18. *Volcanoes of Kôzu-shima.*

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CONTENTS.

Chapter I. Introduction.

The present study is the result of the writer's geological investigation of the insular volcano Kôzu-shima, in the Seven Izu Islands, conducted under the auspices of the Earthquake Research Institute of the Tokyo Imperial University.

The writer made his first visit to the island in August, 1925, when he was a third year student of geology in the University. In the summer of 1928, he made again a field observation. The laboratory study has been done partly in the Geological Institute and partly in the Earthquake Research Institute.

The chief objects of this paper are: first, to describe the geologic structure and the building materials of the island based on the writer's own observation; second, to show relations, geological as well as petrological, of the island to the neighbouring district.

Here the writer expresses his many thanks to Prof. Dr. S. Tsuboi for cordial guidance which he has received constantly and also for revision of his manuscript. He also wishes his hearty acknowledgement to Prof. Dr. B. Koto, Prof. Dr. T. Kato, and Prof. T. Tsujimura for their much valuable suggestions. For the chemical analyses of the rocks collected during his field work the writer is indebted to Mr. S. Tanaka, an analyst of the Earthquake Research Institute, whose accurate work has thrown much light on the chemical side of the present study. He also thanks to Mr. K. Yasumuro, a cartographer of the Institute, for the preparation of the geologic map annexed to this paper.

Geographical Sketch.—Kôzu-shima is a member of Izu Shichito, or the Seven Izu Islands (all volcanic), and lies about 60 km. south of Shimoda, a well known harbour at the southern end of the Izu peninsula. The highest point of the island, 574.2 m. above the sea level, is situated at 34°12′58″N. lat. and 139°9′12″E. long. The island is guard-shaped and its length from north to south is about 6 km. and its maximum breadth is about 4 km.[1] There are two islet groups belonging to Kôzu-shima, viz. Tadanae-jima (about 1 km. off the shore of Sanuka-saki, the southeastern headland of the main island) and Ombashi-jima (about 4 km. southwest of the main island).

The whole island is thickly covered with vegetation except on Tenjô-san, the largest volcano on the island; but on the wave-cut sea cliffs around the island and the precipitous cliffs along the river-valleys the rocky structure is well exposed. The southwest upland called Membô is the unique arable land on the island. On the low, steep mountains in the northern half grow wild camellia trees from which is obtained superior camellia oil.

For lack of reliable documents it is not known when the island became inhabited for the first time. In ancient times the island together with other members of the Seven Izu Islands was a place of banishment. At present the island is populated over two thousands. The people there live mainly on fishing, while firming and collection of utilizable seaweeds are in women's hands.

Previous Work.—N. Fukuchi,[2] who studied the island of Nii-jima

1) The island is in its size next to Nii-jima or the fifth of the Seven Izu Islands, each of which having the following dimensions:

	Islands	Due N-S km.	Due E-W km.	Circum. km.	Area sq. km.	Height m. above the sea level
1.	Ô-shima	15	8·5	50	103·8	755
2.	Hachijô-jima	14	7·5	39	71	854·3
	Ko-shima	3	1·5	8	3	616·8
3.	Miyake-jima	7	6	30	56	813·8
4.	Nii-jima	11	2·5	27	23	428·5
	Shikine-jima	2·5	2·5	10·5	4	105
5.	Kôzu-shima	6	4	23	17	574·2
6.	Mikura-jima	5	5	16	16·5	850·8
7.	To-shima	2·3	2·5	7·5	4	507·5

2) N. FUKUCHI, "Geology of Nii-jima," *Report Earthq. Invest. Com.*, **39** (1902), 4–40, (in Japanese).

which stands in a kindred relation with Kôzu-shima, referred briefly to the geology of Kôzu-shima. According to him, Kôzu-shima is built up of liparitic lavas and the ''Shiromama''[3] bed similar to that on Nii-jima. He considered Tenjô-san as a distinct volcano.

In July, 1906, when a great landslide occurred on Kôzu-shima, T. Kato[4] examined in some detail the geological structure and gave a full account of the landslide. On the same occasion S. Noda[5] also visited the island and made a geological investigation.

T. Tsujimura,[6] in his morphological work of Kôzu-shima and Nii-jima in 1918, remarked that these two islands are far too young in their morphological aspects to match the Tertiary volcanoes on the Izu peninsula with which they had used to be correlated.

The sequences of the geological elements of the island, as determined by Kato, Noda, and Tsujimura, are shown in the following table:

Kato	Noda	Tsujimura
1. Alluvium	1. Alluvium	1. Tenjô-san lava
2. Younger tuff-bed	2. Tuff-bed	(Kuroshima tholoid)
(coastal terrace)	3. Tenjô-san lava	2. Pumice (Shiroshima
3. Tenjô-san lava	4. Upper pumice-bed	and Kushigamine
(Tenjô-san	(Takôdo-yama	homates)
Takôdo-yama)	Chichibu-yama)	''Shiromama'' bed
4. Tachimoto lava	5. Tachimoto lava	3. Massive lavas
(Nachi-san)	6. Lower pumice-bed	(tholoids at the
5. Earlier pumice-bed	7. Basal lavas	northern part)
(Chichibu-yama)		4. Older pumice-bed
6. Basal lavas.		5. Oldest liparites

In 1909, I. Friedländer[7] made some volcanological observations of the Seven Izu Islands, including Kôzu-shima. He recognized there three extinct

3) The name ''Shiromama'' was given originally by N. Fukuchi to the liparitic tuff-bed on Nii-jima, being introduced from mama, a term for the sea-cliff cut into the tuff-bed.

4) T. Kato, ''Landslips in the Kôzu-shima, Izu,'' *Report Earthq. Invest. Com.*, **63** (1909), 23–32, (in Japanese).

5) S. Noda, ''Geology of Kôzu-shima,'' *Report Geological Survey,* **2** (1906), 29–38, (in Japanese).

6) T. Tsujimura, ''On the Topography of Kôzu-shima and Nii-jima Islands (Izu)'', *Report Earthq. Invest. Com.*, **89** (1918), 57–96, (in Japanese).

7) I. Friedländer, ''Über einige japanische Vulkane,'' *Mitteilungen der Deutschen Gesellschaft für Natur- und Völkerkunde Ostasiens,* **12** (1909–1910), 66–67.

volcanoes, Chichibu-yama, Takôdo-yama, and Tenjô-san. The rocks collected by him were described later (1914) by C. Bacher.[8] According to Bacher, the specimens from Tenjô-san are of "Liparitglas," and those from the southeastern coast are of "Dacitobsidiane."

F. Omori and S. Nakamura[9] compiled the historic records of volcanic eruptions in Japan. They interpreted an eruption on August, 838 recorded in a history without mentioning of the spot of the eruption as that occurred on the island.

S. Tsuboi,[10] in his work on Volcano Ô-shima, discussed the relation between the basaltic and rhyolitic rocks of the Seven Izu Islands. As to their age relation, he endorsed the Tsujimura's view. He divided the insular volcanoes of Izu into two groups, basaltic Ô-shima group and rhyolitic Nii-jima group, according to the nature of the building materials.

The island has no record of earthquake damage, except one that due to an earthquake in 1899 in the sea between the Zenizu rock and the Inamba islets, 43 km. southwest and 72 km. southeast respectively, of Kôzu-shima. According to Fukuchi,[11] who visited Kôzu-shima on that occasion, falling of tombstones and small landslidings were the only effects due to the earthquake. Even the great Kwantô earthquake on Sept. 1st, 1923 which occurred in the sea of Sagami and devastated the larger part of Tokyo was only felt feebly on the island, though Tokyo and Kôzu-shima lie at about the same distance on the opposite side of the probable epicenter of the earthquake.

Chapter II. Morphological and Structural Features.

General Characteristics of the Volcanic Products.—The island is characterized, in common with the other of the Seven Izu Islands, by the absence of the fossiliferous beds. Its building materials are lavas and ejecta of liparitic nature.

The lava-flows are generally thick, sometimes attaining hundred meters

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8) C. Bacher, *Über die Laven der kleineren Izu Inseln, Ein Beitrag zur Petrographie Japans.* (Munchen, 1914), 16–18.

9) F. Omori and S. Nakamura, "Historical Sketches of the Volcanic Eruptions in Japan," *Report Earthq. Invest. Com.*, **86** (1915), 106–108, (in Japanese).

10) S. Tsuboi, "Volcano Ô-shima, Izu," *Jour. Col. Sci., Tokyo Imp. Univ.*, Art. 6, **43** (1920), 128–133.

11) N. Fukuchi, "On the Earthquake of Nov. 5th, 1900, off the southern coast of Izu," *Report Earthq. Invest. Com.*, **38** (1902), 39–53, (in Japanese).

in thickness. As is usually the case with extrusive rocks of acid composition, those on Kôzu-shima are glassy, with extremely diversified appearance. They vary from white to black, phyric to aphyric, dense to highly vesicular. These varieties pass to one another through intermediate ones, even within a single mass of lava. Spherulitic structure due to small spherulitic growths is seen in almost all the lavas. Some of the lavas have flow-structure marked by straight, tortuous, or convoluted lamination resulted from (a) the alternation of thin layers of obsidian and pumice; (b) the banding of the lavas of different shades of color; and (c) the arrangement of spherulites in line. The weathered surface of these laminated lavas show ridges and furrows due to different resistance to weathering. The lava exposed on the northern coast of the Membô upland exhibits the most striking flow-structure consisting of beautiful color bands.

Fragmentary materials constitute some portions of the island, either as tuff-beds made up of fine ashes or as agglomerate-beds composed of blocks mingled with bread-crust bombs, thread-lace scoria, lapilli, and ashes. Most of the ejected fragments are white juvenile pumices of all grades in size. Mingled with these are found fragments of preexisting rocks. They are stony, vitreous, or pumiceous, according to the nature of the preexisting rocks from whose shattered portions they came on the subsequent eruptions. Accessory or accidental blocks of quartz-porphyry, hornblende-andesite, two-pyroxene-andesite, and porphyritic hornblende-diorite are sporadically found imbedded in the beds, but no fragment of sedimentary rocks has ever been found.

The beds show some signs of stratification, often very finely laminated; nevertheless they have probably been accumulated under subaerial condition. They yield yet no organic remain with the exception of small pieces of carbonized wood, so that it is not certain in what geological age they were formed. There is, however, little doubt about that at least the youngest lava (Tenjô-san lava) on the island is not so old as the lavas of the similar character on the Izu peninsula.

General Features.—Kôzu-shima is not very simple in its morphological features. The mountains are generally flat-topped or dome-shaped rather than conical. Although the present surficial features are the result of counteraction of repeated vulcanicity and erosion, the initial structure of the volcanoes and the nature of the building materials are important factors for the development of the present features.

The order of succession of the volcanic product was determined by geologic structures, but partly by the morphological features effected by denudation. The volcanic sequence, from younger to older is:

(1) Tenjô-san lava (lava of the fourth period).
(2) Cinder-cone ejecta (Shiroshima and Kushigamine cinder-cones).
(3) "Shiromama" ejecta-bed.
(4) Jôgoro-yama, Kaminari-yama, Anagi-yama, and Kôbe-yama lavas (lavas of the third period).
(5) Nachi-san and Takôdo-yama lavas (lavas of the second period).
(6) Chichibu-yama ejecta-bed.
(7) Lavas of the first period.

(1) Tenjô-san Lava.—This lava is the latest one on the island forming the Tenjô-san volcano.

Tenjô-san is a cupola-shaped volcano, its side sloping at an angle of about 35°, and is superior in bulk as well as in height to any of the other volcanoes on the island. It rises to a height of 574.2 m. above the sea level, but to a height varying from 180 m. to 400 m. above the ground around. The base of the volcano is 2.2 km. long and 1.7 km. broad, its circumference being 6.4 km., while the top area is elliptical, 2 km. long and 1 km. broad, with the circumference of about 4.5 km. At the summit is an area of 1.3 sq. km. with the general feature of the so-called "Blockmeer." There the surface of the lava, being cracked and broken in blocks (Pl. XVII, Fig. 1), is dotted with such irregular eminences of broken lava rising to a height from 20 m. to 50 m. as long extended hills with sharp or rounded edge, conical protuberances, dome-shaped swellings, and ring-walls with various diameters. Accordingly, the intervening spaces are also irregular in shape as well as in height. Some of these spaces are hollow, occasionally filled with water, like crater having a shape of inverted cone. Some others are depressed in crescentic form and look like atrio with flat bottoms. Such depressed spaces are covered with white, sandy detritus accumulated like a snow-drift or sand-dune.

The irregularity of the lava surface is liable to be created whenever viscous lava is extruded. When a viscous lava is dammed up to form the so-called "Staukuppe," concentric folding of the lava surface may be formed around the crater. Tsujimura remarked such a case on the summit of Tenjô-san, saying that the small eminences on the summit are arranged in two or three concentric lines.

The northern half of the summit is almost barren; while the southern half is grown with both tiny bushes and short grasses.

The northern and southwestern flanks show the natural slope of talus formed of broken lava detached from the massive lava above. The upper parts of these flanks are scarcely clothed by herbage, the rocky skin being excavated to show frequent scars and slips. The ravines there are spoon-shaped and become narrower as well as shallower downwards.

The southern and eastern flanks have been remarkably demolished and show there steep slope (about 40°). The southern flank fronting the sea of Takô rests on the erosible "Shiromama" bed and looks down directly the sea. Accordingly, the talus which developed primarily there just as now observed on the southwestern flank was largely destroyed at its foot by the sea-waves (Pl. XVII, Fig. 2). The lower steep slope is furrowed by trenches and the sharp ridges between the trenches are the parts left behind denudation of the primary talus. On that side, therefore, the steep slope rises to an altitude of 400 m. above the sea level and thence upward a vertical lava cliff, 100 m. in height, stands high forming an abrupt escarpment. The eastern flank of Tenjô-san shows (Pl. XVII, Fig. 3), in the same manner, vertical escarpment of the upper half and deeply dissected talus of the lower. The foot of the flank has not been attacked by the sea-waves, but there cutting-back at the heads of gorges traversing the hill around is effective for the destruction of the talus.

