain Range ⑬ Akaishi Mountain Range ⑭ Nobi Plain ⑮ Kii Mountains ⑯ Shikoku Mountains ⑰ Chugoku Mountains ⑱ Kibi Plateau ⑲ Iwami Plateau ⑳ Kyushu Mountains

accompanied by intensive volcanism. Volcanogenic sediments were thickly deposited in the arc, and subsequent burial metamorphism of these deposits produced green colored rocks, known collectively as the Green Tuff Formation. The formation of Kuroko-type ore deposits, made up of Zn, Cu, Pb, and Cd sulfides, was also associated with the submarine volcanism. The area has been uplifted above sea level in Quaternary times, and volcanic activity has built up a number of volcanoes along the East and West Japan Volcanic Belts. The volcanism and seismicity are more active in the Northeast Japan Arc and less active in the Southwest Japan Arc.

(Y. O)

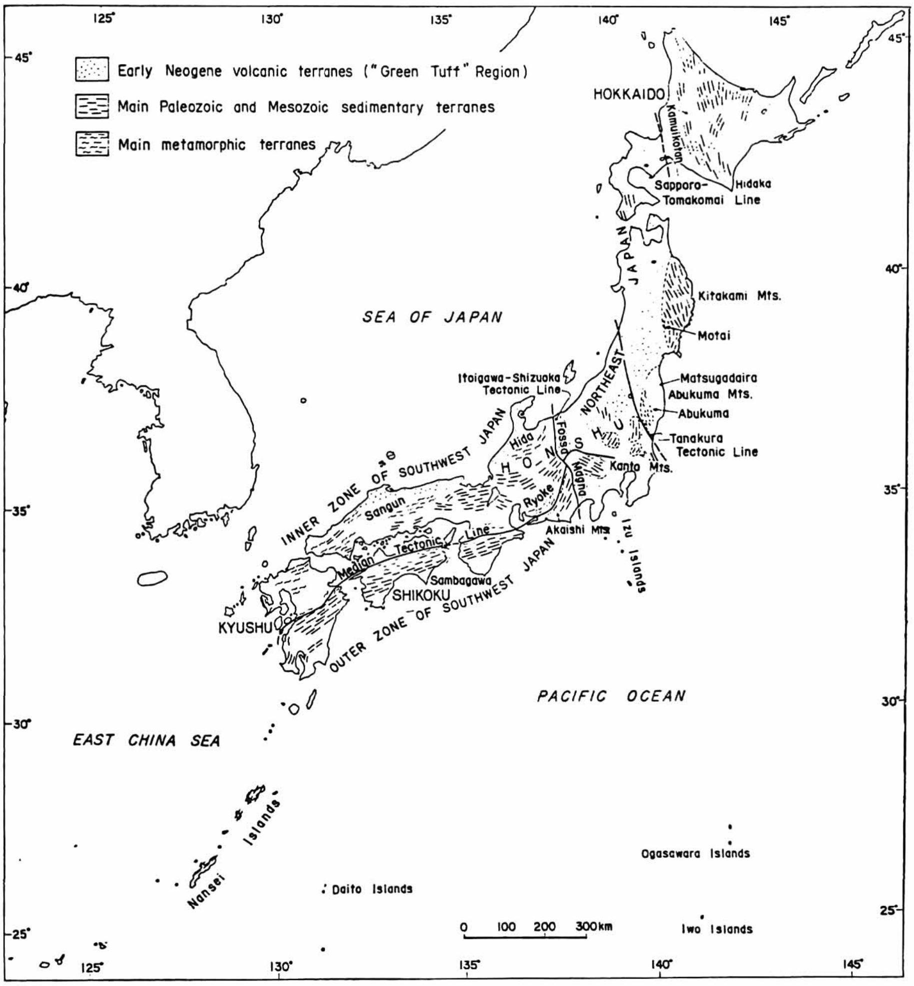


Fig. 2 Major structural elements of Japan (Geol. Survey of Japan, 1977).
Symbols are aligned to represent the general structural trends. Hida, Sangun, Sanbagawa, Abukuma, Matsugadaira, Motai, Kamuikotan, and Hidaka are the names of main metamorphic terranes.

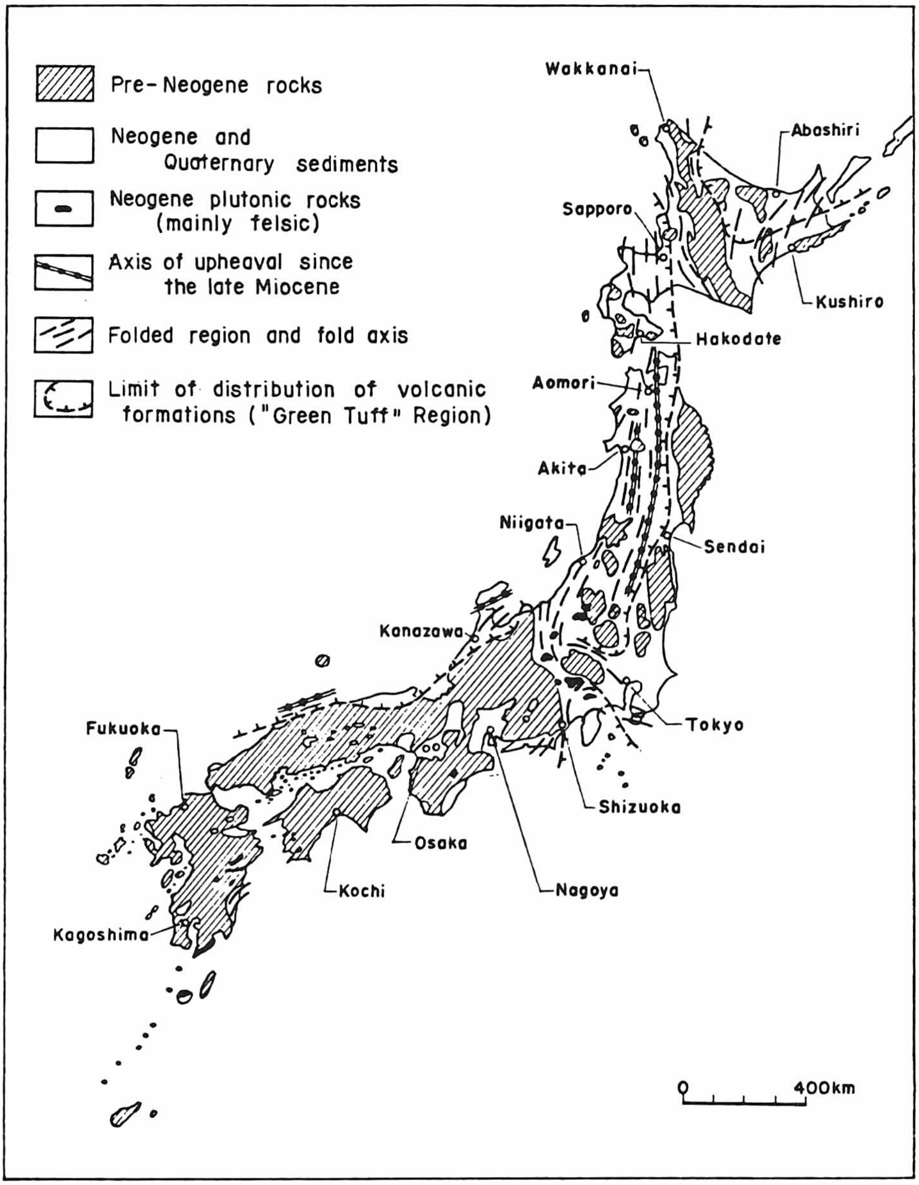


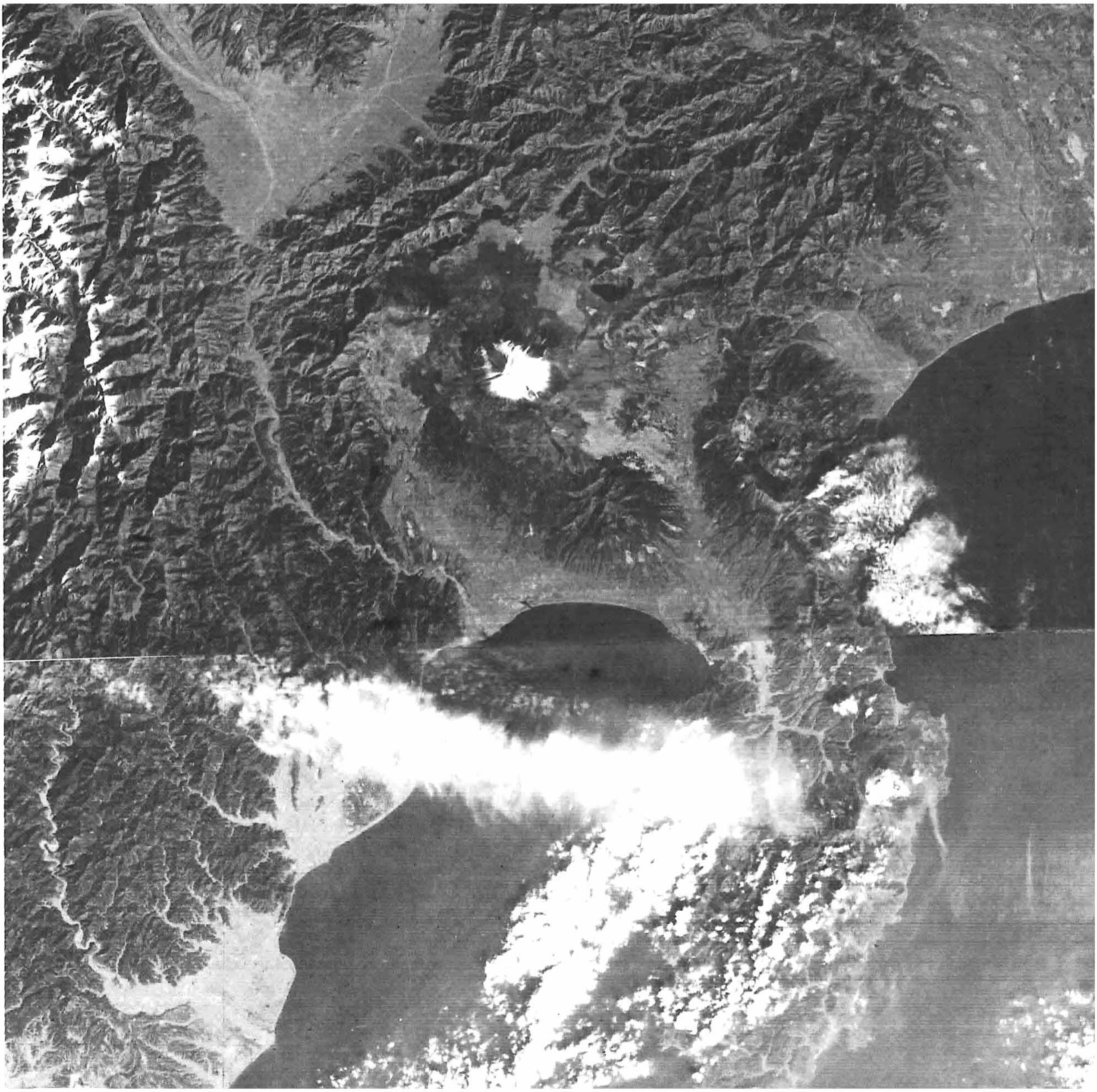
Fig. 3 Distribution and major geotectonics of the Neogene in Japan (Geol. Survey of Japan 1977, mostly from TAKAI and CHINZEI, 1967).

Reference

Geol. Survey of Japan (1977) Geology and Mineral Resources of Japan.

HAKONE-TANZAWA DISTRICT

Fig. O Landsat image of the South Fossa Magna region, showing Mt. Fuji in the center, the Hakone volcano on the east and Tanzawa mountains on the northeast.



Hakone-Tanzawa District

The Fuji volcanic zone, trending N-S in the Fossa Magna, belongs to the East Japan Volcanic Belt. The tectonic setting of the area is quite interesting. The Hakone

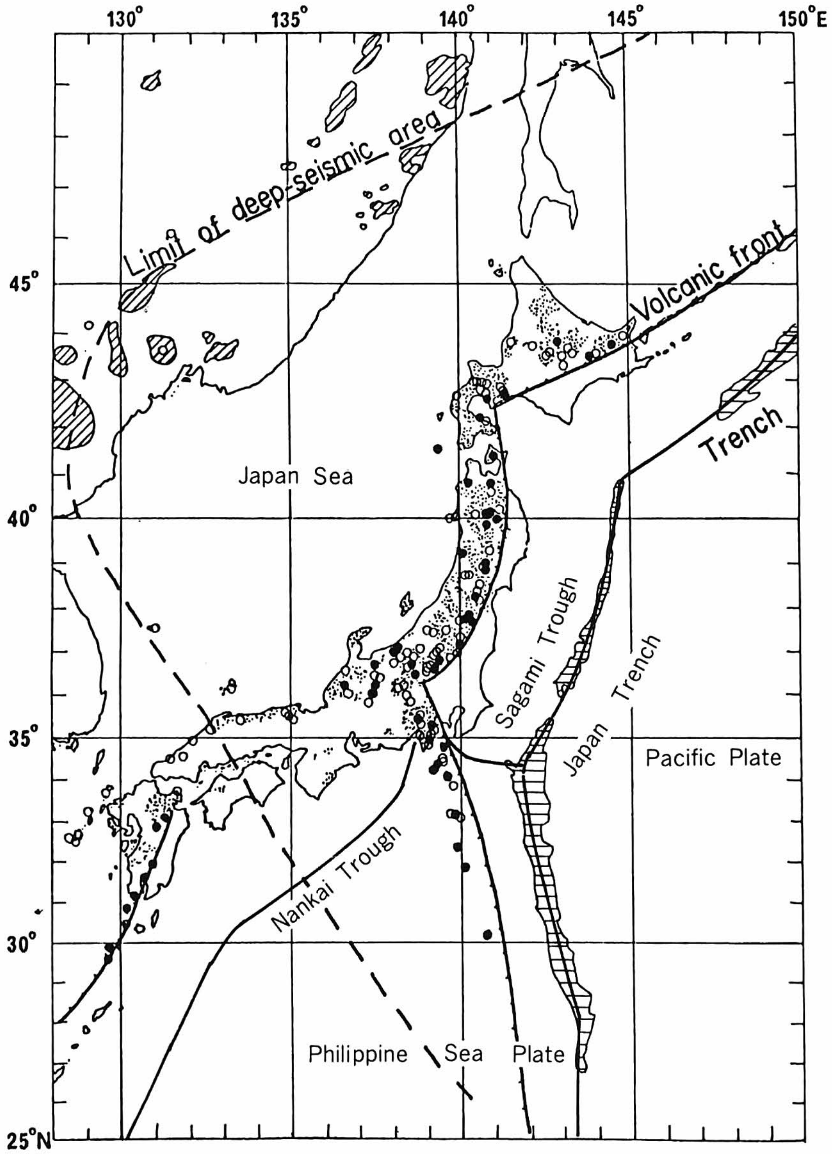


Fig. 1 Trench, volcanic front, volcanoes and deep seismic area around the Japanese islands. Solid circles: active volcanoes; open circles: Quaternary volcanoes; dotted areas: Late Tertiary volcanic rocks; hatched areas: Pliocene-Quaternary regional basalts.

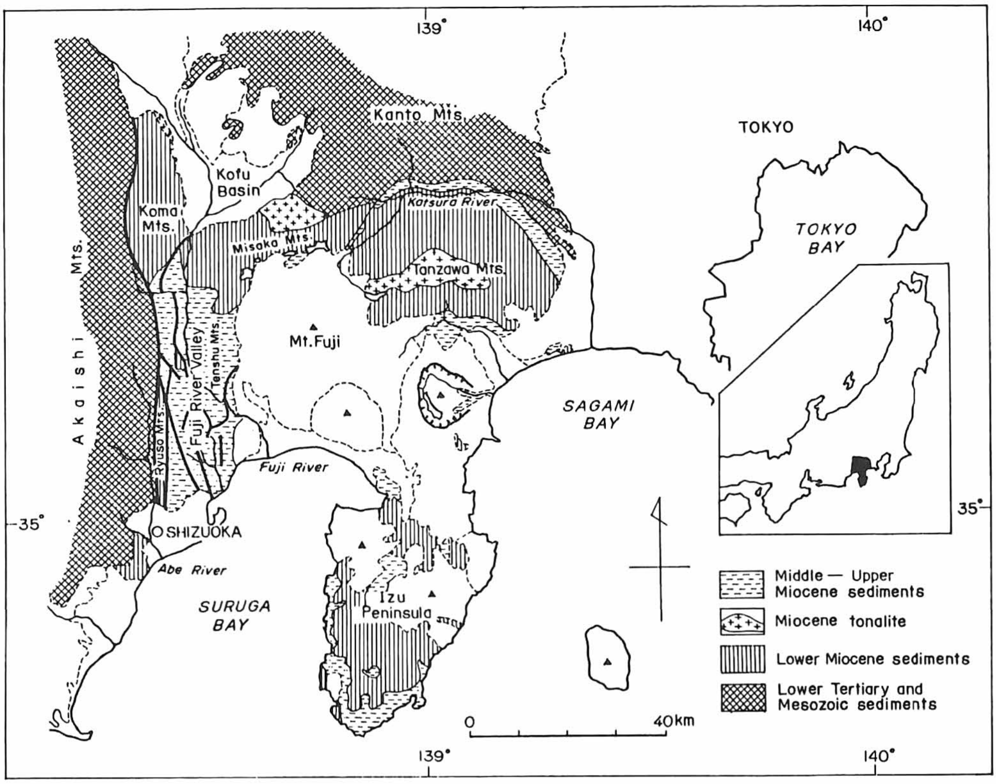


Fig. 2 Geologic map of the South Fossa Magna region (MATSUDA, 1962; partly modified), (Geol. Survey of Japan, 1977).

and Izu Peninsula area occupies the northern-most portion of the Philippine Sea Plate, which has collided against central Honshu during the Quaternary period. Further west, the plate subducts under southwest Honshu along the Nankai Trough. In island arcs, the distribution of volcanoes is often on the continental crust, parallel to the trench axis. The volcanoes of the Hakone and Izu Peninsula area, however, are on the oceanic plate of subduction. In this area, the active colliding plate boundary cuts across the active volcanic arc belt. The Philippine Sea Plate moves transcurrently, with a component of subduction. The last movement in 1923 of this portion of the plate boundary caused the great Kanto earthquake, which killed more than 142,000 people of the Kanto District.

1. ODAWARA

Odawara city, Kanagawa Prefecture, is situated on the Pacific coast 80km south-west of Tokyo, at the eastern foot of the Hakone volcano. It has a population of 170,000. The name Odawara means small (o) paddy (da) field (wara). Close to the Odawara Station is a replica of the main tower of the Odawara Castle, which is now a history museum. In the old days of Japan, Odawara was one of the important post towns on the Old Tokaido Trail. The famous Odawara lanterns were small portable bellows-lanterns made of bamboo and paper and well designed for the outdoors. There is a good fishing port. The chief agricultural products are mandarin oranges, pears and vegetables, as well as rice. Photographic films, drugs, processed fish-food and wooden crafts are the main industrial products. The area is of geological interest, lying on the plate boundary between the Philippine Sea Plate and the Eurasian Plate. See the map and table of the historical large earthquakes (Table 1). (Y. O)

Fig. 3 a Odawara lantern, a small portable bellows-lantern desinged for outdoors, commonly used in 17th to early 20th century.
3 b Odawara lanterns parade of Oshiro (Castle) Festival (Photo courtesy of Odawara City).

