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36. *Volcano-Stratigraphic Study of Ôshima Volcano, Izu.*

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Contents

Abstract

Ôshima Volcano is a basaltic, insular stratovolcano with a summit caldera within which lies an active cone Mihara-yama. Izu-Ôshima island is situated on the northern part of a volcanic chain extending from central Honshû to Marianas. Ôshima Volcano consists an essential part of Izu-Ôshima island which is the largest of the seven Izu-islands, being 92 km^2 in area and 22.5 km^3 in volume above sea-level. Volcanic products of the volcano were studied stratigraphically. The method and results of the study are summarized and discussed in this paper.

A group of erupted material, including lava-flows, scoria- and ash-falls, which successively accumulated without any weathering break is called a member in this paper. A member is the basic stratigraphic unit which is proved to be the product of a single eruptive cycle. Within a member, there is a definite succession of erupted material, scoria-falls→lava-flows→alternation of ash-falls in ascending order. The time needed for the deposition of a member is considered to be 10 years or less from an examination of the latest two records of major eruption (1777∼1792 and 1684∼1690). The time needed for the deposition of the basal scoria of a member is far shorter than that for the deposition of the alternating ash-falls. This is evidenced partly by the examination of historical documents and partly by the simple elliptic shape of the distribution of the basal scoria. Eruptive activity represented by a member may be a continuous process in which the magma in the central conduit rises with explosive eruptions of scoria, overflows and then gradually falls with an ejection of ash for many years. Ôshima Volcano is composed of more than a hundred members. The youngest twelve members are lumped into the Younger Ôshima Group, with which this paper is chiefly concerned.

Dates of the deposition of the twelve members are inferred by the correlation with historical documents and excavated fragmental pottery remains and by radiocarbon measurements. As a result, the Younger Ôshima Group is found to consist of the deposits during the last 1500 years or so, and the deposition of each member, in other words major eruption, to have taken place periodically with an interval of about 135±50 years. The volume of individual members is calculated to range from 0.1 to 0.7 km^3. The volume of the Younger Ôshima Group is estimated to be 3.6 km^3, of which only 0.7 km^3 is now accumulated on the slope of the main cone. The rest is the caldera fill (ca. 2.2 km^3) and the deposits outside the island. The explosion index is calculated to be about 60 for the Younger Ôshima Group. Thermal energy transported by the Younger Ôshima Group attains to the order of 1×10^{26} erg and the rate of energy release is $8.7\sim6.0\times10^{24}$ erg/100 years.

More than forty parasitic volcanoes are distributed within two narrow fracture zones. They are monogenetic, that is, the entire erupted material of each is incorporated within a single member. The summit caldera was formed after the deposition of the twelveth member (S_2) from the surface and prior to that of the tenth member (N_4), or some fourteen centuries ago. The volume of the twelveth and the eleventh member (S_2 and S_1), which are considered to have deposited just before the caldera formation, is estimated to be 0.4 km^3 i. e. one-eighth of the volume of the decapitated summit (3.1 km^3). These are mainly steam explosion breccias and ash-falls with accretionary lapilli. This will indicate that the summit was engulfed associated with intense explosions. The actual course of the engulfment is inferred to be like the eruption of Kilauea in 1924, after a consideration of the similarity of the sequence of events for the both activities. Recent eruptions of Ôshima Volcano after the last major activity (1777~1792, the product of which is the uppermost member Y_1), are very different in nature from those represented by members. Recent eruptions are more effusive (explosion index 10±), smaller in the volume of erupted material (less than 0.03 km^3) and have affected only the interior of the caldera or even of the crater of Mihara-yama. The rate of thermal energy release is also lower (2.7×10^{24} erg/100 years). Moreover, the period after the last major activity is that of repose judging from the deposits on the slope of the main cone.

Chapter 1. Introduction

Izu-Ôshima is a volcanic island with an active central cone, Mihara-yama (Mt. Mihara), within the summit caldera. The island is situated at about 120 km southsouthwest of Tokyo, between latitude 34° 40′—34° 48′ north and longitude 139° 21′—139° 27′ east. It is one of the insular volcanoes belonging to the chain that extends from central Honshu of the Japanese Archipelago to Marianas.

The present paper is a summary of the stratigraphic study of the younger volcanic products of Ôshima Volcano; it also discusses problems related to the volcano-stratigraphy.

Since the end of the 19th century, more than a hundred papers have been written about this volcano. Most of these papers deal with the "present state" of the volcano, that is, they are either studies undertaken from the geophysical standpoint or a description of the eruptions of the day. Now, a comprehensive study of the situation of the "present state", as part of the growth-history of the volcano, seems to be required for a better understanding of the nature of the volcanic activity.

Moreover, most of the past geological studies of the island have been petrological researches of the lavas, and very few studies have been attempted on the growth-history of Ôshima Volcano (Chapter 2.).

In order to reveal a vivid "continuous" history of volcanic eruption, the relationship between the deposition of volcanic products and the relevant eruptive phenomena must be clarified. Such a relationship will also contribute to the principles of pyroclastic stratigraphy. In this connection, Ôshima Volcano seems to have certain advantages as mentioned below ((1)—(4)) over the other volcanoes hitherto studied in detail, namely Kilauea (Powers, 1948), maars in Westeifel (Frechen, 1953), Icelandic volcanoes (Thorarinsson, 1951. 1952. 1953. 1954 and 1958), volcanoes in Hokkaido (Katsui, 1962 and 1963; Kondo, 1963, Yamada *et al.*, 1963), and Asama Volcano (Aramaki, 1963).

(1) Izu-Ôshima island, the essential part of which is represented by Ôshima Valcano, is a simple-formed, isolated island of an easily accessible size (Chapter 3).

The greater part of the island is most certainly composed of ejecta from the central vents of Ôshima Volcano, although some parasitic volcanoes have also contributed to the formation of the island.

(2) Ôshima Volcano is an active volcano, so that the ejecta, at least on the surface, are fresh enough.

(3) The volcano is a basaltic and polygenetic one. Each unit consisting of lava-flows and pyroclastic deposits is thinner than that of andesitic or dacitic volcanoes.

(4) Because the island has been inhabited for several thousands of years, pottery remains which serve as an age-indicator, have been found from various horizons of the ejecta. Moreover, as the island

can be seen from the central part of Honshû, the main island of Japan, chances of historical documents of its eruption are greater than in other places more remote from civilization. As the network of roads in the island is comparatively dense, younger fall deposits are exposed in many places. Such exposures have increased a great deal due to the recent development of the island as a tourist resort.

In December of 1957, following the suggestion by Professor Nobuo Katayama, the writer began the stratigraphic study of Ôshima Volcono. He has been engaged in the field work intermittently during the period 1957—1963. More than 150 days were spent for the field mapping, especially for identification and measurements of the thickness of fall deposits. Some of the results of this work have already published in two papers (Nakamura, 1960·1961) dealing with the activities of the summit and parasitic craters, respectively. Important facts and an interpretation of them, as written in the previous papers, will be reiterated in this paper. The result of mapping is condensed in a geologic (distribution and structure) map (Fig. 21), supplemented with twelve isopach maps (Figs. 9—20), also Table III shows the calculated result of the volume of ejecta. The scheme of the development of Ôshima Volcano may be grasped from Table I and Figs. 4 and 8.

The writer follows Wentworth and Williams (1932) in the terminology of pyroclastics.

Chapter 2. Previous Work

1. General Review

The first scientific report of Ôshima Volcano appeared as early as 1877, when E. Naumann described his trip to the volcano during the eruption from 1876～1877. Since then, more than 180 papers have been published on the volcano including short descriptions of the eruptions as observed during a visit to the summit crater.

The reason why so many papers were written on a single volcano may be because:

1. It is situated near Tokyo where many students of the volcano have lived, especially in the early days.

2. The volcano has erupted every 10 years during this century, whatever the magnitude of eruption may have been.

3. Recent activities have been mostly effusive and rather quiet so that close observation was possible even near the crater.

4. The chemical composition of the ejecta of Ôshima Volcano is so high in iron content (as much as 15 wt. % in the from of Fe_2O_3) that magnetic apparatus is very effective for studying the volcano and its ejecta.

As it is impossible to list all the papers relating to previous work in this short summary, numbers and published dates are shown in Fig. 1 grouped into four categories showing the method and subject of study. From this figure, a general tendency for an increase in the number of papers and a shift in the subject and method of studies can be perceived. Comparing the variation in the numbers of papers with

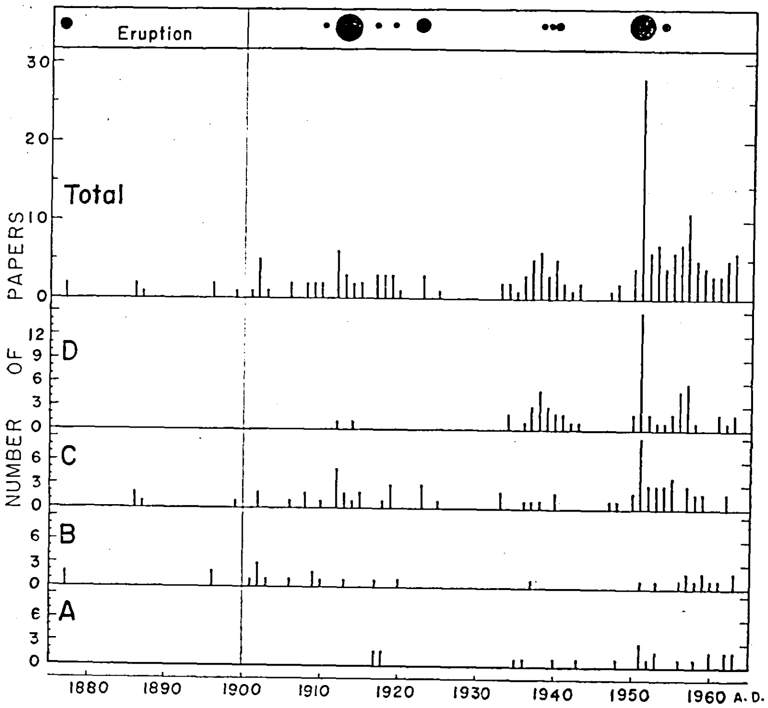

Fig. 1. Annual number of published papers on Ôshima Volcano from 1876 to 1963. They are arbitrarily grouped into four categories.

A: Papers dealing mainly with chemistry and mineralogy of erupted material (rocks, minerals, sublimates and gases).

B: Dittos., geology and the study of the growth-history of the volcano.

C: Dittos., description of eruptions, topographic and archaeologic studies, guide-books and review works being included.

D: Dittos., studies of ejecta, volcanic edifice and eruptive phenomena by means of "geophysics".

the dates of eruptions, it can be clearly understood how the investigations of the volcano have been inspired by its eruptions.

Studies grouped as B in Fig. 1, include chemical analyses of rocks and gases and relevant discussions. Study of this kind has become popular since the 1930's. Chemical analyses of the rocks of the Ôshima Volcano were published by Okamura (1914), Tsuboi (1917), Kani (1934), Iwasaki (1935), Tsuya (1940), Nagata (1941), Morimoto and Ossaka (1951), Tsuya and Morimoto (1951), Sawamura (1952), Tsuya, *et al.* (1952), Katsura and Nakamura (1960), Kuno *et al.* (1962) and Isshiki *et al.* (1963) The rocks of this island are typical theoleiite. Results of the analyses of the gases and the ejecta of the fumarole have been reported by Noguchi *et al.* (1962, 1963).

Group C consists mainly of descriptions of eruptions of the day. A few geomorphologic and archaeologic papers as well as guide-books and review works are also included in this group. These naturally vary in yearly number in accordance with external incidents such as eruptions, excursions, discovery of human remains in the ejecta and so on. Among them, a paper by Kuno *et al.* (1963) in "Catalogue of the active volcanoes of the World" is a comprehensive summary on the study of the volcano from various standpoints so far carried out including the present writer's study (Nakamura, 1960).

One of the biggest activities in this century, the Meiji-Taishô activity (1912~1914) was described in detail by Omori (1915). Tsuya *et al.* (1954 a·b, 1955) gave a detailed description of the course of another great activity (1950~1951). Kizawa (1951a. b) also described the earlier course of the activity (1950) and reported the volcanic microseisms and some other geophysical observations at that time. Foster and Mason (1955, 1956), after reviewing the previous works on the geology of the volcano, described the same activity (1950~'51, 1953~'54) and summarized the studies then undertaken by many Japanese scientists, with their own observations on the surface structure of new lava-flows.

Group D contains "geophysical" investigations by modern methods which have become much more popular than other branches of volcanology these days. Because of these contributions, Ôshima is probably by now one of the most well-studied and best-understood volcanoes in the world from the standpoint of volcanophysics. The following papers comprise the latest instances of the research works; magnetic properties of ejecta, a series of papers by Nagata and his collaborators (1937~1963); the geomagnetic field of the volcano and its change during and after the eruption, Yokoyama (1951 a. b), Rikitake *et al.* (1951), Yokoyama (1954a·b, 1955); archeaomagnetism by Yukutake (1961), Yukutake, Sawada and Yabu (1964) and Yukutake, Nakamura and Horai (1964); Gravity measurement by Yokoyama and Tajima (1957) and its change by eruption by Iida *et al.* (1952); energetics by Yokoyama (1956, 1957a·b); earthquakes in and around the island by Kishinouye (1936), Takahasi and Nagata (1939), Takehana (1940) and Tazawa (1956, 1957); volcanic tremors accompanied by eruption by Kizawa (1951a. b) and Minakami *et al.* (1951) and temperatures and viscosity of lavas by Minakami (1951), Suwa *et al.* (1955).

2. Study of the Growth-History

The asymmetric form of the island between the northeastern and the southwestern parts, as will be described in Chapter 3, has attracted the attention of students from the earliest stage of observation. Naumann (1877) supposed an older volcano under the elevated northern part of the island. Nishiyama (1886) briefly described the topography of the island with a simple geologic profile.

Yamasaki (1896) published the first and outstandingly comprehensive study of the whole island. He divided the history of development into two stages: an older submarine volcano stage and the present volcano stage. The older volcano is buried under the northern and eastern parts of the island and crops out along the coastal cliffs (Gyôja-no-iwaya and Fudeshima volcanoes (Chapter 3) in the present paper). One of the craters of "the older volcano" is called Habuminato, which actually is a steam explosion crater formed after the formation of the summit caldera (Nakamura, 1961). The present volcano by Yamasaki is the somma and the central cone of Ôshima Volcano. He assumed the summit caldera to be a large crater. He also pointed out that black basalt with much plagioclase and sporadic olivine phenocrysts was common among the lavas of the somma and that grey aphyric basalt constituted the uppermost part.

In 1901, human remains, pottery and other things were found under a lava-flow exposed along the western coastal cliff, at Nomashi. Otsuki (1901) surveyed the geology around the site and reported that the lava exposed there was the black basalt of somma after Yamasaki (1896) and that there was another horizon of remains on the mud-flow deposits (S_2 in this paper) which covered the lava-flow. Otsuki pointed out at the same time that the central cone, Mihara-yama, was younger than the date which was inferred to be, some 3000 B. P., from the lower remains in his paper. Torii (1901) described the remains and mentioned the possibility of correlating the record of accident in 684 A. D. to the deposition of the mud-flow (see Chapter 6). Sato and Fukuchi (1902) made a close observation at several places on the island and indicated that Habuminato was a younger explosion crater, and suggested that there was another older volcanic body at the northern part of the island (Okata Volcano in this paper), and that the gourd-shaped summit crater (caldera) was a connected one.

Ohashi (1909, 1910) published the results of his study of the geology of the island and expressed opinions a little different from the former researchers. An important conclusion arrived at in his papers was that the summit caldera was formed not by explosion but by subsidence. He observed that there was not such a great quantity of ejecta corresponding to the amount of decapitated summit, and that the lava-flows being exposed on the caldera wall were cut by the wall and did not flow over the saddle part of the caldera rim. He considered "the older volcanoes" recognized by previous researchers, as older ejecta of the Ôshima Volcano proper, according to the essential similarity of their petrographic characters. Thus, according to Ohashi, ejecta of "the older volcanoes" are the older products of Ôshima Volcano, which contain common phenocrystic olivine. Further, he noticed the common presence of tridymite in the basaltic rocks.

Volcano Oshima Idzu by Tsuboi (1920) is another and the last comprehensive study of the petrology and geology of the island. After giving a detailed summary of the previous works, he described minutely the surface structure of the volcano, and the petrographic especially microscopic characters of the lavas and discussed the history of magma. He regarded Okata Volcano in the northern part as an independent volcanic body of Ôshima Volcano during its activity. He emphasized that basalt lavas of Ôshima Volcano are rich in SiO_2 and CaO and poor in alkali, especially in K_2O. He succeeded Ohashi's idea by adding that Fudeshima and Gyôja-no-iwa volcanos were nothing but the ejecta of Ôshima Volcano.

After Tsuboi's work, the study of the growth-history of Ôshima Volcano has long been suspended. Only the following simple scheme has been presented:

(1) growth of the somma by repeated eruption of lavas and pyro-

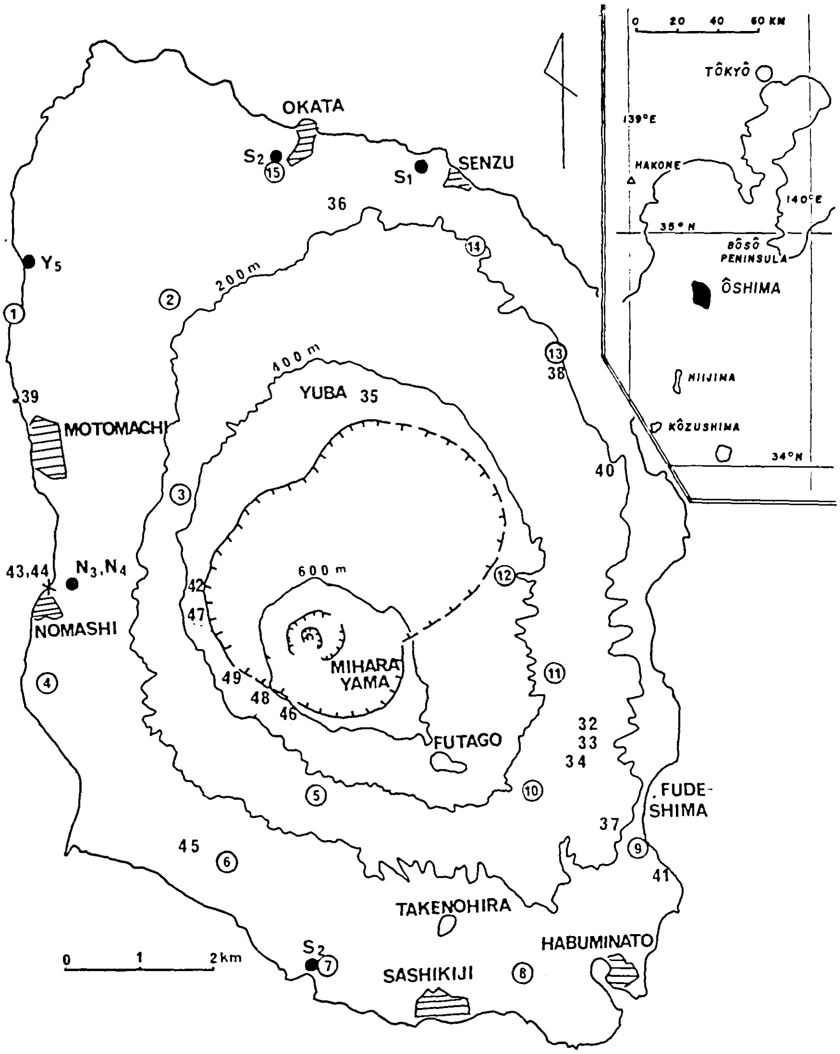

Fig. 2. Locality map. Naked numerals indicate the localities of the figures in the text of corresponding number. Numerals in circle show the localities of columnar sections in Fig. 7. Dots are the localities of pottery remains with the sign of eruptive cycle units which directly overlie the remains.

clastics, (2) caldera formation and (3) growth of the central cone, Mihara-yama.

Ikuma (1955, MS), under the guidance of H. Kuno, studied the petrology and geology of the island with emphasis on its basement. He established that Okata and Fudeshima (and Gyôja-no-iwaya) Volcanoes were the basement to Ôshima Volcano and introduced Kuno's idea that they were younger Pliocene in age.

Tsuya *et al.* (1956) summarized the evolution of the Mihara crater since 1877 (Chapter 8), with the description of the activity of Ôshima Volcano in, 1953～1954.

Sumi *et al.* (1959) studied the northern and eastern coastal area and presented a detailed geologic map of the area. They fully described the stratigraphy and petrography of the ejecta of Okata Volcano. They also studied the petrographic character of a part of the ejecta of the Ôshima Volcano but their stratigraphy on this subject may not be accepted in the form it was presented.

The present writer (1960, 1961, 1963) has studied the history of activities by means of stratigraphy of the ejecta, some of the results of which are incorporated in this paper.

Recently, Isshiki *et al.* (1963) published the results of various investigations on the core samples of five drillings performed on the caldera floor. They assumed the original caldera floor at about 130 m below the present floor.

Chapter 3. Geologic and Topographic Outline of the Island

1. General Statement

Izu-Ôshima is a parallelogram-shaped island of the following dimensions:—92 km^2 in area; 758 m in maximum height and 22.5 km^3 in volume above the present sea-level.

The island consists of volcanic products of Ôshima Volcano proper and three underlying dissected stratovolcanoes, i. e., Okata, Fudeshima and Gyôja-no-iwaya volcanoes. All of them are mostly made up of tholeiitic basalt. Ôshima Volcano comprises the main cone (the somma), Mihara-yama (the central cone inside the summit caldera) and more than forty parasitic volcanoes on the slope of the main cone. The geologic history of the island are schematically shown in Table I.

Bulk density of the island above the present sea-level is calculated as being about 2.1 g/cm^3 from the result of gravity survey (Iida *et al.*, 1952; Yokoyama and Tajima, 1956). Compared with the smaller bulk density of andesitic stratovolcanoes (e. g. 1.8 g/cm^3 of Asama Volcano (Minakami, 1942)), this value may suggest that the nature of eruption is less explosive. Still it is mach smaller than those of common specimens of lava of Izu-Ôshima. (2.5～2.8 g/cm^3, Iida *et al.*, 1952;

Table I Diagram showing the history of development of Ôshima Volcano

	Volcanic products	Years B. P.	Volcanic edifices		
Exposed in the island of Izu-Ôshima	The Younger Ôshima Group (lavas and pyroclastics, 3.6 km³)	—10^3—		Mihara-yama (the central cone) ?	Ôshima Volcano
				← Formation of summit caldera	
	The Older Ôshima Group (lavas and pyroclastics, 40 km³)	—10^4—	Parasitic volcanoes (more than forty) ?	The Main cone (the somma)	
	?				
	?				
	The Senzu Group (4 km³)		Mud-flow deposlts and explosion breccias with minor amount of lavas. Rocks probably of the Yugashima group are found in the mud-flow deposits.		
	?	—10^5—			
	?	—10^6—			
	Lavas and pyroclastics of basement volcanoes		Remnants of three dissected volcanoes (Okata, Fudeshima and Gyôja-no-iwaya Volcanoes)		
	?				
		—10^7—			
	?				
*	The Yugashima Group		A complex of altered andesite and basalt with submarine clastic sedimentaries intruded by quartz-diorites.		
	?				

* Found as accidental fragments in the Senzu Group.

Isshiki *et al.* 1963).