As understood from its topographical feature, the volcano is built up of a single lava, about 200 m. thick, rising from the foundation formed of the ejecta of both Shiroshima and Kushigamine cinder-cones and also of "Shiromama" (p. 277). Inner structure of the lava is distinctly visible on the cliff around. The southern cliff fronting the sea of Takô reveals the lava drawn lines by the flow-banding seemingly dipping to the west. The southern half of the eastern flank shows the lava having flow-structure descending to the south, while the northern half to the north. The lava exposed on the northern flank shows onion-banding which is a characteristic of the so-called "Staukuppe."

From the structure described, it is inferred that the lava was extruded, in a very viscous condition, through an orifice which might be somewhat northsided, probably from a crater adjoining to that of the Shiroshima cinder-cone. The lava was mainly spread to the south, though not distant, because of falling of the ground beneath to that direction; while it was dammed up to the north, resulting in the characteristic structure of the "Staukuppe."

The lava displays vesicular structure at the surface, yet it has not been weathered out in soil, showing very fresh appearance. There can be little doubt about that the last great volcanic activity on that island was the effusion of the Tenjô-san lava.

(2) Cinder-cone Ejecta.—This ejecta form the Shiroshima and Kushigamine cinder-cones.

Shiroshima cinder-cone occupies only a small portion of the northwestern flank of Tenjô-san (Pl. XVII, Fig. 4). It is a snow-white cone composed throughout of liparitic ejecta, resting on the erosion surface of the Nachi-san lava either directly or with the Chichibu-yama ejecta-bed (cf. p. 279) between. Thus, its height above the base is about 250 m., though about 510 m. above the sea level. The eastern half of the cone was destroyed when the Tenjô-san lava was extruded out of the neighbouring vent. At the summit there is a crescentic crater (Pl. XVIII, Fig. 1), a quarter segment of a circular one whose diameter would be about 300 m. if the cone had been a complete form. The northwestern flank of the cone is the only part preserved. It is 20–25° in slope and convex outwards. Neither valleys nor gulches have been excavated on that flank.

The inner structure of the cone is exposed on the rocky cliff at the valley-head of the Kawara, a temporary river which rises at the northwestern flank of Tenjô-san and flows into the sea at Mae-hama. On the cliff is seen the stratified bed of the cone, half-destroyed by the extrusion of the Tenjô-san lava which at that place makes a bluff of 200 m. high. The bed dips apparently southward with an angle of about 40°. Near the upper end of the cliff, that is, near the crater-lip of the cone the bed becomes apparently horizontal. At the northwestern foot of the cone is exposed the bed dipping divergently according to the nature of the underlying ground, though generally about 20° away from the crater. About there, loose materials of liparitic nature, ashes, sands, and lapilli, are finely stratified, occasionally being alternated as much as five times in the thickness of one meter. Pisolitic concretions of ash, 0.5–10 mm. in diameter, are found abundantly.

As above-mentioned the bed exhibits generally the "quaquaversal dip," in other words, it dips away on all sides from the crater and forms a typical cinder-cone. In front of the cliff of the Nachi-san lava facing the valley of the Kawara, the bed of the cone dips in a high angle (70°) off the cliff. Accordingly, it is inferred that the cliff of the Nachi-san lava was already present at the time when the cinder-cone was formed. From its morphological aspect and also from the nature of its products, the cone is supposed to owe its formation to some eruption of comparatively recent date, though earlier than the extrusion of the Tenjô-san lava.

On the eastern side of Tenjô-san is seen another diminutive cone called Kushigamine (Pl. XVIII, Fig. 2). Its height above the surrounding ground is not more than 50 m., while that above the sea level matches the height of

Shiroshima. The diameters of the base and the top of the cone are 500 m. and 200 m. respectively. The northern flank of the cone shows a smooth natural slope, about 30°, being scarcely furrowed by mountain torrents; while its foot is about to be destructed, since the Jôgoro-yama lava beneath has been penetrated by deep gorges. On the other hand, denudation has acted with greater effect on the southern side where a deep gorge has been excavated up to the summit of the cone. Fine stratification of the building materials is seen on the valley-wall. The western side is covered with the Tenjô-san lava. At the contact with the overlying Tenjô-san lava, the white ash of the cone is stained and becomes hard.

The building materials of the cone are the same as those of the Shiroshima. The stratified bed dips away on all sides from the center. In the bed are found pisolitic concretions.

(3) "Shiromama" Ejecta-bed.—"Shiromama" ejecta-bed is a formation of rudely stratified ejecta which covers the decomposition surface of the older volcanic products, both lavas and ejecta (Pl. XVIII, Fig. 3). Its distribution is mainly confined to the low ground near the sea-shore. It makes a cliff of about 20 m. in height fronting the sea and is suggestive of a coastal terrace-deposit (Pl. XVIII, Fig. 4). Inlets are apt to be formed at the places (Takô-hama, Mae-hama, Sawajiri-hama, and Naga-hama) where the bed is developed, since the bed is loose and erosible. The bed is traced landwards along the valley of the Kawara, but soon is kept out of sight by the fluviatile deposit of the valley. It is also found on the flat land at the pass between Takôdo-yama and Chichibu-yama. There the bed rests unconformably on the Chichibu-yama ejecta-bed whose surface has been decomposed in black soil.

The stratification of the bed is visible only from a distance, larger fragments being rudely conglomerated in some horizons (Pl. XVIII, Fig. 3). The building materials are volcanic ashes, sands, lapilli, and blocks of liparitic nature. They are pumiceous, glassy, or felsitic. Besides these are found blocks of hornblende-andesite and quartz-porphyry. Pieces of carbonized wood are often met with in the lower horizons of the bed. No other organic remain has ever been discovered. Accordingly, it is inferred that the deposition of the volcanic fragments was subaerial. In addition, the deposit is of neither fluviatile nor submarine, if not at its very base which is now largely invisible.

The deposition of the "Shiromama" ejecta must have preceded the formation of the Shiroshima and Kushigamine cinder-cones, though both are of successive eruptions. The juvenile ejecta in the bed are identical in petrographic characters with those of the cinder-cones. Probably, the cinder cones were formed by eruptions with decreasing vulcanicity, following the paroxysmal eruptions by which the "Shiromama" ejecta-bed was formed.

(4) Jôgoro-yama, Kaminari-yama, Anagi-yama, and Kôbe-yama Lavas.—The four mountains along the northern sea-coast, viz. Jôgoro-yama, Kaminari-yama, Anagi-yama, and Kôbe-yama are capped with the lavas resting on the Chichibu-yama ejecta-bed. Of the four just-mentioned mountains, the first one is partially covered with the Kushigamine ejecta, though the others are bare (Pl. XIX, Fig. 1).

The Jôgoro-yama lava is the same as the Kaminari-yama lava, both having been primarily connected, but subsequently separated by the erosion. The inner structur of the lava is exposed on the valley-walls which bound the mountains on the west, and also on the steep and rocky declivities by which Jôgoro-yama and Kaminari-yama rise up to the height of 460 m. and 300 m. respectively from the eastern seashore.

The Anagi-yama lava forms the top of the dome-shaped Anagi-yama, a mountain situated between Kaminari-yama and Kôbe-yama, attaining about 100 m. in thickness. It has a horseshoe-shaped depression on the summit. The pumiceous surface of the lava is bare, though the just-mentioned depression is piled deep with huge blocks of the lava. This lava is probably of contemporaneous extrusion, with that of the Jôgoro-yama lava if the two were not extruded from a single vent.

At the northwestern corner of the island rises a dome-shaped hill called Kôbe-yama, one of the most remarkable and perfect volcanoes on the island (Pl. XIX, Fig. 2). It slopes on the west, east, and south sides at an angle of 40°, while the northern flank is somewhat greater in inclination. The steep slopes (Pl. XIX, Fig. 3) show the talus formed of broken lava. The Kôbe-yama lava is about 100 m. in thickness. Its surface is pumiceous, variegated, and cracked into irregular patterns. Thus, the summit of the hill is uneven field of block lava, small eminences and hollows lying scattered as on the summit of Tenjô-san. At the center of the summit is a crater-like depression breached towards the northwest and southeast. From the inside of the depression run down steep-sided valleys through the V-shaped clefts on the rim. The height of the rim around the central depression is nearly 50 m. and on the northern side of the depression towers up precipitous cliff of uncovered lava. The bottom of the depression is piled up with huge blocks of the lava detached from the cliffs around. The depression may have been resulted from breaking-down of the upper surface of the lava.

(5) Nachi-san and Takôdo-yama Lavas.—The lavas are represented by the biotite-plagioliparites of Nachi-san and Takôdo-yama.

The lava exposed on the cliffs which bound the west side of Nachi-san (Pl. XIX, Fig. 4), a mountain forming the basement of the Shiroshima cinder-cone, is about 100 m. in thickness and is sandwiched in between the lower and upper parts of the Chichibu-yama ejecta-bed.

The Takôdo-yama lava forms the top of Takôdo-yama which stands to the southwest of Tenjô-san. Takôdo-yama is a dome-shaped hill (Pl. XX, Fig. 1), 304 m. high above the sea level or 150 m. above the foundation. A pointed eminence on its central summit gives the hill, when viewed from the western side, something of the shape of a peach. On the other hand, its singular shape which attracts attention from a distance to the southeast is compared to a mortar placed bottom upward. The lateral slope has an inclination of about 35°. The summit is elongated in the E-W direction and flattened, being covered thickly with black soil. About a dozen radial valleys are furrowed on the flank around the hill, all having their sources near the summit and on the valley-walls is exposed the lava. The lava occupies only the upper half of the hill and forms a lava-flow of about 130 m. in thickness. It rests on the Chichibu-yama ejecta-bed. High above the pass, Akabane-toge, from the village to the shore of the bay of Takô and within 15 m. of the pass stands an outcrop of the Chichibu-yama ejecta-bed (Pl. XXI, Fig. 1) directly covered with the Takôdo-yama lava.

From the structures described above, it is suggested that the Nachi-san and Takôdo-yama lavas were extruded in the same period with the deposition of the Chichibu-yama ejecta-bed, or a little later.

(6) Chichibu-yama Ejecta-bed.—Covering the erosion surface of the lavas of the first period, the Chichibu-yama ejecta-bed is widely distributed over the island, partially covered with the succeeding formations (Pl. XX, Fig. 2). It forms notched irregular hills of rather low latitude, Chichibu-yama, Takô-yama, and Takane-yama, etc.

Chichibu-yama is the most distinguished mountain consisting of the ejecta. It is situated at the northeastern corner of the Membô upland (Pl. XX, Fig. 3). The land rises gradually to the summit of Chichibu-yama, 282.9 m. high above the sea level, with an inclination from 5° at the skirt to 10° near the summit. The eastern flank of the mountain descends abruptly to the bay of Miura, showing slope as steep as 70° in its lower part and about 50° in the upper. The northern flank is also steep in slope and is incised by a number of empty valleys. On these steep slopes is exposed the horizontal bed of the ejecta. A distant view of the mountain is suggestive to a single volcano, but actually the mountain has been resulted from erosion acting on the horizontal ejecta-bed.

The thickness of the bed varies from a few to 150 m. as is estimated at Chichibu-yama. This is largely due to the subsequent erosion acting on the loose deposit of the ejecta. The center of ejection is entirely obliterated owing to the advanced erosion. Nothing can be inferred as to the position of the centre from the stratification of the bed, since the bed is generally horizontal (Pl. XX, Fig. 4), except at the places where it covers the uneven surface of the underlying lavas. Occasionally, the bed shows false-bedding and unconformity due to temporary erosion. The surface of the underlying lavas exhibits subaerial decomposition, the black soil being sharply contiguous to the overlying white ejecta-bed. Accordingly, it is inferred that the deposition of the ejecta took place on land.

The building materials of the bed are volcanic ashes, sands, lapilli, and blocks (Pl. XXI, Fig. 1), most of them being juvenile in origin. Among them, pumiceous lapilli are exceedingly abundant. Blocks, 5–20 cm. in diameter, of glassy, spherulitic, and felsitic lavas are intercalated in some definite horizons or are scattered through the finer ejecta. Being intermingled with these, are found rather small blocks of quartz-porphyry, hornblende-andesite, porphyritic hornblende-diorite, and two-pyroxene-andesite. Fragments of carbonized wood are also found.

The doposition of the Chichibu-yama ejecta-bed was nearly contemporaneous with the extrusion of the Nachi-san and Takôdo-yama lavas.

(7) Lavas of the First Period.—As far as the visible part of the island is concerned, the liparitic lavas exposed on the sea cliffs around are the oldest and form the foundation of the island (Pl. XXI, Figs. 2, 3). They are of various types which may be grouped as follows:

α-Lava (Potash-liparite).
β-Lava (Hypersthene-plagioliparite).
γ-Lava (Hornblende-bearing hypersthene-plagioliparite).
δ-Lava (Hornblende-plagioliparite).
ε-Lava (Biotite-plagioliparite).

The order of extrusion of these lavas is difficult to be determined.

Chapter III. Petrography.

According to T. Kato,[12] the lavas of Kôzu-shima are: basal lavas, Tachimoto lava, and Tenjô-san lava, enumerating in the order of extrusion, from

12) T. KATO, *loc. cit.*

older to younger. Among the basal lavas he distinguished four varieties, viz. obsidian, agglomerate lava, lava of Kohama type, and spherulitic lava. In his petrographic descriptions he mentioned of orthoclase, plagioclase, and biotite as essential minerals found in all these lavas. Beyond these sporadic occurrence of hypersthene in the basal lavas was remarked.

Bacher,[13] on the other hand, described four rock specimens collected by Friedländer, two from Tenjô-san and two from the southeastern coast.