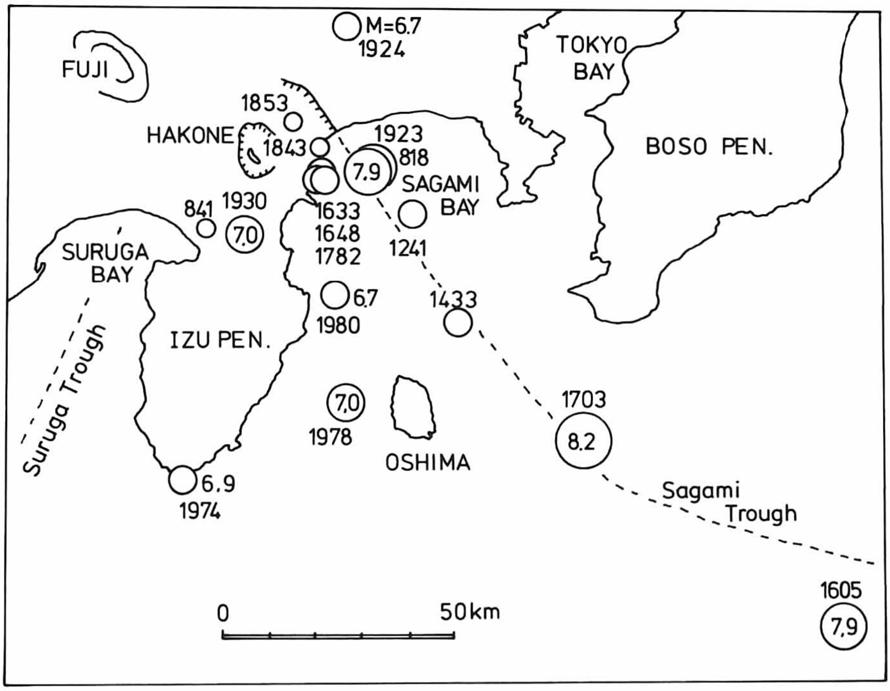


Fig. 4 Distribution of epicenters of destructive earthquakes occurred in the Sagami trough, which is a part of the plate boundary between the Philippine Sea Plate and the Pacific Plate.

Table. 1 Destructive Earthquakes occurred in the Sagami Trough

	Magnitude	Earthquakes	Remarks
818	7.9	Off Odawara E.	Tsunami and landslides.
1241	7.0	Sagami Bay E.	Tsunami collapsed the main Torii-gate of Hachiman Shrine, Kamakura.
1433	7.1	Sagami Bay E.	Head of Deva-king Statue in Oyama Temple fell down.
1605	7.9	Off Boso Peninsula E.	Great damage by Tsunami.
1633	7.1	Odawara E.	Odawara Castle collapsed partly.
1648	7.1	Odawara E.	Odawara Castle destructed.
1703	8.2	Off Boso Peninsula E.	Tsunami and Odawara castle was ravaged by fire.
1782	7.3	Odawara E.	Odawara Castle declined and Tsunami invaded the Castle.
1843	6.3	Odawara E.	Odawara Castle destructed.
1853	6.5	Odawara E.	Odawara Castle destructed.
1923	7.9	Kanto E.	Stone walls of Odawara Castle were seriously damaged. More than 142,000 people of the Kanto district were killed.

2. HAKONE VOLCANO*

Yasue OKI, Hot Springs Research Institute, Kanagawa Pref.

Hakone has been set aside as a National Park since 1933. There are many fascinating scenic volcanoes, historical remains, and hot springs, with comfortable hotels, well protected driveways and railways. In the old days of Japan before development of the modern transportation system, the Hakone volcano presented one of the most serious obstacles to traffic.

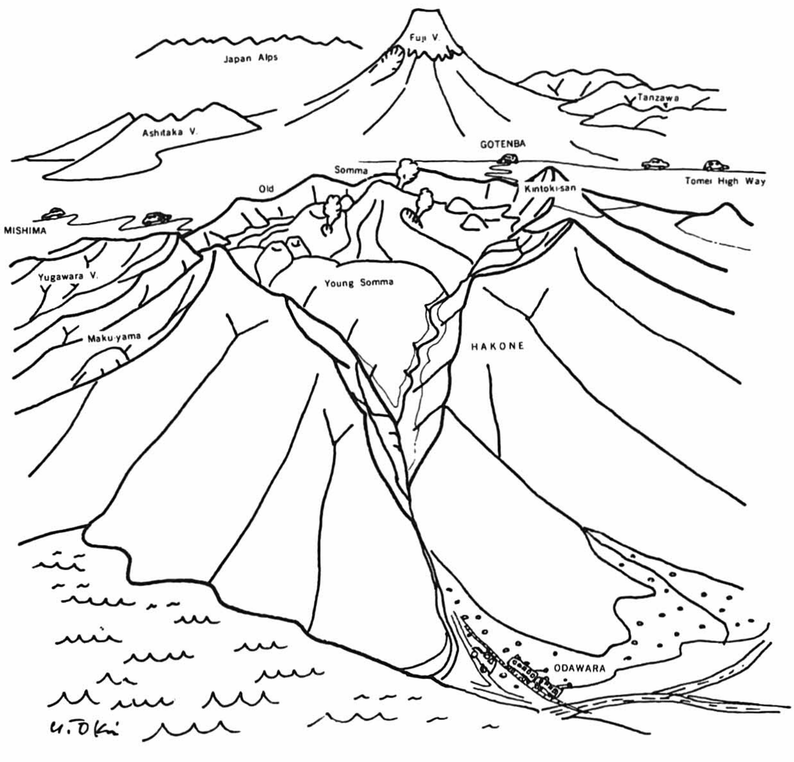


Fig. 5 The Hakone volcano and three entrances.

* This article is a revised summary of "Hakone Volcano" (Oki, et al., 1978), published in Bull. Hot Springs Res. Inst., vol. 9, no. 5, and is followed by several topics of interest, including large fossil trees in Lake Ashi, a folk tail of a nine-headed dragon by Oki (1981) and a tephra-chronological study by Machida (1980).

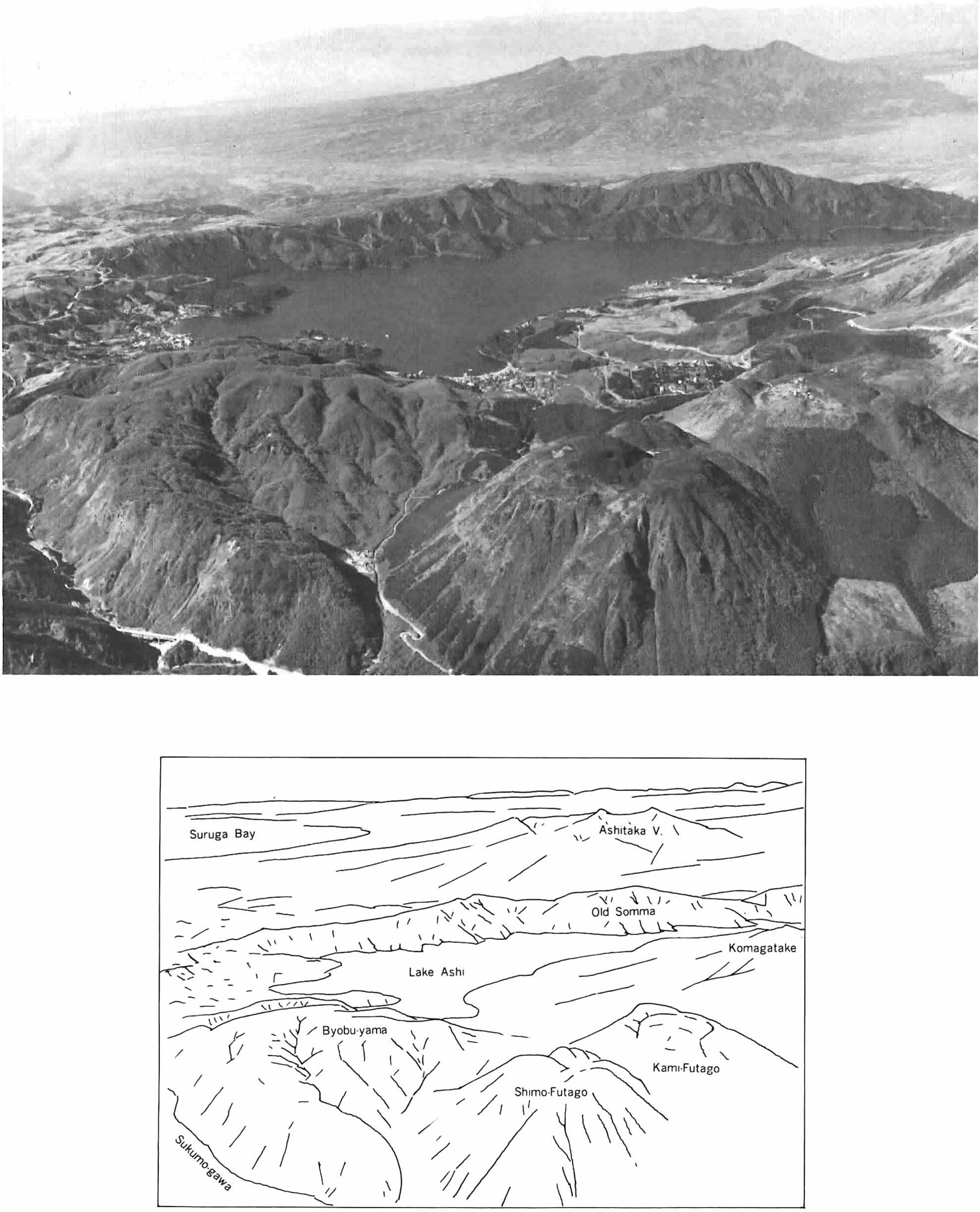


Fig. 6 The Hakone caldera (Photo courtesy of Odakyu Railway Co.).

Fig. 7 Geologic solid-model of the Hakone volcano after Kuno (1950).

Topography

Hakone is a triple volcano composed of two overlapping calderas and seven post-caldera cones (Fig. 5). The main body of the volcanic edifice, about 20 km long and 15 km wide, is a large composite cone, which once reached a height of about 2,700 m above sea level. The 800 to 1,200 m high circular ridge is called the Old Somma and measures 11 km in the N-S diameter and 10 km in the E-W diameter. In the eastern

Table. 2 Geologic map and stratigraphic succession of the Hakone volcano (Kuno, 1950 partly revised).

	Lake deposits, talus and river gravels		
F	**Fuji volcano**		
	Hakone volcano		
	Kanmuri-gatake pyroclastic flow and lava spine		2,900 y B. P.
CC_9	Kami-yama avalanche debris dammed up Ashinoko		3,100 y B. P.
CC_{1-8}	Central cone lavas, including nuée ardente and mud-flow deposits		
———	Second caldera collapse and erosion ———		30,000 y B. P.
P	Pumice flows		45,000 ~ 70,000 y B. P.
YS	Young Somma Lavas		130,000 y B. P.
———	First caldera collapse and erosion ———		200,000 y B. P.
OS_5	Satellite cones	Old Somma Lavas	
OS_4	Kintoki-san lavas	Old Somma Lavas	
OS_2	Andesite lavas	Old Somma Lavas	
OS_1	Basalt lavas and agglomerates	Old Somma Lavas	400,000 y B. P.
~~	Erosion ~~~~		
YV	**Yugawara volcano**		
~~	Erosion ~~~~		
TV	**Taga volcano**		
~~	Erosion ~~~~		
B	**Basalts and andesites of Pliocene** (Younger Pliocene)		
Qd	**Quartz diorite plug** (Pliocene)		
~~	Erosion ~~~~		
T_3	**Ashigara group**	Pliocene~Pleistocene to Miocene	
A_1	**Sukumo-gawa andesite group**	Pliocene~Pleistocene to Miocene	
A_2	**Haya-kawa tuff breccias**	Pliocene~Pleistocene to Miocene	
~~	Erosion ~~~~		
M_2	**Yugashima group**	Older Miocene	

half of the caldera, table mountains, about 800 m high, form an inner circular ridge called the Young Somma. They are the remains of a shield volcano which once filled the caldera.

The highest peak Kami-yama, 1,438 m, occupying the central part of the caldera, is one of the post-caldera cones and is associated with active solfataras. Ashinoko is a caldera lake which was dammed by a dry mudflow (avalanche) produced by the phreatic explosion of Kami-yama. The eastern slope of Hakone has been deeply carved in the Haya-kawa and Sukumo-gawa valleys, in which profiles of the volcanic sequence can be seen. Many hot springs are found along the valleys.

Geology

Kuno (1950) extensively studied the geology of Hakone and identified in the volcano three major geologic units: Old Somma, Young Somma and Post-caldera Cones (Fig. 7). Table 2 gives the stratigraphic succession of the major geologic units associated with Hakone.

Foundations of Hakone

The Hakone volcano stands on flat mountains composed of Miocene and Pliocene sediments of the Yugashima group (lower Miocene), Haya-kawa tuff breccias, Sukumo-gawa andesite group (middle Miocene to Pliocene) and the Ashigara group.

Geological history of Hakone

Kuno (1952) proposed the schematic diagram showing the geologic development of Hakone, as given in Fig. 8. The following interpretation is based mainly on Kuno's classic works combined with new evidence obtained recently.

First stage, huge composite cone

The eruptive activity of Hakone, which began about 400,000 years ago, first built a huge composite cone of 130 km^3 reaching about 2,700 m above sea level. The early stage of activity resulted in the eruption of agglomerates and lavas of tholeiitic basalt, 100 to 200 m thick in places. The later stage was explosive with alternate eruptions of andesite lava and pyroclastic material, which are 300 to 600 m thick as exposed in the present caldera wall. The total thickness at the center of cone seems to exceed 1,000 m. These rocks forming the main cone are known collectively as the Old Somma Lavas.

Volcanic ash, lapilli and pumice produced during this stage are widely spread over areas to the east of Hakone. These layers, called the Tama tephra, are well preserved in a 30 to 60 m thick layer in the Oiso Hills 20 km east of Hakone, suggesting repeated explosions of the violent Plinian to Vulcanian type. The majority of basalts and andesites of this stage are characterized by the presence of pigeonite pyroxene in the groundmass and are classified in the pigeonitic rock series. Thus, the caldera was significantly enlarged toward the east beyond the original boundary of the collapse. The Tertiary basement rocks of Hakone were eventually exposed along the bottom of valleys.

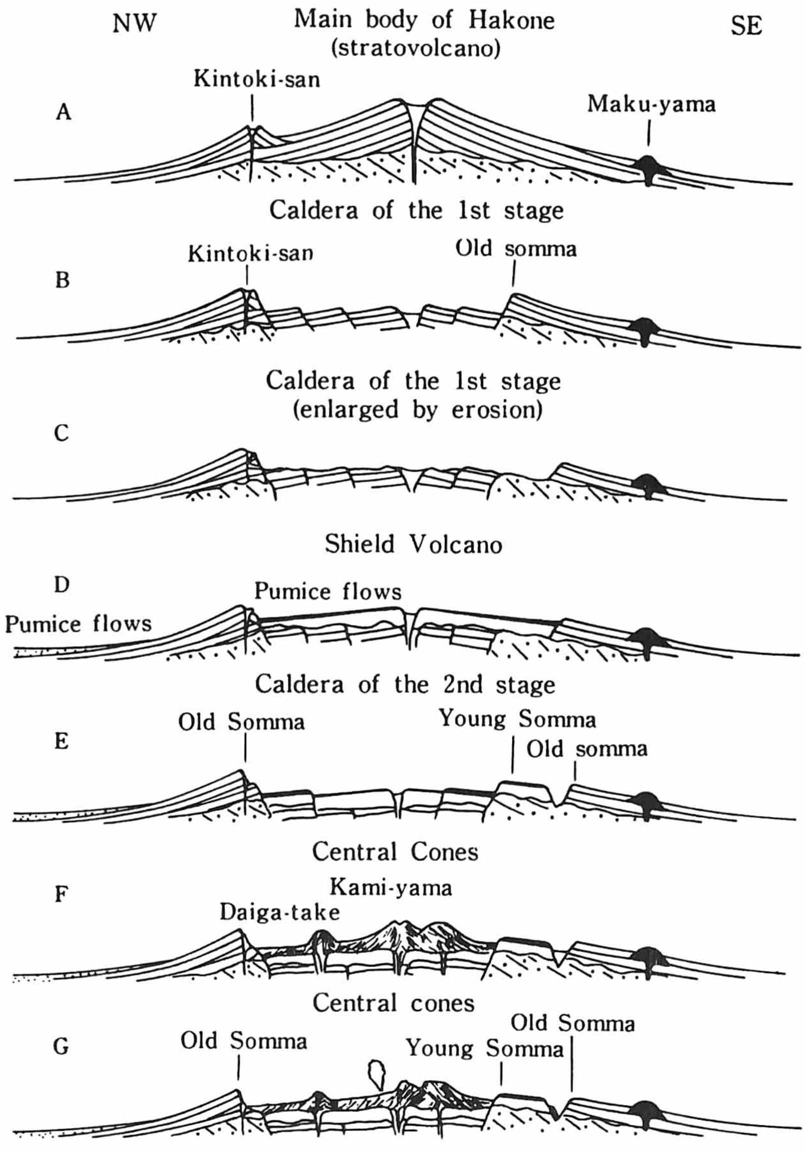


Fig. 8 Geologic development of the Hakone volcano (Kuno, 1950).

Satellite cones and dikes

Several satellite cones of pyroxene andesite and dacite, including Kintoki-san and Maku-yama, were formed on the main cone along the northwest-southeast trending Kintoki-san–Maku-yama dislocation line. Kuno (1964) observed 96 dikes in an 855 m wide zone on this dislocation line and estimated that approximately 215 dikes filled the zone of dike swarm. This also implies that the intrusion of dikes, with an average thickness of 2.85 m, expanded the edifice by 610 m.

Nakamura (1969) emphasized that the northwest-trending compressional stress prevailed during the first and later stages, resulting in the appearance of several satellitic and central cones as well as the penetration of the dike swarm described above. Hakone is actually a volcano of the central eruption, however, the preferred NW trending distribution of the satellite cones and the dike swarm suggests that a rift zone existed from which magma was extruded.

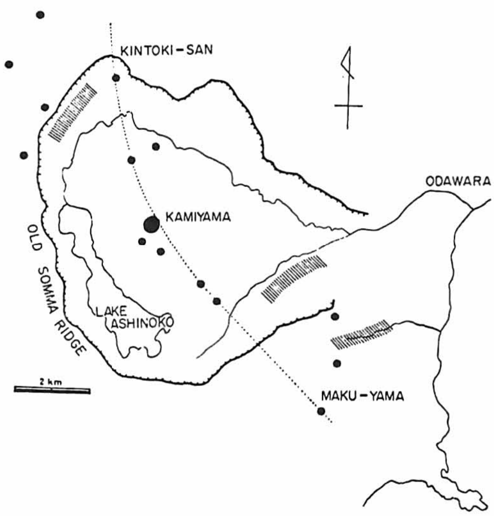


Fig. 9 Distribution of satellite cones, dikes, and post caldera cones (Kuno 1964, Nakamura 1969).

The first caldera

About 200,000 years ago, the central part of the main body collapsed to form the first caldera, which was originally about 8 km in diameter. Machida and Suzuki (1971) recognized three units of the first stage pumice flows in the upper horizon of the tephras on the Oiso Hills, suggesting that catastrophic explosions of the Krakatau type formed this caldera.

The collapse was followed by a long period of erosion, during which the eastern

Fig. 10 Futago-yama (twin domes) of post caldera cones and Ashinoko (caldera lake) (Photo courtesy of Odakyu Railway Co).

part of the caldera was significantly breached. Debris from this area as well as from other parts of the caldera was removed by rivers, which cut a steep canyon into the eastern slope.