The coasts of the island are almost cliffy with narrow lava benches. The eastern and northern cliffs attaining at places 300 m in height are generally higher than others. The higher cliffs may have been formed by the marine erosion of longer duration, where the inner structure of both Ôshima and basement volcanoes is fairly well exposed. Where the lava streams of Ôshima Volcano cascaded down the cliff and spread along the coast, the higher cliffs are preserved at the inner part of the island, thus forming a coast of double cliffs (Figs. 3 and 4.). This

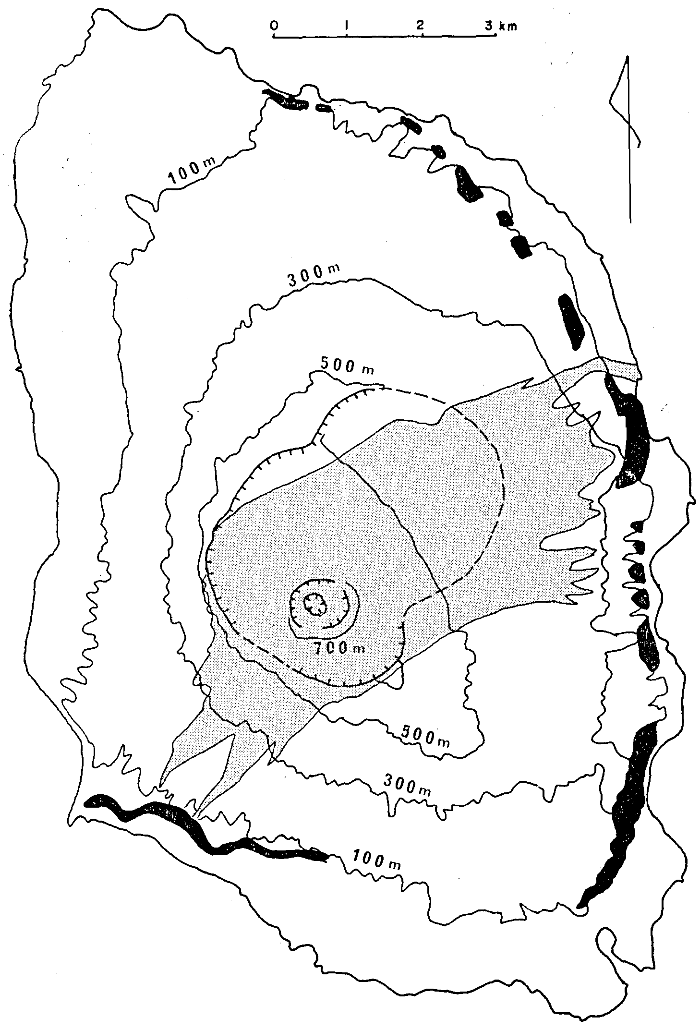

Fig. 3. The distribution of the barren area (stippled area) and the inner cliffs (solid area) of the island. Between the cliffs and the present coastal line, there are lava-flows of relatively younger age. The barren area extends in two directions of prevailing wind off the active central crater. The map is drawn after vertical aerial photographs taken in 1947.

coastal feature seems rather common in the young insular or coastal volcanoes, and may probably be attributed to either the recent interruption of a relative rise of sea-level or to a possible inactive period (Sumi *et al.*, 1959) during the eruptive history. Some previous authors considered the inner cliffs to be a fault line scarp (Tsuboi, 1920, Kuno, 1958·1962), however, the distribution seems to be more reasonably explained by assuming them to be formed by the older coastal erosion.

The directions of prevailing wind at the island are east-northeastward and southwestward (Kizawa and Sakamoto, 1951), similar to conditions prevailing at least during the last 1500 years. This circumstance is clearly revealed by the isopach maps of pyroclastic fall deposits (Figs. 9~20).

The island is mostly covered by vegetation except for the barren strip which extends in parallel to the two directions of the prevailing wind off the active crater (Fig. 3). The barren strip extends from the active crater and includes the outer slope of Mihara-yama, the greater part of the caldera floor and a part of the slopes of the main cone. The strip reaches the coastal areas forming sandy beaches.

In this barren area, agency of erosion and of transportation are very severely active owing to the lack of vegetation, where the younger pyroclastic falls (Figs. 9~14) are frequently absent. The lack of vegetation may be, in turn, due to the constant and direct effect of gases which issued from the active crater. Tsuboi (1920) and later authors attributed the origin of this barren area to the accumulation of recent pyroclastic falls from the central cone, and Tezuka (1960) further discussed the primary plant succession based on the Tsuboi's map. The present study shows, however, that the recent pyroclastic falls had once accumulated on the barren strip and that they were eroded away (Figs. 9~20). Thickness of the falls deposited on the strip is comparable to those deposited on the outside of it.

Two breaks of the caldera wall indicate that valleys had been formed on the slope of the main cone before the subsidence of the summit caldera. The geographic situation of these valleys are the same as those of the present barren area (Fig. 3). This suggests that the origin of the valleys is the same as that of the present barren area where erosion is severely undertaken.

The island has been continuously inhabited for the last five thousand years or so (Torii (1902), Aso (1959) and Nakamura (1960)). Pottery remains by primitive pepole have been excavated from various horizons of volcanic products and afford an important key to their chronology (Chapter 6). The location of the once area of habitation was found, naturally, outside of the present barren area and along the coast.

2. Basement Volcanoes

Ejecta of Okata Volcano (Isshiki *et al.*, 1962; "demolished igneous bodies" of Tsuboi, 1920; "Okata Basalt Group" of Ikuma, 1955, Kuno, 1958, Sumi *et al.*, 1959), cropping out on the northern coastal cliffs, are covered by later volcanic deposits of about 80 m in thickness (Ono *et al.*, 1961). The dissected surface of the volcano is faithfully represented by the present ground surface, e. g. a row of hills independent of the slope of the main cone of Ôshima Volcano. The original extension of Okata Volcano is unknown, but its eruptive centre is assumed to have been near the Okata Harbour, according to the general westerly inclination of the alternation of the lavas and pyroclastics and also to the presence of numerous dykes near the harbour (Kuno, 1958).

The distribution of the remnant of Okata Volcano is mapped in Fig. 5. As shown in the same figure, another dissected volcanic body, Fudeshima Volcano (Isshiki *et al.*, 1962), lies near the southeastern margin of the island (Hudeshima Basalt Group of Ikuma, 1955; Kuno, 1958; Sumi *et al.*, 1959). This is also a stratovolcano with its assumed centre near the opposite coast of Fudeshima, a tiny tower-like island. There, the coastal cliff is composed of massive chaotic essential tuff breccia, being intruded by a network of dykes.

Beside these two volcanic bodies, thick andesitic lava-flows, exposed on the eastern coast near Gyôja-no-iwaya, form the remnant of Gyôja-no-iwaya Volcano (Isshiki *et al.*, 1962). But the product of this volcano, being different from those of the other two, does not form a cone but filled up the former topographic depression.

These three remnants of older volcanoes have common characteristics in that they are unconformably overlain by the Senzu Group (roughly equals to "the older member of the Somma" of Sumi *et al.*, 1959 and Senzu tuff breccia of Nakamura, 1961). The Group consists mainly of mud-flow deposits and explosion breccia with a subordinate amount of lavas.

It is still unknown whether the volcanic activity that formed the Senzu Group represents the first phase of activity of Ôshima Volcano or another volcano prior to the birth of Ôshima Volcano. Senzu Group is unconformably overlain by the Older Ôshima Group which forms an essential part of the main cone of Ôshima Volcano. The Senzu Group shows, however, "island-wide" distribution. Therefore, the Group may possibly be the product of Ôshima Volcano in its earliest stage, when the contact of fresh magma with sea water produced predominantly fragmental ejecta.

Fragments probably derived from the Yugashima Group, lower Miocene complex of altered andesite and basalt exposed extensively in the Izu Peninsula northwestward of the island, are found in the tuff breccia of the Senzu Group. This fact suggests the presence of the Yugashima Group beneath the island (Sumi *et al.*, 1959).

3. The Main Cone (the Somma) and the Caldera

The main cone of Ôshima Volcano is a stratovolcano formed by repeated central eruptions of basaltic magma. The cone is composed of the Younger and Older Ôshima Groups, and possibly of the Senzu Group. Among these, the Older Ôshima Group forms the greater part of the main cone.

The Senzu Group is exposed on the higher, inner coastal cliffs. The Older Ôshima Group chiefly exposes itself both on the lower, outer

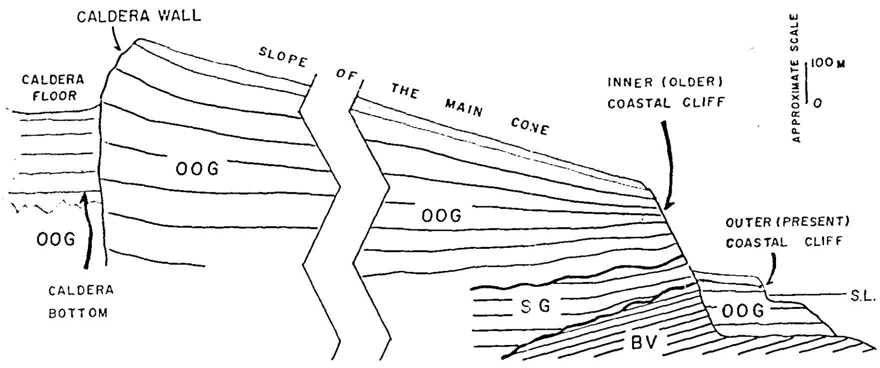

Fig. 4. Schematic section of Izu-Ôshima Island from the summit caldera to the coastal area.
Stippled area: the Younger Ôshima Group
OOG: the Older Ôshima Group
SG: the Senzu Group
BV: erosion remnant of basement volcanoes.
Explanation of these units are given in the text.

coastal cliffs and on the upper part of the inner cliffs. The uppermost part of the Group is also exposed on the wall of summit caldera. The surface of the main cone is almost entirely covered by the Younger Ôshima Group. These relationships are illustrated schematically in Fig. 4.

The present surface of the main cone is thickly covered by vegetation and is still young in dissection. Valleys attaining to fifty metres in depth are not uncommon in some places.

The inclination of the southwestern slope of the cone becomes greater with increasing elevation, attaining to 35° at its summit. Conversely, the northeastern slope is much gentler than that of the former and inclines from 5° to 15°, being abruptly cut by the higher, inner, coastal cliffs. This asymmetry of the slope of the main cone may be attributed to the existence of older volcanic edifices under the northeastern part of the cone and also possibly to the southwesterly tilting of the island.

At the summit, there is a gourd-shaped caldera, 3 to 4 km in diameter and 10 km^2 in area. The caldera is surrounded by steep walls less than 100 m in relative height except at its northeastern and southwestern parts. The continuity of the wall at the southwestern break is easily observable on the heads of valleys cutting a little into the caldera floor (Fig. 46). On the other hand, the northeastern part of the caldera is deeply buried by later deposits. The location of the wall of the northern part is inferred by the distribution pattern of the central cone lava flows (Isshiki *et al.*, 1963).

The present caldera floor at the northern part is elevated at least about 140 m from the original caldera bottom mainly due to accumulation of lavas repeatedly issued from the central vents. During the last three major activities, i. e. those in 1552, in 1684 and in 1778, the lava-flows from the central vents overflowed from the two breaks of the caldera wall, and finally reached the shore line running down the slope of the main cone.

4. Mihara-yama (the Central Cone)

Mihara-yama, an active post-caldera cone, situated at the southwestern part of the caldera floor, rises about 160 m from the surroundings and has an outer slope of about 30°, like a normal scoria cone (Nakamura, 1961), except its foot where the original slope is covered by ash, lapilli and blocks of talus debris.

The upper part of the present cone is made up essentially of layers of agglutinated scoria of the Y_1 time or some 190 years ago, as seen on the eastern crater wall. The cone is partly veneered by 1950～1951 lavas, which overflowed from the crater to the northwestern floor of the caldera. The diameters of the base and summit crater of the cone are 1500 m, and 700～800 m, respectively. Inside the crater, there is a crater floor made up of lava-flows, containing a central pit approximately 300 m in diameter.

The crater of Mihara-yama has been the only site of activity since 1876 (Tsuya *et al.*, 1956). Since then, the crater floor has gradually been filled up by lavas and pyroclastics, more than 150 m in thickness. At present, the 1950～1951 lavas, which again filled up the central pit, cover the crater floor as high as the lowest saddle part of the crater rim. During the same period of activity, scoria and spatter have formed a small cone at the southern part of the crater floor (Fig. 31). The top of the cone represents the highest point in the island. Later, the pit-side of the new cone has slid down as the former pit gradually becomes deeper again. Now it is a half cone on the crater floor.

5. Parasitic Volcanoes

More than forty parasitic volcanoes on the slope of the main cone are arranged on the two parallel rift zones running parallel to the long axis of the island with NNW-SSE trend (Nakamura, 1961). Mihara-yama is situated at the centre of the western zone. Two fissure zones of "fissure eruption" (the S_2 and the Y_4 time) and seven vertical dykes related to Ôshima Volcano are same in their direction (Fig. 5). Moreover, the zones are parallel to the fissures in the adjacent areas including the Izu Peninsula and a few island in the neighbourhood (Nakamura, 1961). The direction of these zones may probably depend on the distribution of regional stress rather than on the upward pressure of rising magma (Kuno, 1958) under the particular island. The zones of structural weakness in the basement rock may probably have provided paths for subsidiary channels branched away from the main conduit.

All the parasitic volcanoes so far studied in detail by the writer are of monogenetic nature and are formed by the simultaneous activity with that of the summit craters, resulting in their simple cone shape. The oldest known one is Futago-yama (43 in Fig. 5), erupted in the later stage of the Older Ôshima age, or some ten thousand years ago.

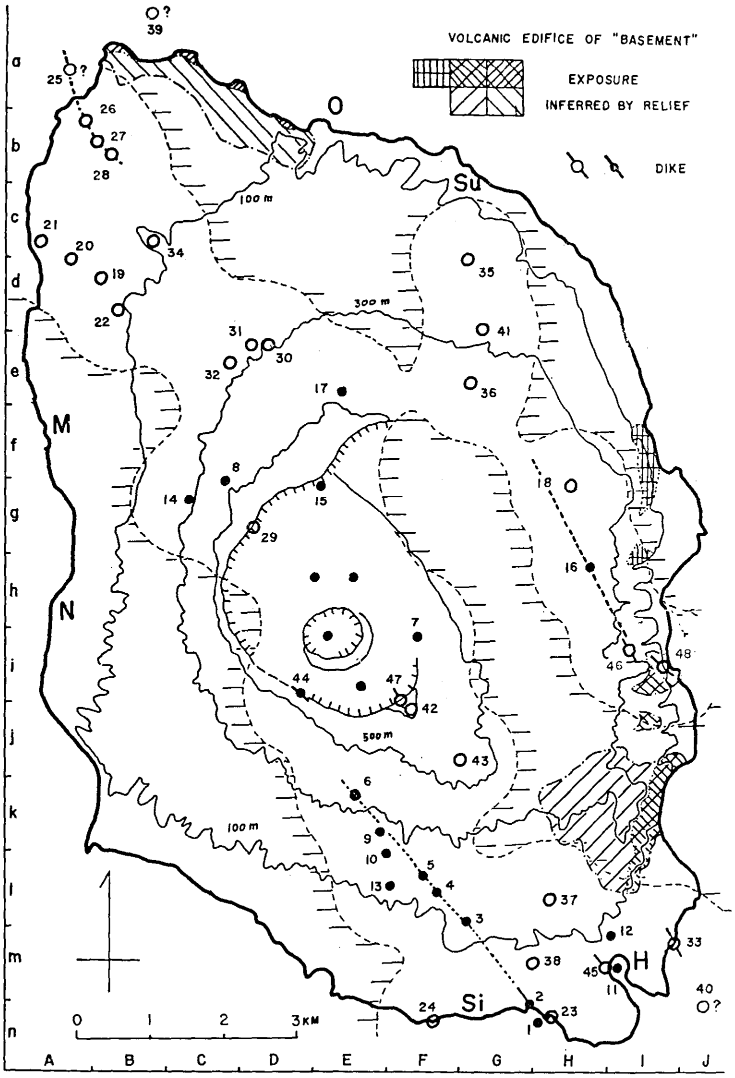

Fig. 5. Distribution of vents in the island of Izu-Ôshima including dykes (Nakamura, 1961).

open circle: the Older Ôshima age

solid circle: the Younger Ôshima age

Three solid circles at the foot of the central cone indicate the crater whence the lava-flow of Y_1 issued. Hatched lines are drawn so as to be 800 m distant from the nearest crater. Numbers are referred to in Table VI of Nakamura (1961) in which volume of parasitic volcanoes is enumerated.

The youngest flank eruption occurred in the Y_4 time, about 1420 A. D., along a fissure zone in the southern part of the island. The main scoria cone, Takenohira (3 in Fig. 5), born at the time of this activity, is nearly perfect in its conical shape in sharp contrast to the dissected cone of Futago-yama.

Parasitic vents, erupted after the caldera formation, are crowded in the central and southern parts of the western rift zone.

The scoria cones and other direct product of fresh magma are distributed at all elevations, while the steam explosions, resulting in either the formation of explosion craters (e. g. Habuminato and Hikubo [11 and 38 in Fig. 3, respectively]) or the deposition of explosion breccias, are confined to the coastal area. In view of this, the presence of (sea) water seems to be indispensable for the steam explosions of parasitic volcanoes (Nakamura, 1961).

Chapter 4. Volcano-Stratigraphy

1. General Statement

The island of Izu-Ôhima is composed mostly of subaerial volcanic products of basaltic nature, *i. e.*, pyroclastic fall deposits (scoria and ash) and lavas, with subordinate amounts of agglutinated driblets near the vents and secondary deposits at the foot of cones. The lava flows mainly fill the valleys and other depressions, whereas the pyroclastic falls tend to be distributed more uniformly and widely, being controlled by the direction of prevailing winds and the distance from the craters.

The history of the volcanic activities, will be revealed if the stratigraphic and chronologic sequence of the fall deposits is known. Also, the horizons of lava flows and other local deposits will be compiled into a single stratigraphic column. For this purpose, the most important task may be that of tracing a succession of falls at a certain exposure or correlating the falls with those of a distant area.

A simplified presentation of an idealized exposure at a point nearly half way up the slope of the main cone is given in Fig. 6. Actual exposures are photographed in Figs. 32 and 35. As these shallow cuttings are made at places more or less higher than the surrounding surfaces, they are naturally composed largely of the accumulation of subaerial pyroclastic fall deposits with minor amounts of lava- and mud-flow deposits.

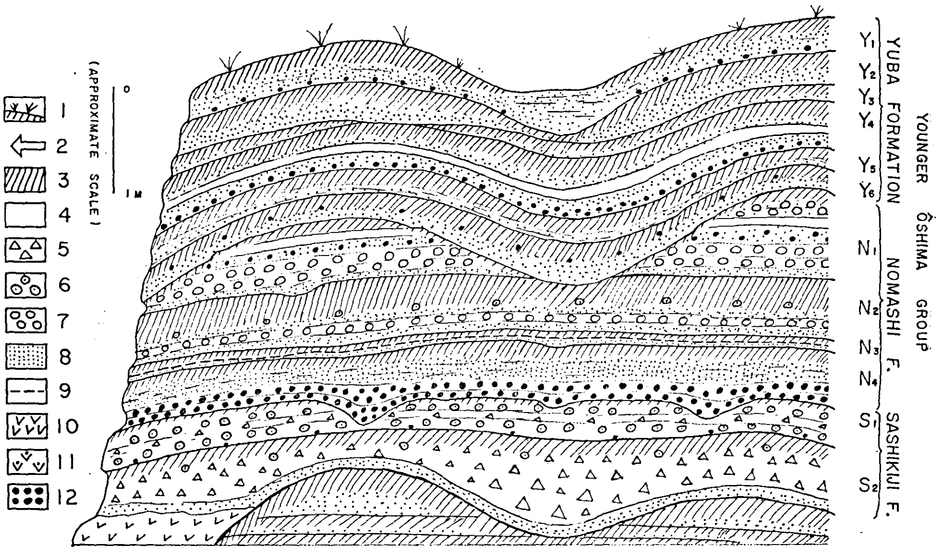

Fig. 6. An idealized sketch of an exposure on the mid-slope of the main cone (Nakamura, 1960).

1:	present ground surface.	2:	horizon of pottery remains
3:	weathered ash or soil	4:	fine volcanic ash
5:	tuff breccia	6:	accretionary lapilli tuff
7:	rounded lithic lapilli	8:	coarse volcanic ash
9:	rhyolite ash	10:	lava-flow
11:	aggulutinated driblet	12:	scoria-fall

2. A Fall Unit

The problem is, what would be the best division of the deposits for the stratigraphy throughout the island as well as for reconstructing the history of eruptive activities? First, the smallest unit of the deposits is discussed below.

Subaerial pyroclastic fall deposits generally show distinct stratification, and the deposits in Ôshima are not exceptional (Figs. 6, 32 and 35). A closer view reveals that the stratified deposits are composed of beds differing from one another in colour, grain size, rock facies and other features. Each constituent bed is unstratified but is generally well-sorted. The minimum geologic unit of such a bed of fall deposits is here called a fall unit.

A single fall unit can be recognized at a certain exposure, but tracing its areal extension is often difficult. Consequently, the nature of a fall unit can be synthetically inferred from the descriptions of a unit larger than a fall unit. A fall unit will continuously decrease in thickness and grain size reciprocally with increasing distance from the vent. The unit will cover an elliptical area, with the vent located nearly at the focus of the area.

Even a thick fall unit of scoria or lapilli in a certain exposure thins out at a certain distance. The thickness of individual fall units changes more rapidly along a route concentric with the summit crater than along a route radial from it. Most of the fall units cannot be traced beyond the area spreading more than 90° when viewed from the summit crater.

Thus, a unit larger than a fall unit should be adopted as a stratigraphic unit for the island-wide stratigraphy.

3. Stratigraphic Units of Volcanic Products

Observing the exposures as shown in Figs. 32 and 35, it is easily noticed that they are composed of two kinds of alternately accumulating deposits—massive brownish ash and stratified fresh ash of multiple fall units.

The massive ash deposits are generally brown in colour probably due to oxidation on the surface, although the tint varies slightly with the horizon. The uppermost of such deposits develops under the present ground surface. The deposits are 5~40 cm thick, with almost negligible local differences. In places they contain pieces of charcoal several millimetres in diameter. The deposits are more or less loamy in composition and have fine fraction so that in winter frost forms even on the vertical exposures. The deposits are covered by the upper fresh deposits with a relatively sharp boundary, and grade downward into the lower fresh deposits through a narrow transitional zone (Fig. 33). This feature of the massive ash deposits somewhat resembles that of silt layers in a sand-silt alternation of ordinary flysch deposits. When the massive deposits are developed obliquely to the bedding planes of the underlying fresh deposits, clino-unconformity* of small scale appears to exist between the two.

The fresh deposits are well stratified and coarser, black in the case of scoria. The thickness of the deposits and the number of fall units

* Here, the term unconformity is used for the discordant relationship of the stratification of the overlying strata (or surface of the underlying one) not being parallel to that of the underlying strata. Therefore, the unconformity in this sense is an angular one in nearly all cases.

in them, vary conspicuously from place to place. Stratification is parallel to that of the underlying beds. These features of fresh deposits are common to all pyroclastic fall deposits. Within the fresh deposits, there is no trace of surface weathering, but minor erosional breaks can be observed in places (Fig. 34). In the upper part of the deposits, remains of plant fibre are not rare.

Marked or slight but regional unconformities are found between the lower massive deposits and the upper fresh, stratified deposits in the exposures.

From these observations, the whole exposure is considered to represent a rhythmic accumulation of a group of deposits comprising an upper massive and a lower fresh stratified deposit of multiple fall units (Fig. 6 is simplified from this viewpoint). In other words, these exposures record the repetition of relatively rapid, successive deposition of multiple pyroclastic falls of the fresh part and succeeding surface weathering of a longer period. This group of deposits is defined as a member which is a minimum stratigraphic unit applicable to the whole island. As will be stated later, the unit can be traced in the field 360° around the summit crater and throughout the island; moreover, the unit has a definite volcanological significance (Chapter 7).