These descriptions, however, are fragmentary and not sufficiently detailed. Here more systematic descriptions of the rocks of Kôzu-shima are given in the order as follows:

I. Lava of the Fourth Period.
- 1) Biotite-plagioliparite .... Tenjô-san lava

II. Shiroshima and Kushigamine Ejecta.
- 2) Biotite-plagioliparite .... Juvenile ejecta

III. "Shiromama" Ejecta.
- 3) Biotite-plagioliparite .... Do

IV. Lavas of the Third Period.
- 4) Biotite-plagioliparite .... { Jôgoro-yama lava, Anagi-yama lava, Kôbe-yama lava }

V. Lavas of the Second Period.
- 5) Biotite-plagioliparite .... { Nachi-san lava, Takôdo-yama lava }

VI. Chichibu-yama Ejecta.
- 6) Biotite-plagioliparite .... Juvenile ejecta
- 7) Liparite
- 8) Quartz-porphyry
- 9) Porphyritic hornblende-diorite
- 10) Hornblende-andesite
- 11) Two-pyroxene-andesite

  (7)–11)) ... Accessory ejecta

VII. Lavas of the First Period.
- 12) Biotite-plagioliparite .... ε-Lava
- 13) Hornblende-plagioliparite .... δ-Lava
- 14) Hornblende-bearing hypersthene-plagioliparite .... γ-Lava
- 15) Hypersthene-plagioliparite .... β-Lava
  (Basic xenoliths)
- 16) Potash-liparite .... α-Lava

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13) C. Bacher, *loc. cit.*

I. *Lava of the Fourth Period.*

1) Biotite-plagioliparite....Tenjô-san lava. (Pl. XXII, Fig. 1.).

Mode of Occurrence.—This occurs as a massive lava forming the latest volcano, Tenjô-san, on the island.

Megascopic Characters.—The rock is generally pumiceous and highly vesicular. It is commonly white; while in many places, especially at the northwestern part of the summit, it is stained throughout with varying shades of a yellow, citron, brown, or scarlet color. These varying shades of color may be attributed to the effects of the exhalations which were probably evolved through crevices from the interior of the lava. Moderate phenocrysts of plagioclase, quartz, and biotite are scattered through the vitreous groundmass.

Microscopic Characters.—Microscopically the most conspicuous phenocrysts are of plagioclase. They are euhedral or subhedral and about 1 mm. in average diameter. Sometimes the mineral is zonally built, showing inner calcic zone coated with outer less calcic one. From the optical constant on cleavage flakes as determined by Tsuboi's method,[14] the outer shell (n_{1D}=1.533(5)) of the zonal plagioclase was identified as a sodic oligoclase $Ab_{88}An_{12}$, and the core part (n_{1D}=1.535) as a little less sodic one $Ab_{85}An_{15}$. Small inclusions of colorless glass are often arranged in concentric zones. The phenocrysts of sanidine are of very rare occurrence.

Quartz is angular or subangular. Apart from the irregular outline, the mineral does not shows no special features to be remarked here.

Biotite occurs as flakes, up to 1 mm. long. It is of greenish-brown color with the refractive index: $\gamma_D=1.665$. Accompanying with this are found often flakes of reddish-brown biotite of another type. The latter is very high in refraction, $\gamma_D>1.700$, higher than any biotite yet recorded.[15]

14) S. TSUBOI, "A Dispersion Method of Discriminating Rock-Constituents and its Use in Petrogenic Investigation," *Jour. Fac Sci., Imp. Univ. Tokyo,* Part 5, **1** (1926); *Miner. Mag. (London)*, **20** (1923), 93–107.

15) N. Fukuchi, describing two kinds of biotite in the biotite-liparite of Nii-jima, pointed out their dissimilarity to each other, one being of reddish-brown color and larger in optic axial angle than the other greenish-brown biotite, though both shows similar crystal form and equally strong pleochroism. According to him, the greenish-brown biotite is a decomposition product of the reddish-brown one. The specimens collected by the writer on Nii-jima contain biotites showing $\gamma_D>1.700$. See N. FUKUCHI, *op. cit.*, *Report Earthq. Invest. Com.*, **39** (1902), 18–19, (in Japanese).

A. L. Day noticed a biotite in a 1915 lava (quartz-bearing andesite) of the Lassen Volcano, California, which showed γ varying from 1.680 to 1.700. See A. L. DAY, "The Volcanic Activity and Hot Springs of Lassen Peak," *Carnegie Institution of Washington*, **360** (1925), 49.

As will be shown in the next chapter, these flakes are of the thermally decomposed biotite.[16)]

The groundmass of the Tenjô-san lava is colorless and entirely glassy. Flow structure is well marked. Dusty substances of brown color to which the various colors of the hand-specimens are due, are scattered through the groundmass. The refractive index of the glass is 1.490 for Na light.

Chemical Composition.—A specimen of uniformly pumiceous white rock having phenocrysts of feldspar, quartz, and biotite, from the north-western part of the summit of Tenjô-san was analysed by S. Tanaka of our Institute, with the result shown under the column I of Table I.

TABLE I.

	Wt. % I	Wt. % II
SiO_2	76·60	76·05
Al_2O_3	13·22	12·44
Fe_2O_3	0·27	0·84
FeO	0·43	0·22
MgO	0·19	0·17
CaO	0·75	0·87
Na_2O	4·62	4·31
K_2O	1·61	2·88
H_2O +	1·50	1·66
−	0·11	0·11
TiO_2	—	0·12
P_2O_5	—	tr.
MnO	0·16	0·07
Total	99·46	99·74

Norms	I	II
Quartz	41·6	37·9
Orthoclase	9·4	17·2
Albite	38·8	36·1
Anorthite	3·6	4·2
Corundum	2·5	0·7
Hypersthene	1·2	0·5
Ilmenite	—	0·1
Magnetite	0·2	0·4
Hematite	—	0·5

Ratios	I	II
Sal/Fem	67·6	59·3
Q/F	0·8	0·6
$\frac{K_2O'+Na_2O'}{CaO'}$	7·0	6·6
$\frac{K_2O'}{Na_2O'}$	0·3	0·4

For comparison, the chemical composition of the Mukô-yama lava (biotite-liparite) of Nii-jima, by the same analyst, is shown under the column II of the table. The Tenjô-san lava is lower in ferriferous oxides and potash, but a little higher in lime than the Mukô-yama lava. Moreover, in the former ferrous oxide dominates over the ferric one, as contrasted with the inverse relation in the latter. The normative quartz of the Tenjô-san lava is present in much greater amount than that of Mukô-yama lava, in correspondence with the reverse relation of the normative orthoclase. . Thus,

16) Cf. p. 307 of this paper. From the thermal study of biotite, it is inferred that reddening, increasing of optic axial angle, and rising of refractive indices of biotite is carried out during a process of thermal decomposition acting on a common biotite.

the norms, also shown in that table, place the Tenjô-san lava in Tordrillose (I. 3. 1. 4) and the Mukô-yama lava in Alsbachose (I. 3(4). (1)2. 4), according to the C. I. P. W. quantitative system of classification. As compared with the type liparite, these rocks are quite different, Na_2O being much higher and K_2O much lower, differences that are in accord with the dominant sodic plagioclase in these rocks. Indeed, so small is the percentage of the potash-feldspar, if present, that the rocks deserve the name of dacite rather than that of liparite, according to the current classification. But the chemical composition and microscopic characters of the rock of Tenjô-san reveal much of the characteristic feature of liparite. Accordingly, the name "plagioliparite," a name proposed by Koto, should be applied to this rock, as has been given to the liparitic rocks with dominant plagioclase among the Tertiary volcanics in our country. On the same reason all the rocks, except for the potash-liparite, of Kôzu-shima may be called plagioliparite.

II. Shiroshima and Kushigamine Ejecta.

2) Biotite-plagioliparite....Juvenile ejecta.

Pumiceous ejecta of this rock forms the entire masses of the Shiroshima and Kushigamine cinder-cones. In the rock the phenocrystic plagioclase was identified as an oligoclase $Ab_{88}An_{12}$ (n_{1D}=1.533). Biotite has the refractive index: γ_D=1.666.

III. "Shiromama" Ejecta.

3) Biotite-plagioliparite....Juvenile ejecta.

This occurs as the fragmentary products (volcanic ashes, lapilli, and bombs) forming the greater part of the "Shiromama" bed. Mingled with pumice, dense ejecta and bread-crust bombs, though of very rare occurrence, are also imbedded. The outer crust of the bread-crust bomb is rather dense, while the core part is highly vesiculated, there the glass being drawn out into fine thread-lace with silky luster.

The ejecta contain megacrysts of plagioclase, quartz, and biotite. The composition of the plagioclase is $Ab_{86}An_{14}$ (n_{1D}=1.534). The refractive index γ_{1D} of the biotite is 1.664. A specimen of bread-crust bomb from the bed on the shore of Mae-hama contained reddish-brown biotite with the refractive index: $1.680<\gamma_D<1.695$.

Besides the juvenile ejecta, the accessory ones of hornblende-andesite and quartz-porphyry are found in the bed. They are identical in petrographic characters with those found in the Chichibu-yama ejecta-bed and will be described later.

The juvenile ejecta from the "Shiromama" bed and the cinder-cones are identical in the composition of the phenocrystic plagioclase and the refractive indices of biotite with the lava from Tenjô-san. Field relations also show that the ejection of these ejecta and the extrusion of the Tenjô-san lava took place in the same general period of volcanic activity on the island.

IV. *Lavas of the Third Period.*

4) Biotite-plagioliparite.... { *Kôbe-yama lava.* Pl. XXII, Fig. 2). *Anagi-yama lava.* *Jôgoro-yama lava.*

Mode of Occurrence.—This occurs as the dome-shaped masses, about 100 m. thick, of Kôbe-yama and Anagi-yama and also as a lava-flow, 150 m. thick, forming the flat-topped mountains—Jôgoro-yama and Kaminari-yama.

The Kôbe-yama lava rather resembles in its petrographic characters the Tenjô-san lava. The hand-specimen of the lava is pumiceous and finely vesiculated. The phenocrysts of plagioclase, quartz, and biotite are scattered through the vitreous groundmass. Occasionally, the rock is stained throughout with varying shades of color. The phenocrystic plagioclase shows indistinct zoning with less or more calcic material alternating, though generally the outer zone is less calcic than the neighbouring inner zone. The outer shell was identified as a sodic oligoclase $Ab_{88}An_{12}(n_{1D}=1.533(5))$. Biotite occurs as brownish flakes with the refractive index: $\gamma_D=1.664$, 1 mm. long, and is often contorted. The groundmass is entirely colorless glass having $n_D=1.490$.

V. *Lavas of the Second Period.*

5) Biotite-plagioliparite.... { *Takôdo-yama lava.* (Pl. XXII, Fig. 3). *Nachi-san lava.* (Pl. XXII, Fig. 4).

Mode of Occurrence.—This occurs as a massive lava, about 130 m. thick, forming the upper portion of Takôdo-yama and also as an extensive lava-flow, the best exposure of which is seen on the 100 m. cliff at Tachimoto near the head of the valley of the Kawara (Pl. XIX, Fig. 4).

Megascopic Characters.—A specimen from an outcrop near the summit of Takôdo-yama is pumiceous through which are scattered megacrysts of plagioclase, quartz, and biotite. On the other hand, a specimen from the foot of the hill is compact and of ash-gray color. It is strongly porphyritic, with numerous phenocrysts of plagioclase and quartz, with subsidiary amount of biotite. The hand-specimen of the Nachi-san lava often exhibits spherulitic growths of the groundmass. In a dense one a distinct flow-banding is shown by alternating lamination of various shades of color.

Microscopic Characters.—The thin section of a compact specimen from the Takôdo-yama lava shows phenocrysts of plagioclase, quartz, and biotite in a devitrified groundmass. The phenocrystic plagioclase is euhedral, commonly twinned, and indistinctly zoned. It is a calcic oligoclase $Ab_{73}An_{27}$ (n_{1D}=1.541). Biotite is frequently bordered with a resorption-rim. Unaltered flake of the mineral has the refractive index: γ_D=1.656. The groundmass is composed of interlocking mosaic of quartz and feldspar, with a few glass base. The groundmass glass of a pumiceous specimen has the refractive index: n_D=1.4985.

The thin section of the Nachi-san lava shows phenocrysts of plagioclase, quartz, and biotite in either finely crystallized or entirely vitreous groundmass. The phenocrystic plagioclase, up to 1 mm. by 2 mm. in size, is poorly built in zones. It was identified as an oligoclase $Ab_{82}An_{18}$ (n_{1D}=1.537). When it shows zoning, the inner zones are more calcic than the outer zones. Biotite is of brown color with refractive index: γ_D=1.660(5), but one separated from a rather pumiceous specimen is reddish-brown in color and is very high in refraction, γ_D>1.700, showing distinct biaxiality.

VI. Chichibu-yama Ejecta.

6) *Biotite-plagioliparite....Juvenile ejecta.*

The juvenile ejecta are naturally greater in quantity than the others and are largely of pumice, mingled with a small amount of other varieties of the same lava. They are of every conceivable size from what may be called volcanic ashes to volcanic bombs as large as human's head and are essentially composed of plagioclase, quartz, biotite, and glass. Ashes are generally snow-white, but often of chocolate color. The composition of the phenocrystic plagioclase is $Ab_{80}An_{20}$(n_{1D}=1.539). The refractive index of the biotite is: γ_D=1.651.

7) *Liparite.*

Mingled with the juvenile ejecta are found numerous fragments of preexisting rocks. Among them, liparite is about 3 cm. in diameter, yellowish gray in color, and fine-grained. Thin section of the block shows a brecciated structure, microscopic rock fragments, 1.5 mm. in diameter, being cemented with minute interlocking mosaic of orthoclase and quartz. Every one of the microscopic rock fragments shows a porphyritic texture with phenocrysts of orthoclase scattered through a trachytic groundmass. In the groundmass are arranged small prismoids of orthoclase lengthways in the direction of flow.

8)..Quartz-porphyry.