Shield volcano, the second stage

The second period of eruption began 130,000 years ago with the explosion of more sialic material. After repeated explosions of pumiceous ash and lapilli, fluid lavas of felsic andesite and dacite of the pigeonitic rock series poured forth and built a flat shield volcano within the caldera. These fluid lavas flowed into and filled the canyon. The aggregate thickness of the lavas reaches a maximum of about 300 m and the volume of materials erupted during this second stage is about 14 km^3, one-tenth of the volume of the main cone. The pyroclastics of the second stage, which are mainly pumice falls, are well preserved in the Oiso Hills.

The second caldera

About 45,000 to 70,000 years ago, a large volume of dacite and andesite pumice was erupted from the central crater of the shield. Pumice flows spread out over the surface of the shield and over the outer slopes of the main cone, one pumice flow reaching a point as far as 50 km from the crater. Eleven successive flows have been recognized, and the total volume of the pyroclastic flows is 15 km^3. After the pumice eruptions, the central part of the shield volcano collapsed to form the second caldera, which largely overlaps the collapsed area of the first caldera. The eastern part of the shield volcano remains as table mountains, whose summits form an arcuate ridge defining the eastern rim of the second caldera, called the Young Somma (Fig. 10). Two major drainages have developed inside the caldera just along the boundary between the Young Somma Lavas and the Old Somma Lavas.

Post-caldera cones, the third stage

During the third period of eruption, viscous magma was extruded, consisting of augite-hypersthene andesite of hypersthenic rock series. In the early stage, about 30,000 years ago, violent explosions took place and scattered pyroclastic fragments, mainly pumice, over extensive areas of the southern Kanto district. Immediately following this event, seven Post-caldera Cones, one composite cone and six lava domes were built along the Kintoki-san–Maku-yama dislocation line. The order of formation of the Post-caldera Cones from north to south can be determined from the degree of denudation of the dome slopes. A nuée ardente discharged from the summit crater of Kami-yama, a Post-caldera composite Cone, flowed down the Haya-kawa canyon to Yumoto, the east entrance of the Hakone volcano. A charcoal fragment from the nuée ardente has been dated by ^{14}C at 20,000±690 years B. P. The total volume of the post-caldera eruptives amounts to 10 km^3.

Ashinoko, caldera lake

During the last phase of activity, a large phreatic explosion was followed by the extrusion of a lava spine in the explosion crater. Much of the northwestern part of Kami-yama collapsed due to the phreatic explosion, and the debris flowed down to the west wall of the caldera as a dry avalanche. This dammed a drainage of the caldera floor, forming the caldera lake Ashinoko. The ^{14}C age of a cedar fragment from the avalanche deposit is 3,100±90 years B. P. Following this explosion, the central part of the explosion crater was updomed by the rising of a very viscous magma, which was finally extruded as a lava spine through the roof of the dome. Another thin pyroclastic flow veneered the surface of the avalanche. The ^{14}C age of a charcoal trunk from the pyroclastic flow is 2,900±100 years B. P. (Oki and Hakamata 1975). Solfataric activity still occurs on the flank of Kami-yama at places such as Owaku-dani, Bozu-jigoku, Soun-jigoku and Yunohana-zawa, on the east flank of Koma-gatake.

Eruptive history of the Hakone volcano deduced from tephrachronology

Kuno (1950) described the history of the Hakone volcano based on geomorphological and petrological evidence and classified the volcanic edifice into three geologic units of the Old Somma, the Young Somma, and the Post-caldera Cones. Machida (1980) recognized the significance of the tephra deposits, which are both time-markers for stratigraphic correlation, as well as useful indicators of a volcanic explosion. He estimated the volumes of the 116 major tephras from Hakone, combined with some of their radioactive datings by ^{14}C and fission tracks, as shown in Fig. 12. Several large tephras were followed by tephra-flows, which may indicate that catastrophic explosions took place simultaneously. The sequence of activity suggested by tephra-chronology is that the first caldera, initially assumed to be a Glencoe type (where a volcanic edifice surrounded by a circular fault quietly sinks into the magma reservoir to form a caldera), was formed by a catastrophic eruption of the Krakatau type. A long quiet period was assumed to follow the formation of the first caldera (200,000 years B. P.), as indicated by the deep erosion of the eastern wall of the caldera. Machida, however, denies that the quiet period followed caldera formation, but suggests

Fig. 11 Kanmuri-gatake, a lava spine towering on the roof of lava dome appeared in the crater of phreatic explosion in Kami-yama, major Post-caldera Cone. The flat plane in the front view is a deposit of dry avalanche. Steaming grounds are seen at the foot of the lava dome in the crater.

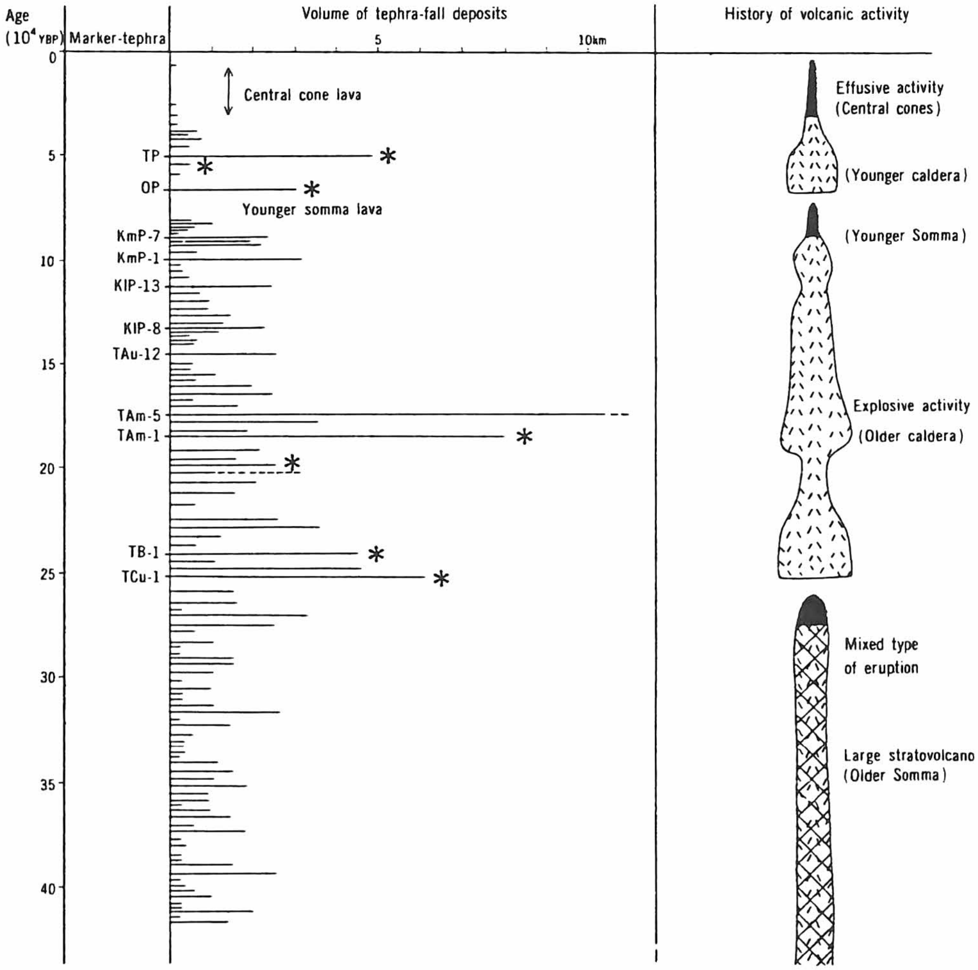


Fig. 12 Eruptive history of the Hakone volcano deduced from the study of tephras. Asterisks show the eruption accompanying tephra-flow (pyroclastic flow). Usually, volume of tephra with tephra-flow amounts to several times as large as that of tephra-fall only (Machida 1980).

instead that a period of repeated explosive activity continued until the final phase, which was dominated by lava eruptions. The revival of activity in the next phase began with the voluminous eruption of felsic tephras as falls and flows. This may correspond to the phase of the caldera formation. In Kuno's interpretation, the formation of the caldera marks the end of the large cycle of volcanic activity, whereas Machida (1977) defines the appearance of the caldera as the initial phase of the second and third volcanic cycles.

Fossil Trees in Lake Ashi

Many large fossil trees are submerged in Lake Ashi. Some of the trees are 6 to 30 m tall and stand on the lake floor as if in their natural mode of growth, suggesting that a large needle-leaf forest which once thickly covered the caldera floor had since been flooded by the appearance of Lake Ashi. The ^{14}C age of the fossil trees is about 1,600 years B. P., which suggests that the phreatic explosion of Kami-yama occurred 1,600 years ago. However, chronological evidence from the two scoria deposits and the pyroclastic flow overlying the dry avalanche, and the ^{14}C ages of the cedar and the charcoal trunk in the flows, do not indicate that a phreatic explosion occurred 1,600 years ago, forming Lake Ashi.

We believe that a large earthquake of magnitude 8 may have shaken the area 1,600 years ago, resulting landslides on the steep slopes of the caldera wall. Some tall trees growing on large blocks of land were moved into the lake, as if on a conveyor belt. A recent landslide has occurred which supports this interpretation. During the 1930 North Izu earthquake of magnitude 7.0, a landslide on the southern rim of the Hakone

Fig. 13 Fossil cedar trees in Lake Ashi (Photo courtesy of the Yomiuri).

caldera transferred down to the lake site a 20 m tall, large standing fir tree. The appearance of landslides on the caldera wall, large trees standing on the lake floor, the occurrence of large earthquakes and the folk tale of the nine-headed dragon in Lake Ashi, all appear to be connected, indicating that the Hakone and Izu areas lie in a country of earthquakes.

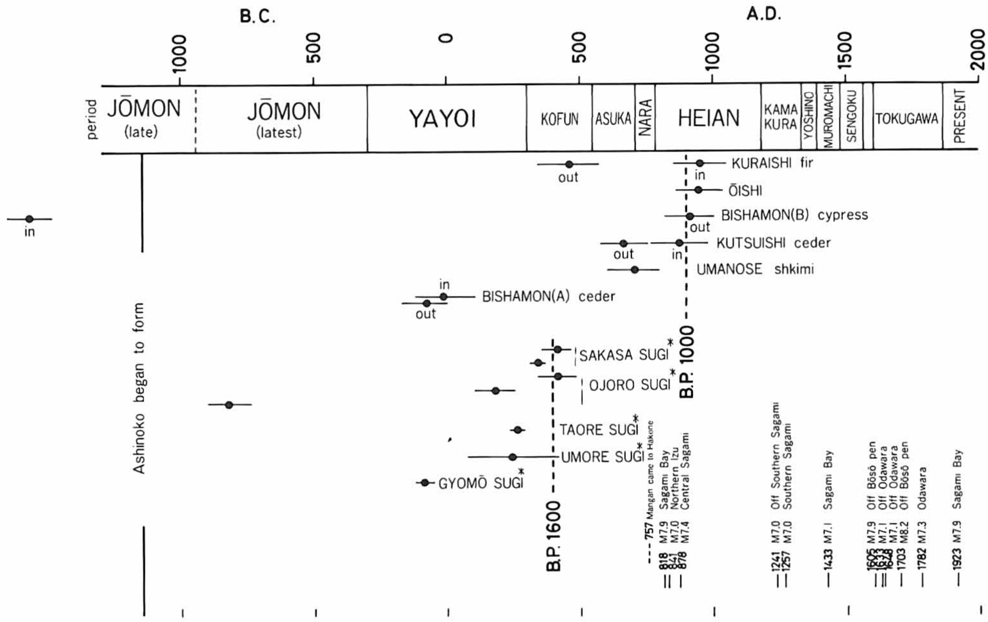


Fig. 14 Diagram showing the chlonological correlation of fossil trees in Lake Ashi and historical destructive earthquakes of the Kanto district (Oki et al. 1982).

Nine-headed dragon (Kuzuryu) in Lake Ashi

Once upon a time, in the water of Lake Ashi, there lived a huge nine-headed dragon. He was very temperamental. When he was angry, he jumped out from the lake, destroying farm yards, collapsing houses and sometimes killing people. The villagers were terribly frightened by his barbarism, and to prevent his violence, they had to offer one of their lovely daughters as a human sacrifice to the dragon every summer. When summer arrived, the villagers felt very sad, thinking about the next sacrifice to the dragon.

A famous priest called Mangan-shyonin (719-816), who had memorized 10,000 scrolls of Buddhist scriptures, heard this sad story. He had come from Kyoto to Hakone in 757 A. D. to combine Shintoism, the native religion, with Buddhism from China and Korea, into a new Shinto-Buddhism. During the period from the sixth to the eighth centuries, there was a heavy flow of Chinese culture into Japan, and Buddhism served

Fig. 15 Nine-headed dragon of Lake Ashi.

as an important vehicle for the transmission of Chinese culture. Mangan-shyonin thought that the noble power of Buddhism could solve this sad story. He made a large pile of the 10,000 scrolls of Buddhist scriptures on an altar beside the lake and read all of them in a loud voice for several days. His calm voice penetrated the lake water. The nine-headed dragon finally opened his rude mind. He appeared on the water and promised never to kill the villagers and never to destroy the farm yards. He also promised to be a guard for the lake and the Hakone shrine. The priest forgave the dragon's faults. But he tied each of the nine heads with chains to the trunks of cedars in the lake.

In this folk tale, the image of the nine-headed dragon may have come from the many landslides on the caldera wall caused by the large earthquake. The distribution of landslides may have given the impression of deep nail marks on the wall scratched by a huge monster like a nine-headed dragon. You may wonder why a nine-headed dragon was created instead of a "one-headed dragon". Kuzuryu (nine-headed dragon) is a compound word composed of ku (nine), zu (head), and ryu (dragon). Phonetically, "kuzu" is also the stem of "kuzu-reru", which implies collapse. Kuzu can be naturally converted into nine (ku) heads (zu), giving rise to the folk tale of the nine-headed dragon. A famous river in the Fukui Prefecture is called Kuzu-ryu, because of the terrible floods in the rainy season.

3. HAKONE HYDROTHERMAL SYSTEM*

Yasue OKI, Hot Springs Research Institute, Kanagawa Pref.
Tomio HIRANO, Hot Springs Research Institute, Kanagawa Pref.

Historical aspect

Hot springs of Hakone, like others of Japan, have long been used for special cures in medical treatment as well as for bathing and relaxation. Priest Shaku-Joteibo discovered the Yumoto Hot Springs in 738, and since then, many new hot spring sites have been found. During the Edo era about 300 years ago, Hakone was known for its seven hot spring areas, most of which were located along the deep Haya-kawa valley. In addition to their contribution to general health, hot springs are believed to be very useful in treating cases of specific physical and medical diseases, not including

---

* This article is an abridged summary of Oki (1978), "Hot Springs and Hydrothermal System of Hakone," published in Bull. Hot Springs Res. Inst., vol. 9, no. 5, additional topics include isotope geochemistry by Matsuo, et al (1979).

Fig. 16 Treatment of moxibustion for hemorrhoids after the treatment of steam bath at Miyanoshita, Hakone (Toto Bunso and Roka, 1811).

those caused by bankruptcy and broken hearts. In Hakone, for example, Ubako Hot Springs are used for the treatment of eye disease. During the Edo era, a steam bath at the Miyanoshita Hot Springs combined with moxibustion was the treatment for hemorrhoids (Fig. 16).

There is an old saying about the occurrence of hot springs in this district: "We can't expect hot springs where we can see Mt. Fuji". Kuno proposed a new saying that hot springs are expected where the Yugashima group, the basement rocks of the Izu and Hakone district, is exposed. We will demonstrate that both of these sayings are valid in light of our scientific work on the hydrothermal system.

Thermal Structure

There are more than 300 deep wells penetrating thermal waters. Their average depth is about 500 m, and several reach a depth of 1,000m. More than 60 temperature logs of deep wells were made, from which an isothermal map at sea level was drawn, as shown in Fig. 17. It is interesting that the temperatures are highest in the central part of the caldera, decreasing outward in a concentric pattern, in correlation with the structure of the caldera. The isothermal line contours are more closely spaced on the western side than on the eastern side. The wider contours to the east suggest a flow mechanism of thermal water from west to east.

Hydrology of thermal waters

The hydrology of the Hakone system is essentially controlled by the water level of Ashinoko (lake) in the west and by that of the Haya-kawa valley in the east. The water table appears to dip gently to the east based on water levels observed in the deep wells. An interesting fact is that with increasing depth during drilling, the water level of perched water in the drillhole declines and finally holds a stable level when the hole reaches the major reservoir. Water level measurements in the deep wells again suggest a subsurface flow from west to east. The temperature in the body of the Old Somma is relatively low, which indicates that the body of the composite cone can be compared to a sponge, partly filled with cold groundwater.

Zonal distribution of thermal waters

Zonal mapping of thermal waters is mostly based on the relative abundance of major anions such as Cl, SO_4, and HCO_3. Four zones are recognized, as shown in Fig. 19.

Zone I is characterized by acid-sulfate waters associated with solfataric fields, and is found at the highest part of central cones Kami-yama and Koma-gatake.