In the stratigraphy of the subaerial volcanic products, especially of pyroclastics, it is considered that uncoformity should be a term for phenomenal descriptions, and the interpretation of the significance of the unconformity should be given in other terms. Because, firstly, the significance of the observed unconformity is understood after detailed survey and can even be different depending on the interpretation; secondly, both the conformable and the unconformable relationship between two strata can be brought about during the same lapse of time; thirdly, the small-scale unconformity as shown in Fig. 34 represents a far shorter period than that represented by two conformably overlying members.

4. Correlation and Areal Variation of the Stratigraphic Unit

The stratigraphic unit, member, adopted here consists of lower pyroclastic falls and upper weathered ashes and lava-flows are intercatated in places. A close observation, however, reveals that each member has a unique succession and nature of the constituent fall units.

Characteristic features which distinguish one member from another are, for example, the number of the overlying member, the tint of

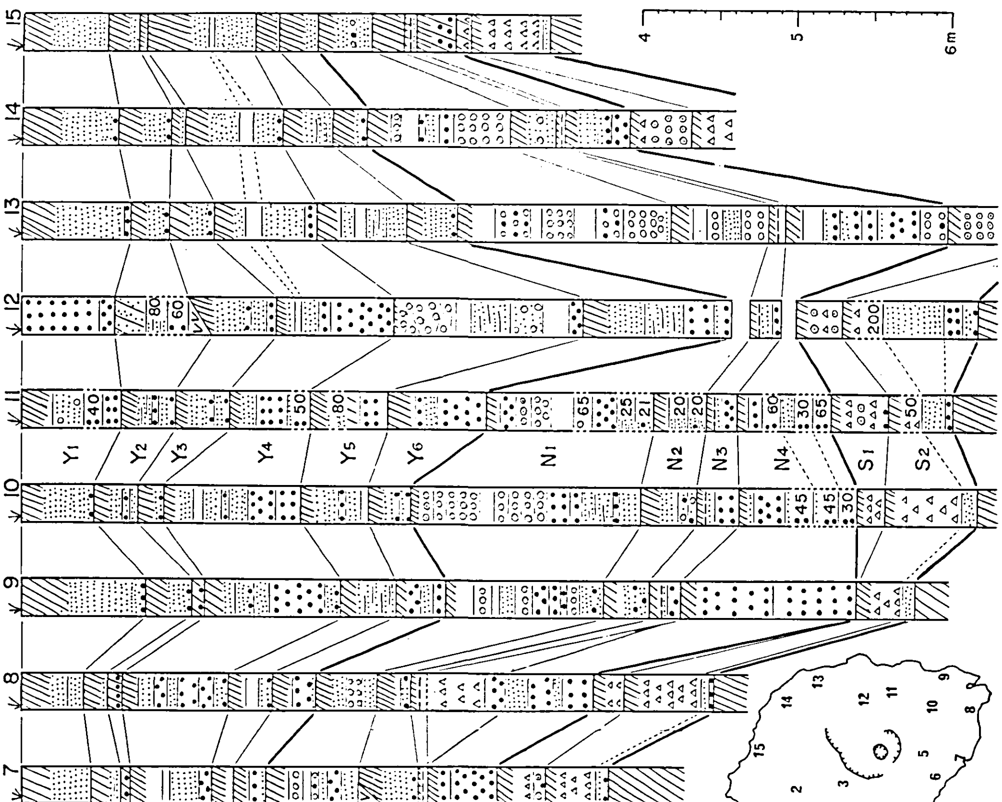

Fig. 7. Columnar sections of the Younger Ôshima Group at 15 localities. Symbols used in the figure are the same as in Fig. 6. Numerals in columns are the thickness of the layer in cms (Nakamura, 1960 partly revised).

the upper weathered ash deposits, and the sequence of fall units of different nature in the fresh deposits.

With the help of these features, each stratigraphic unit is traceable or correlatable over the greater part of the island. Towards the summit of the somma, the fresh part of each unit increases in grain size, in number of the fall units contained and generally in thickness. Unconformity between two members tends to be exaggerated with poorer development of the upper weathered deposits (Figs. 48 and 49).

Towards the foot of the somma, humus has accumulated in the uppermost part of the weathered deposits of each member, to turn the colour darker. Unconformities between two members become less distinct, and only the most distinct ones in the upper slope of the somma remain recognizable. In the northwestern part of the island, which is distant enough from the summit crater, shallow exposures are composed mostly of parallel soil layers showing various tints of brown (Figs. 7—1, 15 and 36).

These facts indicate that the unconformity, the weathered ash deposits and the soil, as observed in different localities but in the same horizon, were formed simultaneously and represent a quiescent period of deposition.

The stratigraphic horizon of lava-flows and other local ejecta from parasitic vents is assigned to the sequence of the fall deposits ejected from the summit vent on the basis of the following observations:

(1) The horizon of the ejecta is self-evident where they are thin enough or thin out in a wedgeshape at the margin of its distribution into the conformably overlying falls (Figs. 38 and 39).

(2) In a case where only the surface of the ejecta is observable, and if the fall deposit, which directly covers the surface without any sign of weathering time interval, can be traced over a considerably extensive area, it can be concluded that the ejecta are intercalated in the same stratigraphic unit as the overlying fall deposit.

(3) In a few places the ash-fall deposits are oxidized by the heat of the *underlying* lava-flow or welded deposits near the vent, as is the case with S_2 and Y_4. This phenomenon clearly shows that the ash deposited itself while the lava or the welded deposit was still hot enough and that it belongs to the same stratigraphic unit as the overlying ash.

Thus, all the volcanic products can be included in any one of the stratigraphic units. Correlation of the deposits in various localities is shown by the columnar sections in Fig. 7.

5. Sequence of Volcanic Products

Twelve members or stratigraphic units, directly underlying the

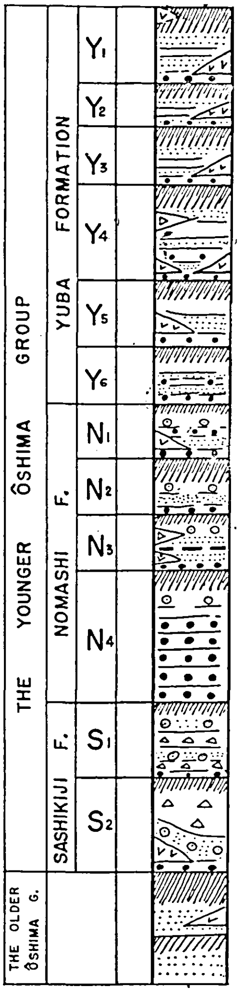

Fig. 8. An idealized columnar section of the Younger Ôshima Group. Symbols are the same as in Fig. 6.

present ground surface of the somma slope, that is, Y_1 to Y_6, N_1 to N_4, S_1 and S_2, are collectively called the Younger Ôshima Group. The underlying volcanic products similar to the above group are tentatively named the Older Ôshima Group.

In dividing the rocks of Ôshima Volcano into two groups the following points were considered:

1. Between the two groups there is a remakable and widely observable unconformity.
2. Steam explosion breccias from the summit vents, which characterize the lowest two members of the Younger Ôshima Group, are peculiar deposits among the ejecta of Ôshima Volcano. They contain some plutonic cognate ejecta and may be of particular importance in the history of eruptive activities.
3. Exposures of the Younger Ôshima Group are abundant enough for detailed stratigraphic investigation.

The Younger Ôshima Group is subdivided into three formations, namely, the Yuba, the Nomashi and the Sashikiji in descending order. Each formation comprises a few to several members. The three formations differ in their characteristic fall deposits (Fig. 28) and are bounded with each other by fairly distinct and regional unconformities (Figs. 32, 35 and 42).

Several road cuts near Yuba on the northern slope of the somma were taken as the type localities of the twelve members, consequently of the three formations and the Younger Ôshima Group. Fig. 35 shows one of the localities.

Fig. 8 is the established sequence of the Younger Ôshima Group. It illustrates an idealized columnar section in which all the important units occur successively.

The Older Ôshima Group is distributed with a thickness ten times as much, or more, as the Younger Ôshima Group. But, its exposures are much more limited, being restricted mainly to the caldera walls and the past and present coastal cliffs.

This paper deals chiefly with the Younger Ôshima Group.

Such terms as member, formation and group are stratigraphic nomenclature for sedimentary rock units. It is questionable whether such terms are adequate to represent the stratigraphic units as defined above. Besides, from the foregoing descriptions it will be evident that the stratigraphic units in this paper are time-rock units. In this sense, nomenclature of time-rock unit, such as system, series and stage, may be better. However, the writer does not intend here to go further into the problem of stratigraphic nomenclature of subaerial volcanic products. A more reasonable nomenclature will be established after a number of studies of this kind are undertaken on various types of volcanoes. Hence, previously used names (Nakamura, 1960, 1961) are again adopted in this paper to avoid confusion.

Chapter 5. Description of the Younger Ôshima Group

1. General Statement

The writer has already described in detail the deposits of the Younger Ôshima Group, the ejecta from the summit craters (Nakamura, 1960) and those from the parasitic craters (Nakamura, 1961). Also, Katsura and Nakamura (1960) gave the chemical compositions of lavas and bombs of several members. In this chapter, the writer will summarize the published description of each member supplemented with distribution maps (Figs. 9～20 and Tables II and III). Table II is a summary of the published descriptions and Table III is the result of calculation of the volume of component unit of members based on Figs. 9～20. Additional descriptions of accretionary lapilli tuff are also given.

Main constituent units in the lower fresh part of a member consist of various kinds of pyroclastic fall deposits or scoria, ash and explosion breccia, and flow deposits or lava- and mud-flow. These deposits in a single member locally alternate with each other, especially in the cases of scoria- and ash-falls. In most cases, however, individual component deposits form a separate unit in a member. Both presence and characteristic features of each component unit in a member, which will serve for distinguishing different members in the field, are summarized in Table II. Presence of ejecta from the parasitic craters are also indicated in the Table.

Besides these units directly recording volcanic eruption, their

Table II. Component units and characteristic features of the members of the Younger Ôshima Group

members (strati-graphic unit)	lower fresh part				upper weathered part	characteristic features of the member as observed in the fields
	(1) basal scoria	(2) lava-flow	(3) layer-ed ash	(4) explosion breccia	(5) weathered ash	
Y_1	○	○	○	—	●	The main part of (3) is thinly-bedded coarse ash similar to the present wind-blown desert deposits.
Y_2	○	○	○	—	●	(3) includes a few layers of pink ash consisting of oxidized particles.
Y_3	○	○	○	—	●	(3) is the thinnest as a whole and consists mainly of oxidized particles
Y_4	○∘	○∘	○	∘	●	(3) comprises lower dark purple and upper varicoloured ash. Phenocrystic olivine is present.
Y_5	○∘	∘	○	—	●	(5) is orange brown. No mafic phenocryst is found.
Y_6	○	—	○	—	●	(5) is dark brown and (3) is bluish purple.
N_1	○∘	∘	○	—	●	(3) comprises a number of fall units including scoria-falls, and is distinctly stratified.
N_2	○	—	○	—	●	(5) is the thickest. (3) is similar to N_1 but is thinner.
N_3	○∘	—	○	∘	●	(3) carries white, biotite rhyolite ash 0.5~1 cm in thickness. (5) is the thinnest.
N_4	○∘	—	○	—	●	(1) is the thickest in most exposures, comprising several fall units.
S_1	○	—	○	○	●	Alternating (4) is resistant and projects from exposures. (5) is poorly developed.
S_2	○∘	∘	○	○	●	(4) is coarser than that in S_1 and often substituted with mud-flow deposits, a secondary derivative.

○: products from the summit craters
∘: products from parasitic craters

secondary deposits which are not directly connected with eruptive phenomena are also included in members. They are ash and lapilli reworked by water and/or wind into a more stable condition and are confined to the upper portion of the fresh part or just below the weathered ash.

Distribution of each member is shown by separate maps (Figs. 9~20). Thickness of each member except lava-flows is one metre or less on an average, although it increases considerably near the vents. Distribution and structure of the Younger Ôshima Group, or the sum of the twelve members, are shown in Fig. 21.

2. A Common Succession in Each Member

As each component unit other than weathered ash and fresh finer falls in a member is limited in distribution, it is only by a rare chance that all the units of a certain member in Table II are observed at a given locality. Compilation of succession of units by means of precise correlation within a single member over the whole island reveals that the succession of component units is common to all twelve members.

The common succession in a complete form within a member is, in ascending order :–

(1) Scoria-falls
(2) Lava-flows
(3) Alternating ash-falls, occasionally with minor amounts of scoria-falls and accretionary lapilli tuffs
(4) Explosion tuff breccias, sometimes with accretionally lapilli tuff
(5) A brown loamy ash layer

The succession is also shown in Table II and in Fig. 26 (p. 703).

Such component units, as lava-flows (2) and explosion breccias (4) are not present in some members. Lava-flows from the summit craters are intercalated in Y_4 and in younger members, those from the parasitic craters are in Y_4, Y_5, N_1 and in S_2. Explosion tuff breccias from the summit craters are found in the two members of the Sashikiji Formation, those from parasitic craters occur in Y_4 (Imasaki (1)) and N_3 (Habuminato (11)). Accretionary lapilli tuffs are so far known in the Nomashi and Sashikiji Formations.

The uppermost weathered ash (5) has the widest distribution among the component units within a member, followed by layered ash deposits (3), and then by basal scoria-falls (1). Consequently, in many exposures on the lower slope of the main cone, individual members consist of lower finer pyroclastic falls and upper weathered ashes as seen in Figs. 6, 33, 35 and 37. In an extreme case, as in the northern coastal area, the exposure is an accumulation of brownish soils of different tint (Fig. 36).

There are, of course, some exceptions to the common succesion. For example, in S_1, layered ashes (3) and explosion breccia (4) occur together in alternation.

3. Volumetry of Erupted Material

The volume of the Younger Ôshima Group is calculated as about 3.6 km^3 as shown in Table III (IT+IIT+IIIT). Of the total material erupted, 60% in volume is pyroclastic deposits, the rest being lava-flows. Only 0.73 km^3 [20% of the total volume, I(S+P)+II(S+P)+III(S+P)] is now observable on the slope of the main cone, the rest being inside the caldera and outside the island.

Calculations were made on the basis of the distribution maps of the twelve members (Figs. 9~20). These maps comprise two elements, *i. e.*, isopach contours of the fall deposits and distribution of lava-flows and scoria cones. Dots in the maps indicate the points where the thickness of the fall deposits was measured. Thickness was measured where the

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Figs. 9~20. Geologic maps of twelve members of the Younger Ôshima Group.

Arrangement is from older to younger.

Stippled area: the area where the deposits have entirely removed away.

Pyroclastic fall deposits are shown by isopach lines in cms. Thick line (A) denotes those from summit* craters, thin line (B) those from parasitic craters, and broken line (C) indicates scoria-falls which occupy the basal or the lower part of the member. (A)+(B) represent the total thickness of the fall deposits of the member, and (C) is included in (A).

The crater rim and the pit of the present post caldera cone are shown in each map, irrespective of their presence or absence at that time. —·—· in the map of S_2 (Fig. 9) shows an approximate limit of the distribution of mud-flow deposits, which are the secondary drivative of explosion breccias. Outside the boundary the member consists of explosion breccias and overlying weathered ash.

* Here, the term "summit" is used as "located inside the caldera", so that the Odorijaya-scoria layer of N_4 (Nakamura, 1960, Fig. 6) is included in the falls from summit craters.

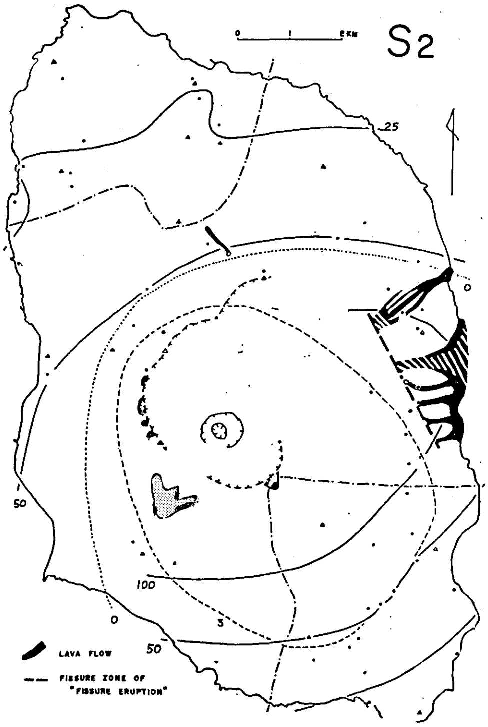

S2
0 1 2 KM
25
50
100
0
3
50
LAVA FLOW
FISSURE ZONE OF "FISSURE ERUPTION"

Fig. 9

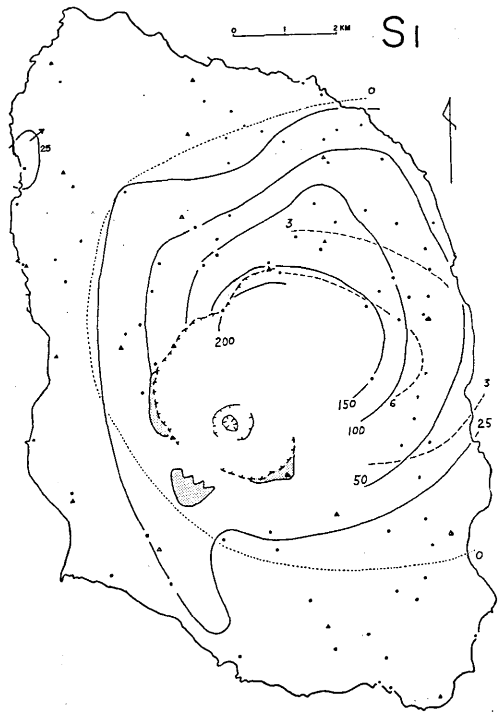

S1
0 1 2 KM
0
25
3
200
150
6
100
50
3
25
0

Fig. 10

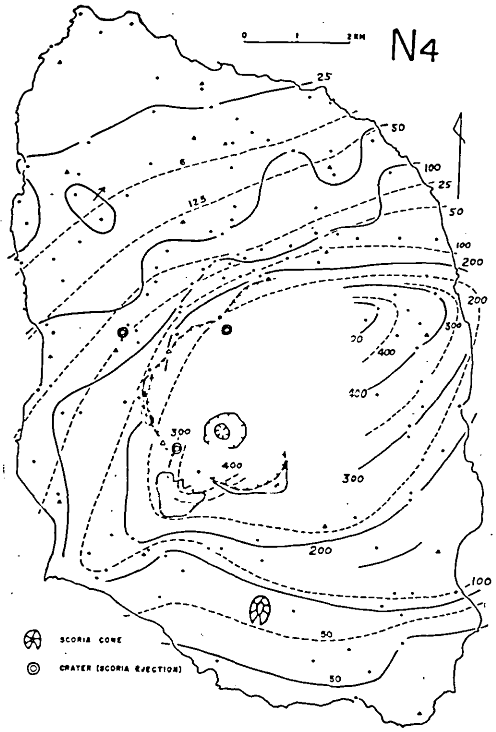

N4
0
1
2 KM
25
50
100
25
50
100
200
200
300
400
400
6
12.5
300
400
300
200
100
50
50
SCORIA CONE
CRATER (SCORIA EJECTION)

Fig. 11

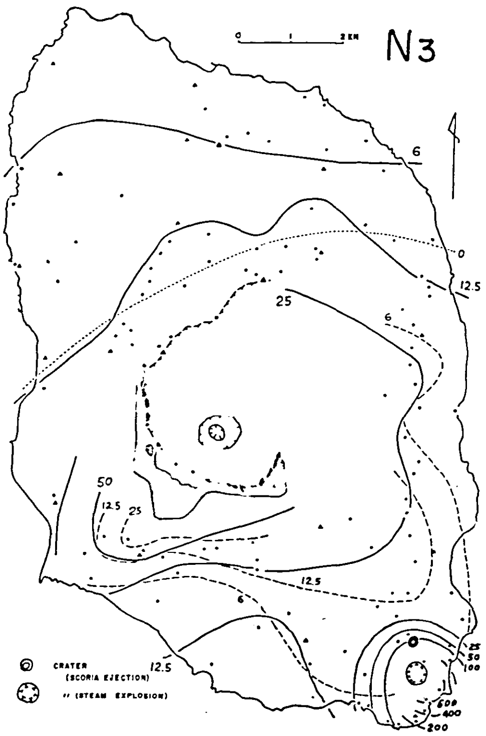

N3
0
1
2 KM
6
0
12.5
25
6
50
12.5
25
12.5
6
12.5
25
50
100
600
400
200
CRATER (SCORIA EJECTION)
" (STEAM EXPLOSION)

Fig. 12

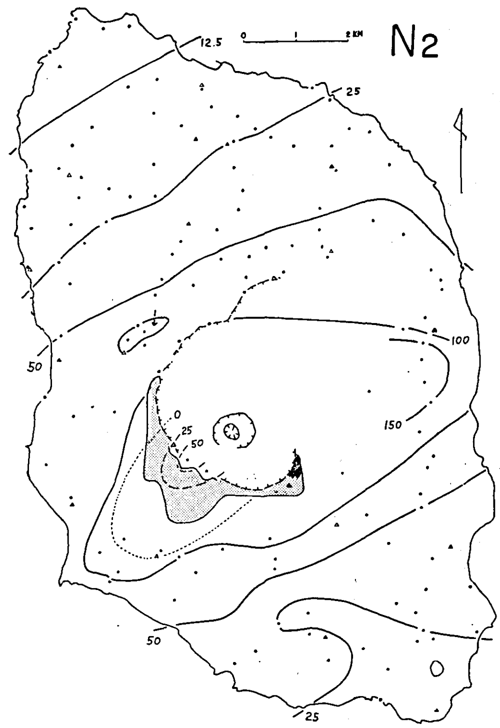

N2
0 1 2KM
12.5
25
50
100
150
0
25
50
50
25

Fig. 13

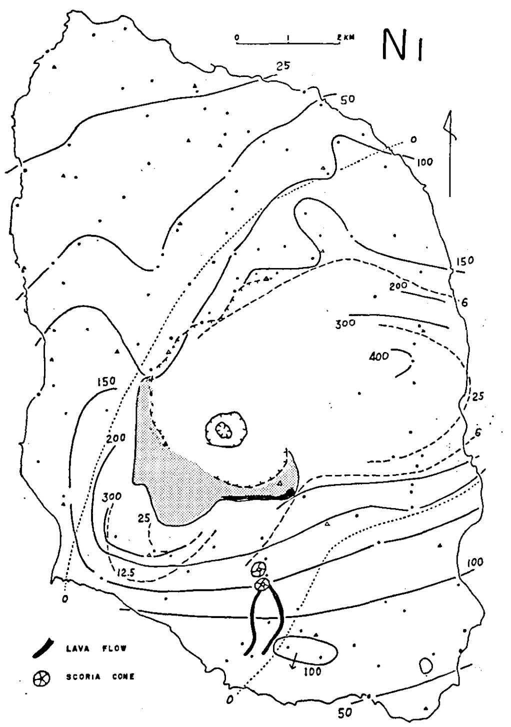
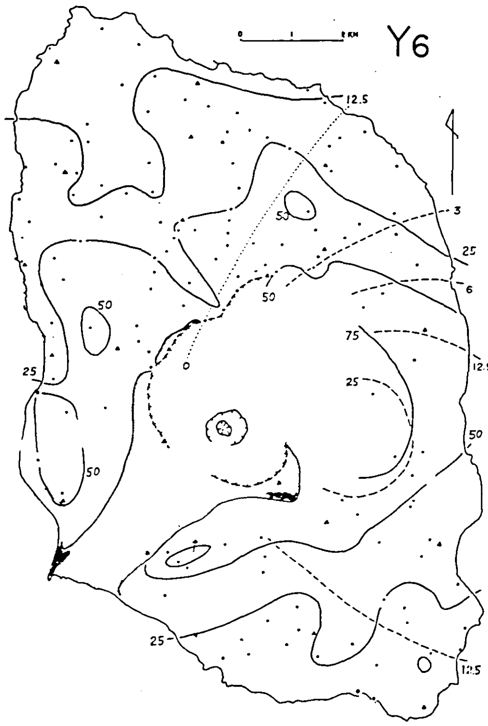
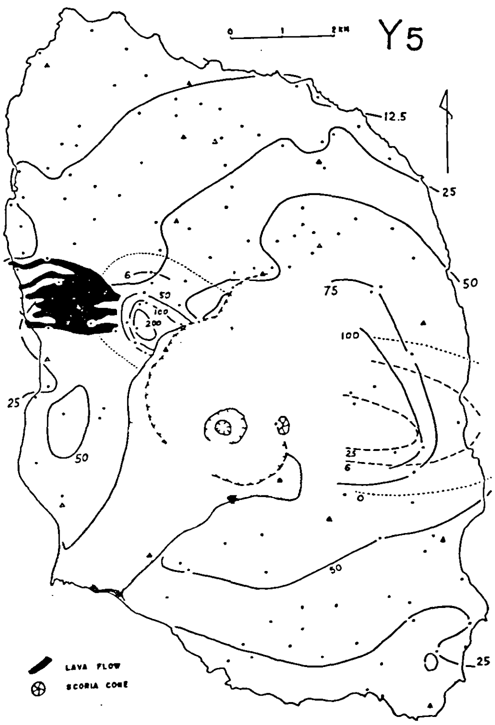