Angular or subangular blocks, up to 5 cm. in diameter, of acidic nature, but more crystalline than the juvenile ejecta are frequently imbedded. Megascopically they are of pale gray color and porphyritic with phenocrysts of quartz and feldspar, up to 5 mm. in diameter, scattered through an fine-grained aphanitic groundmass. Under the microscope the phenocrysts are orthoclase and quartz. Orthoclase, far inferior in quantity to quartz, shows somewhat rounded outline and is often altered to sericite. The groundmass consists entirely of quartz and orthoclase forming an interlocking mosaic.

9) Porphyritic hornblende-diorite. (Pl. XXIII, Fig. 1).

Angular blocks, about 5 cm. in diameter, of this rock were found in the ejecta-bed. The hand-specimens are holocrystalline, medium-grained, and of dull gray color with a tinge of green. Megacrysts, up to 3 mm. in diameter, of plagioclase and hornblende are respectively light pink and dark green in color. In thin section the rock is of hypidiomorphic texture, consisting essentially of plagioclase and hornblende, with some interstitial quartz. Plagioclase was identified as an andesine $Ab_{65}An_{35}$ (n_{1D}=1.545). It shows commonly the twin-lamellation according to the albite law, often accompanied with Carlsbad or pericline twin. Hornblende is of green color and shows very slight pleochroism: X or Y—pale green and Z—deep green. It exhibits twinning parallel to (100). The refractive index of the mineral is: $n_{1D}=1.646$, and the extinction angle is: $c \wedge Z' = 17°30'$. Quartz occurs less abundantly, filling the interstices. As accessory minerals, there occur magnetite and apatite.

10) Hornblende-andesite. (Pl. XXIII, Fig. 2).

This rock are frequently found everywhere in the ejecta-bed as angular or subangular blocks of 5 cm. across. Mingled with other ejected blocks, juvenile as well as either accessory or accidental, these blocks occasionally form agglomerate or rather breccia interstratified in the finer ejecta. Megascopically the rock is of medium gray color, with a tinge of brown, compact, and distinctly porphyritic with phenocrysts, 1–2 mm. in diameter, of plagioclase and hornblende, scattered through a dense aphanitic groundmass.

The thin section of this rock shows numerous phenocrysts of plagioclase and hornblende. Plagioclase is euhedral and commonly twinned according to the albite and Carlsbad laws, but rarely to the pericline law. It is often zoned, more calcic and less calcic layers alternating or otherwise the less calcic crust surrounding the more calcic core. The least calcic part was identified as an andesine $Ab_{59}An_{41}$ with $n_{1D}=1.548$. But none of the plagioclase phenocrysts is as calcic as $Ab_{55}An_{45}$ ($n_{1D}=1.551$). The mineral is optically positive. Hornblende is idiomorphic, of prismoid, and often twinned parallel to (100). It is light green and exhibits a slight pleochroism: X—pale green, Y—medium green, and Z—deep grass green. Occasionally, the mineral has more or less completely altered either to chlorite, often accompanied with epidote, or to red-brown iron-oxide. Unaltered flake has the refractive index: $n_{1D}=1.655$. In some sections a few phenocrysts of quartz are found. The groundmass is various in structure. The cryptocrystalline groundmass is the commonest one and consists of granular crystal-aggregate, often accompanied with microspherulites. The trachytic groundmass is composed of slender feldpar laths, isometric crystals of magnetite, and devitrified glass with specks of alteration products.

11) Two-pyroxene-andesite. (Pl. XXIII, Fig. 3).

At the headland between the bays of Miura and Takô, was found a block, 8 cm. in diameter, of this rock. It is of dark gray color, compact, and strongly porphyritic with numerous phenocrysts of plagioclase, 1–3 mm. long, scattered through a very dense, fine-grained aphanitic groundmass.

Under the microscope the phenocrystic plagioclase is euhedral, of rather equant habit, and twinned according to the albite and Carlsbad laws. It is not zonally built and was identified as a labradorite $Ab_{27}An_{73}$ with $n_{1D}=1.568$. Inclusions, most of which are of brown glass, are often arranged in zones. Augite is light greenish and euhedral, ranging up to 1 mm. by 1.5 mm. in size. Two or more individuals of this mineral occasionally form a grouped phenocryst. The mineral is often twinned parallel to (100). On the cleavage flake the refractive index is: $n_{1D}=1.691$. Hypersthene is subordinate in amount. It exhibits a slight pleochroism: X—light green, Y—light brown, and Z—green. The groundmass consists of plagioclase prismoids, 0.1 mm. long, minute augite grains, and isometric magnetite, with a small amount of brown glass.

VII. Lavas of the First Period.

12) Biotite-plagioliparite....ε-Lava. (Pl. XXIII, Fig. 4).

Mode of Occurrence.—This forms two distinct lava-flows (ε_1-lava and ε_2-lava) exposed on the sea cliff running around the southeastern shore of the island. The ε_1-lava extends from Sanuka-saki to Kannon-ura and is exposed on the 150 m. sea cliff. On the southeastern side of Tenjô-san it crops out 300 m. up and is overlain by the Tenjô-san lava. But the greater part of the lava is unconformably covered with the Chichibu-yama ejecta-bed, though the latter is but barely left from erosion. A noticeable feature of the lava is that it consists of distinct layers: pumiceous in the upper part, glassy in the middle, and felsitic in the lowermost layer which is just above the sea level. Forming the headland between the bays of Miura and Takô, another lava (ε_2-lava) is exposed on the sea cliff. West side of the head-land, on the point north of the bay of Miura it is in contact with the hypersthene-plagioliparite of the Membô upland, though it is veiled by the debris in the valley that open to the bay which of the two has been extruded first.

Megascopic Characters.—Megascopically three principal varieties of the biotite-plagioliparite from the ε_1-lava may be distinguished. Felsitic variety is white or pale gray in color and very compact. Phenocrysts of plagioclase are scattered through the aphanitic groundmass, but those of biotite are little or entirely absent. Glassy variety is a jet-black obsidian. A splinter from it shows a conchoidal fracture and has a sharp knife-edge. A thin piece is translucent, darkening as it becomes thick. In the obsidian, phenocrysts of plagioclase are fairly abundant, while a few crystâls of biotite are looked through the black glass. Frequently, the obsidian is traversed by numerous perlitic cracks and the hand-specimen is easily crumbled into pieces. Pumiceous variety is white and vesicular. The specimens from the ε_2-lava are rather pumiceous and strongly porphyritic, with numerous phenocrysts of plagioclase, quartz, and biotite.

Microscopic Characters.—In thin section of a felsitic specimen of the ε_1-lava there are a few phenocrysts of plagioclase and biotite scattered through a largely devitrified groundmass. The phenocrystic plagioclase is commonly twinned and zonally built, though very faint. The extreme margin of the crystal was identified as an oligoclase $Ab_{75}An_{25}$ with $n_{1_D}=1.541$, and slightly more calcic core part, $Ab_{71}An_{29}$ with $n_{1_D}=1.541$. Biotite is greenish brown with $\gamma_D=1.661$. Sometimes it has been decomposed into grains of magnetite. No phenocryst of quartz is to be seen. The groundmass is largely microcryptocrystalline, though glassy base has been left in lenticular patches arranged lengthways in the direction of flow. It occasionally ex-hibits microspherulitic crystallization.

A thin section of the obsidian is colorless glass in which are poorly found phenocrysts of plagioclase and biotite. The refractive index of the glass is:

n_D=1.484. An obsidian from the southeastern foot of Tenjô-san is traversed with numerous perlitic cracks and contains abundant phenocrysts of plagioclase, quartz, and biotite. The groundmass shows perfectly clear glass crowded thickly with incipient crystallizations such as crystallites, trichites, margarites, etc. (Pl. XXIII, Fig. 4). Sometimes devitrified aureole, brown in color, is seen around the phenocrysts. The refractive index of this glass is: n_D =1.494, far higher than that of the just-mentioned obsidian.

The white pumiceous specimen is nothing but highly vesicular form of the former ones. As to the specimen, the only point of interest is that the refractive index of the glass is higher than those of the obsidian glasses, giving n_D=1.498(5). From this it is inferred that volatile substances that have been preserved in larger amount in obsidian glass than in pumice lower the refractive index of the glass.

The thin section of the ε_2-lava shows phenocrysts of sanidine, plagioclase, quartz, and biotite. Sanidine is negligible in amount. Plagioclase exhibits slight zonal structure, though not striking enough to be optically analysed. Thus, the mineral was identified as an oligoclase $Ab_{82}An_{18}$ (n_{1D}=1.538). Small inclusions of apatite, magnetite, and of a few biotite flakes are seen. The phenocrystic biotite is brown in color, frequently with a tinge of either red or green. Contortion of the flakes is frequent. The refractive index is: γ_D=1.661. In some specimens, however, are found a few flakes of reddish-brown biotite which differ optically from the just-mentioned one. Basal section of this biotite shows low but distinct biaxiality, with the refractive index: γ_D=1.684, far higher than the above one. As already remarked this biotite has possibly been derived, through a thermal decomposition, from the normal biotite (γ_D=1.661).

Tadanae-jima islets are formed of the same lava as that of Sanukasaki (ε_1-lava).

Ombashi-jima islet-group consists of two larger islets, Ombashi-jima and Sappan-jima, with many stacks ("Ne") and reefs ("Asara") around them. The islets are formed of felsitic lava with a marked flow structure. The rock is entirely devoid of phenocrysts and the whole mass is hyaline or cryptocrystalline with very poor crystals of plagioclase and seemingly of biotite (Pl. XXIV, Fig. 1.) Jet-black obsidian occasionally is sandwiched in between the felsitic part. Chemical composition of a felsitic specimen from Sappan-jima is shown in Table II (Analyst S. Tanaka).

TABLE II.

Wt. %		Norm	
SiO_2	74·93	Quartz	33·2
Al_2O_3	13·52	Orthoclase	20·0
Fe_2O_3	0·76	Albite	38·2
FeO	0·72	Anorthite	3·9
MgO	0·32	Corundum	0·9
CaO	0·93	Hypersthene	1·3
Na_2O	4·50	Magnetite	1·2
K_2O	3·39	Ilmenite	0·3
H_2O +	0·46	Apatite	0·3
−	0·33		
TiO_2	0·13	Ratios	
P_2O_5	0·08	Sal/Fem	31·0
MnO	0·08	Q/F	0·5
Total	100·15	$\frac{K_2O'+Na_2O'}{CaO'}$	6·7
		$\frac{K_2O'}{Na_2O'}$	0·5

13) *Hornblende-plagioliparite*....δ-Lava. (Pl. XXIV, Fig. 2).

Mode of Occurrence.—This constitutes a lava-flow, about 150 m. in average thickness, and forms the western part of the basement of the island. On the 60 m. cliff around the northwestern foot of Kôbe-yama, a glassy lava, rich in spherulite, is seen, being overlain by the Chichibu-yama ejecta-bed. From this place to the shore of Mae-hama the lava continues and exposes on the sea cliff. Platy banding is a characteristic feature of this lava.

Megascopic Characters.—This rock exhibits diverse megascopic appearances, pumiceous, glassy, and felsitic. Pumiceous portion is megascopically of porphyritic texture, megacrysts of plagioclase, quartz, and hornblende being scattered through a white glass base. Sometimes, the alternating laminae of vitreous and felsitic materials are developed, showing viscous flowage of the lava. Much more frequently, however, are found spherulites either scattered or arranged in parallel lines through a vitreous base. These spherulites attain occasionally a diameter of 3 cm., but far often they are 2–5 mm. in diameter.

Microscopic Characters.—Under the microscope are found phenocrysts of feldspar, quartz, and hornblende. Of the feldspar sanidine is far less in amount than plagioclase.

Phenocrystic plagioclase is euhedral and of prismoid, 3–5 mm. long, with the usual twin-lamellation. The indices of refraction of the mineral are: $\alpha_D<1.544<\beta_D 1.548<\gamma_D$ or $n_{1D}=1.541$. Thus the plagioclase was identified as an oligoclase $Ab_{74}An_{26}$. Sometimes it exhibits indistinct zonal structure, the outermost part being slightly more sodic ($Ab_{76}An_{24}$, $n_{1D}=1.540$) .

Quartz is abundant, its amount being competed with that of the plagioclase. It is rounded, angular, but rarely euhedral. The euhedral one is dihexagonal and six-sided, often being indented to result in inlets of the groundmass. Minute inclusions are commonly visible in the mineral.

Hornblende occurs as idiomorphic prismoids of about 3 mm. in length. It is usually of pale green or of greenish brown and is moderately pleochroic, giving pale green (X), greenish brown (Y), and greenish brown (Z) colors respectively for the three directions of absorption. Basal section shows a set of prismatic cleavage, so characteristic of the mineral. Lamellar twinning is often developed. The refractive index is: $n_{1D}=1.644$. The extinction ngle $c \wedge Z'$ is about 11°. As inclusions are found plagioclose, magnetite, but rarely glass. The mineral is generally fresh and has suffered no resorption, while that in the felsitic variety has undergone some alteration.

Much less commonly are found biotite flakes, of very small size, scattered through the groundmass.

In accordance with the diverse megascopic appearances of the rock, the groundmass exhibits various textures and structures. The vesicular structure is commonly of the pumiceous specimen. The groundmass in which neither microlite nor crystallite is visible is but a vesicular form of natural glass. The vesicles are drawn out in the direction of flow. The vitreous but non-vesicular groundmass is a common structure assumed by obsidian. The colorless glass traversed with or without perlitic cracks is crowded with minute laths of crystallites arranged lengthways in the direction of flow. Occasionally, they are crowded in bands exhibiting megascopic lamellation of the rock. In a specimen from Mae-hama are scattered through the groundmass a number of crystallites of a colorless mineral forked in swallow tail. The cryptocrystalline groundmass is of the felsitic variety. It consists in the interlocking masaic of minute crystals of quartz and feldspar. In the devitrified groundmass of a specimen from the shore of the bay of Nagumi was found secondary diaspore filling the interstices. It is blue in color and strongly pleochroic, varying from deep blue to light blue or to almost colorless.