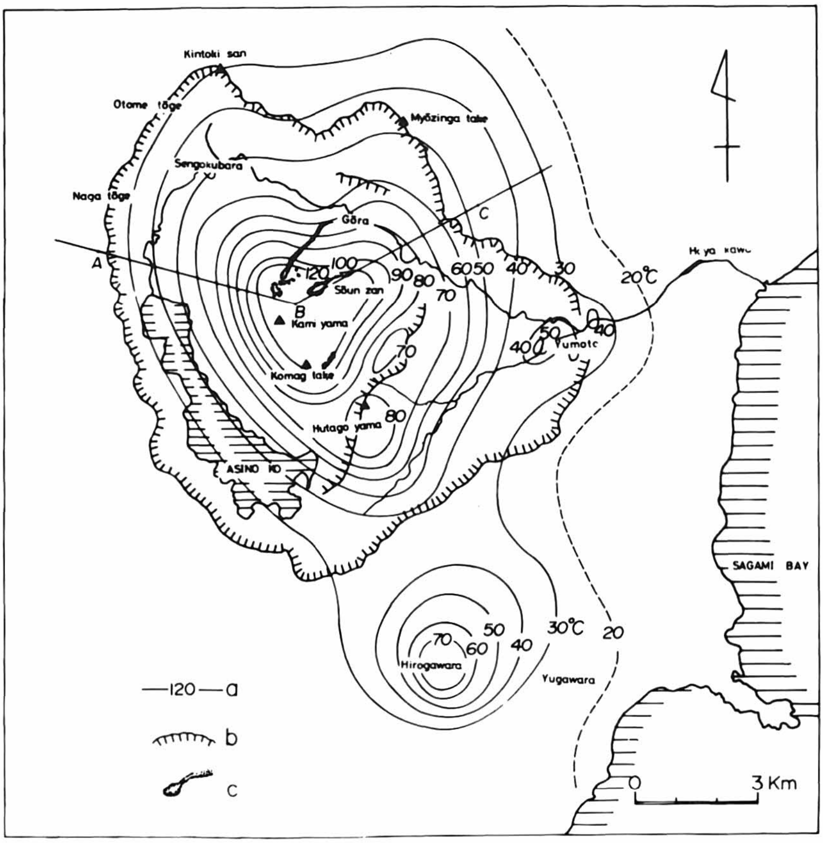


Fig. 17 Thermal structure of the Hakone volcano at the sea level (Oki and Hirano. 1970).
a : Isotherm, b : Caldera rim, c : Solfatara

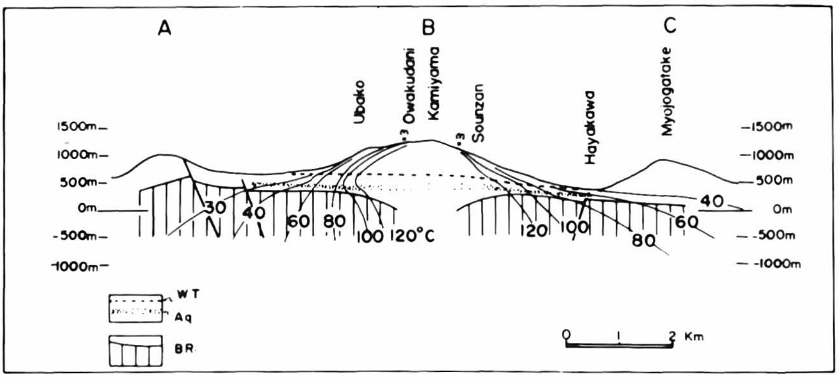


Fig. 18 East-west cross section of Hakone illustrating geologic structure and isothermal profile (Oki and Hirano. 1970).
WT : Water table, Aq : Aquifer, BR : Basement rocks

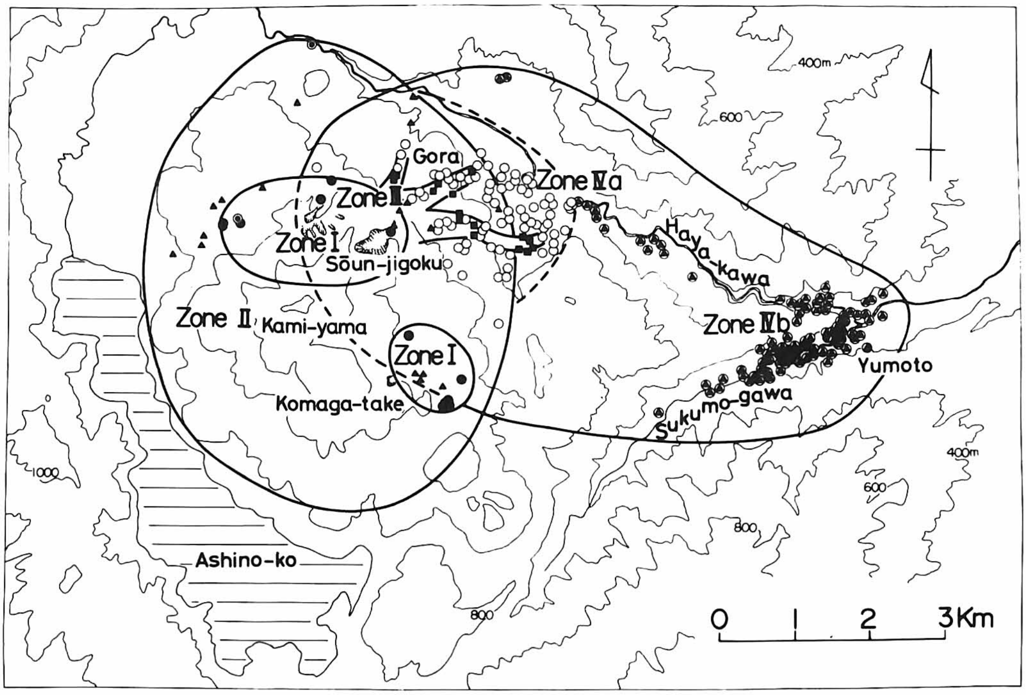


Fig. 19 Zonal mapping of thermal waters (Oki and Hirano 1970).
Zone I : Acid sulfate waters
Zone II : Bicarbonate-sulfate waters
Zone III : Sodium chloride waters
Zone IV : Mixed type waters

Zone II is characterized by bicarbonate-sulfate waters with moderate temperature and pH which are widely distributed in the western half of the caldera. The distribution and mode of occurrence of zone II waters strongly suggest that the major part of HCO_3 is supplied by the decomposition of fossil plants, which are commonly intercalated in the volcanic deposit.

Zone III is characterized by sodium chloride waters with high temperature. These waters originate as subsurface streams, which start from a depth of 300 m beneath an active solfatara, Soun jigoku, trend to the east, and finally appear as hot springs on the steep slopes of Haya kawa valley.

Zone IV waters, sometimes referred to as mixed type waters, are widely distributed in the eastern side of the caldera, which is deeply dissected by the two drainages of Haya-kawa and Sukumo-gawa.

Zone IVa consists of mixed type waters restricted to the basal part of the central cones.

Zone IVb consists of waters restricted to the basement rocks of the Hakone volcano.

Table. 3 Chemical composition of Hakone thermal waters (Oki and Hirano 1974).

ZONE	I	II	III	IV	
Type	A. S.	B. S.	NaCl	M.	(M.)
Temp. °C	49.7	57.5	91.5	65.5	56.0
pH	2.9	8.1	7.7	8.4	8.0
H^+(ppm)	1.18				
Li^+	0.0	0.068	2.43	0.27	0.042
Na^+	42.7	88.5	1490.	441.	348.
K^+	8.90	12.1	154.	39.8	3.40
Ca^{2+}	87.4	140.	114.	106.	53.9
Mg^{2+}	24.3	84.9	0.0	16.8	0.0
Fe^{2+}	0.099	0.56	0.105	0.257	0.00
Al^{3+}	22.6	0.22	0.12	0.05	0.03
Mn^{2+}	n. d.	0.00	0.007	0.44	0.00
Cl^-	7.15	19.8	2568.	617.	549.
HSO_4^-	52.4				
SO_4^{2-}	526.	381.	81.5	226.	85.1
HCO_3^-	0.	590.	29.7	287.	36.7
CO_3^{2-}		1.72		2.11	0.26
BO_2^-		0.34	3.58	2.34	0.70
$HSiO_3^-$		5.87	4.09	13.9	1.74
H_2SiO_3	301.	238.	411.	282.	67.2
HBO_2		5.79	122.	16.1	20.6
CO_2		14.2	2.19	2.75	
Total	1074.	1583.	4983.	2053.	1166.
Li/Na		0.00077	0.0016	0.0006	0.00012
K/Na	0.21	0.14	0.10	0.09	0.01
B/Cl				0.006	0.01
ΣCO_2/Cl		22.5	0.009	0.35	0.016
SO_4/Cl	80.8	19.2	0.032	0.366	0.155
Depth of well	Hot Spring	525m	506m	351m	650m

Analyzed by T. Hirano and Y. Tajima

A. S. Acid sulfate water.
B. S. Bicarbonate-sulfate water.
NaCl Sodium-chloride water of central cones area.
M. Mixed type (sodium chloride-bicarbonate-sulfate water).
(M.) Mixed type (from basement rocks, sodium chloride-bicarbonate-sulfate water).

Table 3 shows the chemical composition of each type of thermal water. Water of zone I is low in pH and Cl, but high in SO_4, Ca, Mg and Al. Water of zone II is also low in Cl, but high in SO_4, HCO_3, Ca, and Mg. Water of zone III is quite high in Cl, Na, and SiO_2, but low in SO_4 and HCO_3. Water of zone IV contains various amounts of the major anions.

Compositional trend of thermal waters

Like the ties of parents and children, there are some compositional trends in the chemical properties of thermal water. Fig. 20 is a triangular diagram of the three

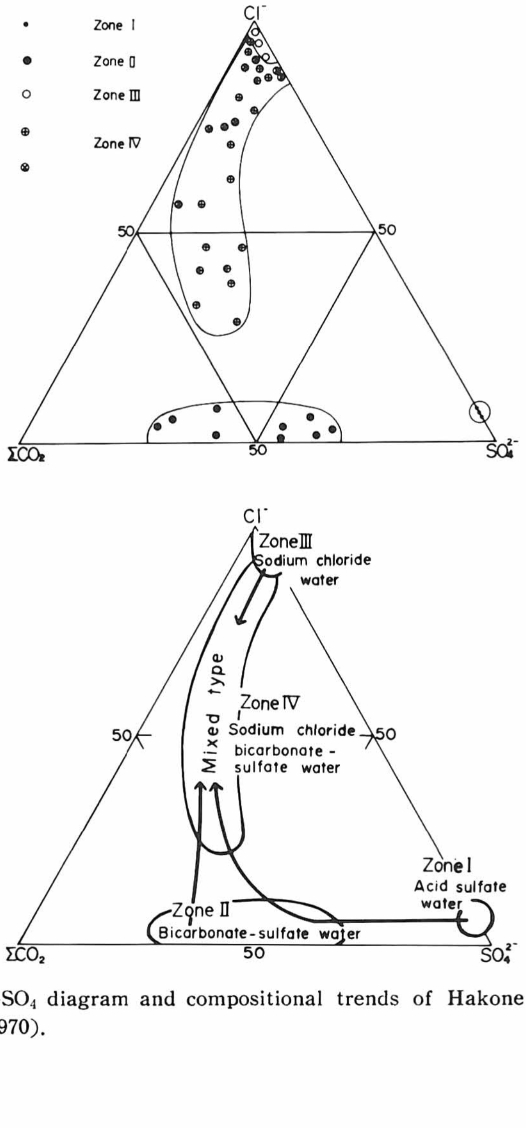


Fig. 20 Cl-total CO_2-SO_4 diagram and compositional trends of Hakone thermal waters (Oki and Hirano, 1970).

major anions showing the compositional trends of the Hakone thermal waters. Zone I waters of the acid-sulfate type are in the SO_4 corner and zone III waters of the sodium chloride type are in the Cl corner. Zone II waters of the bicarbonate-sulfate type consist of deep groundwater which has infiltrated through the caldera floor and central cones, and they extend along the CO_2-SO_4 line. Zone IV waters are distributed in an area suggesting the mixing of zone II and zone III waters. The convex trend of zone IV waters toward the total CO_2 apex may indicate the formation of bicarbonate during mixing and flowing of thermal waters.

Genetic model of Hakone hydrothermal system

Fig. 21 is a genetic model of the Hakone hydrothermal system (Oki and Hirano, 1970). The asymmetric pattern of isothermal contours, the zonal distribution of thermal waters, and the eastward inclination of the water table all suggest the following mechanism for the genesis of the Hakone hydrothermal system.

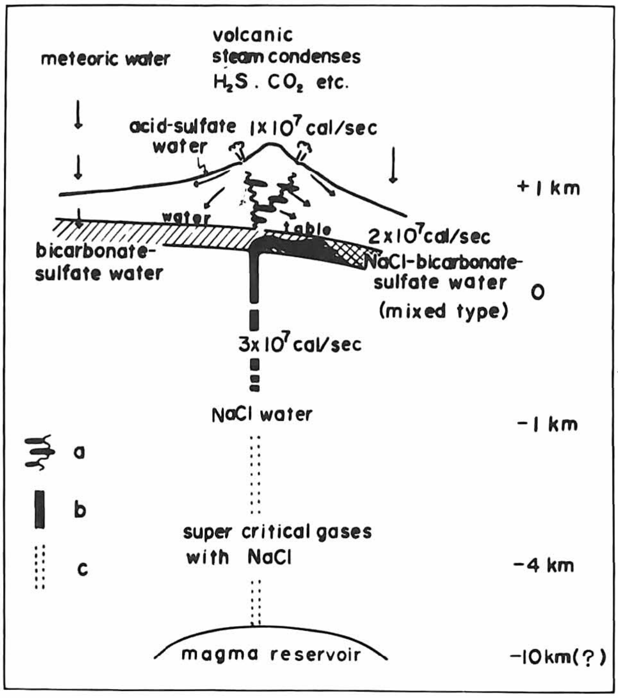


Fig. 21 Genetic model of Hakone hydrothermal system (Oki and Hirano 1970).

a : Repeated processes of vaporization and condensation of volcanic steam resulting in concentration of volatile components such as H_2S and CO_2.

b : Sodium chloride water (zone III).

c : Super critical gases (steam) with NaCl.

Groundwater which infiltrates the western side of the caldera flows eastward, passes through the basal part of the central cones, and then contacts high temperature volcanic steam coming up through the volcanic conduit. At a depth of a few kilometers below the central cone Kami-yama, the temperature and vapor pressure are high enough to dissolve a considerable amount of sodium chloride and silica in the steam. By the mixing of low temperature groundwater with high temperature dense steam, high temperature streams of sodium chloride water are formed, that flow through the permeable zone, mix with groundwater percolating down from the surface, and finally appear as hot springs on the steep slopes of the Haya-kawa valley.

At the top of the major reservoir being penetrated by the steam vent, the thermal water boils. The confining pressure on the thermal water decreases as the water approaches the surface. This means that most salts dissolved in the original gas phase are left behind in the liquid phase. Condensation of secondary steam derived from depth may take place repeatedly within local layers of thermal waters located above the major reservoir, in the body of the central cone.

After repeated vaporization and condensation of the thermal water, volatile components such as hydrogen sulfide and carbon dioxide are enriched in the gas phase, and finally appear as volcanic gases in solfataras. We would like to propose a term "volcanic cone effect" for this process. The physical and chemical properties of the high temperature steam will be given in a later section.

Seismic activity of Hakone

Local seismic activity sometimes takes place in the Hakone caldera. Since the

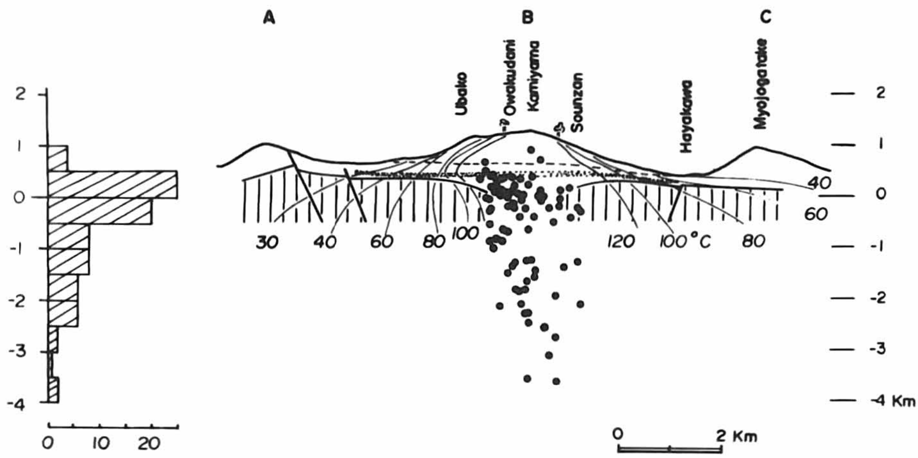


Fig. 22 Distribution of micro-earthquakes and the depth frequency relation plotted on east-west cross section (Minakami 1960, Minakami et al. 1969, Hiraga 1972, and Oki and Hirano 1974).

earthquake swarms of 1959 and 1960, seismic observations have been made by Minakami, and more recently by Hiraga of the Hot Springs Research Institute. Minakami (1960) reported that the Hakone earthquakes occur mostly in a narrow area bounded by the isothermal line of 100 °C at sea level. Depths of the foci are generally shallower than 4 km, and mostly 1 to 2 km below the surface (Fig 22). The generation of the Hakone earthquakes may be triggered by the boiling of thermal water at various depths in the central part of the caldera.

Sodium chloride waters

White (1957) emphasized the importance of sodium chloride in the origin of volcanic thermal waters based on experiment in the H_2O-NaCl system, which demonstrated that superheated dense steam at above 374 °C and 221 bars (critical temperature and pressure) can dissolve a considerable amount of sodium chloride in the gas phase. Thus, the existence of sodium chloride water may indicate the presence of a high temperature hydrothermal system capable of geothermal power generation.

As shown in chemical analyses, zone III waters are extremely rich in sodium chloride, but are poor in SO_4 and HCO_3. Fig. 23 is a Cl-SO_4 diagram of zone III waters. For convenience of description, subscripts a, b, and c refer to each branch of zone III (Fig. 24). Zone III waters of each branch are fitted to a straight line, and these best fitting lines extrapolated to SO_4 equals zero indicate a possible content of sodium chloride in the original steam. The Cl content of original steam for zone IIIa is 6.010 g/kg, which is equivalent to 9.907 g/kg of sodium chloride. Similarly, that for zone IIIb is 3.406 g/kg, corresponding to 5.615 g/kg of sodium chloride. Thus, the sodium chloride content of volcanic steam responsible for zone III waters ranges from

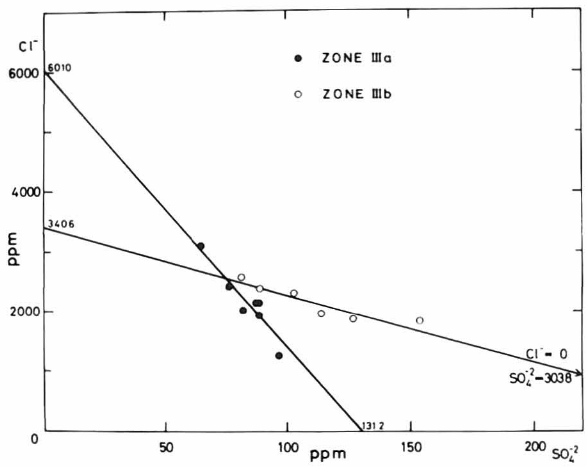


Fig. 23 Cl-SO_4 diagram of Zome III waters (Oki and Hirano, 1974).

0.6 to 1%.

We can estimate that the temperature and pressure of the volcanic dense steam containing 0.6 to 1% sodium chloride is approximately 374 to 385°C and 220 to 230 bars based on the experiment of Sourirajan and Kennedy (1962) in the NaCl-H_2O system (Fig. 25). When the temperature falls below 374°C (the critical temperature of water), sodium chloride is barely soluble in the steam, and is mainly retained by the liquid phase.

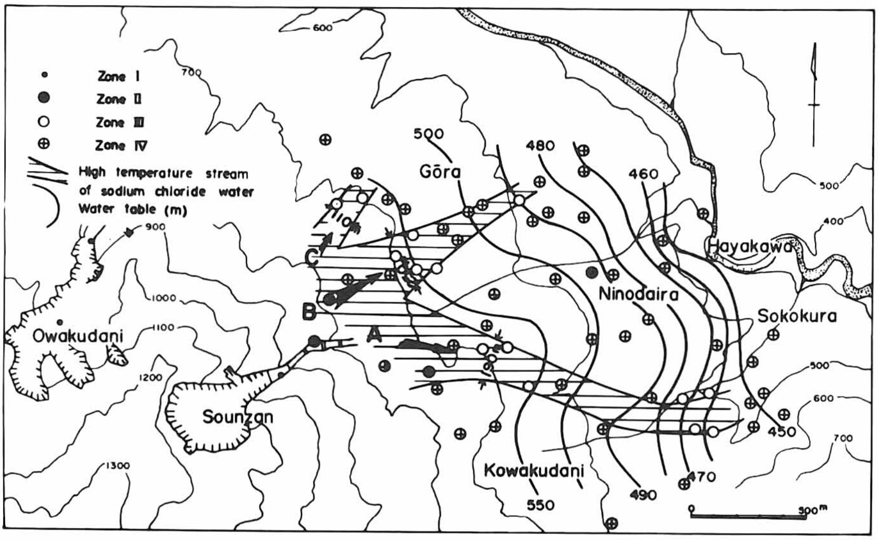


Fig. 24 Distribution of Zone III waters (Oki and Hirano, 1974).