N1
0 1 2KM
25
50
0
100
150
200
6
300
400
25
6
150
200
300
25
12.5
0
100
100
0
50
LAVA FLOW
SCORIA CONE

Fig. 14



0 1 2 KM
Y6
12.5
3
25
6
12.5
50
50
75
25
0
50
25
50
25
12.5

Fig. 15



0 1 2 KM
Y5
12.5
25
50
6
50
100
200
75
100
25
25
6
0
50
50
25
LAVA FLOW
SCORIA CONE

Fig. 16

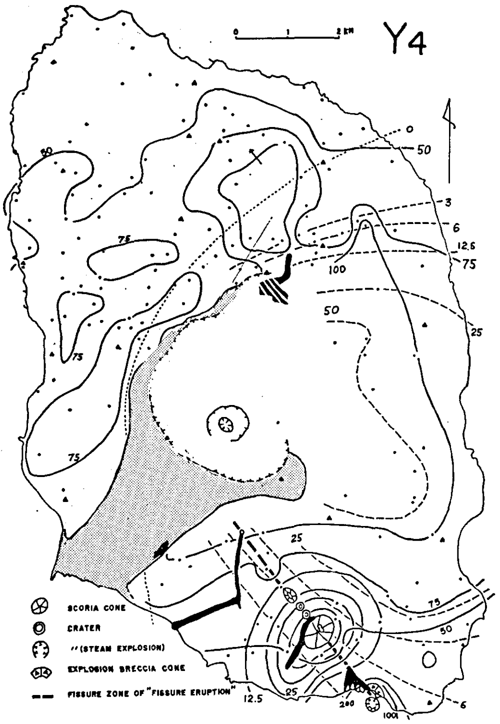

0 1 2 KM
Y4
0
50
3
6
12.5
75
100
50
25
75
75
75
25
75
50
0
6
12.5
25
200
100
SCORIA CONE
CRATER
" (STEAM EXPLOSION)
EXPLOSION BRECCIA CONE
FISSURE ZONE OF "FISSURE ERUPTION"

Fig. 17

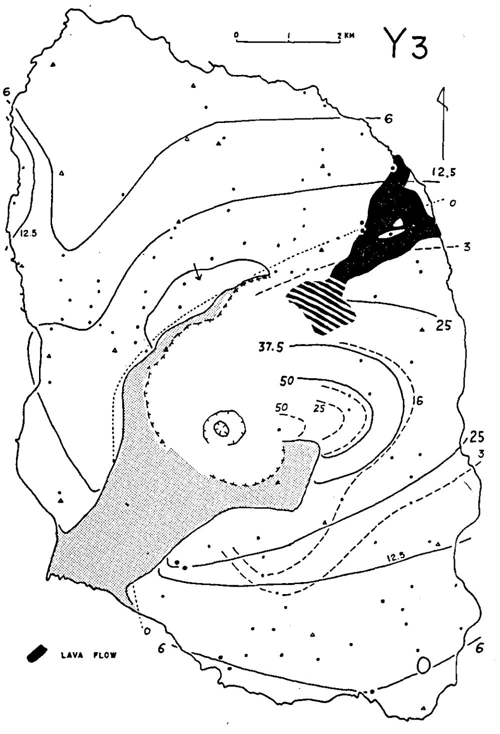

0 1 2 KM
Y3
6
6
12.5
0
3
12.5
25
37.5
50
50
25
16
25
3
12.5
0
6
6
0
LAVA FLOW

Fig. 18

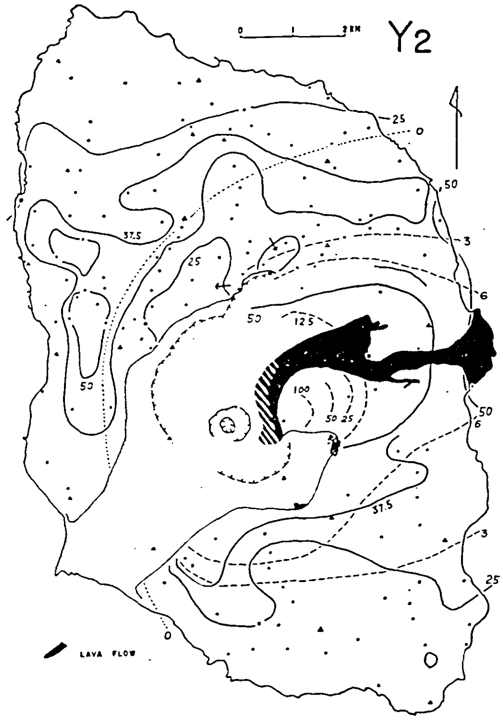


Fig. 19

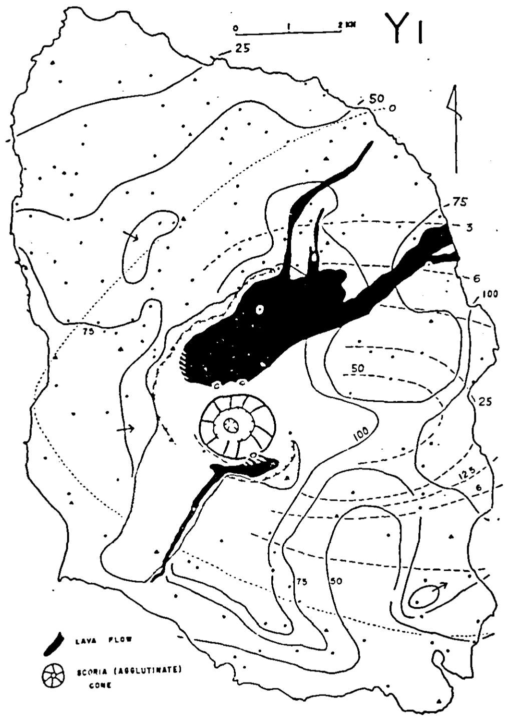


Fig. 20

Table III. Volume of the Younger Ôshima Group

stratigraphic unit	Volume of erupted material ($\times 10^{-1}$ km^3)										Total mass of erupted material ($\times 10^{15}$g)	Energy trans-ported by the material ($\times 10^{25}$ erg)	Estimated beginning date of eruption (A. D.)
	I. Basal scoria			II. Lava			III. Alternation of ash			IV. (IS + IIIS)			
	S	P	T	S	P	T	S	P	T				
Y_1	0.06	—	0.35	0.08	—	1.4	0.59	—	1.7	0.65	0.65	0.82	1777
Y_2	0.029	—	0.28	0.2	—	0.8	0.26	—	0.8	0.29	0.35	0.44	1684
Y_3	0.021	—	0.17	0.19	—	1.4	0.12	—	0.36	0.14	0.42	0.53	1550
Y_4	0.11	0.2	0.9	0.0008	0.007	1.3	0.48	(0.04)	1.5	0.59	0.65	0.82	1420
Y_5	0.03	0.03	0.13	—	0.06	1.3	0.34	—	1.1	0.37	0.51	0.64	1335
Y_6	0.099	—	0.63	—	—	1.25	0.12	—	0.41	0.13	0.44	0.55	1200
N_1	0.051	0.02	0.4	—	0.0004	〃	1.1	—	2.7	1.2	0.76	0.95	1100
N_2	0.0051	—	0.043	—	—	〃	0.54	—	1.6	0.55	0.55	0.69	960
N_3	0.073	0.0005	0.27	—	—	〃	0.15	(0.1)	0.48	0.22	0.42	0.53	860
N_4	0.83	0.01	4.3	—	—	〃	0.25	—	1.2	1.1	0.92	1.2	750
S_1	0.011	—	0.063	—	—	〃	(0.33)	—	0.8	0.34	0.34	0.46	650
S_2	0.014	0.001	0.027	—	0.16	0.16	{0.2 (0.4)}	—	1.3	0.61	0.24	0.20	500
Total	1.3	0.26	7.6	0.5	0.17	14	4.9	(0.1)	14.0	6.2	6.25	7.83	

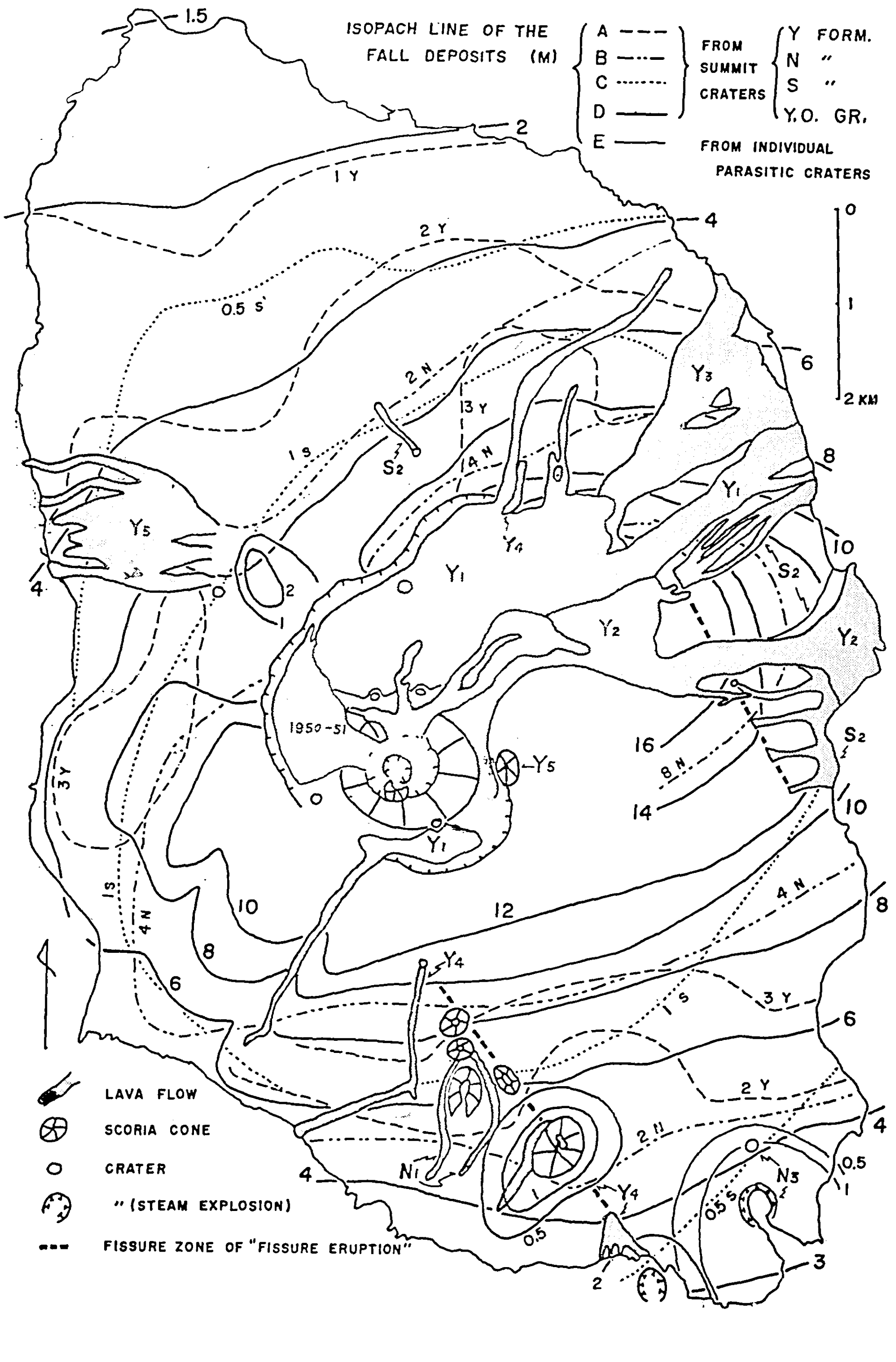
S and P, in column I—IV, denote materials erupted from summit and parasitic craters, respectively, which are now on the slope of the main cone (the somma).

I—P includes scoria cone referring to Table VI of Nakamura (1961).

T represents the estimated total volume of erupted materials, including those deposited outside the island and inside the caldera. Explosion breccias are given in III in parentheses.

IV is the total volume of the fall deposits erupted from the summit craters of the main cone and accumulated on the slope. It represents the average thickness of the deposit in metres (∵ area of the island roughly equals 100 km^2). Basic assumptions and method of calculation are explained in the text. Graphic representation the column IV and released thermal energy is given in Figs. 23 and 27, respectively.

fall layers were nearly horizontal and/or uniform in thickness, at least throughout a certain exposure. Values obtained from such exposures as in Fig. 37 where they vary largely within a short distance are omitted in the maps. The figure of the thickness is given to the order of centimetres according to local measurement, however, the accuracy for the entire area does not go to that extent. In the southwestern part of the island there is an area where the deposits were entirely eroded away. This fact was taken into account when the volume of the


ISOPACH LINE OF THE FALL DEPOSITS (M)
A B C D FROM SUMMIT CRATERS
Y FORM.
N "
S "
Y.O. GR.
E FROM INDIVIDUAL PARASITIC CRATERS
0
1
2 KM
LAVA FLOW
SCORIA CONE
CRATER
" (STEAM EXPLOSION)
FISSURE ZONE OF "FISSURE ERUPTION"
1950-51

material on the slope of the main cone (S in Table III) was calculated.

Calculations were made by classifying the erupted materials into three kinds, scoria, lava and ash (1, 2 and 3~5 of Table II, respectively). That such a classification of erupted material is possible presents a problem on the mechanism of eruption; in other words, the mode of eruption seems to be different between ash and scoria.

In order to calculate the total volume of pyroclastic fall deposits, first, more than four curves for thickness-distance from the assumed vents (which are considered to have been at the same place as the present active crater of Mihara-yama except that of S_1) were prepared for the two kinds of falls of individual members. Then, the curves were extended outside the island and inside the caldera. Around the vent inside the caldera, the circular area 1.5 km in diameter was left for central scoria cones, the volume of which was calculated by a different assumption as is explained below.

Distribution of the fall deposits of Y_1, Y_2, Y_4, and Y_6 (Figs. 20, 19, 17 and 15) is rather irregular due to reworking; volumes of material of these members deposited outside the island were inferred from the data obtained for the other members, assuming that a linear relation exists between the volumes of material deposited on the slope of the main cone and outside the island.

The next step to calculate the total volume was to infer the structure of caldera, because a good deal of material is supposed to have filled the depression. The caldera is assumed to be gourd-shaped and 10 km^2 in area (Nakamura, 1963), the wall to be vertical (Isshiki *et al.* 1963) and the original floor or bottom (Fig. 4) to be flat and situated 330 m above the present sea-level (Isshiki *et al.* 1963). Thus, the total volume which filled the caldera depression was calculated as 2.2 km^3 (Fig. 22).

Below the central cone, there must be older scoria cones

Fig. 21. Distribution and Structure of the Younger Ôshima Group.

This map shows compiled and simplified results of twelve maps (Figs. 9~20) for each member of the Younger Ôshima Group. Pyroclastic fall deposits, related to parasitic craters, are presented separately from those of summit craters. A, B and C denote the thickness of the Yuba, the Nomashi and the Sashikiji Formations, respectively in metres. D is the sum of the three (D=A+B+C). D plus E shows total thickness of the fall deposits of the Group. These thicknesses represent, so to speak, the expected maximum values at individual points. Actual thickness is often much reduced by erosion.

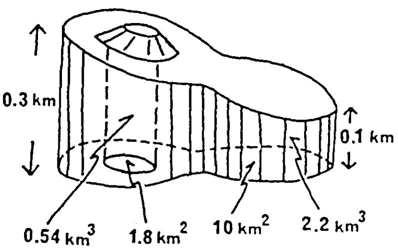


Fig. 22. An assumed shape of the caldera-fill for calculation of its volume.

successively overlapping since the caldera formation. This is supported by lower values in Bouguer anomaly on the rim of the cone than on the surrounding floor of the caldera (Yokoyama and Tajima, 1957). Subsequently, a cylinder, 300 m in height and 1.8 km^2 in basal area and 0.54 km^3 in volume, is split into eleven members, which are assumed to have deposited after the caldera formation, proportionally to the maximum thickness of the basal scoria at the vent.

The rest of the caldera filling material (2.2−0.54=1.66 km^3) is assumed to be composed of lava-flows and pyroclastic falls. The volume of the fall deposits was already calculated as 0.34 km^3 by the extrapolation of isopach contours. This value is equivalent to 20% of the above-mentioned volume (1.66 km^3), and may not be unreasonable as compared with the result of drillings (Isshiki *et al.* 1963) of which pyroclastics occupy 25% in volume of the whole section above the bottom of caldera. The volume of the lava-flows filling the caldera is estimated at 1.66−0.34=1.32 km^3.

The volume of the lava-flows of Y_1 and Y_2 which filled the caldera is estimated from the maps (Figs. 19 and 20) at 0.13 and 0.06 km^3, respectively, by assuming the thickness to be 30 m. The rest of the volume (1.32−(0.13+0.06)=1.13 km^3) is equally divided among the nine members ($Y_3 \sim S_1$, 0.125 km^3 per member).

From the result thus calculated, the average ratio of the scoria, the lava and the ash of the twelve members is known to be about 1:2:2, from which the explosion index (Rittmann, 1962) is calculated as being about 60.

The total mass in Table III was calculated assuming the density of scoria, lava and ash to be 1, 2.4 and 1.5 g/cm^3, respectively. Thermal energy transported by the mass is computed by the formula in Yokoyama (1957a),

$$E_{\mathrm{th}} = M(1000°\mathrm{C} \times 0.25\ \mathrm{cal/g°C} + 50\ \mathrm{cal/g})J\ (\mathrm{ergs})$$
$$= M \times 1.254/\mathrm{g} \times 10^{10}\ (\mathrm{ergs}),$$

where the specific heat and the latent heat of erupted material are assumed to be 0.25 cal/g°C and 50 cal/g, respectively. J is the equivalent work of heat. In the case of explosion breccia, thermal energy is estimated by

$$E_{th}=M(500°C\times 0.25\ cal/g°C)J\ (ergs)\ .$$

Thermal energy for each member attains the magnitude of $0.2\sim1.0\times10^{25}$ ergs. Relation between age (Table V) and released thermal energy is graphically shown in Fig. 23.

Among various forms of energy released through volcanic activities, thermal energy transported by erupted material is by far the largest in amount (Yokoyama, 1956). Therefore, the constant rate of thermal energy release in Fig. 23 will duly indicate that Ôshima Volcano has constantly released energy at a rate of about 6×10^{24} erg/100 years, during these 1500 years or since the caldera formation (Chapter 8).

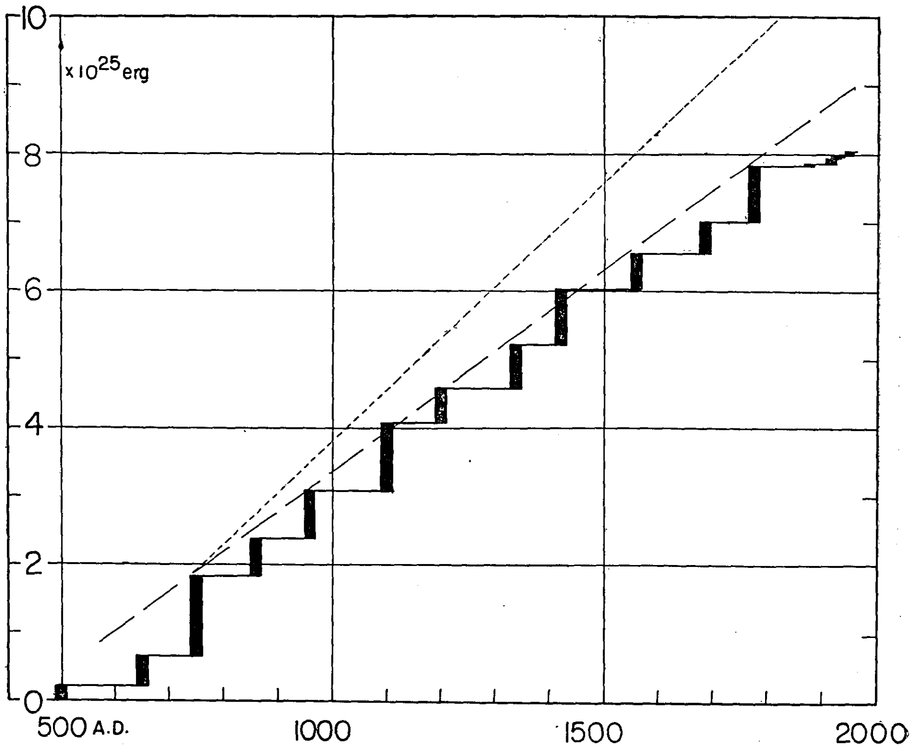


Fig. 23. Rate of release of thermal energy during the Younger Ôshima age. Drawn from the data given in Table III and V.

4. Notes on Component Units of Members

Scoria-fall deposits are confined to the basal part of each member in most cases, but they are intercalated in a considerable quantity in the layered ash of N_1. Most of them consist of less than a few fall units, but those in N_4 are made up of eight or more fall units that were erupted from different vents.

These scoria-falls display a typical occurrence of fall deposits, although there are a few cases showing a slightly different character from typical ones.

Such scoria-falls are exemplified by the S_2 scoria distributed along a fissure in the eastern part of the island, Motomachi scoria (Y_5) and Imasaki scoria cone (Y_4) (Nakamura, 1961). In Table IV, features of these scoria-falls are compared with those of typical ones.

Table IV. Comparison of features of two types of scoria-fall

		typical scoria-fall	non-typical scoria-fall
1	sorting	very good	not so good
2	shape of vertical section	(wavy) uniform sheet	often lenticular
3	distribution	wider ($>10\,km^2$)	narrower ($<5\,km^2$)
4	rate of change of thickness with distance from vent	smaller	greater
5	welding	rare	common

These features of non-typical falls as a whole seem to suggest that they are, so to speak, a transition from normal scoria-falls to spatter cone-forming ones. Feature 2 in the Table may suggest the presence of horizontal partial force on falling. In other words, they are well explained by less intense eruption, nearer to boiling than to explosion. The fact that the scoria-falls of this type so far found are restricted to the ejecta from parasitic vents is consistent with the above interpretation.

Below the basal scoria of Y_5, S_2 and N_1, there are very fine and thin ash layers, the nature of which has not yet been investigated.

The sites of the thickness measurement for the S_2-explosion breccia are so sparsely distributed, especially on the upper slope of the main cone, that the accuracy of the volume of this member in Table III is lower. The S_2 member is very frequently represented only by mud-flow deposits. The sagging of larger blocks of the mud-flow deposits into the underlying ash layers is often observed. This phenomenon, which is commonly observed with explosion breccias from parasitic craters, may be explained as suggesting the vertical force at the landing, although Fujimoto *et al.* (1959) considered it to be a sedimentary load cast structure.