The spherulitic structure is exhibited by the groundmass in which spherulites, about 0.05 mm. in diameter, composed of radiating crystals with negative character of the principal zone are imbedded. These microspherulites are often enclosed in some larger spherulites, 2–5 mm. in diameter, scattered through the groundmass when develop but poorly, otherwise arranged in straight or tortuous layers. In thin section the larger spherulites are made up of radiating but markedly branching fibres which may possibly be the so-called trichites. Phenocrysts of quartz and feldpar are often enclosed in these spherulites and have served as the nucli for the radial development of the spherulites. The spherulites sometimes show concentric zones, along with the radial structure, the more crystalline zones alternating with the less crystalline ones. Thus, largely devitrified spherulites show between crossed nicols optically positive character. In the groundmass with spherulitic crystallization minute lods of crystallites are distributed equally in both the spherulites and the main groundmass and are arranged lengthways in the direction of flow. Accordingly, it is inferred that the spherulites, microscopic as well as macroscopic, were formed after the extrusion of the lava. There is no mistake about that the spherulites came into existence after the flowage of the lava and could not be due to liquid immiscible in the magma.[17)]

Chemical Composition.—An uniformly pumiceous specimen from Naga-hama was chemically analysed by S. Tanaka, the result being as shown in Table III.

TABLE III.

Wt. %		Norm	
SiO_2	75·10	Quartz	41·2
Al_2O_3	13·36	Orthoclase	8·9
Fe_2O_3	0·30	Albite	35·1
FeO	0·74	Anorthite	6·9
MgO	0·27	Corundum	2·3
CaO	1·43	Hypersthene	0·6
Na_2O	4·21	Magnetite	0·2
K_2O	1·58		
H_2O +	2·27	Ratios	
−	0·17	Sal/Fem	168·0
TiO_2	—	Q/F	0·9
P_2O_5	—	$\frac{K_2O'+Na_2O'}{CaO'}$	3·3
MnO	0·10		
Total	99·53	$\frac{K_2O'}{Na_2O'}$	0·2

According to the C. I. P. W. quantitative system of classification, the rock resembles very closely the hypersthene-plagioliparite (cf. p. 296), both falling in Alsbachose (I. 3. 2. 4), though the latter is almost in quardofelic.

17) J. W. GREIG: "Liquid Silicate Immiscibility," *Amer. Jour. Sci.*, **15** (1928), 375–402.

14) Hornblende-bearing hypersthene-plagioliparite....γ-Lava. (Pl. XXIV, Fig. 3).

Mode of Occurrence.—This is exposed along the coast of Ushi-hana at the northeastern corner of the island, forming a lava-flow of about 170 m. in thickness. Its surface is likewise pumiceous, while the lower portion is compact and shows magnificient columnar structure. The lava is covered with the Chichibu-yama ejecta-bed which is in turn overlain by the Jôgoro-yama lava.

Megascopic Characters.—Megascopic appearance is quite various. The chief variation is from a dense rock with abundant megacrysts, up to 2 mm. long, of plagioclase and quartz scattered through the aphanitic groundmass, to a glassy one.

Microscopic Characters.—Microscopically the rock contains phenocrysts of plagioclase, quartz, hypersthene, and hornblende.

Plagioclase is euhedral or subhedral, and of prismoid. Multiple twinning according to the albite law, often combined with the Carlsbad twinning is commonly developed. Zonal structure is very faintly exhibited. The mineral was identified as an oligoclase $Ab_{72}An_{28}$, with $n_{1D}=1.542$.

Hypersthene is euhedral (laths up to 1 mm. long), pale brownish, and pleochroic, viz. Z—light greenish, Y—brownish, and X—pale brownish. Conoscopically two forms of the mineral are distinguished. One has the optical plane parallel to the elongation direction (c-axis) and the other transverse to it. The former is the normal form and is by far the more of the two. The normal form exhibits more prismatic cleavage but less pleochroism than the other. The transverse cleavage are equally developed. Two or more individuals of this mineral occasionally form a grouped crystal associated with those of the plagioclase.

Quartz occurs in somewhat rounded crystals broken by irregular fractures. Hornblende is negligible in amount. It is euhedral (0.1–0.2 mm. long) and light green in color. Twinning lamellae are often exhibited.

The groundmass is various, from extremely hyaline one to more or less crystalline. The dense specimen from the lower portion of the lava has a groundmass consisted of minute mosaic of feldspar and quartz, sometimes with the spherulitic crystallization. Besides, slender flakes of biotite are rarely found.

15) Hypersthene-plagioliparite....β-Lava. (Pl. XXIV, Fig. 4).

Mode of Occurrence.—This forms a lava-flow, about 100 m. thick constituting the rectangular table-land at the southeastern part of the island.

Where the lava cut back into sea cliff, a distinct flow line dipping northeast is exhibited. The flow banding is often contorted as shown by color differences between the bands, which vary from faint to quite pronounced. Small outcrops of the same rock are also found at Yoko-kawa and Tadanuke, on the middle course of the Kawara.

Megascopic Characters.—Megascopically the rock is various, as it exhibits every gradation between the pumiceous and stony characters. Specimens from the upper portion of the lava-flow are highly pumiceous, while those from the interior are dense. Sometimes it is strongly variegated with the colors of white, gray, brown, and black. Megacrysts of plagioclase, and quartz lie in a glassy or vesicular groundmass. Spherulites are frequently scattered through the vitreous matrix.

Microscopic Characters.—The thin section shows numerous phenocrysts, of staut prismoid, 0.5 to 1 mm. long, of plagioclase. The plagioclase is oligoclase-andesine $Ab_{68}An_{32}$, with n_{1D}=1.544 and the extreme margin an oligoclase $Ab_{77}An_{23}$, with n_{1D}=1.539(8), the lowest refractive index measured. Twinning is commonly of the albite law showing rather narrow twin-lamellation. As inclusions occur euhedral hypersthene, minute grains of magnetite, and slender prisms of apatite, along with small patches of colorless glass crowded with microlites.

Phenocrystic quartz is always present in less amount than plagioclase. It is subhedral or anhedral, with rounded or irregular outlines, but exceptionally occurs in bipyramidal crystals. The mineral contains inclusions, mostly of glass thickly crowded with microlites.

Hypersthene is euhedral, yellowish brown, moderately pleochroic: X—yellowish brown, Y—pale brown, Z—yellowish green. The refractive index is: n_{1D}=1.700(5). The optical plane is parallel to the elongation direction of the crystal. It is practically free from inclusions, except a rare small grains of magnetite.

In very rare instances, minute flakes of biotite are recognized.

The groundmass is very glassy, of various colors, and is generally crowded with microlites which are arranged in the sinuous flow lines. Sometimes the groundmass shows a vesicular structure, the vesicles being elongated in the direction of flow.

Chemical Composition.—An analysis, by S. Tanaka, of a specimen from Himmashi-hana gave the result shown in Table IV, there being also given the ratios, according to the C. I. P. W. quantitative system of classification, which place the rock in Alsbachose (I. 3′. 2.4).

TABLE IV.

Wt. %		Norm	
SiO_2	75·35	Quartz	37·1
Al_2O_3	13·49	Orthoclase	15·0
Fe_2O_3	0·95	Albite	36·1
FeO	0·55	Anorthite	7·2
MgO	0·36	Corundum	1·0
CaO	1·61	Hypersthene	0·9
Na_2O	4·28	Ilmenite	0·5
K_2O	2·52	Magnetite	1·2
H_2O +	0·61	Hematite	0·2
—	0·06		
TiO_2	0·20	Ratios	
P_2O_5	—	Sal/Fem	36·0
MnO	0·08	Q/F	0·6
Total	100·06	$\frac{K_2O' + Na_2O'}{CaO'}$	3·3
		$\frac{K_2O'}{Na_2O'}$	0·4

Basic Xenoliths. (Pl. XXV, Figs. 1, 2).

Mode of Occurrence.—The basic xenoliths lie scattered in the hypersthene-plagioliparite exposed along the shore from Himmashi-hana to Ichinokubi on the southwestern coast of the island. There the agglomeratic appearance of the lava is due to these xenoliths. Many of the xenoliths are quite angular, while some are well rounded, their size ranging from a few cm. to 15 cm. in diameter. The liparite surrounding these xenoliths is very vitreous.

Megascopic Characters.—The xenoliths are dark or almost black in color, often with a tinge of brown or dark green. In most hand-specimens no phenocryst is observed, but in a specimen are found glistening black prismoids of hornblende, about 3 mm. in length.

Microscopic Characters.—One specimen, that which was chemically analysed, is composed almost wholly of plagioclase, hornblende, augite, and magnetite, with a little glass. It is not strongly porphyritic, while all the plagioclase crystals are idiomorphic against the other essential minerals.

Plagioclase is dominantly lath-shaped and about 0.5 mm. long. With the refractive index, $n_{\gamma D}=1.561(5)$ this plagioclase was identified as an intermediate labradorite $Ab_{37}An_{63}$. Zonal structure due to chemical difference is very faintly exhibited. The mineral is twinned, either multiply or simply, according to the albite law.

Hornblende is euhedral or subhedral, and equant in habit. The cleavage is perfectly developed, the transverse section of the mineral exhibiting the characteristic cleavage lines intersecting at an angle of 124°. The mineral is brown in color and strongly pleochroic, its axial colors being: X—light brown with a tinge of green, Y—yellowish green, and Z—brown. The refractive index is: $n_{1_D}=1.682$. The extinction angle is: $c \wedge Z'=7°$.

In less amount than the hornblende are present equant grains of light greenish augite, much of it are subhedral or anhedral individuals of about 0.5 mm. in diameter. The mineral is scarcely pleochroic, varying from light green to almost colorless. The extinction angle of the mineral is: $c \wedge Z'=53°$ and the refractive index is: $n_{1_D}=1.696(5)$. It is often surrounded with the reaction-rim of hornblende.

Isometric crystals of magnetite, 0.05–0.2 mm. in diameter, are present in moderate amount. There is some ill-defined, colorless glass interstitial between the crystals.

Chemical Composition.—A specimen from Himmashi-hana was analysed by S. Tanaka, with the result shown under the column I of Table V. It is there compared with the olivine-basalt from Udone-shima (col. II. Dittrich, Analyst), an islet to the north of Nii-jima. The close correspondence between these analyses is well brought by the calculation of the norms which are also shown in the same table.

TABLE V.

Wt. %	I	II
SiO_2	50·74	50·79
Al_2O_3	18·59	16·16
Fe_2O_3	9·23	6·96
FeO	1·01	3·51
MgO	5·37	7·63
CaO	10·21	10·03
Na_2O	2·35	2·58
K_2O	0·57	0·55
H_2O +	0·74	0·31
—	0·16	0·07
TiO_2	0·98	1·01
P_2O_5	0·06	—
MnO	0·16	—
Total	100·14	100·05

Norms	I	II
Quartz	6·5	4·4
Orthoclase	3·0	3·3
Albite	19·9	22·0
Anorthite	38·4	32·0
Diopside	9·1	13·8
Hypersthene	9·4	12·7
Magnetite	0·3	8·4
Ilmenite	1·8	1·9
Hematite	8·6	1·2

Ratios	I	II
Sal/Fem	2·3	1·6
Q/F	0·1	0·1
$\frac{K_2O'+Na_2O'}{CaO'}$	0·3	0·4
$\frac{K_2O'}{Na_2O'}$	0·1	0·1

According to the C. I. P. W. quantitative system of classification, the xenolith analysed belongs to Hessose (II. 4(5). 4. 4(5)), and the basalt to Auvergnose ((II)III. '5. 4. 4(5)). The close correspondence between the xenolith and the basalt is a fact of some interest in view of the origin of the xenolith, since the similar xenolith is found in the biotite-liparite exposed at Awai-ura, northeastern shore of Nii-jima and only 1 km. to the south of Udone-shima.

The xenoliths from Nii-jima occur as ellipsoidal patches, up to 20 cm. in average diameter, arranged in the direction of flow of the Awai-ura lava.[18] A specimen collected by the writer is megascopically almost black in color and somewhat vesicular, the vesicles being filled with the white pumiceous lava. Plagioclase phenocrysts are rarely seen with the naked eyes. Under the microscope the essential constituent minerals are plagioclase, augite, and magnetite. Among them, plagioclase and augite occur as phenocrysts. The plagioclase phenocrysts were identified as a calcic bytownite $Ab_{15}An_{85}$ with $n_{1D}=1.572$. Zoning due to chemical difference of the mineral is scarcely visible, while a distinct zone of less calcic plagioclase frames not infrequently the thinnest margin of the phenocrysts. Phenocrystic augite is of very rare occurrence. It is rimmed with narrow zone of hornblende. The groundmass is composed of plagioclase, augite, hornblende, magnetite, and a little interstitial glass. Plagioclase was identified as an andesine $Ab_{54}An_{46}$, with the refractive index $n_{1D}=1.552$. Hornblende is strongly pleochroic, exhibiting the axial colors: Z—reddish brown, Y—brown, and X—yellow, with absorption $Z>X$. The refractive index is: $n_{1D}=1.713$. The mineral occurs not only as euhedral crystals but also as reaction-rim surrounding augite crystals in the groundmass.

Another specimen of xenolith from Kôzu-shima is somewhat different from the above-mentioned one, though identical in mineral constitution. It is almost black in color, having a number of megacrysts of hornblende. In thin section plagioclase, 0.05–0.5 mm. across, is multiply twinned and often exhibits very faint zoning. With the refractive index $n_{1D}=1.566(7)$, it was identified as a labradorite-bytownite $Ab_{29}An_{71}$. The slender laths of plagioclase are enclosed ophitically in both hornblende and augite. The hornblende crystals are of prismoids, 0.5–2 mm. in length, and greenish brown in color. They are moderately pleochroic, showing axial colors: Z—greenish brown, Y—brown, and X—light green, with absorption $Z>X$. Extinction angle is: $c \wedge Z'=15°$. The refractive index is: $n_{1D}=1.672(5)$. The augite crystals are mostly subhedral, equant in habit and light-greenish. The refractive index is: $n_{1D}=1.694(5)$. The crystals are surrounded with the

18) N. FUKUCHI, *op. cit.*, *Report Earthq. Invest. Com.*, **39** (1902), 8–10, (in Japanese). Fukuchi described these xenoliths under the name "diorite-porphyrite."

reaction-rim of green hornblende. The interstitial glass is light brown in color and is highly vesiculated.