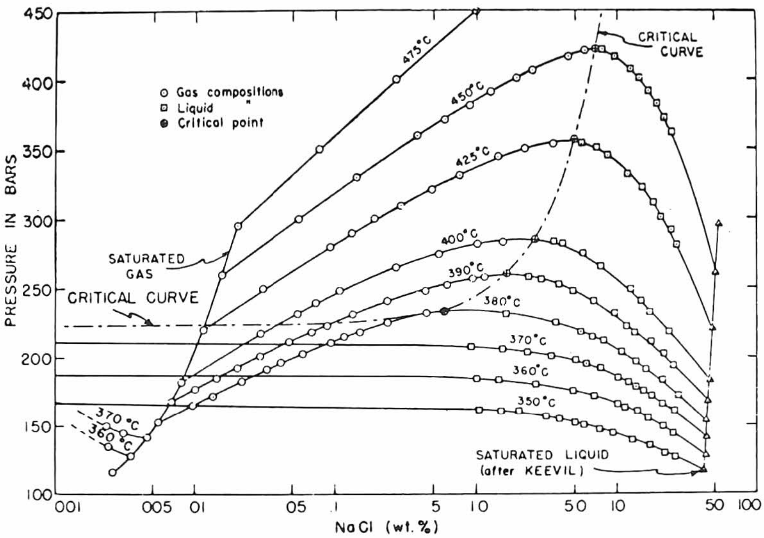


Fig. 25 Isotherms at 350-450°C showing composition of coexisting gases and liquids in NaCl-H_2O system (Sourirajan and Kennedy, 1962).

Sodium chloride budget

An evaluation of the sodium chloride discharged from entire hydrothermal system permits an evaluation of the energy discharged by hydrothermal activity. The sodium chloride discharged by thermal waters that are directly related to the hydrothermal activity of Kamiyama is measured to be 0.22 kg/sec. The contribution of zone I and II waters to the discharge of sodium chloride is fairly small, about 0.01 kg/sec, and can be neglected. Most of the sodium chloride is transferred by the zone III and IV waters and is probably supplied by the high temperature dense steam coming up through the volcanic conduit.

Dividing the total discharge of sodium chloride (0.22 kg/sec) by the sodium chloride content in the inferred original steam (0.6 to 1%) gives a steam discharge of 36.7 to 22 kg/sec through the conduit. With an approximate value for the heat content of steam of 600 kcal/kg, the thermal energy discharge amounts to 2.2 to 1.3×10^7 cal/sec. Adding the energy discharged by thermal waters from the areas of the basement rocks (zone IVb), 0.48×10^7 cal/sec, results in a total discharge for the Hakone hydrothermal system of 2.7 to 1.8×10^7 cal/sec.

Yuhara and his colleagues (1966) measured the thermal discharge from the solfataric fields of Kamiyama to be 0.7×10^7 cal/sec, not including thermal waters from deep wells. We measured the energy discharged by thermal waters from deep wells to be 1.98×10^7 cal/sec. The total energy discharge actually measured amounts to 2.68×10^7 cal/sec, which is in good agreement with 2.2 to 1.3×10^7 cal/sec, the energy discharge obtained from the chloride chemistry.

Isotope Geochemistry

Hydrogen and oxygen isotopic values of the Hakone waters, including thermal waters, groundwater, surface water, stream water and rainwater, are presented in Fig. 26 (Matsuo et al., 1979, 1983). The average rainwater and most of the groundwaters lie near the straight line $\delta D = 8\delta^{18}O + 17$ or Japanese meteoric water as defined by Sakai and Matsubaya (1974). The Hakone thermal waters are distributed in another straight line $\delta D = 2.1\delta^{18}O - 33.5$, which is given by the least squares best fit. The two lines intersect at a point with $\delta D = -51‰$ and $\delta^{18}O \doteqdot -8.5‰$. Since most Hakone groundwaters are concentrated at the intersection, this point is referred to as the "representative groundwater" (RGW) by Matsuo et al. (1979). Many isotopic values from surface waters such as lakes and ponds, which are all open to evaporation, are heavier than those from groundwater and thermal waters. The isotopic enrichment in lake and pond waters relative to the average rain and RGW can be reliably attributed to kinetic evaporation.

As previously described, four zones of thermal waters are recognized in Hakone,

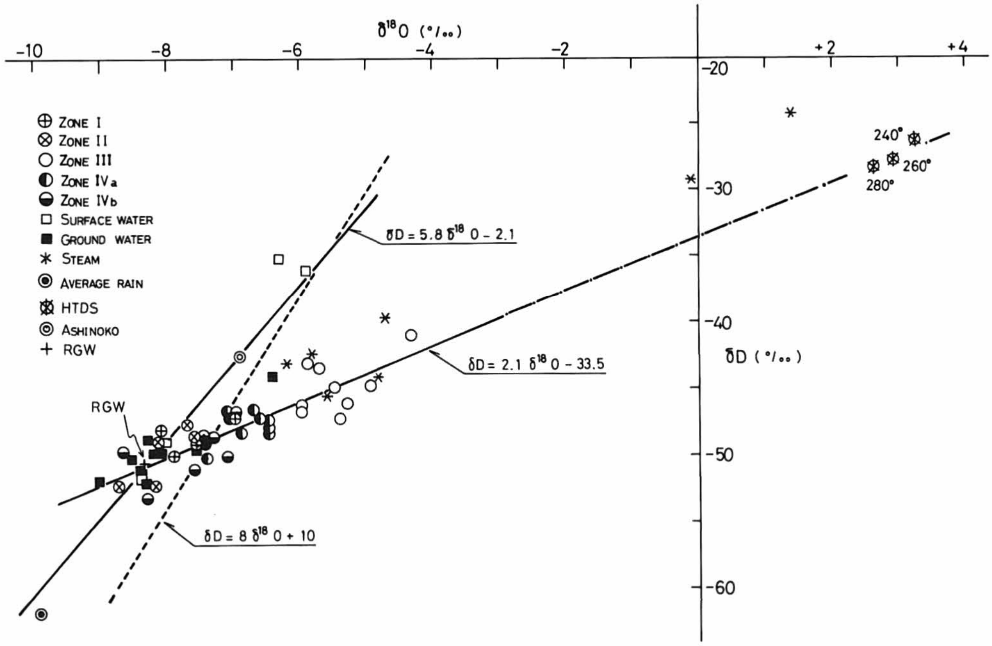


Fig. 26 δD vs δ18O plot for thermal waters of Hakone (Matsuo et al. 1979 and 1983).

based on the major anion content and water temperature. The results of isotopic analyses by Matsuo et al. conform quite well to the zonal mapping of thermal waters.

Zone I waters are low in pH 2–3, and high in sulfate. Their isotopic values are as low as those of groundwater.

Zone II waters are characterized by pH∼8 and are high in bicarbonate and sulfate, and extremely low in chloride. The isotopic values of zone II waters are low and are similar to those of groundwater. The small positive oxygen shift by less than 0.5‰ in $\delta^{18}O$ is regarded as the result of interaction between deep groundwater and the central cone material.

Zone III waters are high in temperature (boiling point) and neutral in pH. The major dissolved chemical constituents are sodium chloride and silica. The isotopic values, particularly $\delta^{18}O$, are considerable higher than those of the other waters.

Zone IV waters are of sodium chloride-bicarbonate-sulfate type, and are referred to as mixed type waters. The isotopic values of zone IV waters are plotted in an area between waters of zone III and II or groundwater.

Steam condensates collected from steam wells and fumaroles in zone I and III show isotopic values close to those of zone III thermal waters, with the exception of two extremely heavy samples.

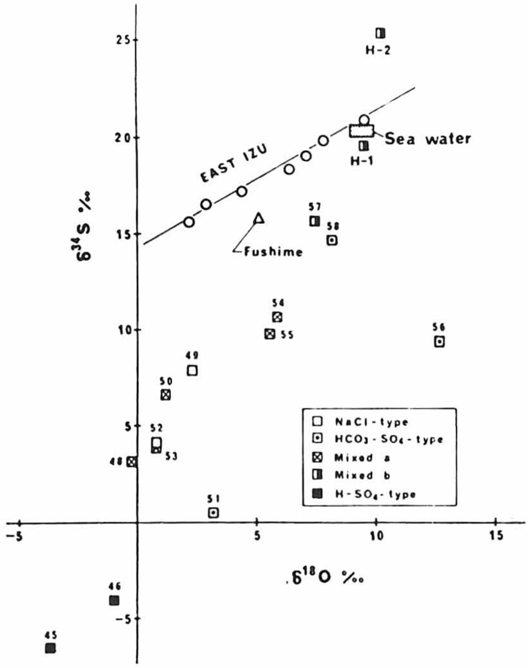


Fig. 27 $\delta^{34}S$ vs. $\delta^{18}O$ plot for sulfates from the eastern Izu Peninsula and Hakone (Sakai and Matsubaya, 1977).

Fig. 27 is an isotopic diagram of $\delta^{34}S$ vs. $\delta^{18}O$ for sulfate from the eastern Izu Peninsula and Hakone thermal waters (Matsubaya et al., 1973; Sakai and Matsubaya, 1977). Sakai and Matsubaya (1977) mentioned that the $\delta^{34}S$ values of sulfate in acid water (zone I) are similar to those of native sulfur in the Owakudani solfataric areas (-5.2 and -8.2‰) and suggest that the sulfate was formed by the surficial oxidation of volcanic sulfur and hydrogen sulfide. On the other hand, the NaCl-HCO_3-SO_4 type waters contain heavier sulfate, the $\delta^{34}S$ values rapidly increasing with increasing distance from the central cones. The three heaviest $\delta^{34}S$ values are found in waters from the basement Green Tuff formation and are considered to be similar in origin to the sulfate in Green Tuff-type thermal waters, which extract sulfates such as gypsum and anhydrite from the altered Tertiary marine sediments. The $\delta^{34}S$ and $\delta^{18}O$ values of sulfate from the NaCl-type and from the subgroup zone IVa of the mixed type thermal waters are intermediate between the two types of sulfate mentioned above. The sulfate may essentially be formed by the surface oxidation of volcanic sulfur in the fumarolic areas. Secondary sulfate may become isotopically heavier through partial reduction by bacteria. As shown in Fig. 27, two waters with isotopically heavy sulfate were found, a groundwater sample and a thermal water of the HCO_3-SO_4 type. Note that both are from the western caldera and are not directly related to the Tertiary basement rocks.

Sakai and Matsubaya (1974, 1977) recognized that sulfate from the thermal waters of the eastern coast of the Izu Peninsula lie close to a line extending from oceanic sulfate to the lower left in Fig. 27. The isotopic ratios of sulfate (open circles in Fig. 27) decrease steadily to the lower left as one moves southward from the base of the Izu Peninsula.

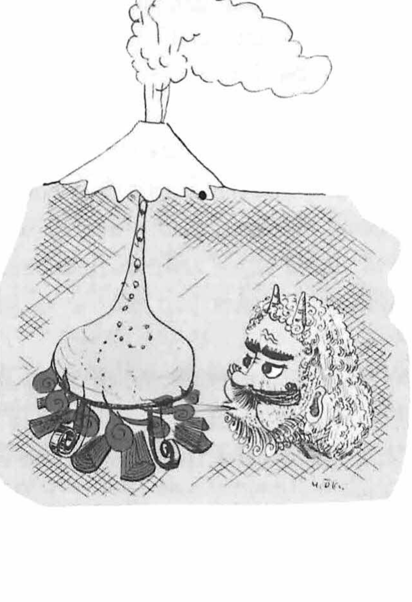
Discussion

Although zone I is the surface counterpart of zone III, it is unlikely that zone III waters appear directly in zone I as steam in solfataras or in shallow drillholes, 50 to 100 m deep. The steam generated at shallow depth is produced by the interaction of groundwater with heated country rocks. At around 200°C, deuterium is enriched in the aqueous phase and is low in the clay minerals formed by water-rock interaction (O'-Neil and Kharaka, 1976). For this reason, the hydrogen shift associated with the oxygen shift takes place during the boiling of zone I water.

The two steam samples with high isotopic values are from steam wells in Owakudani, a steaming valley at the foot of the Kamiyama explosion crater. They plot slightly above the Hakone thermal water line of $\delta D = 2.1\ \delta^{18}O - 33.5$. A gap in the isotopic trend between the heavy steams and thermal waters is interpreted as follows. The subsurface temperature of the major thermal water reservoir was estimated to be 240°C by Yuhara (1968). If the heaviest isotopic values observed in the Owakudani steam $\delta D = -25‰$ and $\delta^{18}O = +1‰$, are assumed to relate isotopically to a "fossil vapor phase" of a high temperature dense fluid carrying considerable sodium chloride and silica, the isotopic composition of this liquid phase is calculated to be $\delta D = -26‰$ and $\delta^{18}O = +3‰$, with the use of liquid-vapor fractionation factors at 240°C of Bottinga and Craig (1968). The estimated result plots just on the extension of the Hakone thermal water line.

The contribution of the high temperature dense fluid to zone III waters is isotopically evaluated to be 25%, ranging from 20 to 36%. This evaluation agrees well with the contribution of 30 % calculated from the Cl-SO_4 chemistry of zone III waters (Oki and Hirano, 1970).

As seen in Fig. 26, the isotopic values of Lake Ashi water are considerably higher than those of the average rainwater and local meteoric water, due to kinetic evaporation of rainwater at the surface. This also applies to waters of the other caldera lakes (Sakai and Matsubaya, 1977, Matsuo, et al., 1979). Matsuo et al. deny the possibility of lake water being the major source for thermal waters, because there are no thermal waters plotted on the line connecting the heavy lake water and the calculated high temperature heavy water. The hydrogeological features of Hakone are essentially controlled by the water level of the caldera lake in the west and the levels of the two major drainages of Haya-kawa and Sukumo-gawa in the east. The geologic structure of the Hakone caldera obviously allows the percolation of lake water into the major aquifer of thermal waters. The isotopic behavior of heavy lake water remains a puzzle. Since the lake is located at a high elevation, the vertical sense of flow may initially predominate down to a depth of a few hundred meters. Further isotopic investigations on thermal waters and rocks from deep wells are required to explain the behavior of the lake water.



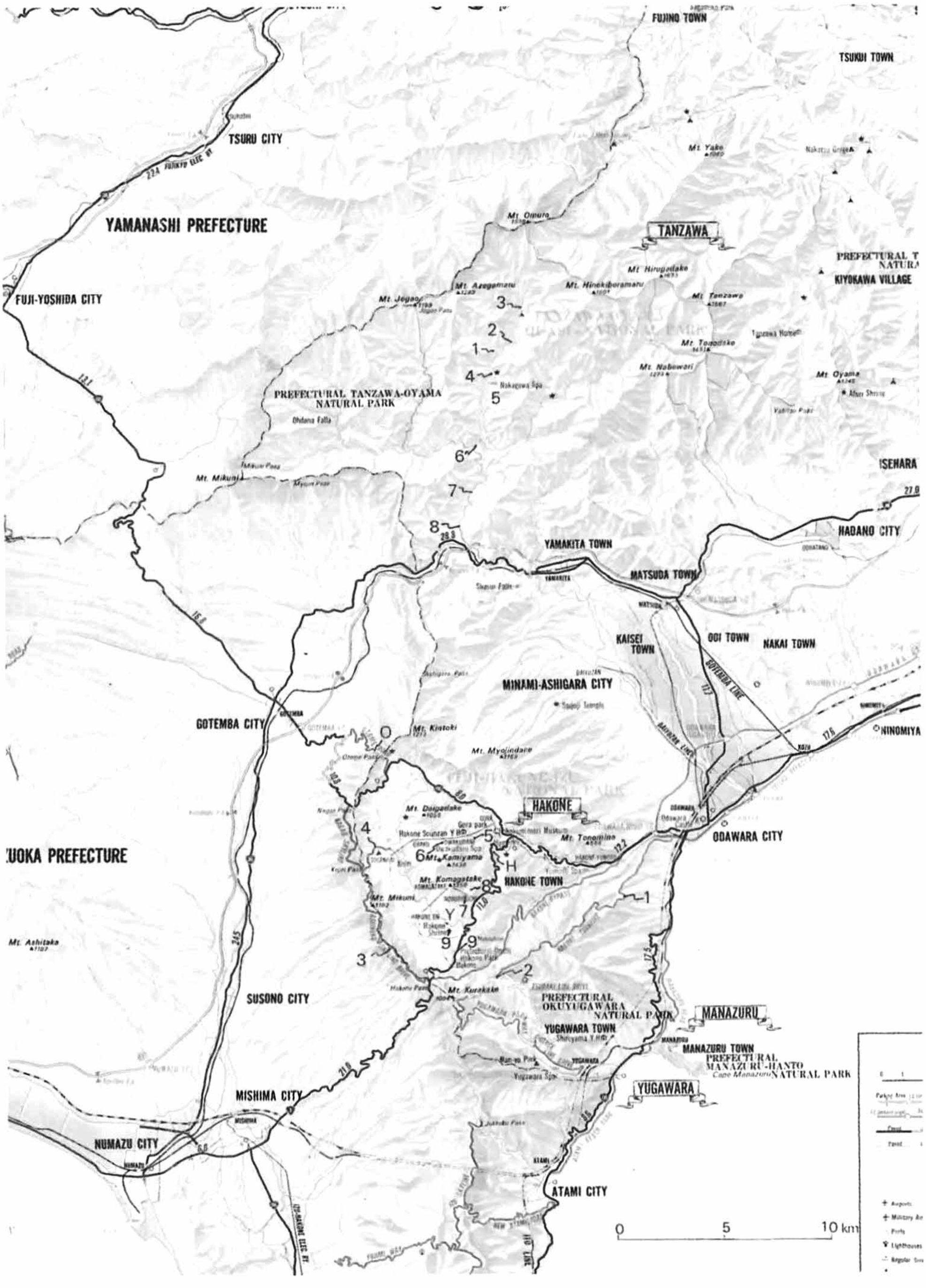


Fig. 0 Route map of Hakone and Tanzawa District.

ITINERARY

HAKONE (1)

Stop	Time	Description
	13:10	Leave **Hot Springs Research Institute** of **Kanagawe Prefecture** and visit **Hakone** by car.
1	13:30-13:50	**Observation stop on Hakone Turnpike.** Bird's eye view of a scenic spot 410 m high on the south-eastern slope of the Hakone Volcano. Toward the east lies the Ashigara Plain bordered in the background by a large fault scarp of the Oiso Hills and on the right by Sagami Bay. The Ashigara Plain, which is now crowded with many houses of Odawara City, was a beautiful paddy field until 20 years ago. The Oiso Hills are composed of gravels and sand mostly derived from the Hakone volcano, which accumulated during the period from 400,000 to 200,000 years ago. In 1981, the Geological Survey of Japan drilled to a depth of 500 m in the plain, again finding gravels and sand from Hakone. All the facts indicate that considerable tectonic movement has been taking place along this plate boundary.

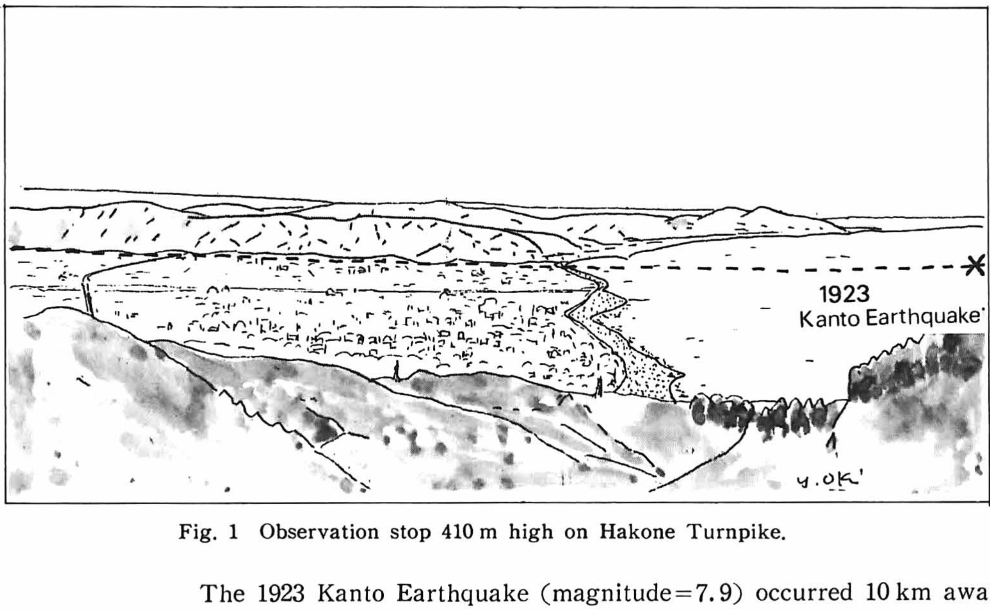


Fig. 1 Observation stop 410 m high on Hakone Turnpike.