There are two other minor "members" in the Younger Ôshima Group between S_1 and S_2, and above Y_1. They are distributed within areas narrower than 10 km^2 on the upper portion of the eastern slope (between S_1 and S_2) and the southern slope (above Y_1). Yet, they show the sequence (scoria → ash → weathered zone) common to the major members. Because of their narrow distribution, they are for the time included in S_1 and Y_1, respectively.

5. Accretionary Lapilli* Tuff

Six horizons of accretionary lapilli are recognized in the Younger Ôshima Group *i. e.*, S_2, S_1, N_4, N_3, N_2 and N_1.

There have been observed three processes in forming accretionary lapilli, as recently reviewed by Moore and Peck (1962).

(1) Accretion on the ground of fresh ash around a nucleus blown by the wind or rolling down a slope (Stearns, 1925).

(2) Absorption by fresh ash of the water of a fallen rain drop during light rain (Scrope, 1829, Lacroix, 1904).

(3) Accretion of moist ash in an eruptive cloud to form mud-pellet rains (Perret, 1924, Stearns, 1925).

Almost all the lapilli under present consideration were apparently formed by accretion of moist ash in eruptive clouds by explosive eruptions, were carried by the wind and fell on the ground as mud pellet rains.

The following occurrence and nature of the lapilli of the Younger Ôshima Group are best interpreted by the above-mentioned conclusion.

(1) Layers in which lapilli are contained have the character of normal subaerial pyroclastic falls (Nakamura *et al.*, 1963), namely, the

* Term pisolite was used in the writer's previous papers.

layers (a) are uniform in section and parallel to the original topography, (b) decrease in thickness with increasing distance from assumed vents.

(2) The lapilli themselves are normal constituents of the layer, namely, (a) they are comparatively uniform in diameter, (b) the distribution of the lapilli in the layer is uniform, regardless of the inclination of the layer.

(3) There are a few porous layers, especially in the upper parts of N_3, N_2, and N_1 members, which consist mostly of well-sorted accretionary lapilli (Fig. 40). The nature of these layers and constituent lapilli are the same as stated in (1) and (2).

(4) Horizons of the lapilli layers in individual members are confined to the upper parts which consist mainly of ash-fall layers.

(5) Most of the lapilli are aggregate of coarser silt or sand, and few lapilli have scoria as cores.

(6) The outer parts of the lapilli are composed of thin, concentric, and continuous layers which are finer-grained ash than the core of the lapilli and the matrix of the layer.

(7) Most of the lapilli are completely spherical in shape.

Many more layers containing accretionary lapilli of the same nature are known also in the Older Ôshima Group. There are, however, some reasons for attributing the origin of a part of the lapilli to rolling on the slope. The distribution of the deposits containing the lapilli is restricted in the cross-laminated lenticular deposits which are filling small valleys (Fig. 41). Moreover, the lapilli always have cores of scoria, and their shape is more or less controlled by that of the scoria core. The outer parts are composed of the same sand as matrix, and concentric layering is obscure. These characteristics, agreeing well with those described by Stearns (1925) and Macdonald (1949) as rolling origin, are in sharp contrast to those of mud-pellet origin.

Chapter 6. Chronology of the Younger Ôshima Group

1. General Statement

The chronology of the Younger Ôshima Group has already been outlined (Nakamura, 1960) and the evidence obtained later also supports the chronology. In this chapter, the writer will present the data and the process of the chronology collectively. These are condensed in Table V with three different kinds of clues, pottery remains, historical documents and ^{14}C mesurements, which are correlated to an established stratigraphic column (Fig. 8) by regional volcano-stratigraphy.

Table V. Chronology of the Younger Ôshima Group (A. D.)

Stratigraphic succession		Most probable beginning-dates of eruption, deduced from the three different sources (right)	Interval	Dates of eruption as inferred by		
				correlation with historical documents	pottery remains	^{14}C measurement
The Younger Ôshima Group	Y_1		187+			
		1777		1777		
	Y_2		93			
		1684		1684		
	Y_3		134			
		1550±5		1552		
	Y_4		130			
		1420±5		1421		
	Y_5		85			
		1335±10		1338 ?	1300±50	
	Y_6		135			
		1200±50				
	N_1		100	1112 ??		
		1100±50				
	N_2		140			
		960±40				
	N_3		100	886 or 838		
		860±30			750±100	(Gak. 351a, 〃 351b, 〃 353)
	N_4		110			
		750±50			550±100	
	S_1		100			
		650±150			300±100	{620± 90, 600±100, 450±160}
	S_2		150	684 ??		
		500±200			200±200	

It can be concluded from the Table that the Younger Ôshima Group is made up of the volcanic products during the last fifteen centuries or so and that the major activities of Ôshima Volcano have taken place periodically with intervals of 135±50 years, during the period.

Recent archaeomagnetic studies give further support to the chronology. Yukutake (1961, 1964), has studied the secular variation of geomagnetic fields through measurements of volcanic products of Ôshima Volcano which are dated by the writer. An archaeomagnetic research group at Kyoto University reported the results they obtained from measuring old kilns and showed that such results were in good agreement with the data from Ôshima Volcano. This may indicate the validity of the chronology submitted by the writer.

2. Dates Inferred by Pottery Remains

The oldest remains that have been found in the island consist of fragmental pottery of Jûsan-bodai type of Early Jômon age, or some five thousand years old, reported from Senzu by Asô (1957). Younger remains have been excavated from various localities and horizons in the Younger and the Older Ôshima Groups. Human and pottery remains under a lava-flow at the coast of Tatsu-no-kuchi, Nomashi, have been studied by many researchers (Otsuki, 1901; Torii, 1902; Sato, 1902; Sato and Fukuchi, 1902; Kuno, 1957) in connection with their occurrence and the age of the summit caldera formation.

In the Younger Ôshima Group, four horizons of old fragmental pottery were found. The horizons, localities, kinds of pottery and inferred dates were reported, together with those in the uppermost part of the Older Ôshima Group (Nakamura, 1960). Localities of the remains are shown in Fig. 2, and their horizons and inferred dates are given in Table V of this paper. All the remains have been found in the present coastal region, except the area between Senzu and Habuminato. Their horizons are either in the uppermost part of each member or between two members.

The dates inferred from the remains are consistent with each other, but there remains a possibility that the dates may be a little older as a whole, because they are inferred from the chronology in Honshû, the main island of Japan. It is expected that the cultural propagation may have been retarded in an isolated island like Izu-Ôshima.

3. Historical Records of Eruptions

There are many documents recording eruptions of Ôshima Volcano since 684 A. D. Some of them describe the activities which continued for years, with lava flows from the summit craters pouring into the sea. Some activities may have been of minor scale and of short duration, affecting probably just the interior of the caldera or of the post caldera cone.

Records of 684 and those after 1421 have already been quoted in tabulated form (Nakamura, 1960). Of these, five major eruptions, which are considered to have caused the accumulation of various kinds of deposits on the slopes of the mine cone, are reproduced in Table VI, together with two further records of 1112 and 1338.

Table VI. Historical records of major activities of Ôshima Volcano which may have formed pyroclastic fall deposits and/or lava on the slopes of the main cone.

Date (A. D.).	Records
684, Nov. 29	Noises were heard in Kyoto (320 km west of Ôshima) from an easterly direction. These noises were believed to have been caused by the eruption of Ôshima, followed by land-enlargement of more than 300 jô (about 1 km) at two localities of the north-western part of the island.
1112, Nov. 18 to the end of Nov.	Thunder-like noises were often heard in Kyôto from an easterly direction. These noises were attributed to the eruption of one of the Seven Izu Islands.
1338*	Continuously active in these years. Incandescent clouds were seen with heavy ash-falls, smoke and detonation.
1421, May 14	An eruption. Detonation like thunder was heard in Kamakura (70 km north of Ôshima). Sea water became so not as to cause the death of many fishes.
1552, Oct. 15	An eruption broke out. A lava-flow brought about a new island at Kôzu the exact locality of which is not investigated yet. Many earth- and air-quakes. Incandescent clouds were seen.
1684, Mar. 31	A violent eruption broke out.
Apr. 22	A lava flow poured into the sea through a certain fall, called Kokamagataki, 4 km ENE of the summit crater.
1690	The activity continued for seven years. Repeated severe earthquakes destroyed many houses, and ash fell all over the island tens of centimetres in thickness.
1777, Aug. 31	A volent activity, called the An'ei eruption, broke out, followed by a widespread fall of ash, scoria and pele's hair.
1778, Apr. 19	A lava-flow crept down from the northwestern foot of Mihara-yama to the northeast along Nakano-sawa for about 4 km.
Oct.	Activity regained.
Nov. 6	A lava-flow from the southern foot of Mihara-yama crept down to the southwest along Aka-sawa for about 6 km.
15	A lava-flow from the northeastern foot of Mihara-yama poured out along Gomi-sawa into the sea forming a mound.
1779, Jan. 4	Again activity became violent.
8	Smoke and fire at Hajikama in Senzu village, 8 km NE of the Mihara crater. A coloured bird's-eye view of 1778 lava-flows drawn at that time was reproduced and published by S. Nakamura.
1783—1786	Ash fell during these years, accumulating to a thickness of a metre or more.
1792	Activity came to an end.

* K. Musha, 1941

Later five of the seven records in Table VI describe positively the activities of Ôshima Volcano. During the last three activities, lava streams poured into the sea. Some points in the record of 1421 indicate that either an eruption took place near the coast or that lava-flows streamed into the sea. The earlier two activities of Table VI, if they could be assigned to the eruption of Ôshima, seem to indicate far more intense explosions than the normal magmatic eruption of basalt, or rather steam explosions.

It is now necessary to refer to eruptions of two rhyolitic volcanoes situated 45 and 60 km SSW of Ôshima, respectively (Fig. 24). These are the eruptions of Tenjô-san of Kôzushima in 838 (Omori, 1915) and of Mukoyama of Niijima in 886 (Nakamura *et al.*, 1908; Nakamura, 1915). The ash-falls of both or either one of the above-mentioned eruptions according to documents may possibly have deposited on Izu-Ôshima (Nakamura, 1960).

4. Correlation Between Deposits and Records

The result of the correlation between the deposits and the historical records is summarized in Table V (p. 693).

Yuba Formation. The five activities represented by the five members from Y_5 to Y_1 are of a magnitude of the same order (Table III, Fig. 23), and in each activity lava-flow poured into the sea. Because the activity of Y_5, as inferred from pottery remains, is dated about 1300 A. D. and also because both the records and the deposits are regularly cyclic, five members from Y_5 to Y_1 can possibly be assigned to the last five major activities in Table VI.

This possibility is supported by the following considerations:

(a) The distribution of the Y_1 lava agrees well with the record of 1778 (Fig. 20, Table VI), especially as this lava is the last to be poured into the sea and because the vents are located at the foot of Mihara-yama. Hence, Y_1 may reasonably be correlated with the activity of 1777～1792.

(b) Ohashi (1910) stated, although without giving any evidence, that the present writer's Y_2-lava which flowed down to the sea at the ENE coast was older than the lavas of 1778 which occupy the northern floor of the caldera. Later, Sameshima (1957) assigned the "Y_2" lava-flow to the products of the 1684 activity, showing the good agreement of its distribution in the field with that indicated in documents. These views, however, were generally not accepted and the Y_2-lava has been assigned to the products of 1778 (Sumi *et al.*, 1959).

The present writer is of the same opinion as Sameshima, not only because of the agreement of the distribution of the lavas in the field and in documents but also because both the activity of Y_2 and that in 1684∼'90 was the last major one prior to 1777.

The activity of 1684∼'90 has been recorded in several documents. The official report of the eruption starting from 1777 tells us that the last activity 1777 was in 1684. On the other hand, several shrines were built at various places in Izu-Ôshima in the early half of the seventeenth century, indicating that the island has not been sparsely populated since that time. In view of these facts, it may safely be assumed that any large eruption, which took place between 1684 and 1777, must have been recorded in documents.

Thus, Y_2 is judged to be a product of the activity during 1684∼1690.

(c) The record of the activity of 1552, which described the birth of an island, is in some accord with the Y_3 lava-flow which reached the sea. At the time of Y_4, shallow submarine explosions took place on the southern coast of Imasaki (Nakamura, 1961). This might account for both the death of many fishes and for the sound that reached as far as 70 km as stated in records of the 1421 activity.

The possibility that Y_5 resulted from the activity of 1338 is supported by the heavy ash-falls common to the record and the deposit over the whole island and by good agreement of the data with that inferred from pottery remains.

The degree of development of the upper weathered zones of Y_6, Y_5, Y_4 and Y_3 seems to be similar to that of Y_2 which may represent a time lapse of about one hundred years as just examined above.

From these considerations, Y_5, Y_4 and Y_3 are tentatively correlated with the activities of 1338, 1421 and 1552. Further, the activity of Y_6 is supposedly dated at about 1200.

Nomashi Formation If the record of the sound heard at Kyôto in 1112 is proved to be associated with the explosion in Izu-Ôshima, there is a possibility that the date is correlated with that of N_1. This is because, the time lapse between the eruptions of N_1 and Y_6, which is represented by the weathered zone of the upper part of N_1, is inferred to be one hundred years or thereabouts, by the comparison with the weathered zones in the Yuba Formation, and also because N_1 includes the resulting deposits from such intense explosions as exemplified by the lithic lapilli tuff and accretionary lapilli tuff.

Nakamura *et al.* (1908) proposed a view that the sound heard at Kyôto in 1112 resulted from the explosions which blew away the northeastern part of the present caldera. This view is based on the assumption that a proportional relation exists between the third power

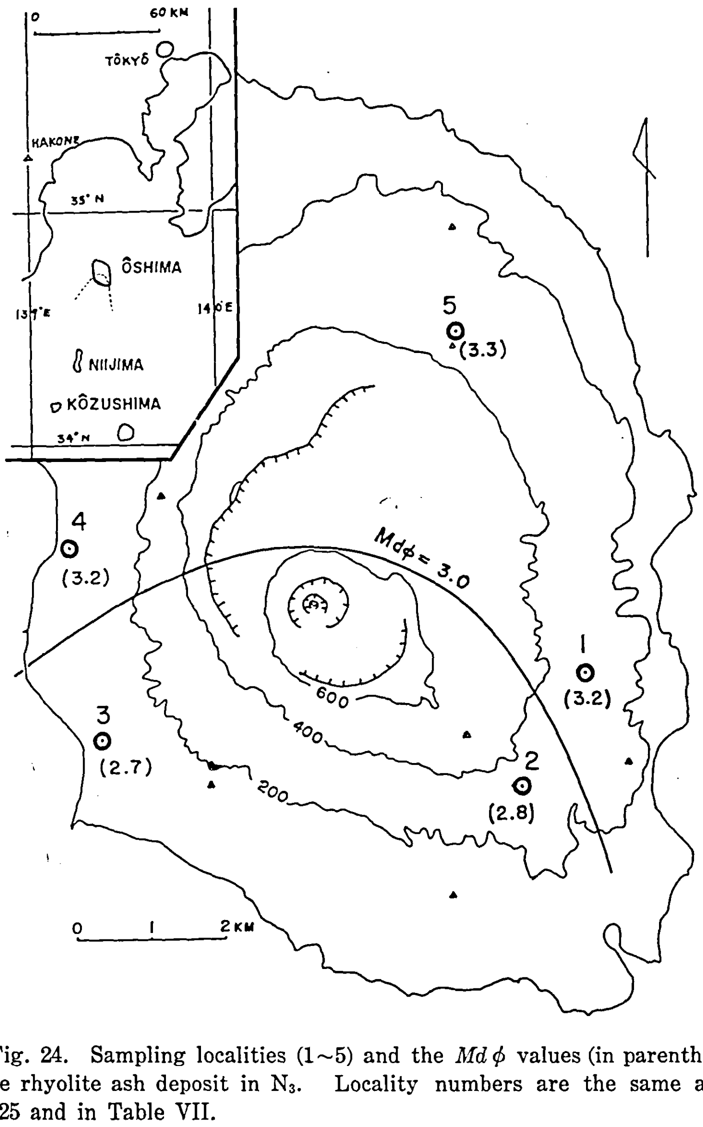


Fig. 24. Sampling localities (1~5) and the $Md\,\phi$ values (in parentheses) of the rhyolite ash deposit in N_3. Locality numbers are the same as in Fig. 25 and in Table VII.

of the radius of the area blown away and the second power of the resultant sound.

The present writer, however, considers the caldera has been formed principally by subsidence (Chapter 8). Besides, the last deposits which might have ejected from the vent located in the northeastern part of the present caldera are represented by S_1 which is probably older than 750 A. D. (Fig. 10).

The rhyolite ash layer in N_3 may most probably be assigned to the eruption of either Kôzu-shima Volcano in 838 or Niijima Volcano in 886. The reasons of the assignment (Nakamura, 1960) are:-

(a) Ash-falls of both or either eruption have possibly deposited over the island of Izu-Ôshima.

(b) The ash layer is practically uniform in thickness (0.5~1 cm) and in grain size throughout the island, indicating that the ash was supplied by a distant volcano.

(c) The dates of the two recorded eruptions are consistent with those being inferred by pottery remains and radiocarbon measurements.

(d) The mineralogy of the ash is similar to the rocks of the two volcanos.

The result of mechanical analyses of the ash, showing that the source volcano lies to the south-southwest of Izu-Ôshima, gives additional support to the correlation.

The ash layer thickens in places, attaining to a few to several

Table VII. Particle size distribution of the rhyolite ash in N_3.

Sample	1 KN 63082903	2 KN 61012408	3 KN 58032008	4 KN 62082801	5 KN 63122401
Dimension of the lenticular layer in cms	3×50	10×60	3×10	2×30	2×80
Total weight in grammes	39.50	334.16	12.43	12.63	23.61
ϕ-scale					
1.5>	0.32	0.77	2.25	0.61	0.17
1.5~2	2.88	8.03	13.11	5.84	1.71
2~3	17.84	27.39	26.47	21.38	19.08
3~4	41.16	44.78	36.80	34.22	39.00
4<	37.80	19.03	22.37	37.95	40.04
$Md\,\phi$	3.2	2.8	2.7	3.2	3.3
$M\phi$	3.2	2.8	2.8	3.1	3.3
$\sigma\phi$	1.1	0.9	1.0	1.1	1.0

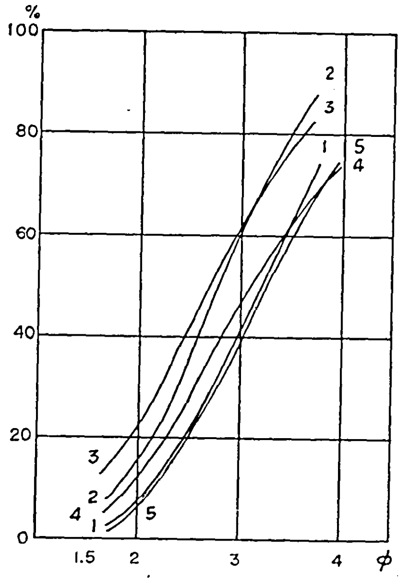


Fig. 25. Cumulative curves showing the particle size distribution of the rhyolite ash in N_3. Numbers are the same as those in Fig. 24 and in Table VII.

centimetres, and is lenticular in cross section, filling a shallow depression (Fig. 37). Five samples were collected from such lenses and differentiated by Taylor sieves. Fractions smaller than 0.058 mm (250 meshes) were not differentiated.

The result is given in Table VII and Fig. 25.

The median values $Md\phi$ ($=\phi 50$) are nearly equal to 3, but as regards to the difference of the second figures of the value, we can draw equi-value lines as shown in Fig. 24, which indicate the source volcano to the south or southwest.

Characteristics of pyroclastic falls as compared with pyroclastic flows (Murai, 1963) are also clearly seen in low values of $\sigma\phi$.

Sashikiji Formation There is a small possibility that the land-enlargement in 684 as described in a document* may explain the explosions of the S_2 time which were followed by widespread mud-flows. This is because, among the deposits which may correspond to the recorded age of 684, only the mud-flows are capable of enlarging the land, and because no marine deposits have been found in the Younger Ôshima Group.

5. Radiocarbon Age

Three radiocarbon ages, 1330±90 B. P., 1350±100 B. P. and 1550 ±160 B. P., were dated by Dr. K. Kigoshi, Gakushuin University, with wood trunks buried in the S_2 mud-flow deposits. The first two dates are of the outermost and the innermost parts of the same trunk, which is about fifty in number of annual rings. The ages are a little younger than those inferred from pottery remains, but are still consistent with historical documents. Taking into consideration these three different ages; 684 A. D. (historical documents), 200 A. D. or later (pottery remains), 400 A. D.±160, 600 A. D.± 100 and 620 A. D.

* 日本書紀 (Nihon Shoki)

± 90 (^{14}C), the age of the deposition of the S_2 member is assumed to be 500 A. D. ± 200.

The samples, two pieces of trunk (Acer mono Maximowicz)*, 15 cm and 5 cm in diameter, were obtained from a coastal cliff (Figs. 4 and 44) 20 m north of the mouth of Omiya-zawa, west of the Nomashi Elementary School, at Nomashi (Fig. 2). The lengths of thick and thin trunks are more than fifty and thirty cm, respectively. The samples are almost fresh, though slightly softened.

The S_2 mud-flow deposit from which the samples were collected, is rich in similar but smaller tree trunks. Here, the mud-flow is covered, without any weathering break, by stratified tuff breccia of the same S_2 which is free from wood debris (Fig. 44). As S_1 is absent in this western coastal area (Fig. 10), N_4 and younger deposits lie successively over the tuff breccia.

The trunk lay almost horizontally in the non-bedded mud-flow deposits. The surface of the exposure was brown in colour but inside, especially bellow the tree trunks, the matrix of the tuff breccia was bluish black, suggesting a reducing condition favourable for the preservation of organic materials.

Chapter 7. Volcanic Activity Represented by Stratigraphic Units

1. A Fall Unit as a Single or Continuous Explosion

Among the three stratigraphic units of different order of grouping, *i. e.*, member, formation and group, member is the most fundamental one. First, consideration is given to the eruptive phenomena represented by a fall unit which is the basic component of fall deposits of individual members.

Aa s fall unit is, by its definition (p. 669), considered to be a layer formed by continuous deposition, it may be the product from a single eruptive column or cloud. So, a fall unit may be formed by a single explosion or by a series of continuous (steady state) explosions, and this may be a common case.

A typical feature of a fall unit would be displayed by what corresponds to a single explosion. A fall unit which is derived from a

* イタヤカエデ, identified by Miss Fumi Yamauchi, Research Institute for Natural Resources.

cloud formed by continuous explosions may be regarded as a transitional type to multiple fall units, and may occasionally show poorly developed stratification and sorting. These features are to be expected also in the deposits near the vent. For discussing the mechanism of deposition or of eruption from resultant deposits, a fall unit should, in principle, always be taken into account.

It has been noticed that the type of stratification shown by multiple fall units is one of the characteristic features of pyroclastic fall deposits as compared with those of pyroclastic flow deposits (e. g. Kuno (1941), Murai (1963)). This characteristic stratification indicates the nature of the volcanic activity in which explosions tend to occur as a series and are then more or less discontinuous thus forming bedded deposits.

2. A Member as an Eruptive Cycle Unit

As defined in Chapter 4, a member in this paper is a time-rock unit in stratigraphy and consists of various kinds of erupted material as pyroclastic falls and lava-flows.

In order to obtain a comprehensive history of the eruptive activity represented by a member, its nature is summarized below from already given descriptions. This subject was partly discussed in a general discussion (Nakamura, 1963 and Nakamura *et al.*, 1963).

(1) A member is composed of erupted material deposited within a short period, probably less than ten years.