The xenoliths described here are somewhat similar in microscopic structure to a secretionary patch discovered by Koto[19] among the ejecta of Volcano Sakura-jima, exhibiting what Lacroix terms "structure enchevetree." But it is difficult to conceive of the formation of such secretionary patches, chemically almost equivalent to a basalt, in the rhyolitic magma. They are probably of preexisting rock caught by the liparitic lavas either before or during the outpouring.

16) Potash-liparite.....a-Lava. (Pl. XXV, Fig. 3).

Mode of Occurrence.—This is exposed at Ôyase on the northern coast, forming an outcrop, 5 m. high above the sea level and 250 m. long along the shore. Whether the rock occurs in an extensive lava-flow, could not be decided from the exposure. The decomposed surface of this rock is covered with the Chichibu-yama ejecta-bed overlain by the Anagi-yama lava. The rock has undergone a certain amount of alteration by the attack of the sea water.

Megascopic Characters.—Megascopically the rock is pale gray in color, of non-vesicular, and porphyritic, having only phenocrysts of orthoclase scattered through an aphanitic groundmass.

Microscopic Characters.—Phenocrystic feldspar is generally euhedral to subhedral. It is low both in refractive indices, $n_{1D}=1.520$, and in double refraction. It is optically negative and shows very small optic angle. The mineral, accordingly, was identified as sanidine. Twinning according to the Carlsbad law is frequently exhibited. Occasionally, the mineral has been altered into kaoline which causes the cloudiness of the mineral.

No mafic mineral is detected, though red iron oxide and epidote, possibly secondary products derived from mafic mineral, are frequently seen.

Rounded phenocrysts of quartz are of very rare occurrence.

The groundmass is hypocrystalline, consisting of sanidine and devitrified glass. Slender prisms of sanidine, commonly twinned according to the Carlsbad law, exhibit trachytic arrangement. The devitrified base consists of quartz and feldspar in a granular mixture and is disseminated with minute grains of magnetite and secondary pyrite. Microscopic veins of secondary quartz traverse the groundmass.

Chemical Composition.—The result of chemical analysis by S. Tanaka

19) B. Koto, "The Great Eruption of Sakura-jima in 1914," *Jour. Col. Sci., Imp. Univ. Tokyo*, Art. 3, 38 (1916), 213.

is shown in Table VI, col. I, there being also given other two analyses of the similar rock from Manzô-yama, Izu.[20]

TABLE VI.

Wt. %

	I	II	III
SiO_2	71·64	70·85	70·75
Al_2O_3	14·13	14·03	12·44
Fe_2O_3	0·34	1·76	2·66
FeO	0·50	0·67	0·79
MgO	0·08	tr.	0·08
CaO	0·17	0·10	0·39
Na_2O	0·50	0·13	0·39
K_2O	10·77	11·36	11·51
H_2O +	0·80	0·66	0·84
−	0·23	0·26	
TiO_2	0·55	0·32	0·53
P_2O_5	0·08	tr.	0·10
MnO	tr.	0·23	0·09
Total	99·79	100·27	100·57

I. Potash-liparite, Kôzu-shima. S. Tanaka, Analyst.
II. Potash-liparite, Manzô-yama, Izu. S. Tanaka, Analyst.
III. Ditto, Manzô-yama, Izu. K. Yokoyama, Analyst.

The potash-liparite of Kôzu-shima resembles, in microscopical and chemical characters, the rock of Manzô-yama, east of Shimoda at the southern end of the Izu peninsula. Under the name "potash-rhyolite" the rock of Manzô-yama has been described by S. Kozu. Column III of the above table shows the chemical composition of the rock originally defined by Kozu. As shown in the table, two analyses, one by Tanaka and the other by Yokoyama, of the rock of Manzô-yama are not seriously inconsistent with each other, and moreover they closely agree with the composition of the potash-liparite of Kôzu-shima. The amount of K_2O is more than 10%, while that of Na_2O is less than 0.5% inclusive.

The norms and ratios calculated, according to the C. I. P. W. quantitative system of classification, are shown in Table VII. These potash-liparites belong to Lebachose (I. 4. 1. 1.).

20) S. KOZU, "Preliminary Notes on Some Igneous Rocks of Japan," V. *Jour. Geol.*, **20** (1912), 1.

TABLE VII.

Norms	I	II	III
Quartz	27·6	26·5	25·2
Orthoclase	63·3	66·7	67·8
Albite	4·2	1·0	—
Anorthite	—	0.5	—
Corundum	1·6	1·3	—
Acmite	—	—	2·8
Diopside	—	—	0·7
Hypersthene	1·6	0·4	—
Ilmenite	1·0	0·6	1·1
Magnetite	—	1·1	0·6
Hematite	0·3	0·9	1·1
Apatite	0·3	—	0·3
Ratios	**I**	**II**	**III**
Sal/Fem	25·1	30·7	14·1
Q/F	0·4	0·4	0·4
$\frac{K_2O'+Na_2O'}{CaO'}$	∞	61·0	∞
$\frac{K_2O'}{Na_2O'}$	14·2	60·0	∞

Chapter IV. Petrology of Kôzu-shima.

In this chapter it is intended to treat the petrology of Kôzu-shima, making the best use of the results of the petrographic investigation.

For this purpose, the method of the optical analyses of rocks recently proposed by S. Tsuboi,[19] was applied to the study of Kôzu-shima rocks.

The rocks of Kôzu-shima contain mostly phenocrysts embedded in the glassy groundmass. The phenocrysts are the ready-made crystals immersed in the magma at the time of eruption. The minerals of the phenocrysts are quartz, orthoclase, plagioclase, hypersthene, hornblende, and biotite. The common accessories are zircon, magnetite, and apatite. Here attention will be mainly confined to the crystallization of the essential minerals.

Hypersthene and Hornblende.—Among the lavas of the first period, β-and δ-lavas carry as phenocrysts hypersthene and hornblende respectively, and γ-lava both of these minerals. Hypersthene and hornblende are not closely associated with each other, while both are respectively in close associa-

19) S. TSUBOI, "The Optical Analysis of Volcanic Rocks as a Means of studying their Genetical Relationship," *Bull. Earthq. Resor. Inst., Tokyo Imp. Univ.*, 4 (1928), 131.

tion with plagioclase. There is nothing to show which of the plagioclase and either hypersthene or hornblende began to crystallize first. There is also no evidence for the discontinuous reaction relation between pyroxene and hornblende. In the rocks, in which either hornblende or hypersthene occurs as phenocrysts, are found very minute flakes of biotite. Although little can be said with certainty in the present case whatever of reaction relation or of concomitant crystallization of biotite and either hypersthene or hornblende, there are some reasons for considering that the magmas were saturated with neither hornblende nor hypersthene, but with biotite when the lavas were extruded. The reasons for this will be stated later.

Plagioclase.—The plagioclase forms a perfectly continuous series of mix-crystal of two components—albite ($NaAlSi_3O_8$) and anorthite ($CaAl_2Si_2O_8$)—which are reciprocally miscible each other (solid solution Type I of Bakhius Roozeboom). It follows, therefore, that the plagioclase crystals separated at any temperature are always richer in the higher melting component (anorthite) than the liquid with which they are in equilibrium. If the cooling is so slow that perfect equilibrium is maintained between the crystals and liquid, the ready-made crystals are continuously made over to the homogeneous crystals with composition richer in the lower melting component (albite) as the temperature continues to fall. But this process is specially difficult of attainment in shallow-seated magmas from which volcanic rock are derived. When the equilibrium is not fully attained, that is, cooling is too rapid for the interchange of materials between the ready-made crystals and the liquid, the crystals are zonally built, their core part containing too much the higher melting component.

The rocks of Kôzu-shima, with the exception of the potash-liparite, contain dominant phenocrysts of plagioclase. The crystals are commonly more or less zoned, showing a chemical change from the more calcic inner zones to the less calcic outer zones. Sometimes the zoned crystals change their compositions continuously from the core to the margin. The repeated zonal structure in which reversed order of zones happens may be explained by undercooling and recurrence of equilibrium introduced at the time when the zoned crystals are forming. When a crystal shows numerous zones, each visible zone has a width ranging from 0.01 mm. to 0.1 mm. The inner zone is occasionally encroached upon, showing indentation or is woven irregular figures by the substance of the near-by outer zone.

TABLE VIII.

Lavas	Ab(max.)	Ab(min.)
β-Lava	77	68
γ-Lava	72	—
δ-Lava	76	74
ε_1-Lava	75	71
ε_2-Lava	82	—
Takôdo-yama lava	73	—
Nachi-san lava	82	79
Jôgoro-yama lava	82	—
Anagi-yama lava	83	—
Kôbe-yama lava	88	86
Tenjô-san lava	88	85

As a whole, cooling of the magma from which the various rocks have been derived was not so slow as to form homogeneous phenocrysts of plagioclase, but stepwise, rapid and slow cooling alternating, to show partial remaking of the ready-made crystals by reaction with the liquid. In the above table are shown the compositions of the plagioclase phenocrysts.

The compositions of the plagioclases were determined by using the diagram for determining plagioclases proposed by S. Tsuboi.[20] The cleavage flakes of plagioclase are immersed in sequence in liquids whose refractive indices and dispersions have been determined with the Abbe's refractometer. The smaller refractive index n_{1D} on cleavage flakes parallel to M(010) or to P(001) is compared with the refractive index of the liquid used under the microscope. Then the refractive index of the plagioclase can easily be determined by Tsuboi's dispersion method.

From the table we see that the plagioclase phenocrysts are nearly within the limit of oligoclase-plagioclase ($Ab_{70}An_{30}$—$Ab_{90}An_{10}$) and their compositions have been but slightly affected by zoning. But the plagioclase phenocrysts in various lavas are not uniformly sodic, those in the later lavas being generally more sodic. Accordingly, it is inferred that the plagioclase phenocrysts in various lavas have separated out of the magma effected by either:

20) S. TSUBOI, "A Dispersion Method Discriminating Rock-Constituents and its Use in Petrogenic Investigation," *Jour. Fac. Sci., Tokyo Imp. Univ., Sec. II,* **2** (1926), 5.

1. local grouping of the ready-made crystals under uniform rate of cooling, while the temperature falling is slight, or

2. somewhat long extended cooling within the period of forming the various lavas, or

3. local diversity of rate of cooling.

Local grouping of the phenocrysts in the rhyolitic magma is not likely to take place, if the magma is really of such a high viscosity as may be postulated from the artificial siliceous melt. Now if we assume for a while that the phenocrysts were freely movable through the magma, there must have been an opportunity for either sinking or floating of them according to the relative densities of the crystals and the magma under plutonic condition. The specific gravity of oligoclase-plagioclase at room temperature and under normal atmospheric pressure is far high in comparison with that of rhyolitic glass, as seen in the following table.

TABLE IX.

Glass	Sp. Gr.	n_D	Crystal	Sp. Gr.	n_{1D}
1. Liparite	2·33	1·500	5. Ab	2·605	1·534
2. Dacite	2·51	1·510			
3. Obsidian	2·106	1·485	6. Ab_2An_1	2·660	1·549
4. Miharaite	2·84–7	1·593–6	7. Ab_1An_5	2·733	1·577

1., 2. Average liparite and average dacite; See W. O. GEORGE, "The Relation of the Physical Properties of Natural Glasses to their Chemical Composition," *Jour. Geol.*, **32** (1924), 353–372.
3. Obsidian glass of Kôzu-shima.
4. Hyaline part of miharaite; See S. TSUBOI, "Volcano O-shima, Izu," *Jour. Col. Sci., Imp. Univ. Tokyo*, Art. 6, **43** (1920), 84.
5–7. Albite, oligoclase-andesine, and bytownite; See E. S. LARSON, "Relation between the Refractive Index and Density of Some Crystallized Silicates and Their Glasses," *Amer. Jour. Sci.*, **28** (1909), 263–274.

As a basis for comparing the specific gravity at high temperature and at high pressure of solid crystals with that of liquid magma in which the crystals are immersed, the specific gravity at ordinary temperature and at normal atmospheric pressure are quite unreliable. But as has been suggested by Daly,[21] the difference of density between the magma and the crystals

21) R. A. DALY, "Mechanics of Igneous Intrusion," *Amer. Jour. Sci.*, **15** (1903). 269; **16** (1903), 107.

would but slightly be affected through the pressure. Assuming, on the other hand, the high coefficients of cubic expansion of sodic plagioclase, the difference of density between the rhyolitic magma and the crystals may become smaller as the temperature is raised. But water and mineralizers in depth would increase by far such difference calculated for one atmosphere and ordinary temperature. Thus, there is reason for supposing that the sodic plagioclase crystals would sink due to gravitation in the rhyolitic magma even under plutonic condition. The existence of basic seggregations in granites does not necessarily show that these seggregated minerals were floating in the granitic magmas.

From what has been said, the diversity of composition of the phenocrystic plagioclases in various lavas may or may not be explained by only effect of sinking of the ready-made plagioclase crystals in the magma.

Plagioclase phenocrysts always associate with the mafic minerals, showing simultaneous crystallization with the latter. They frequently enclose mafic minerals arranged in zones in accord with the zonal structure of the plagioclase.