The 1923 Kanto Earthquake (magnitude=7.9) occurred 10 km away on the floor of Sagami Bay, along the southern continuation of the Kozu-Matsuda fault (plate boundary).

2 14:15–14:45 **Mt. Taikanzan,** southern rim of the Hakone caldera. Panoramic view of the Hakone double calderas, post caldera cones and Lake Ashi, with the Fuji volcano in the background.

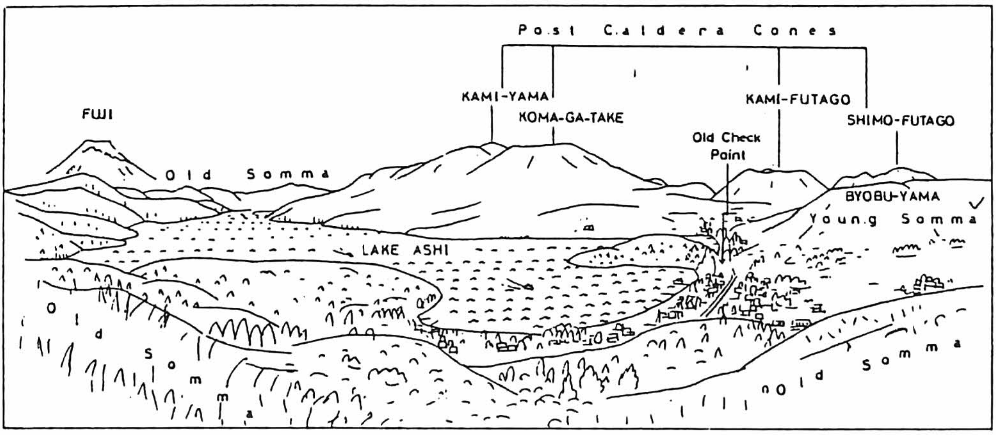


Fig. 2 Hakone-toge panoramic view of the Hakone caldera and central cones.

Taikan-zan, 1011 m, is the highest peak on the southern rim of the Hakone caldera. To the north is a view of the two overlapping calderas, called the Old Somma and the Young Somma. Komagatake, Kamifutago and Shimofutago are post caldera cones, and Ashinoko is a caldera lake. The Hakone volcano is often referred to as a triple volcano, composed of the Old Somma, the Young Somma, and the seven post-caldera cones. Based on the degree of denudation, the volcanic edifice can be classified into three geologic units. The old edifice has a number of deep valleys on its slopes in the manner of wrinkles on an old person. The young edifice of the post-caldera cones has a smooth surface, like a baby's skin. The slopes of the Young Somma are intermediate between them. Byobuyama (948 m), a large flat topped mountain in the foreground, was once classified as a central cone and sometimes as a part of the somma (circular ridge). After very careful consideration, Kuno (1950) recognized Byobuyama as a new category of the Young Somma. This new classification of the Hakone volcanic edifice has been well supported by the petrographic classification of the volcanic rocks. The Old and Young Somma lavas belong the pigeonitic rock series and the lavas of the central (post caldera) cones all belong to the hypersthenic rock series(Kuno, 1950). This finding was one of the epoch-making advances in the development of volcanology.

3 15:10–15:40 **Yamabushi Pass**, western rim of the Hakone caldera. Close-up views of the central cones, Komagatake, Kamifutago and Shimofutago, and Lake Ashi.

4 16:00–16:30 **Kojiri**, a bank of the Kamiyama dry avalanche formed 3,100 years ago by a phreatic explosion of Kamiyama, which dammed the caldera floor to form Lake Ashi. A small exposure (Fig. 3) indicates that the dry avalanche, containing rocks coated with creamy solfataric clays, is overlain by an unsorted, coarse grained and poorly foamed pyroclastic flow 1 m thick, which was derived from Kanmuri-gatake 2,900 years ago. By careful inspection, you will find small fragments of charcoal in this flow. This pyroclastic flow from Kanmuri-gatake is overlain by two layers of scoria falls, the Sengoku scoria and the Zunasawa scoria, which are found interlayered in the lower horizon of the brown volcanic ash falls. The scoria and brown ash falls are derived from the Fuji volcano.

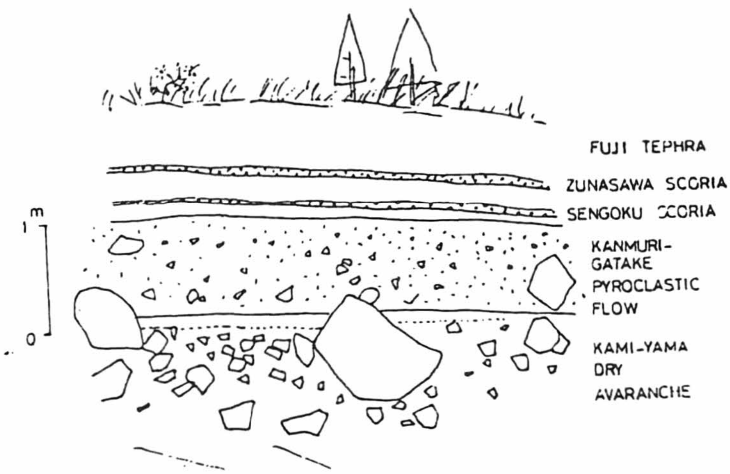


Fig. 3 The Kamiyama dry avalanche and the Kanmurigatake pyroclastic flow overlain by the Fuji tephras.

ITINERARY

HAKONE (2)

Stop	Time	Descrption
5	08:40–09:00	**Soun-zan steaming area.** Soun-zan is the highest point of the crater wall, formed on the eastern slope of Kamiyama, a main central cone. Venting of volcanic steam is taking place at the bottom of the dissected crater. On 26 July, 1953, a landslide occurred, originating from the highest point of the crater wall. A debris flow struck a temple located on a small platform 40 m above the valley floor, killing 10 people. Prior

Fig. 4 Owaku-dani steaming ground, in the bottom of a explosion crater of Kamiyama. The high peak behind the steaming ground is a lava spine Kanmuri-gatake appeared after the explosion crater was formed.

to the landslide, there were very heavy rains. Volcanic earthquakes which occurred on 24 and 25, July were said to trigger this landslide. A number of concrete dams, rock-walls placed in echelon and steam wells have been constructed for protection from landslides.

6 09:10-10:30 **Owaku-dani steaming area.** Owaku-dani is in the bottom of the explosion crater formed in the northwest slope of Kamiyama about 3,100 years ago. Owaku-dani means a large (o) steaming (waku) valley (dani) Formerly this area was known as Enmadai (pedestal of the Ruler of Hell). The hydrothermal manifestation is intense in the valley below the rim of the explosion crater. Thermal waters discharged in the steaming area are high in sulfate and low in pH and Cl. The Owaku-dani Natural History Museum is nearby, which displays the geology and the ecology of plants and animals of the Hakone volcano. Walk down along a trail in the steaming valley for a close inspection of sublimates around fumaroles, rock alteration, mud pots and thermal springs. Volcanic steam tapped from drill-holes 50 to 100 m deep is mixed in a tower with surface water that has been pumped up from a pond in the caldera floor. The heated water is supplied as man-made hot springs for domestic use. Board the bus parked in the bottom of the valley.

Koma-gatake Cable car Station. Panoramic view of the Hakone double calderas with volcanoes of the Izu Peninsula in the background. The southern wall of the old Hakone caldera encircles Byobuyama (mountain standing like a folding screen), which is a flat-topped

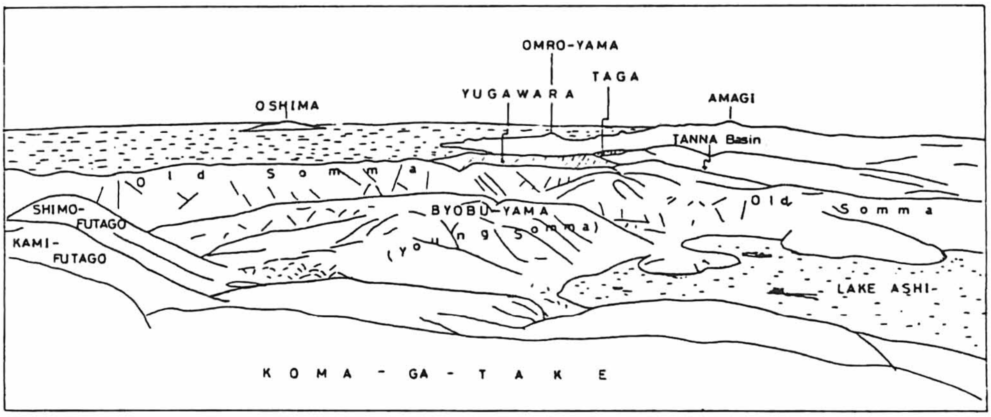


Fig. 5 Panoramic view of the Hakone double calderas.

Fig. 6 A steam production well at Yunohana-zawa, Hakone.

mountain whose steep fault scarp forms the wall of the young caldera, Ashi-no-ko (lake of reeds), a caldera lake, and Futagoyama (twin mountains), the youngest of the lava domes.

7 11:00–11:30 **Yunohana-zawa** means a valley with the flowers of hot springs, i. e. sulfur precipitates and silica sinters. It is located at the eastern foot of a central lava dome, Koma-gatake (horse peak) and is known for its solfataras and hot springs. From 1967 to 1971, three wells drilled to a depth of about 300 m successfully tapped steam, which is used for bathing and space heating. From 1982 to 1983, two additional production wells were drilled for the same purpose. The orifice temperature of the steam ranges from 132.6 to 97.7°C. One of the steam wells is now out of control due to intense corrosion of the steel casing by acid sulfate waters at shallow depth. Condensed steam from the other wells is almost neutral in pH.

8 11:50–12:50 **Take** iunch.

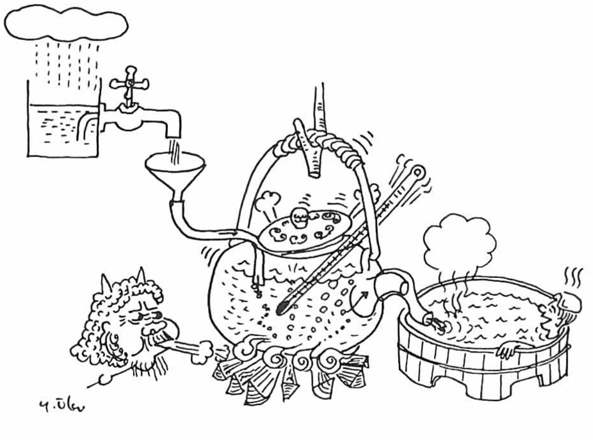
9 13:00–13:30 **Hakooe Shrine.**

10 13:40–14:20 **Hakone Check Point.** This building is a replica of the Hakone Check point built by the Tokugawa Shogunate Government in 1619, to monitor the transit of military troops. The passing of weapons and

Fig. 7 The major central cone Kamiyama with explosion crater and a lava spine towering in it. A large fan coming down from the bottom of the explosion crater is a dry avalanche which formed Lake Ashi 3,100 years B. P. (Photo courtesy of Ariyoshi SHIMA).

ladies was considered to be the initial proof of rebellion of local Feudal Lords, and was thus seriously checked at this point. The original checkpoint was abolished and destroyed during the Meiji Restoration in 1869.

Nagao Pass offers a panoramic view of the Hakone caldera and post-caldera cones. As you look from left to right, five of the seven peaks of the post-caldera cones can be seen. They are Kozuka-yama (small mound), Dai-gatake (pedestal mountain), Kamiyama (god mountain), Koma-gatake (horse mountain: Koma, the family name of Korean Royalty who immigrated in the middle of sixth century, was offered to the peak) and Jingasa-yama (combat helmet). On the right, the flat mountains, about 800 m high between Lake Ashi and the Old Somma, are called the Young Somma. The major central cone Kami-yama, 1,438 m high, is a small strato-volcano, and the other six are lava domes. The important feature of Kami-yama is the explosion crater, with the lava spine of Kanmuri-gatake (pointed crown) towering in it. A debris fan extends widely from the bottom of the explosion crater down to the caldera floor.



References

Bottinga, Y. and Craig, H. (1968) High temperature liquid-vapor fractionation factors for H_2O-HDO-$H_2{}^{18}O$. Trans. Amer. Geophys. Union, vol. 49, 356-357.

Kuno. H. (1950) Geology of Hakone Volcano and adjacent areas. Part 1. Jour. Fac. Sci., Univ. Tokyo, sec. 2, vol. 7, 257-279.

Kuno. H. (1951) Geology of Hakone volcano and adjacent areas. Part II. Jour. Fac. Sci., Univ. Tokyo, sec. 2, vol. 7, 351-402.

Kuno. H., Oki, Y., Ogino, K. and Hirota, S. (1970) Structure of Hakone caldera as revealed by drilling. Bull. Volcanologique. vol. 34, 713-725.

Hiraga, S. (1972) Earthquake swarms of geothermal fields in Japan. Jour. Japan. Geoth. Ener. Associ., vol. 9. no. 1, (ser. no. 32), 30-39.

Machida, H. and Suzuki, M. (1971) A chronology of the late Quaternary period as established by fission-track dating. Kagaku, vol. 41, 263-270.

Machida, H. (1980) Tephra and its implications with regard to the Japanese Quaternary period, in Geography of Japan (edited by Assoc. Japan. Geographers), 29-53, Teikoku-Shoin.

Matsubaya, O., Sakai, H., Kusachi, I. and Satake, H. (1973) Hydrogen and oxygen isotopic ratios and major element chemistry of Japanese thermal water system. Geochem. Jour., vol. 7, 123-151.

Matsuo, S., Kusakabe, M., Niwano,. M., Hirano, T. and Oki, Y. (1979) Water budget in the Hakone caldera using hydrogen and oxygen isotope ratios. Isotopes in Lake Studies, IAEA, Vienna, 131-144.

Matsuo, S., Kusakabe, M., Niwano, M., Hirano, T. and Oki, Y. (1983) Origin of thermal waters from the Hakone geothermal system, Japan as deduced from stable isotopic evidences. Jour. Volcanol. Geothermal Res. (in press).

Minakami, T. (1960) Fundamental research for predicting volcanic eruptions. Part I. Bull. Earthq. Res. Inst., vol. 38, 497-544.

Minakami, T., Hiraga, S., Miyazaki, T. and Uchibori, S. (1969) Fundamental research for predicting volcanic eruptions, Part II. Bull. Earthq. Res. Inst., vol. 47. 893-949.

Nakamura, K. (1969) Arrangement of parasitic cones as a key to regional stress field. Bull. Volcanol. Soc. Japan. vol. 14, 8-20.

Oki, Y. and Hirano, T. (1970) Geothermal system of Hakone volcano. U. N. Symposium on the Development and Utilization of Geothermal Resources, Pisa. Geothermics, Spec. Issue 2, vol. 2, part 2, 1157～1161.

Oki, Y. and Hirano, T. (1974) Hydrothermal system and seismic activity of Hakone volcano, The Utilization of Volcanic Energy, Proceedings of United States-Japan Cooperative Science Seminor at Hilo, Hawaii, 13-40.

Oki, Y., Hirano, T. and Suzuki, T. (1974) Hydrothermal metamorphism and vein minerals of the Yugawara geothermal area, Japan. Proc. of Water-Rock Interaction Symposium at Prague, Czechoslovakia, Geol. Surv. Prague. 209-222.

Oki, Y. and Hakamata, K. (1975) Geologic history of caldera lake, Ashinoko. Kokudo to Kyoiku, ser. no. 30, vol. 5, no. 6, 2-9. (in Japanese).

Oki, Y., Aramaki, S., Nakamura, K., and Hakamata, K. (1978) Volcanoes of Hakone, Izu and Oshima. Bull. Hot Springs Res. Inst. Kanagawa Pref. vol. 9, no. 5, 1-88.

Oki, Y. (1981) Nine-headed Dragon (Kuzuryu) in Lake Ashi. Bull. Hot Springs Res. Inst. Kanagawa Pref., vol. 12, 133-135.

Oki, Y., Odaka, S. and Sugiyama, S. (1982) Finding of fossil trees 1,100 years B. P. in Lake Ashi resulted by a large earthquake (in Japanese). Bull. Hot Springs. Res. Inst. Kanagawa Pref., vol. 14, 31-34.

O'Neil, J. R. and Kharaka, Y. K. (1976) Hydrogen and oxygen isotope exchange reactions between clay minerals and water. Geochim. Cosmochim. Acta, vol. 40, 241-246.

Sakai, H. and Matsubaya, O. (1974) Isotopic geochemistry of the thermal waters of Japan and its bearing on the Kuroko Ore solutions. Econ. Geol., vol. 69, no. 6, 974-991.

Sakai, H. and Matsubaya, O. (1977) Stable isotopic studies of Japanese geothermal systems. Geothermics, vol. 5, 97-124.

Sourirajan, S. and Kennedy, G. C. (1962) The system H_2O-NaCl at elevated temperatures and pressures. Amer. Jour. Sci., vol. 260, 115-141.

Suzuki, M. (1970) Fission track dating and Uranium contents of obsidian (II). Quat. Res., vol. 9, 1-6.

Toto Bunso and Roka (1811) Seven Hot Springs of Hakone, translated by H. Sawada (1975), Hakone Town Office. 75.

White, D. E. (1957) Thermal waters of volcanic origin. Bull. Geol. Soc. Amer., vol. 68, 1637-1658.

White, D. E., Muffler L. J. P. and Truesdell A. H. (1971) Vapor dominated hydrothermal systems compared with hot-water systems. Econ. Geol., vol. 66, p. 75-97.

Yuhara, K., Kodai, K., Abe, K. Kotoda, K., and Hosono, Y. (1966) Hydrothermal system of Owakudani-Gora zone, Hakone volcano. Rep. Cooperative Res. Disaster Prevention, no. 8, 29-42.

Yuhara, K. (1968) Quantitative estimation of hydrothermal system of Owakudani and Sounzan geothermal areas, Hakone volcano (in Japanese). Bull. Volcanol. Soc. Japan, 2nd Ser. vol. 13, 74-83.

4. TANZAWA MOUNTAINS

Yotaro SEKI, Saitama University
Yasue OKI, Hot Springs Research Institute, Kanagawa Pref.

The Fossa Magna Region is located in a large graben formed in earliest Neogene time, which crosses the central part of Honshu with a nearly N–S trend (Fig. 1). It corresponds to the southern extension of the Green Tuff Region on the Sea of Japan side of Tohoku (Northeast Honshu) and occupies the northernmost part of the Izu-Mariana Arc. A distribution of thick geosynclinal deposits is associated with basalt and andesite lavas and pyroclastic materials.

These volcanic rocks were altered to green colored rocks due to low-grade regional metamorphism. Particularly in the region of the Tanzawa Mountains, extremely thick geosynclinal piles were deposited. These were subsequently exposed on the present surface after an intense upheaval associated with the intrusion of quartz diorite in the central part of the mountains. A series of metamorphic rocks ranging from the zeolite facies through the prehnite-pumpellyite and the greenschist facies to the amphi-

Fig. 0 Togatake (1491 m), one of the main peaks of the Tanzawa Mountains, with Fuji Volcano in the background.