This is evidenced both by the already given description of a member (Chapter 4) and from historic records correlated to members as discussed in Chapter 6. Namely, a member has no weathered zone within itself, and scarcely includes erosional breaks of the smallest scale (Fig. 34). Most of the lapsed time between two successive activities is recorded as a brown, loamy ash layer developed at the top of a member, which layer is formed by surface weathering after its deposition.

This is also deduced from the fact that all the horizons hitherto known to contain pottery remains are either in the weathered ash or between two members. Further, heavy ash-falls that continued for a few years are described in the historical documents, which are correlated to Y_5 and Y_3 members, respectively. It took seven and fifteen years before the entire cessation of the activities correlated to Y_2 and Y_1, respectively.

(2) As stated in Chapter 5 each member has a common succession of its component units which is shown below in ascending order:

① fallen scoria → ② lava-flow → ③ layers of ash occasionally accompanied with steam explosion breccia and accretionary lapilli → ④ their secondary deposits → ⑤ weathered ash.

Among these, the succession ① → ② → ③ during a short period, is always found as an important succession for volcanic eruption.

Although the lava-flows from summit craters now observable on the slope of the main cone are confined to a later period than Y_4 time, lava-flows of the older period are reasonably considered to have been consumed for filling the caldera depression. The secondary deposits are considered to be unrelated directly to eruptive phenomena. The weathered ash at the top of the member records practically no deposition there.

(3) It is considered that the more the phases of eruption proceed to advance (① → ② → ③) the longer time they take, especially that of the last phase ③ (ejection of ash) which continues much longer than the earlier ones.

This is illustrated by comparison of the distribution of the basal scoria with the whole fall deposits (Figs. 9～20) and partly by a few historical documents.

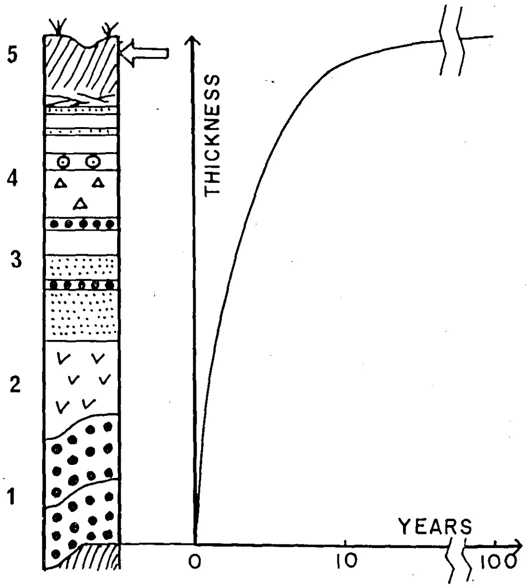


Fig. 26. An idealized succession of deposits in a member, and a probable time versus thickness curve. Explanation is in the text.

Isopach contours for the basal scoria-falls are relatively regular and the vent is located nearly at one end of the long axis of the elliptical area enveloped by the 0 cm-contour. Contours for the whole falls, most of which are made up of ash-falls, are rather concentric with the vent at the centre. This difference between the location of the vents will be explained by assuming that the time needed for the deposition of the ash-fall was much longer than that of the scoria-fall so that every direction of surface wind is included in the period. It was illustrated in the case of the Parícutin eruption that the ejection of ash which lasted for years produced distribution having concentric contours with the vent at their centre (Segerstrom, 1950).

According to historical documents (Table VI, p. 695), it is evident that the ejection of ash lasted for years at the Y_5, the Y_3, the Y_2 and the Y_1 activities, and that the initial explosive ejection of scoria and the succeeding lava-outflow came to an end within a year or two at the Y_2 and the Y_1 activities.

These three characters ((1)$\sim$(3)) of a member as illustrated in Fig. 26, may collectively indicate that a member consists of volcanic deposits erupted during a single eruptive cycle, as we can now observe on an active volcano. The cycle starts with the initial explosion mostly from a pre-existent vent and grades into the next phase when lava-outflow occurs, as the head of the magmatic column rises and the magma becomes poorer in volatile content. Then a phase follows when ejection of ash predominates. This last phase of activity probably indicates the lowering of the magma level into the depth of the vent, although the level of magma head may often fluctuate. This will be inferred by the following observations and considerations.

In the declining stage or the last phase of eruptive activity, it seems rather common to find that the ash-ejection endures or the explosive eruption regains its momentum, especially at the volcanoes of fluidal magma or of basaltic nature. This was the case during the activities of Hekla in 1948 (Thorarinsson, 1950), Parícutin in 1952 (Fries and Gutierrez, 1954), Ôshima Volcano in 1951 (Tsuya *et al.*, 1955), Vesuvius in 1906 (Rittmann, 1962) and in 1944 (Bullard, 1962) Etna in 1958 (Rittmann, 1962) etc.

The presence of steam explosion breccia at the uppermost horizon of a few members may be interpreted as the result of the lowering of magma colum below the ground water-table (Chapter 8) as in the explosive eruption of Kiluauea in 1924 (Jagger, 1947).

Similar phenomena may be indicated by accretionary lapilli tuff in the layered ash of several members. As reviewed by Moore and Peck (1962), accretionary lapilli of basaltic volcanoes have mostly been formed at their steam explosions such as Vesuvius in 1906, Taal in 1911, Kilauea in 1790 and 1924. It is suggested that a high eruptive cloud sufficient for the condensation of water is needed for the formation of accretionary lapilli as hail in a gigantic column of cloud, and that such an explosion of basaltic volcano is possible only by steam explosions (Chapter 5).

Thus, member is the stratigraphic unit that is considered to represent a period and a group of erupted material of definite significance in volcanic activity. This conclusion is also supported when parasitic activity of this volcano is taken into account. As was described and discussed previously (Nakamura, 1961,) all the materials that erupted from a single parasitic vent are included in a single member which consists mostly of those from the summit vent. Therefore, parasitic volcanoes (scoria cones and steam explosion craters) are to be called monogenetic, while the main cone is polygenetic. This means, as Tsuya (1943) suggested, that once the activity ceased, the vents freeze so completely that they cannot be paths of erupting magma any more after a single repose period of about one hundred years represented by the weathered zone of a member. The vents of parasitic volcanoes are possibly dykes of a few metres in width (Nakamura, 1961).

One of the characteristics of parasitic activity is that the duration of activity is much shorter than that of the summit crater, or in other words, parasitic volcanoes never display a long-endured phase of ash-ejection. This characteristic of parasitic volcanoes is also in sharp contrast with that of the simultaneous activity of the summit crater, and suggests that parasitic vents were narrower and shallower in direct origin.

There are a few examples of the study of volcanoes in which the same stratigraphic unit of volcanic products just like the member in this paper is taken as a grouping unit. Such a grouping of fall deposits has been worked very well as has been demonstrated by several authors including the writer (e. g. Thorarinsson, 1950, Nakamura, 1960, Katsui, 1963 and others) in their study of the history of volcanic activity.

Powers (1948), in his pyroclastic study of Kilauea, called the unit somewhat implicitly as "eruption" which is actually a group of volcanic products including lava-flows and pyroclastic falls. Between the two "eruptions" there is either a desert or a soil surface. Breaks in deposition are included in an "eruption". Thus, from a similar observation and method as the present writer's, Powers gave a composite stratigraphic column and chronologic sequence of explosive activity for Kilauea. Aramaki (1963) adopted the same unit in his geologic study of Asama Volcano, giving an alphabetical name to the unit. His "A" "B" and possibly "C" units include also pyroclastic flows (Aramaki, 1957) besides lava-flows and pyroclastic falls (Aramaki, 1963, Nakamura and Aramaki, in preparation).

Ewart (1963) investigated the mineralogy and petrology of the Taupo ash shower sequence and grouped the showers into the "eruptive sequences". The eruptive sequence seems to be the same grouping unit as the member of this paper, although it consists solely of fall deposits at a locality. At any rate, he showed that an inquiry into the history and location of the vesiculation of magma in the underground reservoir was possible through this grouping.

These studies, together with the present one will indicate that the study of volcanic products, grouping them into a member (eruptive cycle unit) or eruptive squence (whatever it may be called), is one of the hopeful approaches to the history and mechanism of eruptive activities.

The following two considerations should be borne in mind when we reconstruct the history of volcanic activity by the nature of relevant members.

(1) The history of Ôshima Volcano is revealed by the products deposited on the slope of the main cone. Such small or non-explosive eruptions as affected only the inside of the caldera (e. g. activities since the 19th century, Chapter 8) are not recorded in members. In other words, undetected small or non-explosive eruptions might have broken out during the repose period of eruptive history reconstructed from members. This is clearly shown in Fig. 27. A horizontal portion in the extreme right of the figure shows a non-depositional or weathering period, when effusive activities as tabulated in Table VIII (p. 718) have actually broken out. Therefore, the repose period represented by a member may more properly be called a period of lower activity rather than just a certain level.

(2) More generally speaking, even in stratigraphic columns

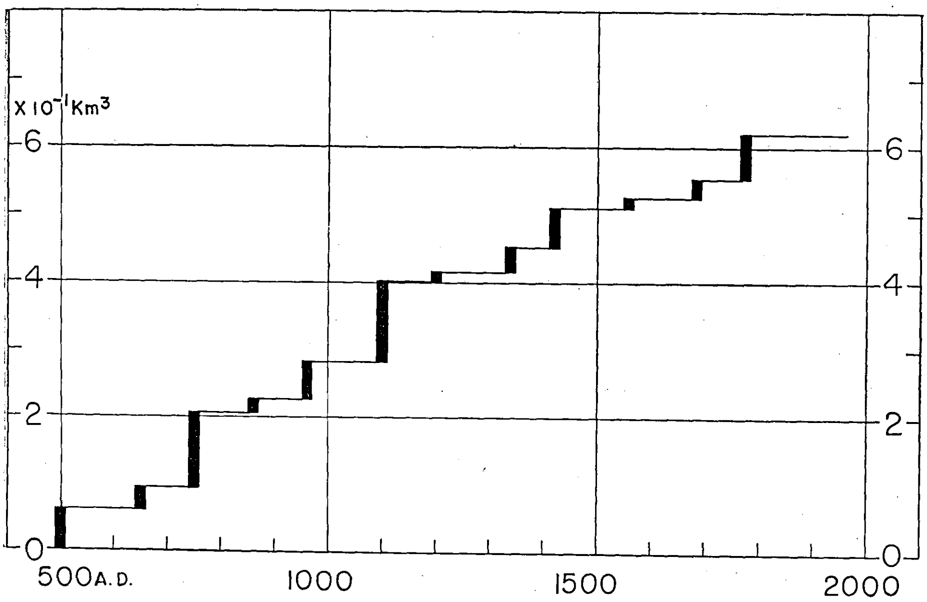


Fig. 27. Rate of accumulation of fall deposits from the summit craters on the slope of the main cone. Horizontal portions indicate the periods of practical non-deposition or weathering. Data from Tables III and V.

representing the same lapse of time, the number of members varies according to the distance and the direction from the vent. This means that the number of members observed at a single locality does not directly give the actual rhythm of eruptive activity, the actual one being revealed through both the stratigraphy of an area 360° around the vent and the volume calculation of erupted material.

3. Formations and Groups

Three formations of the Younger Ôshima Group comprise two, four and six members in ascending order. Between the formations there extends an erosional unconformity of moderate scale over the island (Chapter 4). But the unconformable relation does not represent a longer interval than the conformable relation between members, as shown in Table V.

The unconformity between the Younger and the Older Ôshima Groups is larger in scale than the ones between formations, however, it can also be a different expression of the same lapse of time as to those between members of the Younger Ôshima Group. This is because ^{14}C age of peat from a peaty soil layer, which is stratigraphically about the tenth member below the top of the Older Ôshima Group, is about a thousand years older than the top (470±150 B. C., Gak. 362), and also because the degree of development of the weathered zone just under the Younger Ôshima Group, seems to be similar as those of the weathered zone in the above Group.

Thus, formations and group seem to be units separated by the same order of time interval as the members are.

At present, the definite volcanological significance of formations and groups in the sense of the present paper, is not yet clarified. But some speculative considerations as below are possible.

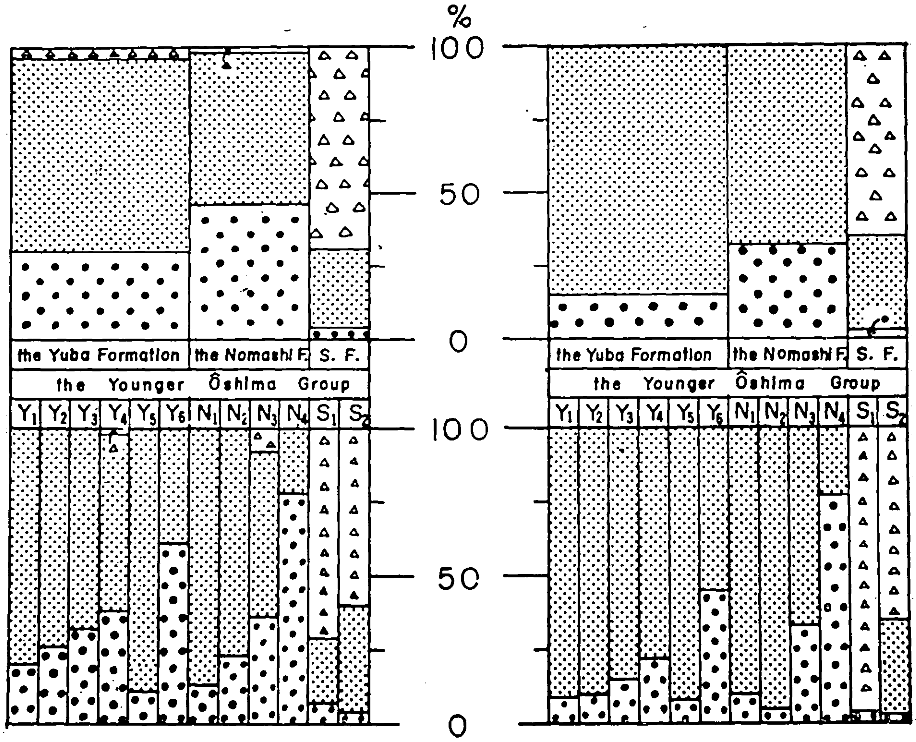


Fig. 28. Volume percentage of the three kinds of fall deposits within the members (lower half) and formations (upper half) of the Younger Ôshima Group. Data from Table III.

Right : Result from the total volume.

Left : Ditto from the fall deposits from the summit craters, on the slope of the main cone.

Symbols are the same as in Fig. 6.

The Nomashi and the Yuba Formations show a tendency to decrease with time in the volume percent of scoria among the whole fall deposits of individual members, or to an increase of ashy material (Fig. 28, lower half). The tendency may actually be more distinct, because the crater was much lower in elevation during older activities. The tendency may also indicate that eruption from lower magma levels endures longer as the time proceeds, or in other words, the internal pressure of magma is gradually decreasing throughout the period represented by the Nomashi and the Yuba Formations.

In the sense that the Younger Ôshima Group represents the volcanic products during and after the caldera formation, the Group is rightly separated from the older one. Moreover, the change in proportion of three kinds of fall deposit such as scoria, ash and explosion breccia among the three formations seems to bear some similarity to that within a member (Fig. 28, upper half). The Sashikiji Formation abounds with explosion breccia from the depth of the conduit; the Nomashi Formation is relatively richer in coarser- or scoria-fall deposits than the Yuba Formation. Among the fall deposits of the Yuba Formation, fine ash predominates although the crater must have been higher by about one hundred metres. This might suggest that the cycle of volcanic activity represented by the Younger Ôshima Group is declining.

In any case, these cycles of activity represented by the formations and the groups which are longer than a single eruptive cycle, are expected to be governed by the phenomena of deeper origin.

Chapter 8. History of Volcanic Activity

1. Outline

In the first place, the history of the island prior to the deposition of the Younger Ôshima Group is summarised below, and is according to the already published papers (Kuno, 1958; Sumi *et al.*, 1959; Nakamura, 1960·1961; Isshiki *et al.*, 1962; Kuno *et al.*, 1962 and Isshiki *et al.*, 1963) combined with the results of later observations of the writer.

The whole scheme of the history of the island is shown in Table I (p. 660). Okata, Fudeshima and Gyôja-no-iwaya Volcanoes (Fig.5, p. 667) grew up during later Plicocene (Kuno, 1958) at the northern, southeastern and eastern part of the present Izu-Ôshima island, respectively. These older stratovolcanoes may have been the same as or a little smaller than the present Ôshima Volcano in size. The greater part of the edifice of these volcanoes was eroded away by the succeeding marine erosion over a period of hundreds of thousand of years and more. Fudeshima Volcano, for example, exposes its central chaotic part on the coastal cliff opposite to the islet, called Fudeshima (Fig. 2). The erosion remnants of these volcanoes had probably formed a group of small islands before the birth of Ôshima Volcano.

About a few to several tens of thousand years ago, a new volcanic activity broke out on the shallow sea bottom on the southwestern part of the islands. Material erupted during the initial stage of this activity was predominantly explosion breccia and mud-flow deposits derived from the former, being associated with smaller amounts of lava-flows (the Senzu Group). This explosive activity was probably due to contact of the magma with sea water. As a result of this activity, the pre-existent dissected islands were probably connected into a new volcanic island. During this activity rocks probably of the lower Miocene Yugashima Group and quartz diorites intruded into the group were ejected (Sumi *et al.*, 1959). After deposition of the Senzu Group, a period of erosion succeeded.

About a few tens of thousands of years ago, the activity of Ôshima Volcano proper began at the subaerial craters which were probably located near the centre of the present island and has continued up to the present, erupting lavas and pyroclastics about 45 km^3 in volume. The greater part of this activity is recorded as the Older Ôshima Group. From the observation of scattered exposure of the Older Ôshima Group, as shown in Fig. 45, an outline of the history of the activity during the Older Ôshima age* can be understood, although its details are not yet clarified.

Activity of Ôshima Volcano during this age is inferred to have been essentially the same as those represented by the Younger Ôshima Group. The activity broke out almost periodically. No exceptionally long period of repose was found between any two of the activities. A single cycle of activity was of shorter duration and followed a similar course as represented by the member of the Younger Ôshima Group (Chapter 7). Even in the active period, ejecta did not always cover the whole island. Therefore, along coastal areas deep weathered zones

* The periods represented by deposition of the Older and the Younger Ôshima Groups are called the Older and the Younger Ôshima age, respectively.

were sometimes formed, as observed by Kuno (1957) in the western coast of the island. Duration of the Older Ôshima age is estimated at a few tens of thousands years on the basis of the number of eruptive cycle units and the degree of apparent weathering at their tops.

The history of Ôshima Volcano during the Younger Ôshima age will be grasped by a series of maps (Figs. 9~20). Twelve major activities have broken out periodically during this age of about 1500 years. A single cycle of activity has a common character as discussed in Chapter 7 (Fig. 26), and as indicated in the right-hand column of Table IX (p. 719). Component unit and volume of erupted material during each activity are tabulated in Table II and III, respectively. Volume percent of three kinds of fall deposits of members and of formations is given in Fig. 28. From this figure, change of mode of explosive eruption of members and formations of the Younger Ôshima Group can be understood (Chapter 7).

About forty parasitic volcanoes were active on the flank of the main cone during a period from the later stage of the Older Ôshima age to 1420 A. D., namely from the time when the volcanic edifice of Ôshima Volcano grew up into a fairly large dimension to the time when a stable central conduit re-opend in the summit caldera (Table I and Nakamura, 1961). Parasitic volcanoes are chiefly scoria cones with or without lave-flows, and a several steam explosion craters. Some of them were formed by fissure eruptions. Areal distribution of them is shown in Fig. 5. They are distributed in two parallel zones. Parasitic activity of the Younger Ôshima age is almost entirely confined to the southen part of the larger zone. The total erupted material attains less than one percent only of that from the summit craters in volume (Nakamura, 1961). During the younger Ôshima age, the total volume erupted from parasitic vents is about two percent of that from the summit vent.

Estimated rate of energy release during the Younger Ôshima age is shown in Fig. 23 (p. 689). It is nearly constant, *i. e.* $6 \sim 8.7 \times 10^{24}$ erg/100 years. This rate may possibly be extended back to the Older Ôshima age, if we assume the volume and density of the Older Ôshima Group to be 40 km^3 and 2.1 g/cm^3, respectively, and the whole mass to be essential, the length of the age twenty to thirty thousand years. Periodic energy release of nearly the same order of magnitude, at least during the Younger Ôshima age, suggests a geyser-like mechanism of volcanic eruption. When either the quantity of magma in an assumed reservoir or accumulation of heat in the depth where generation of magma could occur reached a certain level, eruption on the surface would break out.

Sugimura *et al.* (1963) gave preliminary results of estimation of the thermal energy transported by lavas and pyroclastics in the Japanese main islands during the last 10^6 years (the Quaternary) to be 10^{23} erg, or 10^{25} erg/100 years. This rate is almost the same as that obtained from Ôshima Volcano alone, during the last 1500 years. Because it may be naturally considered that more than ten volcanoes like Ôshima Volcano should have been active during any period of the Quaternary in Japan, the actual rate of release of thermal energy during the Quaternary would be expected to amount to ten times more, even if the Quaternary be extended to a few million years.

2. Caldera

The summit caldera of Ôshima Volcano is gourd-shaped and about 10 km^2 wide, the wall being less than 100 m in relative height (Chapter 3). The eastern part of the rim is hidden beneath the later erupted material (Fig. 21). Rocks of the post-caldera age represent an advanced stage of crystallization of pre-caldera ones, there being no change between the rock series of the pre- and post-caldera age, unlike the caldera of the Krakatau type (Kuno, 1954).

Yokoyama (1963) classified the caldera of Ôshima Volcano as one of the high Bouguer gravity anomaly type together with that of Kilauea, while the calderas of Krakatau type belong to his low anomaly type. This indicates that below the caldera floor of Ôshima Volcano, excess mass over the mean density of the volcano above sea-level, should be expected. Yokoyama (1958) presented a tentative cross-section of the island including the caldera, by which the Bouguer anomaly up to +15 mgal* in the caldera was interpreted. The bottom of the caldera which is assumed to be filled by material of higher density by 0.4 g/cm^3, reaches 1.6 km below the present caldera floor.

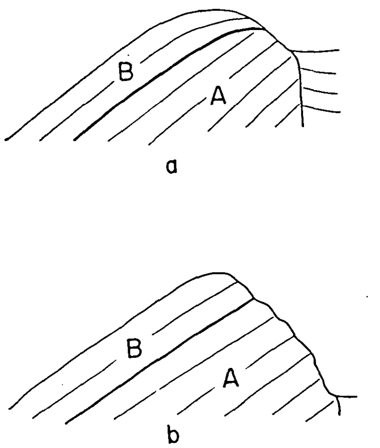


Fig. 29. Schematic cross-sections of the caldera rim.
A : pre-caldera deposits including lava- and mud-flow.
B : post-caldera fall deposits.
The rim has mostly the section shown in "b", but at a few places where the wall is low, section like "a" is observed.

* Actual anomaly responsible for the caldera seems to be only 6~8 mgl taking the general easterly increasing tendency into consideration.

Age of formation Age of the caldera formation can be revealed by observing the field relation among the deposits composing the caldera rim, as shown in Fig. 29-a. Obviously, the upward extension of the slope of the main cone beyond the height of the rim, must have existed during deposition of the latest flow-deposit on the rim, designated A in Fig. 29. At the same time the present rim and the wall must have existed prior to deposition of the earliest fall-deposit shown as B in Fig. 29-a.

Thus, formation of the caldera, at least of the present caldera wall, is assigned to the period between deposition of S_2 and that of N_4, or to 550 A. D. ± 250.

Examples of the actual relation between these member are shown in Figs. 47 and 48 which show the S_2 mud-flow deposit on the caldera rim and the N_4 scoria-fall deposit covering conformably the caldera rim topography. The earliest fall deposit, which covers conformably the rim at individual places, is often the later one rather than N_4 (N_3 in Fig. 49). Moreover, at most places, stratification of these deposits is parallel to that of the underlying flow deposits (Fig. 29-b). This parallel stratification may be due to rapid erosion along the caldera wall. On the other hand, along the caldera wall, lava-flows of the Older Ôshima Group which underlie S_2, are widely exposed, being topographically cut by the wall.