Quartz.— Quartz in the rocks of Kôzu-shima has the high temperature crystal form traversed with numerous microscopic cracks due to high-low inversion. The biotite-plagioliparite of Sanuka-saki (ε_1-lava) is devoid of quartz phenocrysts, while it contains plagioclase and a little biotite. But in other parts of the same lava quartz is present along with plagioclase and biotite. Generally quartz crystals are scarce where the lava is poor in plagioclase phenocrysts. In the felsitic rock of Ombashi-jima neither quartz nor plagioclase is found. In this respect it is to be noted that quartz is heavier than liparitic magma. The specific gravity of the mineral is 2.649 at 20°C. and under 1 atmospheric pressure. At 900°C. and under 1 atmospheric pressure it is 2.529.[22] On comparing the density of quartz at 900°C. with that, at ordinary temperature, of the liparitic magma, it is remarkable that the mineral is heavier than the magma. Therefore the difference will be increased when the magma is under plutonic conditions. (cf. Table IX, p. 304). Local diversity of the amount of this mineral in the liparites may be explained by local sinking of the mineral. The potash-liparite is almost devoid of the phenocrysts of quartz. The similar rock from Manzô-yama in the Izu peninsula (p. 300) is partly devoid of the mineral but partly enriched with conspicuous phenocrysts of quartz. This diversity may be ascribed to the local sinking of the phenocrysts.

22) A. L. DAY, R. B. SOSMAN, and J. C. HOSTETTER, "The Determination of Mineral and Rock Densities at High Temperatures," *Amer. Jour. Sci.*, 37 (1915), 16.

There is no indication in the rocks of Kôzu-shima, which of quartz and other minerals began to crystallize first.

Biotite.—The molecular constitution of biotite is extremely complex, though it is generally accepted that the mineral is an alumino-silicate of both alkali and either iron or magnesia or of both, along with hydroxyl. In all probability, the mineral forms a mix-crystal series and its crystallization must be spread over an interval of temperature, falling at least partly on that of plagioclase. Then the composition of the mineral has to change, along with the change of plagioclase, to cooling within a range of temperature. Thus, the paragenic relations of plagioclase and biotite have already been ascertained by studying these minerals in some genetically related rocks, the change of their compositions being confirmed by variation of their optical constants. For the purpose, the refractive indices of biotites in the rocks of Kôzu-shima were measured for Na light. They are shown in Table X, there being accompanied with the compositions of the phenocrystic plagioclases in the corresponding rocks.

TABLE X.

Lava	Plagioclase	Biotite (γ_D)
ε_1-Lava	$Ab_{75}An_{25}$	1·661
ε_2-Lava	$Ab_{82}An_{18}$	1·661
Takôdo-yama lava	$Ab_{73}An_{27}$	1·656
Nachi-san lava	$Ab_{82}An_{18}$	1·661
Jôgoro-yama lava	$Ab_{82}An_{18}$	n. d.
Anagi-yama lava	$Ab_{82}An_{18}$	n. d.
Kôbe-yama lava	$Ab_{88}An_{12}$	1·664
Tenjô-san lava	$Ab_{88}An_{12}$	1·665

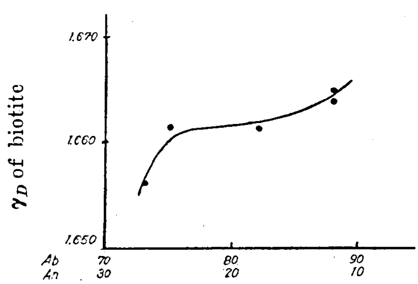

Fig. 1. The paragenic relation between plagioclase and biotite.

From the data given in Table X, the paragenesis diagram of Fig. 1 is constructed. As seen in the figure, the biotites become high in some extent in their refractive indices as the associating plagioclases become rich in albite. This is just what might be expected if the biotite forms a mix-crystal series and if its refractive indices become higher as the biotite grows rich in the lower melting component of the series. Chemical analyses of a number of biotite show that magnesia is in antipathetic relation with iron oxides, addition of the former to the biotite reducing the latter still further, and that magnesia-rich biotites are more common in basic rocks than in acidic ones.[23] On the other hand, the more the rocks become acidic, the higher the refractive indices of the biotites are. Accordingly, it is inferred that the addition of iron oxides raises effectively the refractive indices of biotite.

Besides the biotites cited in Table X, the Tenjô-san lava occasionally contains biotite with the refractive index: $\gamma_D > 1.700$. The ε_2-lava, Nachi-san

TABLE XI.

T (in C.)	γ_D	2E	Type
23	1·665	37° 38′	meroxene
120	1·665		
160	1·665		
220	1·669		
260	1·669		
290	1·671	46° 26′	meroxene
320	1·671		meroxene
360	1·678		meroxene
420	1·684		meroxene
450	1·684		
490	1·690		
530	1·699		
720	n. d.	50° 58′	meroxene
760	n. d.		
800	n. d.		
900	n. d.	60° 18′	
1000	n. d.		

23) GERDA SCHAUBERGER, "Biotit in tertiären Eruptivgesteinen Böhmens," *Centralblatt für Mineralogie, Geologie und Paläontologie,* Abt. A, (1927), 89–105.

lava, and Jôgoro-yama lava also contain biotites, unusually high in the refractive indices. From the thermal study on biotite flakes collected from the Tenjô-san lava, it was confirmed that increase of the refractive indices might be due to a thermal decomposition to which the normal biotite was subjected.

The greenish-brown biotite, whose refractive index is: $\gamma_D=1.665$, collected from the Tenjô-san lava was heated by means of an electric resistance furnace, the temperature being measured with a Pt.-Pt.Rh. thermo-couple connected to a millivoltmeter. The biotite flakes were heated an hour at a constant temperature and then they were dropped to quench into water by cutting the suspension wire of the substance heated. The treatment was done at various temperatures from 120°C. to 1000°C., and the refractive indices for Na light of the heated biotites were determined by the immersion method. The results obtained are tabulated above and are graphically represented in Fig. 2.

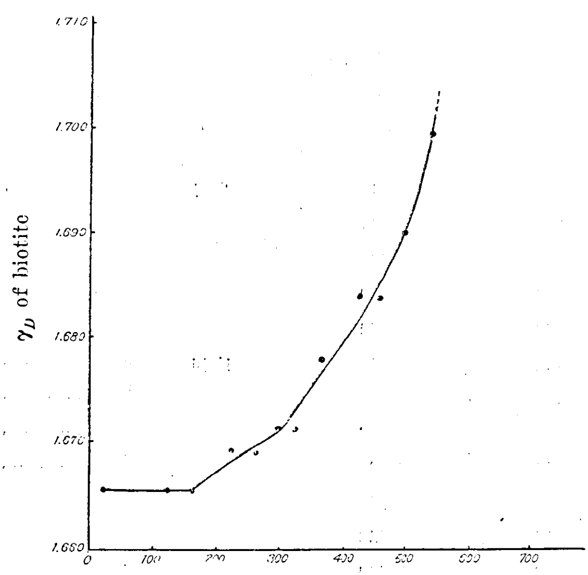

Fig. 2. The thermal change of biotite.

On heating, the biotite shows already a slight heat effect just above 200°C. and the refractive indices become higher and higher as the heating temperature increases, attaining $\gamma_D=1.699$ at 530°C. The biotite heated at 720°C. and upwards shows γ_D decidedly higher than the refractive index of methylen iodide ($n=1.741$–50)). Macroscopically, it is noticed that the heated biotite intensifies its luster, becoming golden-colored at temperatures above 500°C., while at first it is almost black. Under the microscope the biotites heated at higher temperatures are more red in color than those at lower temperatures. The optic axial angles increase as the heating temperature is raised, though their systematic variation is left uninquired, their optical orientation being unaltered.

The unusual yellowish-brown biotite found in the Tenjô-san lava resembles in its characters, macroscopical as well as microscopical, the product obtained by heating above 720°C. the greenish-brown biotite found in the same lava. It may, therefore, be presumed that the unusual biotite is not magmatic in origin, but a secondary product due to a thermal action, probably volcanic, on the greenish-brown biotite which is uniformly distributed in the lava. In this connection it is also remarkable that the unusual biotite is mainly confined to the portion where the lava is highly vesicular.

The thermal studies on biotites have been done by S. Kozu[24] and by A. L. Day and others.[25] The results obtained by these authors are qualitatively in accord with the writer's ones. While Kozu has done the heat treatment of biotite in a neutral air, his results are in accord with those obtained by heating biotites in the air. It is, therefore, inferred that the change of biotite due to heating does not mean simple oxidation of the biotite. According to Day, the transformation of the biotite in the lava of Lassen Volcano is due to decomposition which occurs in two ways; one by the loss of the volatile matter, the other by oxidation.

From the experimental data above given, it is probable that heat generated by the volcanic gases escaping from the lava surface will have far-reaching effect upon forming the unusual biotites.

The biotites in the rocks of Kôzu-shima are higher, whatever the just-mentioned unusual biotite may be, in their refractive indices than those of the other localities. This fact may probably mean higher content of iron oxides. They are generally fresh, without suffering magmatic resorption, but in devitrified rocks they are often partly resorbed. Some specimens stained with various shades of color, of the Tenjô-san lava contain biotite crystals which have been completely decomposed, probably due to volcanic emanation. These altered biotite must be carefully excluded for petrogenic discussion.

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24) S. Kozu, "The Influence of Heat on the Refractive Indices and Optic Axial Angle of Biotite," *Chikyu* (*the Globe*), **9** (1928), 330–338 (in Japanese).

25) A. L. Day and E. T. Allen, *op. cit.*, *Publ. Carnegie Inst. Wash.*, **360** (1925), 49.

Groundmass.—By sudden chilling of the lavic magma at the time of extrusion, the magma in which the ready-made crystals had been immersed consolidated as the groundmass. The groundmass of the rocks of Kôzu-shima has consolidated to result in very poor crystallization. Excepting the fugitive substances, therefore, the groundmass is just the same in composition at one stage of the cooling magma. The composition of the groundmass may be various in different rocks, since the phenocrysts with which the magma was in equilibrium at the time of extrusion are not always same both in composition as well as in kind. The variation of the chemical composition of the groundmass must correspond to the variation of its optical constants. The refractive indices of the groundmasses of various rocks are given in Table XII, with the compositions of the phenocrystic plagioclases in parallel col.

TABLE XII.

Lava	n_D	Plagioclase
β-Lava	1·497	$Ab_{77}An_{23}$
γ-Lava	1·499 (5)	$Ab_{72}An_{28}$
δ-Lava	1·497	$Ab_{76}An_{24}$
ε_1 Lava	1·498	$Ab_{75}An_{25}$
ε_2-Lava	1·494	$Ab_{82}An_{18}$
Takôdo-yama lava	1·498 (5)	$Ab_{73}An_{27}$
Nachi-san lava	1·494	$Ab_{82}An_{18}$
Jôgoro-yama lava	1·493 (5)	$Ab_{82}An_{18}$
Anagi-yama lava	1·491 (5)	$Ab_{82}An_{18}$
Kôbe-yama lava	1·490	$Ab_{88}An_{12}$
Tenjô-san lava	1·490	$Ab_{88}An_{12}$

All the refractive indices in the table were measured on glasses of pumiceous specimens. Obsidian glass has a refractive index different from that of pumice, even though both are of a single lava. The obsidian glass from Sanuka-saki (ε_1-lava) shows $n_D = 1.484$, a value far lower than the pumice ($n_D = 1.498$) from the same lava. Accordingly, it is inferred that volatile substances which have been occluded in obsidian are in larger quantity than those in pumice. The specific gravity of the obsidian is 2.106 at 28°C. (cf. p. 304), while that of the pumice is 2.394 at 28°C.[26] There-

26) A perlite from Shimoda in Izu peninsula: n_D of the groundmass glass = 1.493, sp. gr. of the glass at 28°C. = 2.269, the phenocrystic plagioclase $Ab_{88}An_{12}$.

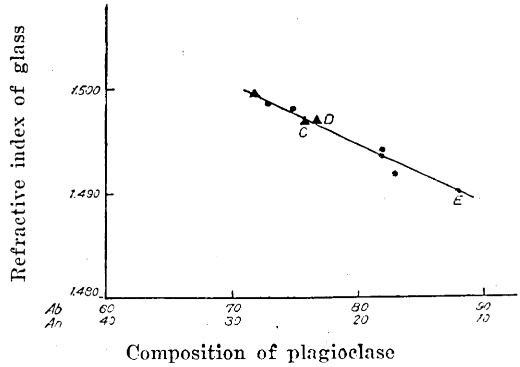


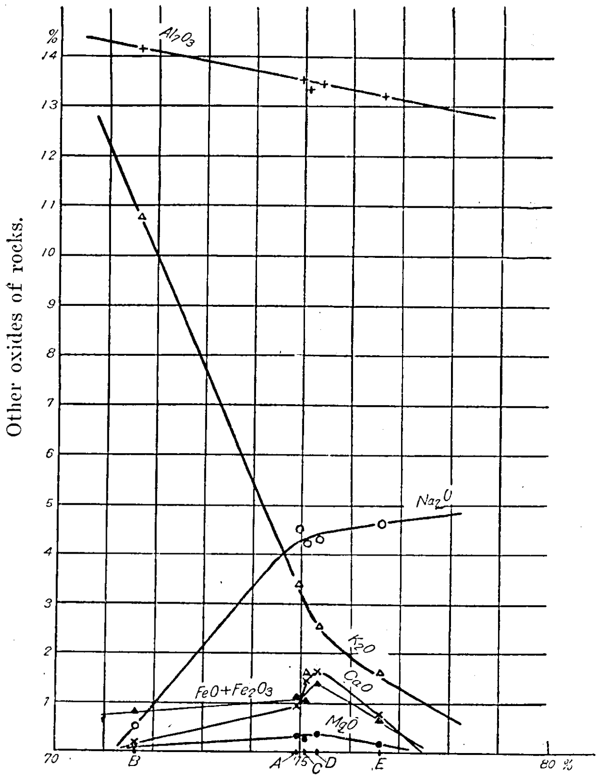
Fig. 3. Relation between the refractive index of natural glasses and the composition of plagioclases in the rocks of Kozu-shima.
● Biotite-plagioliparites.
▲ Hypersthene- and hornblende-plagioliparites.

fore, it is not correct to apply to natural magma the relative densities of crystals to the magma derived from dry melt.