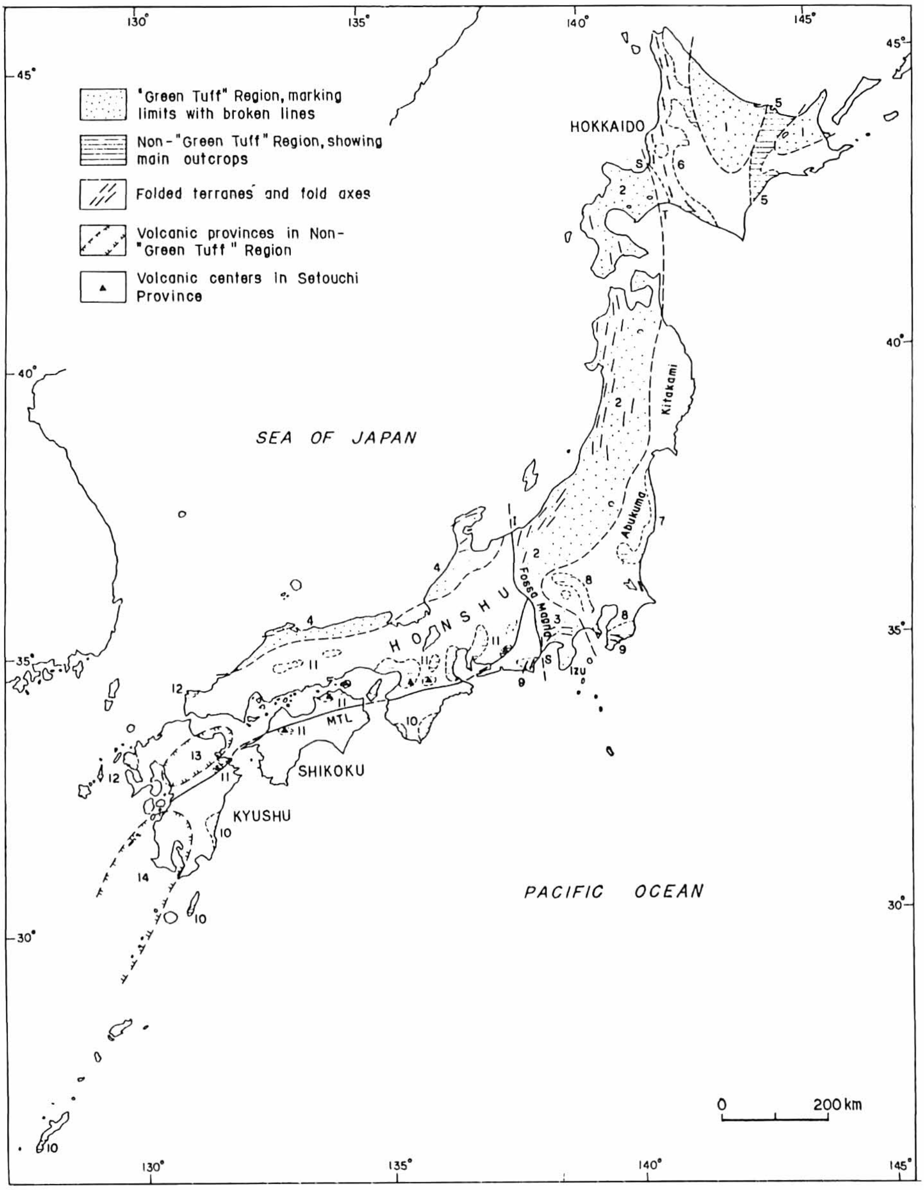


Fig. 1 Neogene geologic provinces of Japan. (Geological Survey of Japan, 1977)

"Green Tuff" Region
1. Kitami-Shiretoko Province
2. Ou-Shin-etsu Province
3. South Fossa Magna Province
4. Hokuriku-San-in Province

Non-"Green Tuff" Region
5. Kushiro-Abashiri Province
6. Central Hokkaido Province
7. Joban Province
8. Kanto Province
9. Oigawa-Boso Province
10. Nankai-Outer Ryukyu Province
11. Setouchi Province
12. Northwest Kyushu Province
13. Hohi Volcanic Province
14. South Kyushu-Inner Ryukyu Volcanic Province

Line I-S. Itoigawa Shizuoka Tectonic Line
Line S-T. Sapporo-Tomakomai Line
Line MTL. Median Tectonic Line

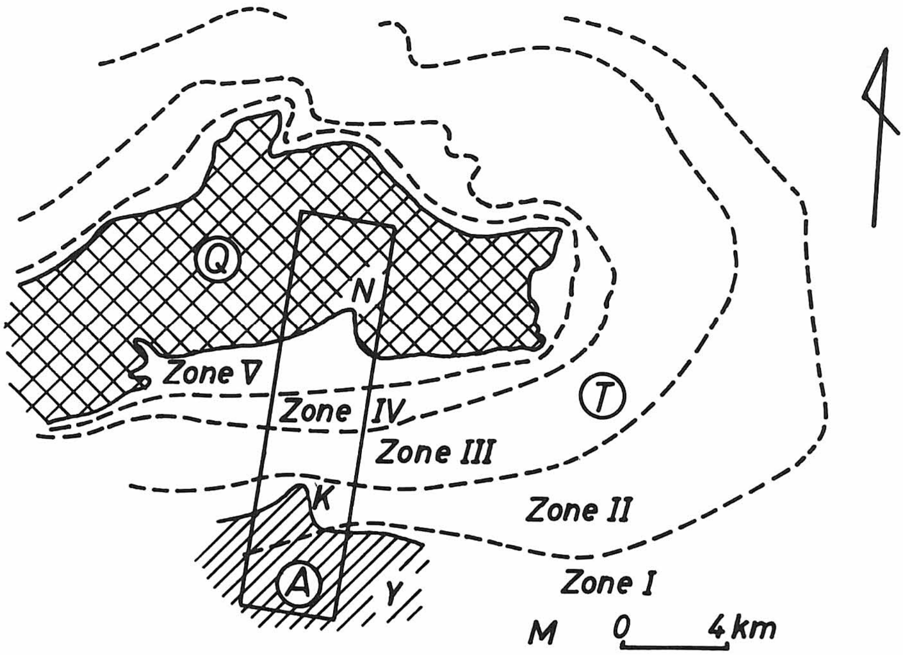


Fig. 2 Metamorphic zones in Tanzawa Mountains, central Japan.
Q: Quartz diorite
T: Lower-Middle Miocene Tanzawa formation
A: Upper Miocene-Pliocene Ashigara formation
N: Nakagawa Spa
K: Kannawa
Y: Yamakita
M: Matsuda

bolite facies, are developed in this area.

The Tanzawa Mountains are located approximately 40 km northeast of Mt. Fuji, and are composed of Lower to Middle Miocene volcanogenic sediments of the Tanzawa Group, estimated to be more than 8,000 m thick. These deposits are distributed around the quartz diorite mass with the lower Tanzawa Group adjacent to the diorite and the upper part of the group away from it. Metamorphism increases in grade toward the diorite intrusion. The schistosity of the high grade metamorphic rocks is well developed in the southern part of the mountains, but is poorly developed in the northern and eastern parts (Fig. 2).

The following metamorphic zoning applies to metamorphic rocks of the Tanzawa Mountains (Fig. 3, 4).

Zone I (low zeolite facies). Both sedimentary and mafic igneous rocks preserve their original texture and show no schistosity. Only the fine-grained matrix and groundmass are recrystallized, the crystallized part is characterized by clinoptilolite, heu-

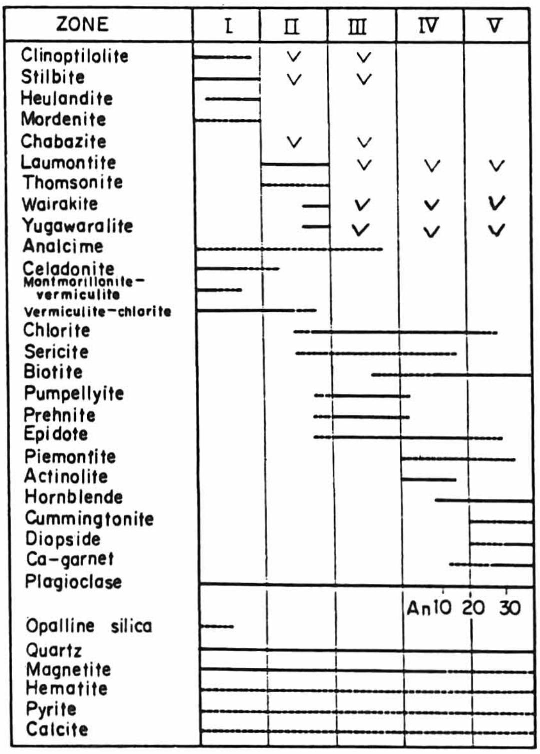


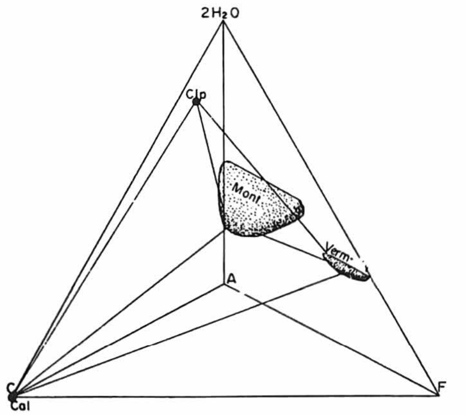
Fig. 3 Stability range of metamorphic minerals in the Tanzawa Mountains. Broken line indicates uncommon occurrence of the mineral. Mark V represents minerals found only as veins.

landite, stilbite and mordenite as well as by smectite-vermiculite and vermiculite-chlorite. Chlorite proper does not occur. Stilbite-bearing veins are common, but no laumontite-bearing veins are observed.

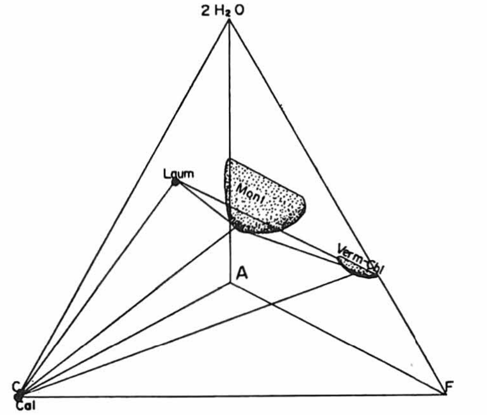
Zone II (high zeolite facies). The rocks are still usually non-schistose and are incompletely recrystallized. This zone is characterized by the occurrence of a laumontite-quartz assemblage. Low temperature alteration in half of this zone is characterized by a mixed-layer clay. The higher temperature alteration consists of common chlorite and rare wairakite and yugawaralite, in association with quartz. Laumontite and stilbite-bearing veins are common.

Zone III (prehnite-pumpellyite facies). The original textures are still preserved, though some rocks show weak schistosity. This zone is characterized by the occurrence of prehnite and pumpellyite. Chlorite, epidote, and albite also occur. Metamorphic rocks are cut by wairakite-, laumontite- and stilbite-bearing veins.

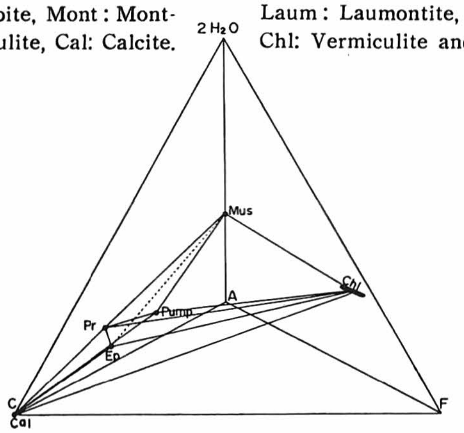
Zone IV (greenschist facies). The boundary of this zone is marked by the first appearance of actinolite in metabasites, and the disappearance of prehnite and pumpellyite. The metabasites are greenschists or greenstones mainly composed of actinolite,



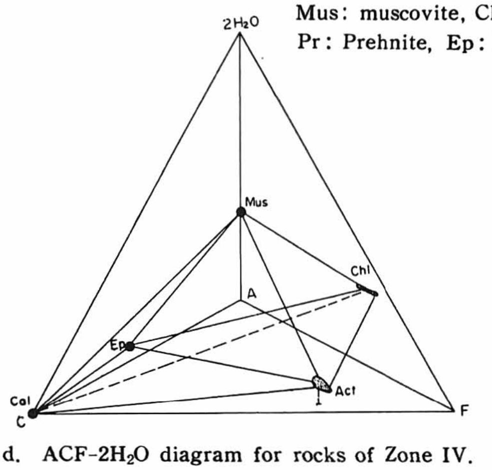
a. ACF-$2H_2O$ diagram for rocks of Zone I. Clp : Clinoptilolite and stilbite, Mont : Montmollironite, Verm: Vermiculite, Cal: Calcite.



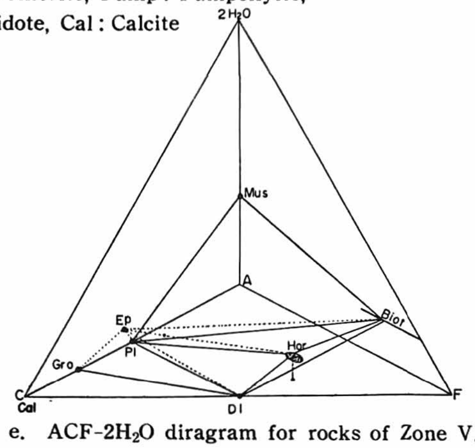
b. ACF-$2H_2O$ diagram for rocks of Zone II Laum : Laumontite, Mont : Montmollironite, Chl: Vermiculite and chlorite, Cal: Calcite.



c. ACF-$2H_2O$ diagram for rocks of Zone III. Mus: muscovite, Chl : Chlorite, Pump : Pumpellyite, Pr : Prehnite, Ep : Epidote, Cal : Calcite



d. ACF-$2H_2O$ diagram for rocks of Zone IV. Mus: Muscovite, Ep: Epidote, Act : Actinolite, Chl: Chlorite, Cal: Calcite.



e. ACF-$2H_2O$ diragram for rocks of Zone V. Epidote appears in rocks rich in ferric iron. Mus: Muscovite, Pl: Plagioclase, Ep: Epidote, Hor: Hornblende, Biot: Biotite, Di: Diopside, Gro: Grossularite, Cal: Calcite.

Fig. 4 ACF-$2H_2O$ diagram for rocks of Zone I～Zone V, chlorite, epidote, and albite with minor amounts of quartz and sphene. Calcite, white mica or biotite may occur. In the higher temperature part of this zone, however, the stable calcic amphibole appears to be hornblende, and the plagioclase is sodic oligoclase. Wairakite, laumontite and stilbite are commonly observed as vein-forming minerals.

Zone V (amphibolite facies). The first appearance of plagioclase with 20 percent An has been regarded as the lower boundary of the zone. The maximum An content observed is 73 percent. Common metabasites are schistose or non-schistose amphibolites. Recrytallization is complete. The hornblende is blue-green in the lowest temperature alteration of this zone and becomes green or brownish green with increasing temperature of metamorphism. The colour generally deepends with advancing metamorphism. The amphibolites are associated with small amounts of metabasites of different compositions, including a cummingtonite-plagioclase rock, an anthopyllite-plagioclase rock, and a grandite-salite-plagioclase rock.

Most of these amphibolite facies rocks have undergone distinct retrogressive alteration, such as chloritization of hornblende and replacement of metamorphic plagioclase by epidote, sodic plagioclase and Ca-zeolites. Veins commonly developed in these rocks are chiefly composed of wairakite, laumontite and stilbite, plus quartz.

The quartz diorite mass which intruded the Tanzawa Group has also undergone retrogressive alteration. For example, most of the hornblende crystals forming the quartz diorite have been replaced by chlorite and epidote along cleavage planes and crystal margins. Andesine or labradorite plagioclase crystals of the quartz diorite have also been partially altered to sodic plagioclase and Ca-zeolites, such as laumontite, along cracks or cleavage planes. Composite veins with laumontite margins and stilbite cores are common. Some wairakite- and laumontite-bearing veins are cut by veins chiefly composed of stilbite.

Stratigraphically, the metamorphic terrane is divided into two units: the Tanzawa and Ashigara Groups. Quartz diorite is exposed in the central part of the Tanzawa Group (early and middle Miocene) which is the host rock for metamorphic Zones V, IV and III and a part of Zones II and I. The southern boundary of this Group is at the Kannawa thrust. The Ashigara Group (Pliocene to Pleistocene) is exposed to the south of the thrust and forms the rest of Zone II and Zone I. Metamophic rock fragments derived from the Tanzawa Group occur as pebbles in conglomerates of metamorphosed sections of the Ashigara Group. In the upper horizons of the Ashigara Group, quartz diorite also occurs as pebbles. The boundary of each metamophic zone is subparallel to the structural trend of the Tanzawa Group and also to the quartz diorite mass. The strike of the Ashigara Group obliquely crosses that of the Tanzawa Group at the Kannawa fault. The boundary between metamorphic Zones I and II, however, cuts the boundary between the two groups and is almost concordant with the general trend of boundaries of the higher grade zones in the Tanzawa Group.

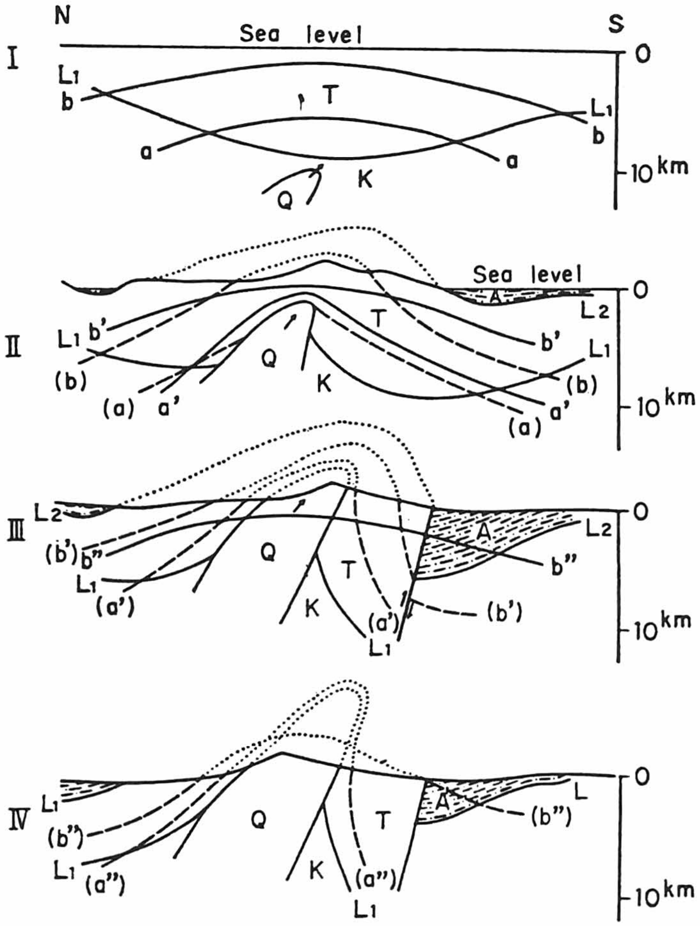


Fig. 5 Schematic representation of tectonic movement accompanied with metamorphism and intrusion of quartz diorite in the Tanzawa Mountains (horizontal: vertical=1:1)

I ; Base of Tanzawa Group
II ; Middle Miocene
III : Pliocene
IV : Present
L_1 Base of Tanzawa Group
L_2 Top of Tanzawa Group
A : Ashigara Group
T : Tanzawa Group
K : Kobotoke Group (pre-Miocene, Paleogene or late Mesozoic)
Q : Quartz diorite

Full lines a-a, a′-a′ : Location of common hornblende isograd for each stage.
Full lines b-b b′-b′, b′′-b′′ : Location of laumontite isograd for each stage.
Broken lines (a)-(a), (a′)-(a′), (a′′)-(a′′) : Location of common hornblende isograd for previous stages. Broken lines (b)-(b), (b′)-(b′), (b′′)-(b′′) : Location of laumontite isograd for previous stages.