As is discussed elsewhere (Yukutake, Nakamura and Horai, 1964) age of the caldera formation may possibly be inferred by measuring the magnetic direction of a series of ash-fall tuffs composing the rim. If the ash-fall tuffs preserve the geomagnetic field at the time of their deposition, the local magnetic anomaly produced by the depression of the summit, may be preserved in the tuffs as an abrupt change in the secular variatian. Preliminary measurements seem to confirm this conclusion.

Isshiki *et al.* (1963) suggested the presence of an older depression below the bottom of the present caldera from the study of core samples of the drill-holes inside the caldera, there benig no further evidence relating to the "older caldera".

Mode formation The caldera of Ôshima Volcano has long been considered, since the discussion by Ohashi (1909), to have been formed by the engulfment of the summit, instead of "blowing its head off". The present study has reached the same conclusion. The course of the writer's consideration is similar to that of Williams (1941).

Volume of the summit collapsed by the caldera formation is estimated at $3.1 \pm 0.3\,km^3$, and two-thirds of the volume (about $2.2\,km^3$) is filled by later ejecta. The calculation was made on the following assumptions:

(1) engulfed area is gourd-shaped and $10\,km^2$ in area as shown in Fig. 2.

(2) bottom of the caldera, or the caldera floor immediately after the formation is practically flat at about 300 m above the present sea-level (Isshiki *et al.*, 1963).

(3) the summit crater before the caldera formation was 1 km in diameter, and 900 m above the present sea-level, and

(4) the ring fault surrounding the caldera is vertical (Isshiki *et al.*, 1963).

The volume of the accessory tuff breccia of S_1 and S_2, either or both of which is considered to have deposited just before the caldera formation, are 0.08 and $0.09\,km^3$, respectively. These are less than one-tenth of the collapsed volume. Essential materials of the two members are $0.2\,km^3$ or less in volume (Table III). Thus, we cannot but conclude that the majority of the decapitated summit was engulfed.

As to the mechanism and the events associated with the engulfment, following speculations may be possible as compared with the explosive activity of Kilauea in 1924 (Jagger, 1947 and Bullard, 1962).

In this rather unusual explosive eruption of Kilauea, the sequence of events was:-

(1) abrupt disappearance of the lava lake in Halemaumau pit (January-March),

(2) rupture of east rift at shoreline (April),

(3) outflow of lava probably on the same rift completely submarine (April-May),

(4) collapse of Halemaumau walls into the emptied depth (May),

(5) spasmodic inrush of ground water at very low levels along the dyke chasm (May),

(6) rhythmic stream blasts through Halemaumau by alternation of avalanche choking and ground-water boiling (May), and

(7) dormant period (1924∼'25).

By this explosion, the diameter of the Halemaumau pit became more than doubled and the wall rocks lost were estimated at $0.2\,km^3$. While the volume of ejected ash and rubble were estimated at $0.0008\,km^3$. The explosion clouds rose up to a height of 6 km and, the ash-falls in many places contained accretionary lapilli.

It is noted that this sequence of events strikingly resembles that which is represented by the S_2 member of Ôshima Volcano. The sequence of events of S_2 (Fig. 9 and Table III) is reconstructed as follows :-
(1) scoria-ejection from the summit crater about 0.0001 km^3 in volume,
(2) a fissure eruption on the eastern coast, with lava-outflow about 0.02 km^3 in volume (Nakamura 1961),
(3) explosive eruptions at the summit crater with repeated ash-falls containing abundant accretionary lapilli (Chapter 5) 0.04 km^3 in volume,
(4) steam explosions at the summit vent, resulting explosion breccia and the secondary mud-flow deposits 0.09 km^3 in volume, and
(5) dormant period for about a hundred years.

These events occurred so closely in succession that no weathering break was observed between the accretionary lapilli tuff, explosion breccia, mud-flow deposits and lava-flow. The accretionary lapilli tuff upon the welded spatter near the parasitic fissure became oxidized and turned reddish in colour. Cognate fragments of plutonic texture (micro-diorite of Tsuboi, 1920) were found in the mud-flow, which may indicate a deeper site of the explosion than the usual magmatic ones.

From the above comparison between the two sequences, a possible mechanism and course of the caldera formation at Ôshima Volcano, can be assumed as follows :—The flank outflow of lava, which took place on a fissure zone in the first stage of the activity, so lowered the magma level in the summit conduit that ground water rushed into the conduit and caused a series of strong explosions producing explosion breccias and accretionary lapilli tuff. The explosions made mechanically weak the summit part of the main cone, thus providing a favourable condition for the engulfment of the wall of the pre-existent crater.

This explanation of the caldera formation resembles in some way that proposed by Escher (1929). Unlike Escher's proposition, the present writer does not intend to cover the mechanism of formation of the Krakatsu type (Williams, 1941) by the same method. However, the role of steam explosions by the contact of ground water with magma appears to be significant as a trigger for the collapse of basaltic volcanoes although Williams (1941) regarded this as an insignificant incident. Because Ôshima Volcano repeatedly experienced an outflow of lava at lower levels, the lowering of the magma level should have occurred all over again, and yet the caldera was formed just after the activity of the S_2 time. We must inevitably pay special attention to the explosion breccia and mud-flow deposits of S_2, which are quite peculiar ejecta among the products of Ôshima Volcano.

In this connection, S_1 also attracts our attention, this comprising an alternation of explosion breccia and accretionary lapilli tuff; Moreover S_1 is the only member in the Younger Ôshima Group which seems to have been ejected from a vent located at the northestern part of the present caldera (Fig. 10). With this in mind, we can further assume another engulfment after the explosion of S_1. If this actually happend, the present gourd shaped caldera would be a connected caldera successively engulfed with an interval of about one hundred years.

How the vacant space for sudden subsidence was prepared remains unknown. There is no positive evidence suggesting that the magma outflowed at a lower level or intruded into some places in large quantity. Nor can the volume having been occupied by the released vapour explain the room for collapse, as proposed by Yamasaki (1959) and Katsui and Murase (1960) for the caldera of Krakatau type. There is anothor possibility that the vacant space for the collapse was not formed just before the engulfment but had grown wider through repeated activities. This idea gains in feasibility over the doubtful interpretation of the vacant space by underground intrusion. However, the mechanical validity for assuming the long endured vacant underfround space may be a matter for dispute.

To sum up, one of the most probable methods of the caldera formation of Ôshima Volcano is as follows:-

First, the summit which had occupied the southwestern part of the present caldera (2.3 km^3) became engulfed immediately after the explosive activity of S_2 (less than 0.2 km^3). Also, another englufment (0.8 km^3) may have occurred just after the explosion of S_1 (less than 0.2 km^3) at the present northeastern part of the caldera. The present gourd-shaped caldera may be a connected one. Since then, the depression of the caldera has been filled up to two-thirds of its volume mainly by repeatedly issued lava-flows. Thus, the present caldera floor is underlain by the material denser by $0.3 \sim 0.4$ g/cm^3 than the whole mountain edifice, however, observed positive Bouguer anomaly ($6 \sim 8$ mgl) cannot be thoroughly explained. At the centre of the southwestern part, scoria cones were formed during more than nine activities, successively overlapping and accumulated into the present cone, Mihara-yama as the floor was raised by 300 m due to burial by lavas and pyroclastics.

3. Historical Evaluation of Eruptions Since the 19th Century

Scientific descriptions of eruption have been published, since the eruption from 1876 to 1877. Before that date, there were brief notes only and not scientific evaluations were made.

Eruptions of Ôshima Volcano after the An'ei or Y_1 activity, took place exclusively in the central pit of Mihara-yama (Tsuya *et al.*, 1956). Moreover, they were predominantly effusive in nature, in sharp contrast to the past major activities represented by twelve members of the Younger Ôshima Group. The date of eruption, duration, volume of erupted materials and thermal energy transported by them after the Y_1 activity (1777~1792) are enumerated in Table VIII.

Activities during the above-mentioned period were mainly quiet lava-outflow and mild scoria-ejection, sometimes forming scoria cones of appreciable dimension on the crater floor. The lava-flow spread over the crater floor during activities Nos. 8, 11 and 18 in Table VIII. During activity No. 18 (1950~1951), the lava overflowed the crater rim and further ran down the slope of the central cone, spreading over the western part of the caldera floor. Throughout these activities, the crater floor of the central cone has been gradually elevated more than 150 m mainly by accumulation of lava-flows.

The central pit inside the crater floor, on the other hand, has repeatedly collapsed into the previous location after the larger eruptions, such as No. 8 and No. 18 (Tsuya *et al.*, 1956). Consequently, the material which erupted during the period after the Y_1 activity did not contribute in a practical way even to the formation of the central cone, the greater part of the erupted material sliding down into the depth of the central pit.

Regarding the nature of activity and in many other respects, as tabulated in Table IX (p. 719), the activity after Y_1 is quite different from the major ones of the past, represented by the Younger Ôshima Group which contributed much to the formation of the main cone of Ôshima Volcano.

Thermal energy transported by erupted material during the period after the activity 1876~1877 and its cummulative curve are given in Table VIII and Fig. 30, respectively. In the figure, curved line represent cumulative curves assuming that the eruption between 1792 and 1876 were small but appreciable in released energy.

Although the absolute amount of released energy of each activity

Table VIII. Dates, duration and volume of erupted material of the activity of Ôshima Volcano, after the An'ei activity (1777～1792, Y_1)

No.	Date	Duration (day)	Preceded years of repose	Volume of erupted solid material ($\times 10^5\ m^3$)			Thermal energy transported ($\times 10^{24}$ erg)
				scoria cone	lava-flow	total	
1	1803, Sept. 26～	10−	11	Eruption, ash fell in Tokyô			?
2	1822 1824	?	9±	Ash fell.			
3	1837～	?	13±	Eruption, cloud with sulphur odour.			
4	1846	?	9±	Eruption for twenty years			
5	1870	4	36±	Small eruption.			
6	1876, Dec. 27～ 1877, Feb. 5	40	6	20	10+	30+	0.07+
7	1910, Dec.	10	33	0.7	—	1	0.001
8	1912, Feb. 23～June 10 July 27～29 Sept. 16～Oct. 30 1913, Jan. 14～25 1914, May 15～26	96 3 44 } 166 12 11	2	0.5 5 } 26 20	60 90 } 300 150	330	1
9	1915, Oct. 10～	15～	1	—	—	1−?	0.001−?
10	1919, May 18～July 5 Dec. 20～23	49 4 } 53	6	—	—	1−?	0.001−?
11	1922, Dec. 8～ 1923, Jan. 30	54	3	4	60	64	0.2
12	1933, Oct. 14	10−?	10	—	+	} 1−?	} 0.001−?
13	1934, Apr. 15	10−?	1	—	+		
14	1935, Apr. 26	10−?	1	—	+		
15	1938, Aug. 11	1	3	—	2	2	0.007
16	1939, Sept. 1～3 Sept. 16	4	1	— —	2	2	0.007
17	1940, Aug. 18～19,	2	1	—	2	3	0.009
18	1950, July 16～Sept. 23 1951, Feb. 4～March 31 Apr. 1～June 28	69 56 } 194 69	10	36	230	270	0.8
19	1953, Oct. 5～12 Nov. 9～13 Dec. 1～18 Dec. 29～Jan. 15 1954, Jan. 27～Feb. 8	8 5 18 } 64 20 13	3	0.5	2.2	2.9	0.008

Compiled and estimated from descriptions by Nakamura (1912), Omori (1915), Tsuboi (1920), Nagata (1941), Musha (1941～51) and Tsuya *et al.*, (1955, 1956).

Density of lava-flow and scoria cone is presumed to be 2.4 and 1 g/cm³, respectively.

Table IX. Nature of eruptive activity which broke out after 1876, compared with those represented by members of the Younger Ôshima Group.

		Activity observed since 1876	Activity revealed by members of the Younger Ôshima Group
Of a single cycle of activity	site	inside the crater of the central cone	at the summit crater, and occasionally on the slope of the main cone
	fall deposit on the slope of the main cone	practically nil	>0.01 km³
	duration	one day to a few years	a few to some ten years
	repose period	<30 years	80~150 years
	volume of erupted material	<0.03 km³	>0.15 km³
	ash-ejection	negligibly small in amounts	considerable amounts in the last stage
	explosive ejection of scoria	practically nil	always in the initial stage
	explosion index	10±	60±
present state		dying stage of 1950~1951 activity	repose period since 1777~1792 (Y_1) activity
rate of energy-release during the total period		2.7×10^{22} erg/year	$8.7\sim6\times10^{22}$ erg/year

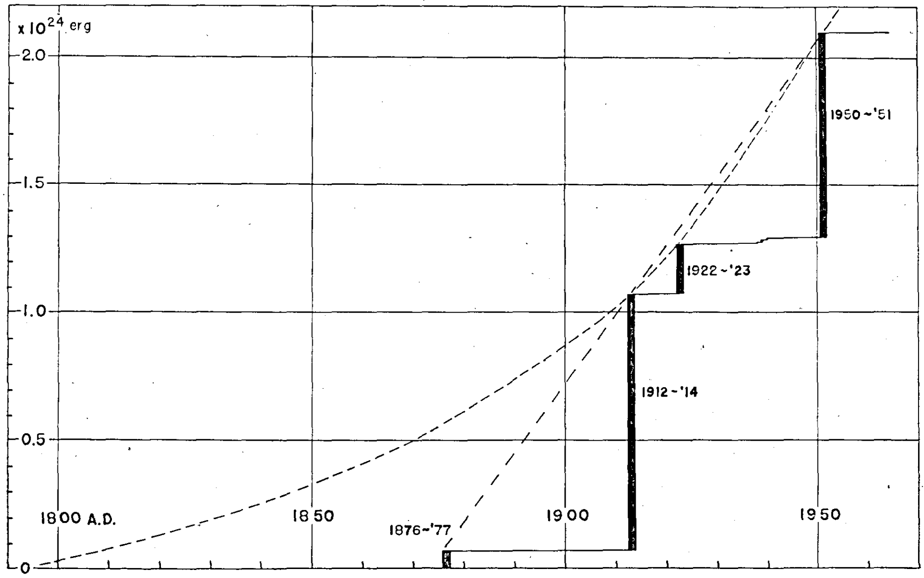


Fig. 30. Rate of release of thermal energy after the Y_1 (1777~1792) activity of Ôshima Volcano, Drawn from data given in Table VIII.

since 1876, has been fairly large, it is still far smaller than those of the activities revealed by members of the Younger Ôshima Group, as graphically shown in Fig. 23, extreme right. In the figure, the broken line represents a cumulative curve of released th ermal energy calculated on the assumption that a similar activity to that which has occurred since 1876 might have taken place during each repose period as indicated by the weathered zone of members.

To sum up, the eruptions since the 19th century may probably be regarded as a mere episode rather than a part of constructive activity in the long history of Ôshima Volcano. Possibility still remains, however, that the mode of eruption itself has changed after the Y_1 (1777–1792) activity.

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36. 伊豆大島火山の火山層位学的研究

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火山噴出物の層位学的研究によつて，火山の活動史を量的に知ることができることを，伊豆大島火山についてのべた．また，一見して同じような噴出物の重なりとみえるものを，“一輪廻の堆積

物”ごとにわけて観察することが有効であることを示し，この層序区分単位と噴火活動との関係を議論した．

伊豆大島は4つの単位——基盤の火山体，大島火山の主火山体（外輪山），中央丘（三原山），寄生火山——に分けて考えることができる．島には二重の海蝕崖があり，また火口から東北東・南西にのびる植生のない地域がある（Fig. 3）．この地域はこれまでは，新しい降下堆積物のために植生がないものとされていたが，そうではなくて，火口からたなびいてくるガスを直接受けるために植生が定着せず，したがつて侵食も激しいものと考えられる．このことは，この地域の外にも中にも同じように新しい積物が一旦は堆積していること（Figs. 9～20）の他，火口からの地域ののびの方向が卓越風の方向と一致していることなどから知られる．上述した大島の4構成単位相互の時間的な前後関係や分布を，成長史の概略を示した Table I，島の模式的断面図（Fig. 4），寄生火山の分布図（Fig. 5）などに示した（第3章）．

火山噴出物の層位学を火山体について行うに際しては，広域にわたつて分布する山頂火口からの降下堆積物の層序をまずきめた．局所的な寄生火口噴出物や溶岩流は，後にこの層序の中に組み入れた．その内部では成層していない，堆積物としての最小単位を fall unit とよぶ．Fall unit に注目して観察することは，降下堆積物の正確な対比や堆積様式などを考える上に必要であるが，この単位の堆積物では，火口から全ての方向に通用する層序単位にはできない．全島的な最小の層序区分単位には，二つの地表風化面に挟まれた各種の噴出物を一括したものが有効である（Figs. 6, 7）．この面は場所によつては規模の小さい侵食面ともなる（Figs. 32, 33, 35, 49 など）．この単位の堆積物は降下堆積物や溶岩を含む，短期間内の噴出物の集りであり，これを本論文では member とよんだ．火山体は結局いくつもの member の重なりでつくられているが，最上部の 12 member を層位学的な観察から，新期大島層群とよんで，下位の古期大島層群から区別した（Fig. 8）．

本論文では，この新期大島層群を主として扱つた（第4章）．

個々の member は $Y_1 \cdot N_3$ 等の記号で示されるが，この単位で，噴出物の記載を行つた。Member 毎に降下堆積物の厚さ，溶岩流の分布を Figs. 9～20 の12枚の図に示した．また，12枚をまとめたものを Fig. 21 に示した．さらに，山頂火口および寄生火口からの降下スコリア・溶岩・火山灰互層などの個々の member 中の有無を Table II にまとめた．次にこれらの噴出物の体積を適当な仮定をおいて計算し Table III に示した．計算は 1 member を構成する降下スコリア・溶岩・火山灰互層を山頂・寄生火口からの噴出物ごとにわけて行つた．この際の最も大きな仮定はカルデラを埋めたてた物質の量とそれらの各 member への配分とに関するものである．

多くの仮定，したがつて不確かさがあるが，一応 Table III の結果をみとめると，新期大島層群全体の体積は 3.6 km^3（内 2.2 km^3 がカルデラを埋めている分），Explosion index は約60，12の個々の member の体積は 0.1～0.7 km^3 となる．また，スコリア・溶岩・火山灰の密度をそれぞれ 1・2.4・1.5 gr/cm^3 として質量を算出し，これに基いて運び出された熱エネルギーを推定した（Table III, Fig. 23）．これによるとエネルギー放出率はほぼ一定で，次にのべる編年の結果とあわせて，最近約1500年間の熱エネルギー（したがつてほぼ火山活動による全放出エネルギー）の放出率は約 6×10^{24} erg/100 年となる（第5章）．

12 の member の堆積した年代の推定を，古記録の吟味・土器・^{14}C 測定の結果などによつて行つた（Table V）．その結果，新期大島層群は最近約 1500 年間の堆積物であり，また各 member の堆積，したがつて噴火は135±50年ごとに周期的に起つていることが分る（第6章）．

堆積物の層位学的な grouping unit として本論文で用いたものには fall unit, member, formation, group があり，それぞれはあとの unit 中の構成員である．これらの堆積物によつて示される火山活動について考察してみると，まず fall unit は1回の爆発，あるいは1つづきの噴煙柱をつくるような連続的な爆発に対応していると考えられる．

Member は多くの fall unit，溶岩の flow unit などを含み，また風化層は含まないが小さな侵食間隙（Fig. 34）を含むことがあつて fall unit よりかなり長い間の出来ごとを記録している．その期間は，野外における観察や古記録との照合から，数年，長くても10年以内と考えられる．

また 12 の member には，下から上に，降下スコリア→溶岩→火山灰互層という順序が共通してみられる．これらの member の性質は Fig. 26 にまとめた．実際に観察される火山活動の性質や長さとくらべて，member で示される火山活動は，マグマの頭位が次第に高まり，流出し，や

がて低下していく1噴火輪廻に相当しているものと考えられる.

この論文に用いた，火山噴出物の層位学的単位としての member は他の火山の噴出物にも適用できる単位であり，火山の噴火の歴史や機構を噴出物から考察する場合には留意されるべき grouping unit であることをのべた. Formation や group は, member によつて表現される活動がいくつか含まれた活動を示している. 新期大島層群全体を通してみると，特徴的な降下堆積物の変化から次第に噴火が爆発的でなくなつてきていることが知られる (Fig. 28). また新期大島層群はカルデラの生成時およびそれ以後の堆積物である. しかし，いくつかの member より成る層位学的な単位 (Formation, Group) のもつ火山活動史上の意味は member ほどはつきりしていない (第7章).

次に，これまでに発表された論文と，筆者の観察結果に基いて，大島火山の活動史の概略を, Table I にしたがつてのべた. 新期大島時代以前の歴史は, Fig. 45 に示したような降下堆積物の露頭を，新期大島層群について得られた結果に基いて観察することにより大要が知られる. すなわち, member で示されるような大噴火が，周期的に, 10^4 年ていど続いて山体が形成されてきた. 新期大島時代には, 12 の memberによつて示される12回の大噴火が，ほぼ135年毎に起つてきた. 初めの2回の噴火の間に，山頂にカルデラが形成された. 噴出中心は S_1 の噴火を除いて，全て現在の三原山の位置にごく近いところにあつた. 12回の噴火のうち $S_2 \cdot N_4 \cdot N_3 \cdot N_1 \cdot Y_5 \cdot Y_4$ の6回の噴火では，山頂火口の活動と同時に寄生火口が生じて噴火を行つた. 12回の噴火はいずれも，まず scoria を投出し，ただちに溶岩の流出にうつり，その後かなり長く火山灰の投出を主とする時期が続くという共通性がある. 1回の噴火は約 10 年で終る.

これらの経緯は, 12 の member の分布図 (Figs. 9～20), 編年表 (Table V), 噴出物量 (Table III), member の性質 (Fig. 26) とそれが示す活動 (Table IX) などによつて知られる.

山頂カルデラの生成時代は, Figs. 46～49 に示したような露頭の観察に基いて, S_2 member 堆積以後, N_4 member 堆積以前と判定された.

カルデラのでき方は，生成時の噴出物量が失われた山体の 1/10 程度であることから，陥没によるものと推定される. また実際のおちこみの経緯は, Kilauea 火山1924年の爆発的噴火との比較から，火道中のマグクの頭位が急激に低下して水蒸気爆発がおこり，それによつて陥没がひきおこされたものと考えることができる. 陥没は一回だけではなく，二回にわたつて起つた可能性 (S_2 直後に南西部が, S_1 の噴火の直後に北東部が) がある.

最後に，科学的記載のある 1876 年以後の噴火が，以上のべてきたような山体を形成してきた噴火活動史の一部としてはどのように評価されるかをのべた. まず 19 世紀以後の噴火の起つた日付・継続期間・噴火様式・噴出物量・固体噴出物によつてもち出された熱エネルギー量などをまとめて Table VIII に示した. 熱エネルギーの放出史は, Fig. 30 にも示した. 次にこの期間内の噴火と, member によつて表わされる新期大島時代の大噴火とを比較し, Table IX にまとめた. 1876年以後の噴火は，外輪山斜面上の堆積物というフィルターをとおしてみると，休止期内のできごとであり (Fig. 27), しかもその噴出物量の80%以上が溶岩であり (explosion index 20 以下) 大半は中央丘の火孔底，火口床にたまつては活動期がすぎると火孔底にくずれおちている. 放出されたエネルギーの大きさも Fig. 23 の右端に見られるように, member によつて示される大噴火のそれに比べると1桁小さいようである.

これらのことから判断すると，1876年以後の最近に至るまでの三原山の噴火は，大島火山の成長史の一部としてみる時は，大活動の間の休止期内のエピソードにすぎない可能性が大きい. しかし，19世紀以後は噴火の様式そのものが変つてしまつたのだ，という可能性もまつたく否定することはできない (第8章).

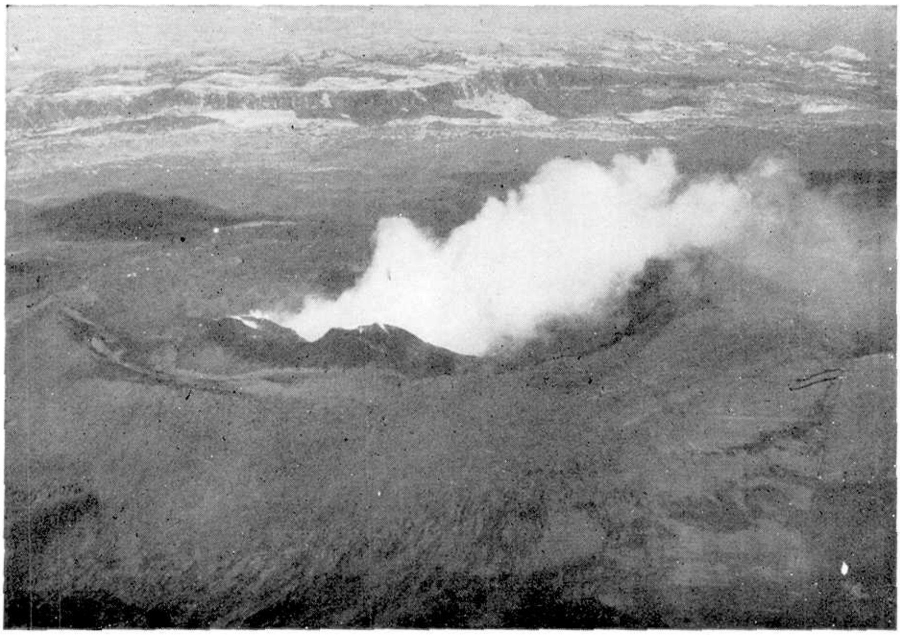

Fig. 31. Aerial view of Mihara-yama, the post-caldera cone of Ôshima Volcano from south. (Jan. 16, 1960). Inside the crater, a small half-collapsed scoria cone formed during the 1950~51 activity is seen. The northen part of the caldera wall can be seen beyond the lava-filled caldera floor.

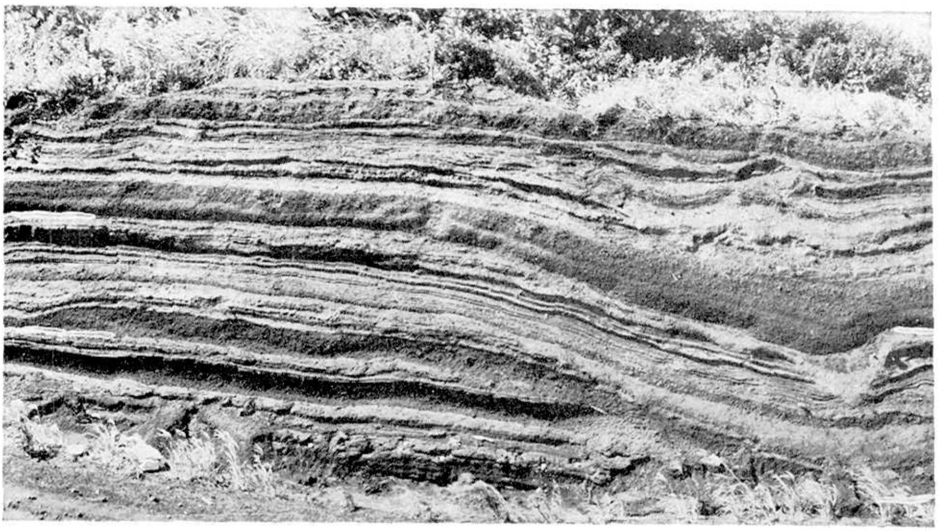

Fig. 32. A road-cut showing the ash and lapilli (scoria) of the Younger Ôshima group on the eastern slope of the main cone (Fig. 2). The upper line at extreme left indicates the boundary between Y_4 and Y_5. The lower indicates the boundary between Y_6 and N_1 or that between the Yuba and the Nomashi Formations.

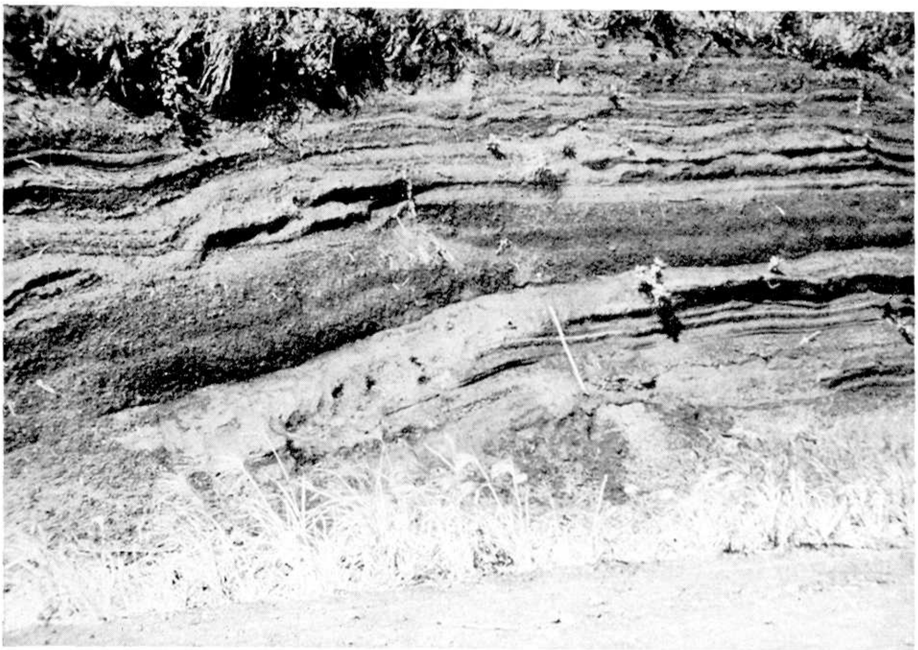

Fig. 33. Scoria-falls of 1 m thick (Y_4) in the middle horizon lies on a weathered *massive ash layer which grades downward into the distinctly alternating ash of* Y_5. A road cut on the eastern slope of the main cone (Fig. 2). Scale lm.

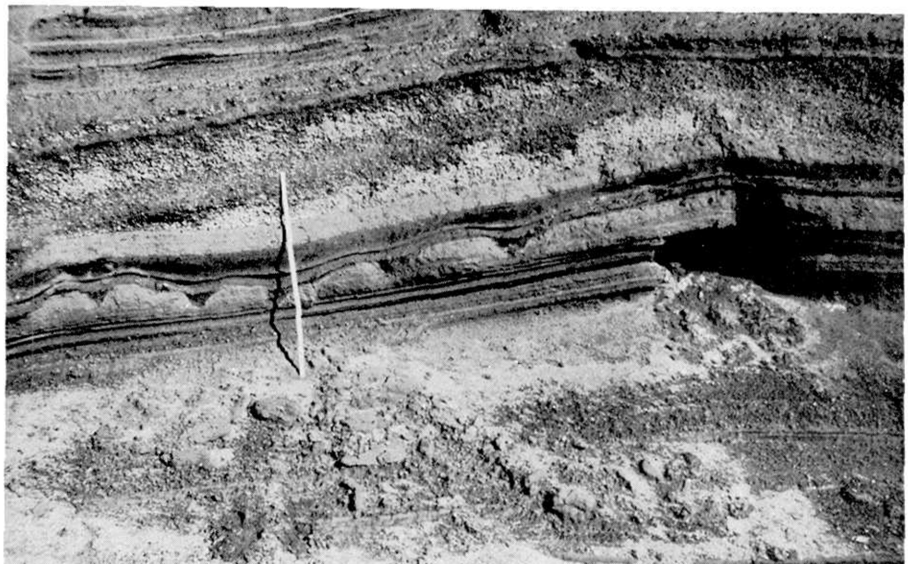

Fig. 34. Small erosional breaks without any sign of weathering in alternating pyroclastic falls of N_1. Scale 1 m. A road cut on the southeastern slope. (Fig. 2)

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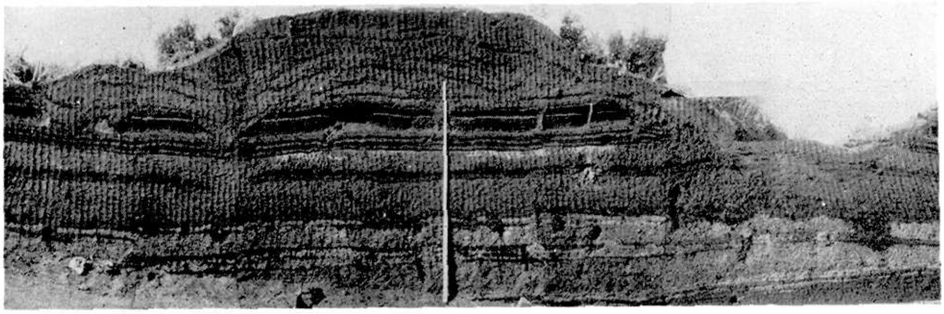

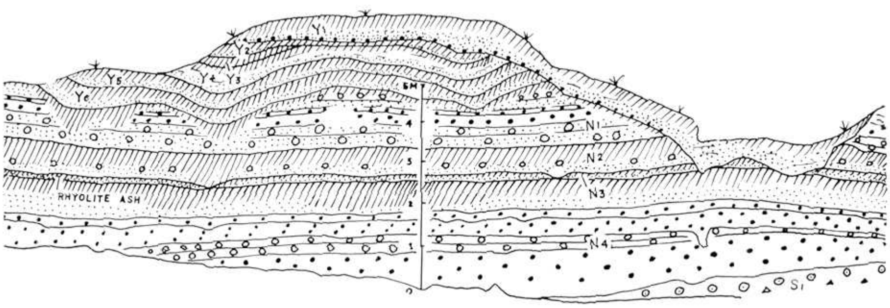

Fig. 35. Erosional break between the Yuba and the Nomashi Formations on the northern slope of the main cone, 400 m east of Yuba. A road cut just made (Fig. 2). Scale : 5 m. Symbols used are the same as in Fig. 6. Distinct upper surfaces of the massive weathered parts of N_2 and N_3 members can be seen (Nakamura 1960).

Fig. 36. The whole exposure consists of fresh and weathered ash deposits from Y_1 to N_4. In the middle of the exposure, N_1 is seen as distinctly stratified layers. A road cut on the northern foot of the main cone (Fig. 2).

Fig. 37. A rhyolite ash layer of white colour in N_3 is seen. The layer becomes unusually thick attaining 3 cm in its maximum thickness. A road cut on the southeastern slope of the main cone (locality 1 in Table VII and Fig. 24).

Fig. 38. The Y_3 lava thins out leftward in a wedgeshape, into conformably accumulating ash-fall deposits. Horizon of the lava-flow in the falls is indicated by an arrow. A road-side exposure on the northeastern slope of the main cone (Fig. 2).

Fig. 39. Cross-section of the Y_5 lava intercalated in the basal part of Y_5 which thins away into conformably accumulating ash-fall deposits. Coastal cliff 500 m north of Motomachi Harbour (Fig. 2). On the left central is seen a lava flow of the same age which once filled a subaerial valley and now projects into the sea.

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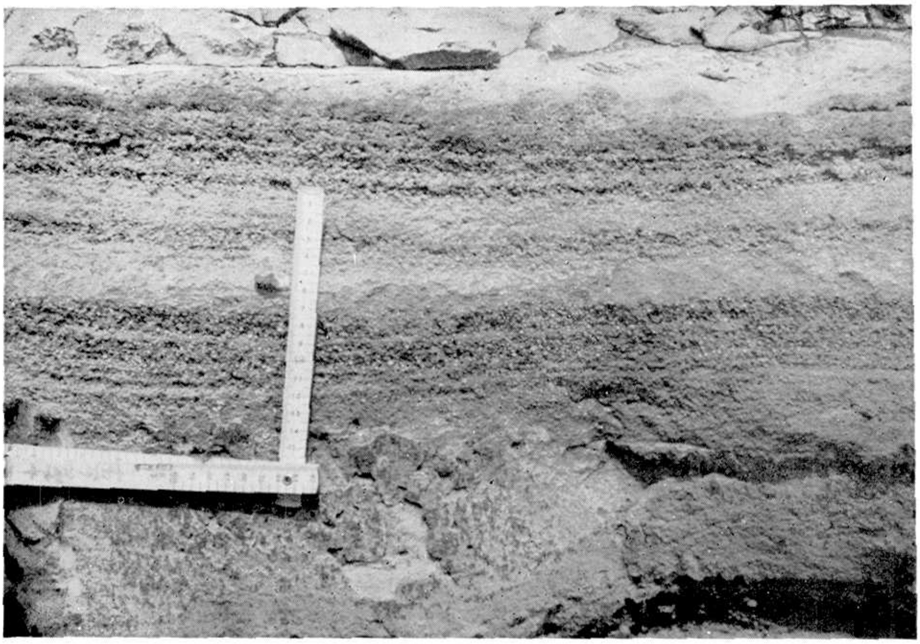

Fig. 40. A part of the alternating ash of N_1. Layers which are composed mostly of well sorted accretionary lapilli may be seen.

Fig. 41. Coastal cliff 1.6 km NNE of Habuminato (Fig. 2). A layer of lenticular cross-section may be seen in the central part. The layer contains accretionary lapilli of various sizes and shapes which include scoria cores. Scale 1 m.

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Fig. 42. Mud-flow deposit of S_2 is covered by a hard alternating accretionary lapilli tuff of S_1. The tuff is partly eroded and covered unconformably by the alternation of scoria-falls of N_4. A road-side exposure on the western rim of the caldera, viewed from west.

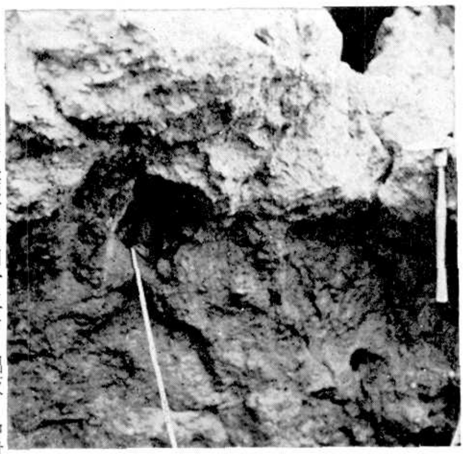

Fig. 43. A wood trunk for ^{14}C measurement (Gak 351 a, b) buried in the massive tuff breccia (mud-flow deposit) of S_2. Coastal cliff at Nomashi. The whole view of this is shown in Fig. 44.

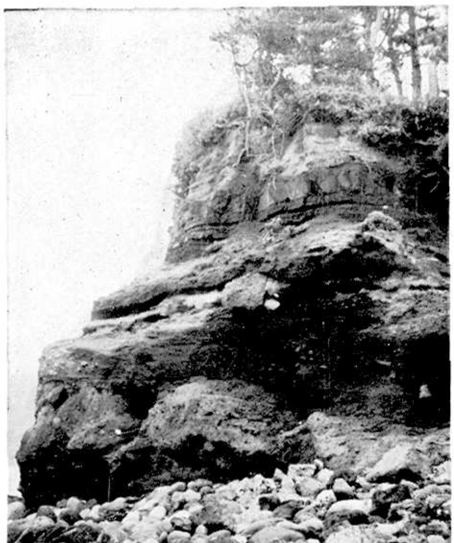

Fig. 44. Coastal cliff at Nomashi. The lower cliff comprises upper stratified and lower massive tuff breceia. The upper part consists of fall deposits of N_4 and the younger.

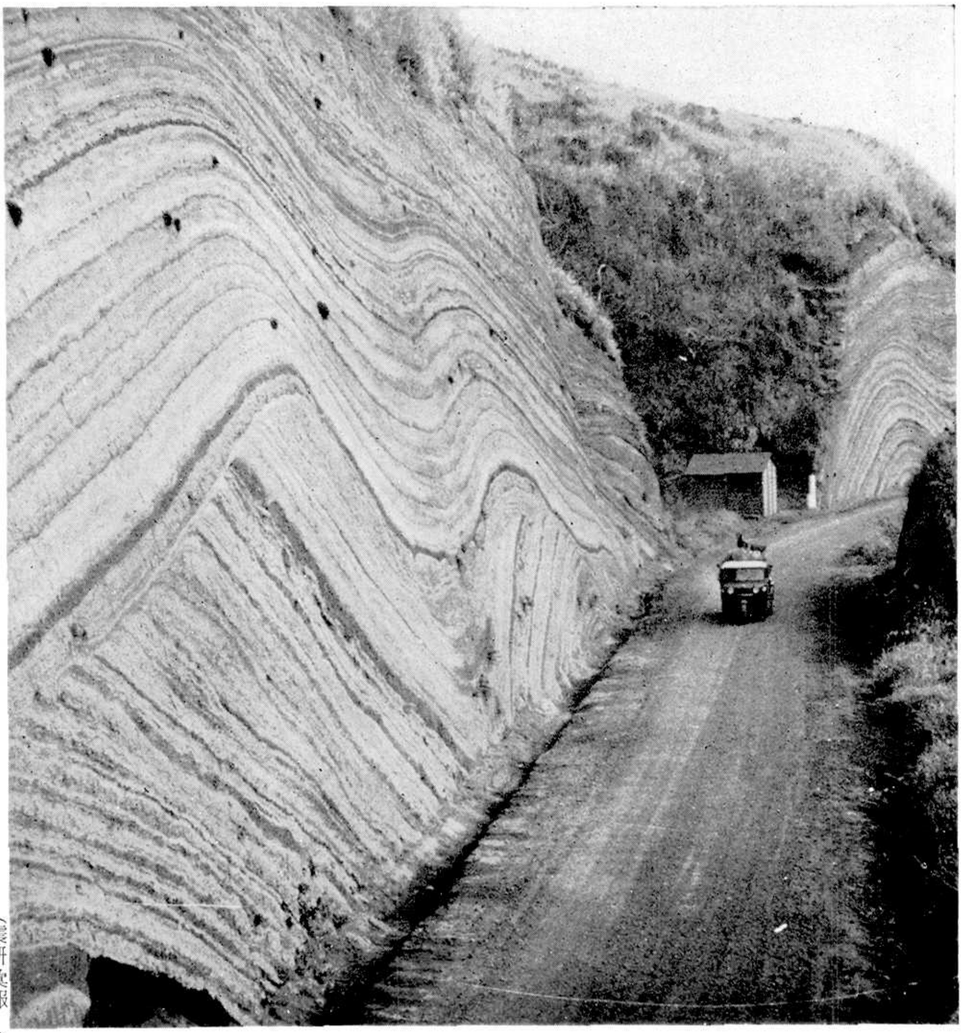

Fig. 45. Pyroclastic fall deposits of the Older Ôshima Group. The road is cut along the higher, inner coastal cliff (Chapter 3) on the southwestern margin of the island. The fall deposits cover almost the entire period of the Older Ôshima age. The marked clino-unconformity is only a local one. Even in the central portion of the larger exposure, the unconformable relationship grades into conformity. All the dips of the fall layers are initial. This is evidenecd by the apparent horizontal stratification of a few secondary wash-deposits intercalated, one of which is to be seen on the extreme right of the larger exposure. A group of beds composed of lower lapilli or scoria (dark coloured) and upper weathered ash (light coloured) has similar features to a member of the Younger Ôshima Group. The group of beds is more than a hundred in number indicating the Older Ôshima age to be extended back to over 10^4 years B. P.

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[Bull. Earthq. Res. Inst., Vol. 42, Pl. 53]

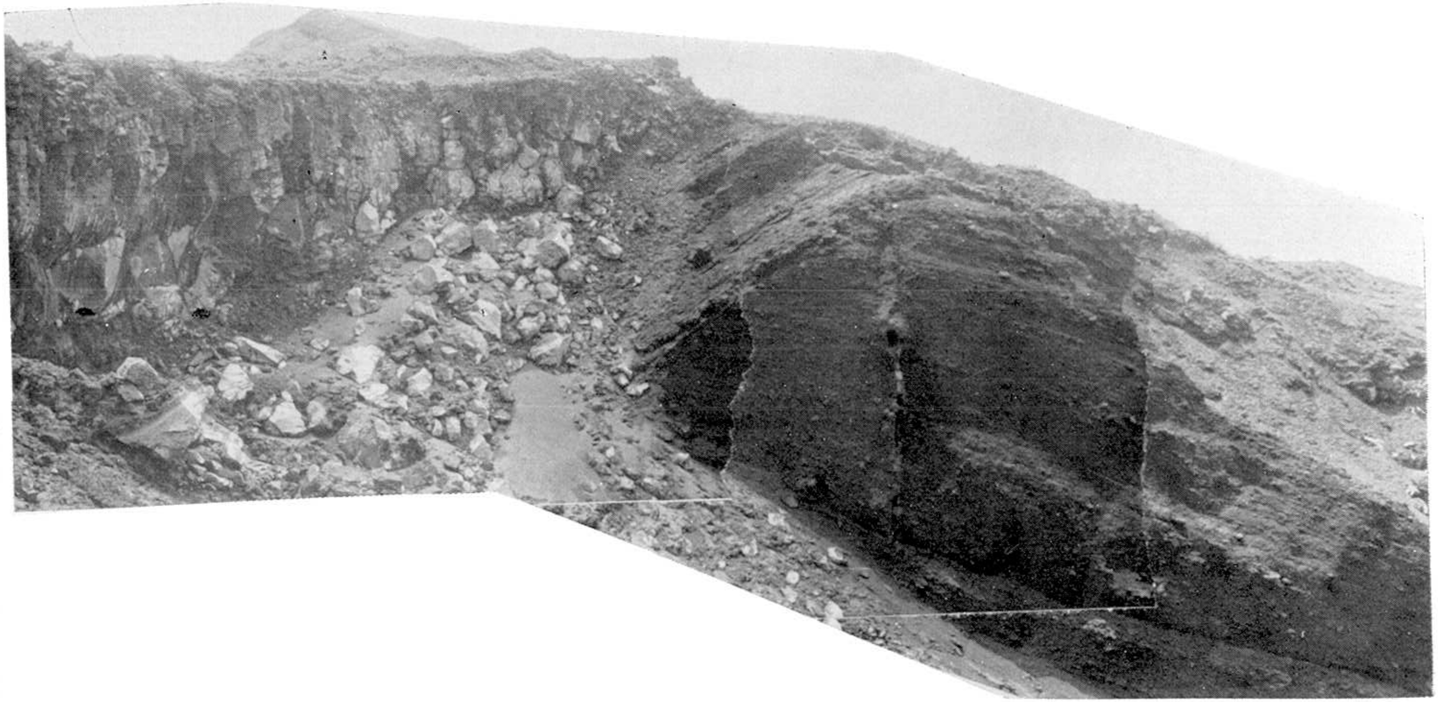

Fig. 46. The photo shows a head of a valley cut into the southwestern part of the caldera floor. Lava-flow (Y_1) which ponded in the caldera is seen on the left. The rim of the caldera is composed of loosely agglutinated scoria of N_4.

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[Bull. Earthq. Res. Inst., Vol. 42, Pl. 54]

Fig. 48. Cross-section of the southwestern caldera rim exposed along a small valley cut into the floor (right). The white arrow indicates horizontal ash layers of N_4 which are unconformably overlain by the basal scoria fall of N_3.

Fig. 47. The S_2 mud-flow deposits on the western uppermost slope of the main cone. The deposits are indicated by an arrow. A part of the caldera floor is seen on the right side.

Fig. 49. The rim of the caldera becomes lower toward this side and continues to Fig. 46 through Fig. 48. The lowest fall deposits parallel to the present rim topography is N_3 at this place. Nearer person indicates the unconformity between the basal scoria of N_3 and alternating ash of N_4 (Chapter 4).

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