It follows that the submarine volcanic deposition of the Tanzawa Group in early and middle Miocene time was probably associated with an early major phase of metamorphism, which formed the progressive series from a low-temperature zone up to Zone V. Then, the quartz diorite mass was intruded, resulting in some additional alteration in the highest temperature zone. Subsequent uplift and erosion exposed this metamorphic and plutonic complex by late Miocene time. A new depositional basin was formed to the south of the uplifted mountains, and many fragments of the exposed rocks were transported southward and deposited, leading to the formation of the Ashigara Group. In Pliocene time, metamorphism continued and especially extended into the newly formed sediments of the Ashigara Group, extending metamorphic Zone II and forming Zone I. The main phase of the higher grade metamorphism and the intrusion of quartz diorite were completed before the deposition of the Ashigara Group, and the lower grade metamorphism which formed Zones I and II continued during and

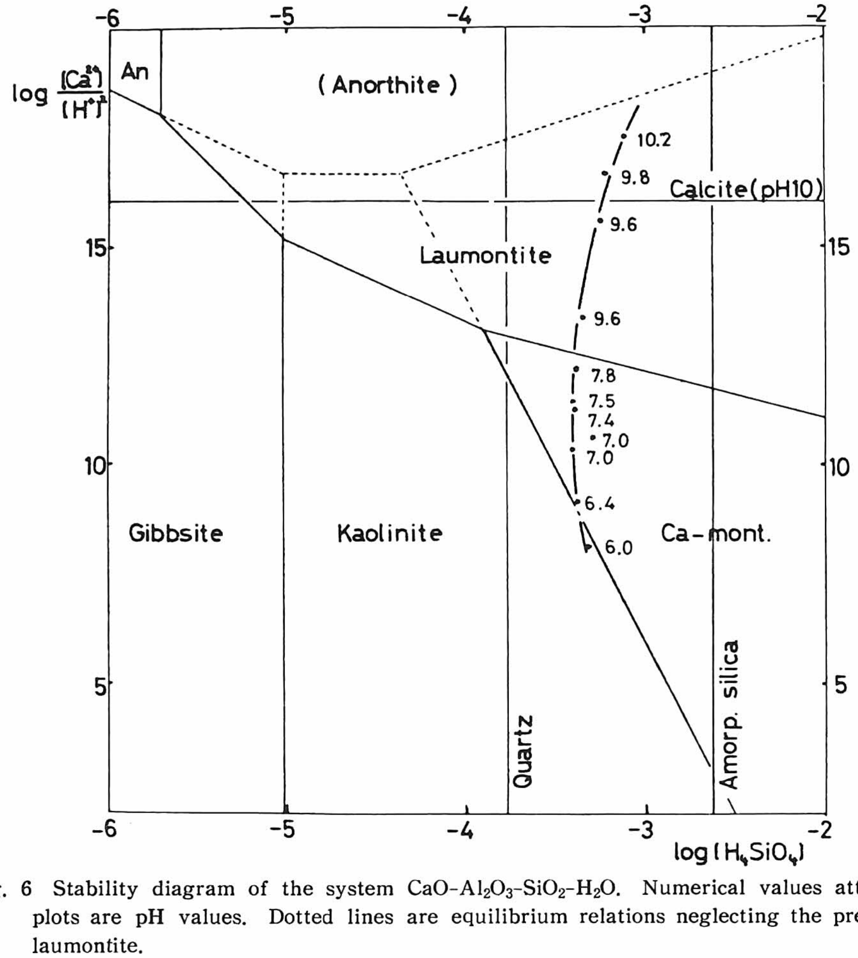


Fig. 6 Stability diagram of the system CaO-Al_2O_3-SiO_2-H_2O. Numerical values attached to plots are pH values. Dotted lines are equilibrium relations neglecting the presence of laumontite.

after the deposition of the Ashigara Group (Fig. 5).

The common occurrence of Ca-zeolites, such as laumontite and stilbite, and the relatively rare occurrence of calcite as metamorphic minerals indicate that the fluid present during hydrothermal metamorphism of the Tanzawa area must have been of high pH and low CO_2 concentration.

In the Tanzawa Mountains, many mineral waters which have high pH values, ranging from 9.5 to 10.3 have been found. These mineral waters are gushing out through fractures and joints, along which Ca-zeolites are commonly developed. Measurements of the geothermal gradient (5.55–12.6°C/100 m) indicate the presence of thermal activity at depth in the Tanzawa Mountains. Thermal water (40°C) of the

Table 1 Chemical composition of warm springs (1 to 4) and cold springs (5 and 6) of Tanzawa mountains.

No.	1	2	3	4	5	6
Loc.		Nakagawa			Kurokura	
Temp. (°C)	27.7	35.0	31.3	40.3	11.7	12.7
Depth of well (m)	501	286.		320.		
Discharge (1/min)	193	177.	n. d.	132.		
pH	9.60	9.80	10.05	10.24	6.4	7.6
Evap. res.	239	450.8	305.	612.		
K^+(ppm)	1.24	1.00	0.83	1.55		
Na^+	67.5	123.	85.9	163.	4.1	4.3
Ca^{2+}	5.98	17.85	7.70	24.9	8.7	13.3
Mg^{2+}	0.017	0.0	0.049	0.0		
Cl^-	13.4	33.68	12.8	45.0	0.9	1.7
SO_4^{2-}	118.	230.6	128.	298.	2.0	2.9
HCO_3^-	18.5	10.24	20.8	9.45	45.6	51.1
CO_3^{2-}	7.13	4.98	5.19	2.74		
OH^-	0.68	1.07	1.70	2.99		
H_4SiO_4	35.2	27.4	73.1	89.3	47.3	35.0
$\delta^{18}O$*	−8.6		−9.1	−9.4		
δD*	−54.1		−55.9	−58.1		

* analyzed by H. Sakai

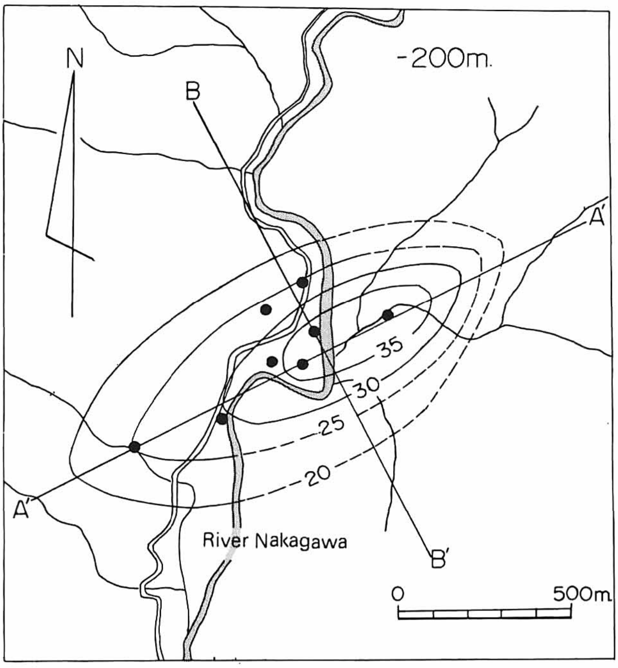


Fig. 7 Isothermal contours of the Nakagawa geothermal area at -200 m level below the river bed at Nakagawa (364 m above sea level). Solid circles are drill-holes.

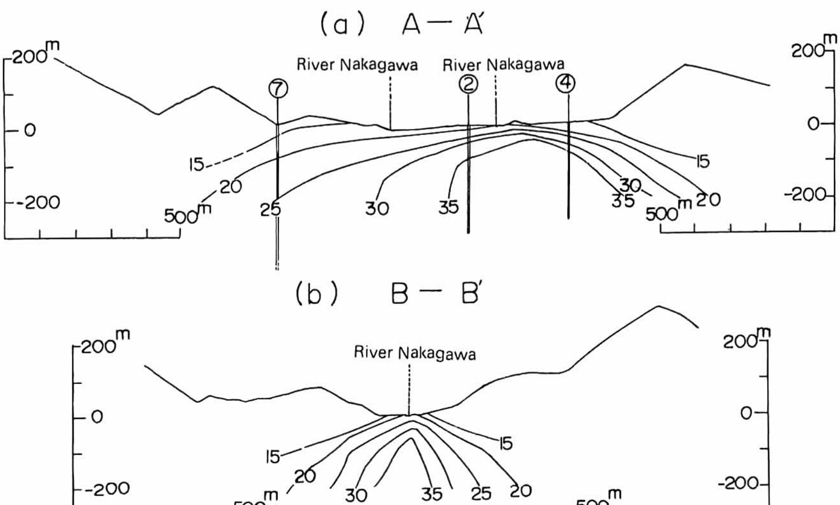


Fig. 8 Isothermal cross section of the Nakagawa geothermal area.

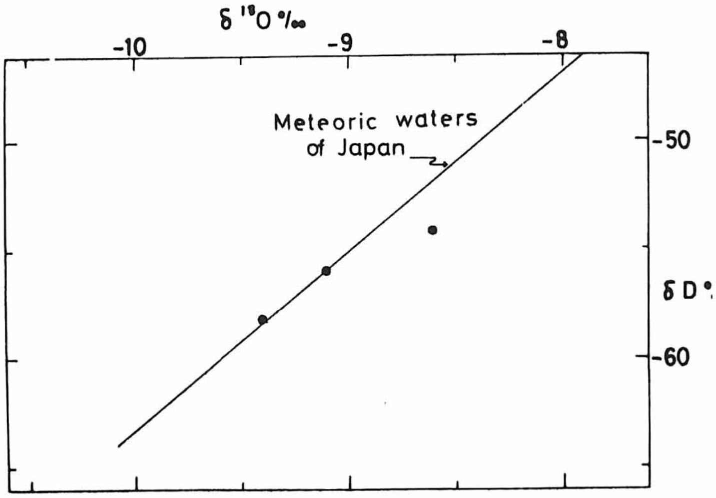


Fig. 9 δD vs. $\delta^{18}O$ plots of the Nakagawa warm springs.

Nakagawa Spa may be regarded as a remnant of the strong geothermal activity associated with intrusion of the quartz diorite.

ITINERARY

TANZAWA

Stop	Time	Description
	08:20-80:30	**Otome Pass** offers the most spectacular view of the Fuji volcano and Tanzawa Mountains.

Fig. 1 View of Mt. Fuji from Otome Pass, Hakone.

Stop	Time	Description
	09:00	**Gotenba City**, a junction for the volcanic and hot spring resorts in the Tanzawa-Fuji-Hakone-Izu areas.
	09:30	**Shimizu**, a small village at the mouth of the Nakagawa river.
1	10:00-10:20	**Otaki-zawa**, an example of quartz-diorite veined by laumontite-quartz and laumontite-stilbite assemblages. Composite veins with a laumontite margin and stilbite center are common. Some laumontite-bearing veins are cut by stilbite-bearing veins.
2	10:30-11:00	**Hoki-Sugi** (broom shaped cryptomeria) 1,200 year old national monument. Highly sheared and hydrothermally altered quartz diorite can be seen. Laumontite- and stilbite-bearing veins are commonly developed along sheared planes and joints. Some of these veins cut wairakite-

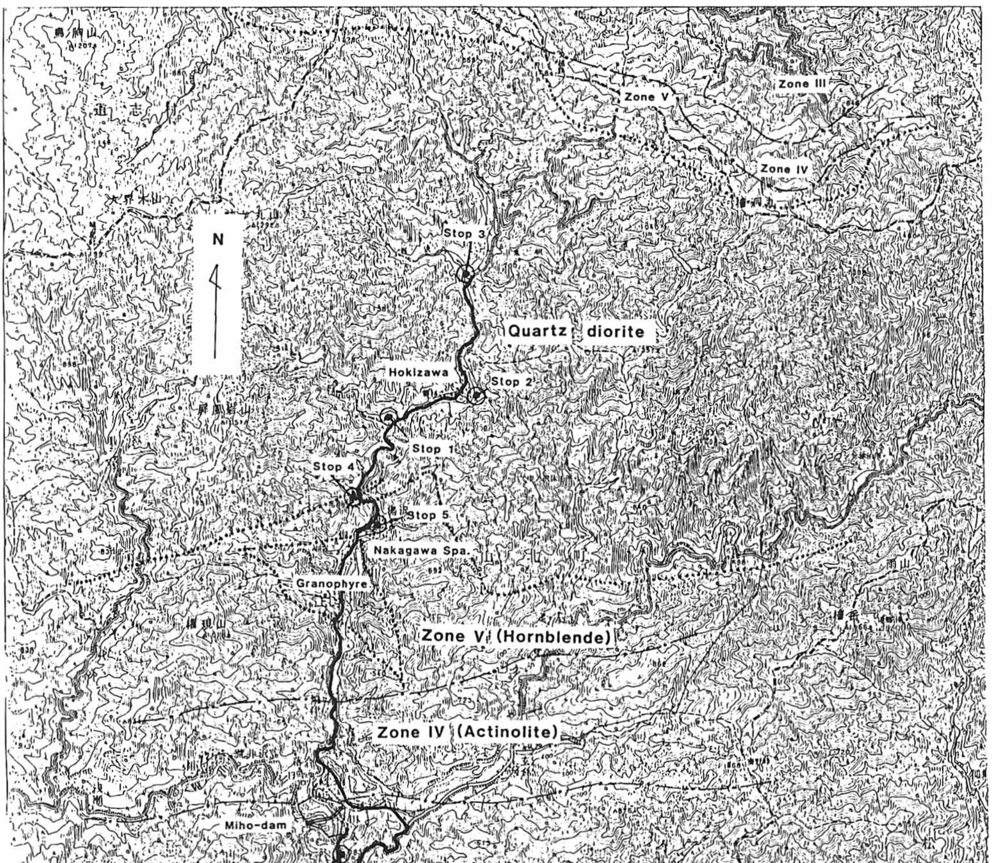


Fig. 2 Route map of the Tanzawa field excursion.

Fig. 3 Tanzawa quartz diorite and Ca-zeolites veins.

quartz-bearing veins.

3 11:30-12:30 **West Tanzawa Visitor Center**. Fresh outcrops of quartz diorite are seen in the stream floor, which include mafic xenoliths derived from the amphibolite of the Tanzawa Group. Composite veins of Ca-zeolites are common (Fig. 3). Polished specimens of the Tanzawa group are displayed in the corner of the parking lot. Take lunch.

4 12:50-13:10 A road-cut 400m north of the **Nakagawa village** exposes a marginal contact between schistose amphibolite and quartz diorite. Both of these rocks have undergone strong retrogressive hydrothermal alteration, with the formation of laumontite-bearing veins. Schistose anthophyllite and/or biotite-bearing metamorphic rocks are exposed, dipping (overturned) to the north.

5 13:20-14:20 **Nakagawa Warm Springs**. Leave the bus at a parking lot on a slope of the valley. Walk down a trail for 5 minutes, carefully cross a suspension bridge one by one and come to the stream floor, where the folded and faulted Miocene volcanogenic rocks of the amphibolite facies (metamorphic Zone V) are freshly exposed (Fig. 4, 5). A reverse fault with N55°W 45°N direction is well exposed in the stream floor. Volcanic breccias are strongly flattened and recrystallized. These am-

phibolite facies rocks have generally undergone retrogressive hydrothermal alteration and are veined by wairakite, yugawaralite, laumontite and stilbite assemblages along sheared planes and joints. Warm waters (25–40°C) of the Na–SO_4–Cl type with pH 10 are discharged from several wells, 200 to 300 m deep, tapping fractures in the amphibolite.

14:40 **Miho Dam** is a modern rock fill dam constructed on highly sheared Miocene volcanogenic rocks of the Tanzawa Group.

6 14:50–15:50 500 m south of **Miho Dam** along an old road is an exposure of Zone III rocks of the Tanzawa Group. Dark bluish green rocks have mineral assemblages of the prehnite-pumpellyite facies. Weak foliation is evident. Epidote-wairakite-quartz and prehnite-quartz veins were formed along sheared planes and these veins were later cut by veins chiefly composed of laumontite and/or stilbite.

7 16:00–16:30 **Yumoto-Daira**. Walk down to the river floor to view a good exposure of Zone II volcanogenic rocks of the Tanzawa Group, near the boundary with Zone III. Schistosity is absent or very weak, but the rocks are highly fractured with the development of wairakite-, yugawara-

Fig. 4 Amphibolites derived from volcanic breccias and tuffs of the Tanzawa group (lower Miocene) are freshly exposed in the stream floor of Nakagawa. Schistosity is distorted by later movements. A reverse fault cuts the stream floor. Overview from a suspension bridge, Nakagawa.

Fig. 5 Volcanic blocks are flattened in the plain of a regional schistosity of the amphibolites at Nakagawa.

lite-, laumontite- and stilbite-bearing veins. Wairakite is mostly observed in epidote-quartz and epidote-prehnite-quartz veins. These wairakite-bearing veins are cut by yugawaralite-, laumontite- and laumontite-bearing veins which are also cut by stilbite-bearing veins. Note the wide occurrence of hematite in the volcanogenic rocks. In this horizon of the Tanzawa Group, gravels of the dioritic and gabbroic rocks which penetrate the Tanzawa Group are observed in association with basaltic and andesitic volcanoclastic fragments. Pyrite is extremely rare.

8 16:40-17:10 Mouth of **Shio-zawa**, Kawanishi. Cross a small bridge on the main stream of Nakagawa to view an exposure of a conglomerate bed of the Pliocene-Pleistocene Ashigara Group. There are a number of pebbles of quartz diorite and metamorphic rocks, of the amphibolite facies (Zone V) and the actinolite greenschist facies (ZoneIV), with minor amounts of the prehnite-pumpellyite facies rocks (Zone III). The matrix of the conglomerate is chiefly composed of fine grained clastic materials derived from the previously mentioned igneous and metamorphic rocks, plus smectitic clay minerals and Ca-zeolites

(chabazite and stilbite). The mode of occurrence of Ca-zeolites in the matrix and in thin films around the pebbles indicates that the Ashigara Group experienced the low temperature metamorphism of the zeolite facies (Zone 1).

References

Ishikawa, T., Okada, N. and Kitasato, H. (1983) Stratigraphy and geologic ages of the Ashigara group. Abstracts of Geol. Soci. Japan, 1983, 98.

Imanaga I. (1982) Geological development of Kanagawa Prefecture—correlation of sequences and geological age. Natural History Rep. Kanagawa, no. 3, 35-38.

Oki, Y., Suzuki, T. and Hirano, T. (1977) High pH groundwaters of the Tanzawa mountains, Japan. Proceedings 2nd International Symp. on Water-Rock Interaction, Strasbourg, Sec. 1, 1-14.

Oki, Y., Ohguchi, T., Hirota, S., Ogino, K,. Hirano, T. and Moriya, M. (1967) Geothermal structure in the Nakagawa district, Tanzawa mountains. Bull. Hot Springs Res. Inst. Kanagawa Pref., no. 5, 23-33.

Seki, Y., Oki, Y., Matsuda, T., Mikami, K. and Okumura, K. (1969) Metamorphism in the Tanzawa mountains, central Japan. Jour. Assoc. Japan. Min. Petr. Economi. Geol., vol. 61, 1-25, 50-75.