From the data given in Table XII, the diagram of Fig. 3 is constructed. The figure shows a linear relation of the refractive index of groundmasses and the composition of accompanying plagioclases. The refractive index of the groundmass glass lowers as the accompanying phenocrystic plagioclase becomes richer in albite. According to W. O. George, the natural glass with higher refractive index is poorer in silica and alkalies, richer in lime and the ferromagnesion oxides. If so, the relation shows that a magma in equilibrium with more sodic plagioclase is more acidic than another one in equilibrium with less sodic plagioclase.

Chemical Composition.—The bulk composition of volcanic rock is the mixture of quenched magma (groundmass) and phenocrysts suspending in the magma.[27] The net composition of the magma is, therefore, obtained by estimating and eliminating the approximate amount of the phenocrysts in the rock. As the rocks of Kôzu-shima are rather poor in phenocrysts, the variation diagram of their bulk compositions must be only slightly shifted from the variation diagram of their groundmasses only. The bulk compositions of the rocks of Kôzu-shima described in the preceding chapter are plotted in Fig. 4. The phenocrystic minerals which seem to scatter the indicative points of the variation diagram of the rocks are quartz and feldspar, but ferromagnesian minerals (hypersthene, hornblende, and

27) S. Tsuboi, "The Genetical Interpretation of Extrusive Rocks," *Jour. Fac. Sci., Imp. Univ., Tokyo, Sec. II,* 1 (1925), 77–86.



Silica of rocks.

Fig. 4. Curves showing the variations in the composition of the rocks of Kôzu-shima.

TABLE XIII.

Rock	Orthoclase	Plagioclase	Quartz
Potash-liparite (α-Lava)	5%	—	—
Hypersthene-plagioliparite (β-Lava)	—	10% ($Ab_{77}An_{23}$)	5%
Hornblende-plagioliparite (δ-Lava)	—	5% ($Ab_{76}An_{21}$)	1%
Aphanitic rock (Ombashi-jima lava)	—	—	—
Biotite-plagioliparite (Tenjô-san lava)	—	5% ($Ab_{88}An_{12}$)	3%

biotite) may be neglected for the present consideration. The approximate percentages of quartz and feldspar in the analysed specimens were estimated under the microscope, the results being shown in the above table. (Table XIII).

Orthoclase, albite, and anorthite have the forms respectively of $KAlSi_3O_8$, $NaAlSi_3O_8$, and $CaAl_2Si_2O_8$, and the composition of these phenocrysts may be eliminated from the bulk compositions. The diagram thus plotted is approximately to show the variation of the groundmass, that is, variation followed by the magma from which the rocks of Kôzu-shima have been derived. By eliminating the dominant phenocrystic minerals, however, the variation diagram of the bulk compositions is but slightly modified. Accordingly, there is no serious error in regarding the variation diagram, Fig. 4, of the bulk compositions as that of the groundmasses. In the figure the amount of Al_2O_3 varies in nearly rectilinear relation with that of SiO_2, while other oxides do not show such relation. The indicative points of each oxide, however, are not irregularly scattered, showing a serial variation. It should be noted that K_2O and Na_2O show an antipathetic variation. There is a distinct tendency for one of these to be low where the other is high.

Differentiation.—The magma from which the rocks of Kôzu-shima have been derived may be regarded as corresponding in essentials to the later stage of crystallization, though it must be left for further study whether the magma is a salic differentiate derived from a basaltic magma by crystallization following the course of the so-called gabbro-granite differentiation or not The groundmass of the volcanic rock represents the residual liquid in which the phenocrysts have suspended. Then, on the assumption that the various rocks of Kôzu-shima have been derived from a common magma, we must search for the sort of material from which differentiation starts and the process of differentiation by which the variation of the succeeding magmas represented by the groundmasses has been brought about. From the variation diagram of the groundmasses, therefore, it is possible to deduce what sort of material would have been separated from a magma to change the composition in such a manner as shown in the variation diagram. If we assume that the diagram in Fig. 4 shows approximately the variation of the groundmasses, there are theoretically two possibilities to produce a change of the required kind: first, change from B to E by subtraction of potash-rich material, and second, change from E to B by subtraction of soda-rich material. But the first possibility is actually improbable. No evidence bearing upon such differentiation was found. As a simple graphic construction will show, the change from E to B is able to accomplish by separation of sodic plagioclase and quartz. These minerals are really the dominant phenocrysts suspended in the liquids E, D, and C. In this case, however, the course of differentiation and the order of extrusion become reverse. Moreover, the rock represented by E contains the phenocrysts of plagioclase and biotite which are of the most advanced stage as shown in Fig. 3. Accordingly, the change of the magma from E to B in the way as above-mentioned is also improbable; indeed the variation can not be explained by only one course of crystallization which changes the magma from B to E or from E to B.

Unfortunately, no silicate system which demonstrates the course of crystallization of liparitic magma has ever been investigated. But if we assume that the liparitic magma is a residual liquid at the later stage of crystallization of the basaltic magma, whatever of the course of the crystallization-differentiation, SiO_2 may be the principal constituent present in addition to feldspar. Therefore, the quaternary mixtures of quartz, orthoclase, albite, and anorthite may be considered here. To point the course of crystallization, it is possible to make some very useful deductions from theoretical considerations on the ternary mixture, orthoclase, albite, and anorthite. Although the equilibrium relations between the three feldspars $KAlSi_3O_8$, $NaAlSi_3O_8$ and $CaAl_2Si_2O_8$, is yet problematical, the ternary diagram of feldspars, Fig. 5, deduced by Bowen[28] may be useful in the present connection.

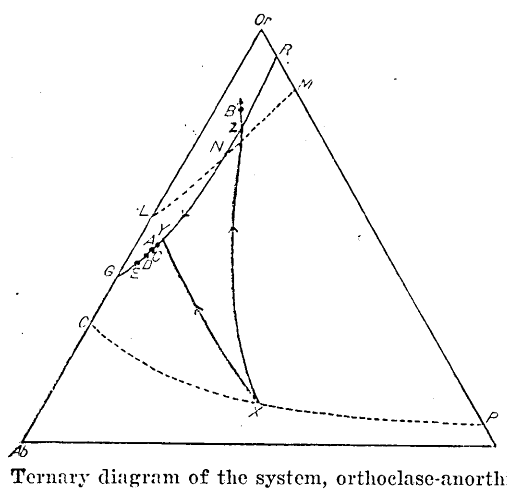


Fig. 5. Ternary diagram of the system, orthoclase-anorthite-albite (after N. L. Bowen).

28) N. L. BOWEN, The Evolution of the Igneous Rocks, (Princeton, 1928), 231.

In the figure the general relations between the three feldspars are represented. The curve GNR is the boundary between the fields of orthoclase and plagioclase. Orthoclase and albite have a eutectic point G with solid solutions on both sides; while orthoclase and anorthite is to be regarded as having a reaction relation at R. The curves OXP and LNM indicate the limits of solid solutions, orthoclase in plagioclase and plagioclase in orthoclase. The incongruent melting of orthoclase need not be considered on the crystallization of a liquid with excess silica. Now, we may take the mixture X which has the composition, orthoclase 10, albite 45, anorthite 45. The mixture crystallizes following the curve XY, if the opportunity for reaction of the separating crystals with the liquid is highly limited since early stage of crystallization. The liparitic magma may be expected in the later stage of crystallization following such a course. When the point Y is reached rather sodic plagioclase is jointed by orthoclase and the liquid changes the composition along the boundary curve towards G. On the other hand, the liquid X crystallizes following the course XZ, if perfect equilibrium prevails at least at the earlier stages. The point Z lies on the boundary curve between N and R where plagioclase reacts with the liquid to produce orthoclase. If the reaction can take place freely the liquid Z will move along the boundary curve towards E. But if reaction is prevented for any reason, the liquid Z will pass into the orthoclase field with separation of orthoclase only.

We may illustrate the variation of the rocks of Kôzu-shima with the aid of the diagram whose theoretical considerations have been outlined above. The potash-liparite (B in Fig. 4) and the plagioliparites (A, C, D, and E in Fig. 4) must have been derived by crystallization-differentiation following different courses, even if they are comagmatic in origin. The liquid X in Fig. 5, whose composition might be either andesitic or basaltic, began to crystallize with separation of plagioclase. As a result of crystal fractionation (either local grouping of the crystals or any method of prevention of reaction between the crystals and the liquid), the liquid followed the course XY. At Y orthoclase began to crystallize along with plagioclase and the liquid changed along YG. Through the course the separating plagioclase became richer in albite. In the actual rock series quartz and biotite show simultaneous crystallization with feldspar, and yet these crystal phases can not be represented in the simple ternary diagram. When the liquid became the composition A, a portion of the liquid free from phenocrysts was extruded as the aphanitic lava whose actual composition is represented at A in Fig. 4. When the liquid became the composition E, it was extruded as the Tenjô-san lava whose actual composition is represented at E in Fig. 4. In the liquid were suspended a little phenocrysts of orthoclase, quartz, plagioclase and biotite. As shown in the paragenesis diagram, Fig. 1, plagioclase and biotite changed their compositions as the crystallization advanced. The plagioclase and biotite suspended in E are of the most advance stage. The rocks represented by C and D in Fig. 4 are of such compositions of the liquid and such stages of crystallization as those represented by the corresponding points in Fig. 5. The rocks C and D contain conspicuous, though sporadical, phenocrysts respectively of hornblende and hypersthene. But there are reasons for believing that these minerals are not ones with which the liquids were saturated, at least when the lavic magmas were about to be extruded. The refractive index of the groundmass glass of the biotite-plagioliparite varies, as has been plotted in Fig. 3, in approximately linear relation with the composition of the plagioclase suspended in the glass. On the other hand, Fig. 1 illustrates a distinct paragenic relation of plagioclase and biotite. Since abrupt change of composition of liquid may be expected whenever a new crystal phase begins to crystallize, it seems probable that, if the liquid were saturated with either hypersthene or hornblende, the liquid (groundmass) might have shown some aberration from the relation shown in Fig. 3. But actually the groundmasses of the hypersthene- and hornblende-plagioliparites fall just on the line in Fig. 3, the plagioclases in these rocks being more sodic ($Ab_{77}An_{23}$) than the least sodic plagioclase ($Ab_{73}An_{27}$) in a biotite-plagioliparite. A deduction from this relation is that the groundmasses of the hypersthene- and hornblende-plagioliparites may have been saturated with biotite. In this connection, it should be noted first, that these two rocks carry minute flakes of biotite, and second, that the hypersthene-plagioliparite carries xenoliths of basaltic nature in which augite has been subjected to reaction with the liparite magma and transformed partly to green hornblende (cf. p. 296). From the behavior of the xenolith it is inferred that, whereas the conspicuous mafic mineral is hypersthene, the groundmass of the hypersthene-plagioliparite has been saturated with biotite, and that, by interaction with this liquid, the augite crystals in the xenolith have been partly converted into hornblende without changing far into biotite. The hypersthene- and hornblende-plagioliparites might be extruded from a portion of the magma where the cooling was a little more rapid than the portion wherefrom the biotite-plagioliparites came. As the results the serial variation of the liquid compositions and the actual relations of the phenocrysts and the groundmasses may be expected.

The variation of the liquid, from which the plagioliparites have been derived, is of only a short interval of the course of crystallization corresponding to AE in the ternary diagram. By simple graphic construction it is ascertained that to change the composition A to the composition B in the variation diagram, Fig. 4, quartz, orthoclase, sodic plagioclase, and some mafic minerals are to be subtracted. All of these minerals are present more or less in the actual rocks. The relative amount of these minerals is dependent on the relative movement of different kinds of the crystals. It was already mentioned that quartz and sodic plagioclase might be rather heavier than the residual liquid even in the plutonic condition.

The potash-liparite represented at B in Fig 4 has been produced by crystallization which might start on X in Fig. 5, but followed a different course XZ. When the liquid reached the point, Z, orthoclase began to crystalize along with plagioclase. But further reaction was prevented and the liquid B was reached with separation of orthoclase only. Accordingly, the liquid is very rich in potash but very poor in soda. The liquid corresponds to the potash-liparite whose actual composition is represented at B in Fig. 4.

From what has been stated, the curves in Fig. 4 can not be considered as the real liquid line of descent for the rocks of Kôzu-shima. They correspond to the curves obtained by plotting, after the method of the ordinary variation diagram, the change of the various oxides at B, A, C, D, and E in the ternary diagram.

Summary.—As the results of this investigation, the petrology of Kôzu-shima is summarised as follows:

All the rocks of the island have been developed from a common magma by fractional crystallization. The magma continued to crystallize following different courses. By low crystal fractionation (high reaction), potash-rich liquid from which the potash-liparite has come was formed. On the other hand, by high crystal fractionation (low reaction) the sodi-potassic liquid from which the plagioliparites have come was formed. Variation within the plagioliparites may be elucidated by the simultaneous separation of feldspar, quartz, and some mafic minerals. The hypersthene- and hornblende-plagioliparites were extruded from a portion where rather rapid cooling limited the opportunity for reaction in such a manner that either hypersthene or hornblende has been left as relict mineral. Among the mafic minerals (hypersthene, hornblende, and biotite), there is indication neither of reaction relations, nor of their simultaneous crystallization. The plagioclase and biotite show a regular paragenic relation, indicating the concomitant crystallization. The plagioliparites are not balanced in proportion of orthoclase and plagioclase, orthoclase being much less in amount than plagioclase. The relative amount of these minerals may be due to their relative movement in the liquid. The variation of the rocks of Kôzu-shima may be explained by fractional crystallization which starts on a common magma. The courses of crystallization correspond fairly well with those expected in the ternary mixtures, orthoclase, albite, and anorthite. The deduced courses of fractionation explain the variation, microscopical as well as chemical of the rocks of Kôzu-shima. Thus, the rock sequence in the order of differentiation:

Original magma → potash-liparite.
Original magma → { aphanitic liparite → biotite-plagioliparites.
hypersthene-plagioliparite.
hornblende-plagioliparite. }

Chapter V. Comparison of Certain Aspects of Volcanoes in the Seven Izu Islands.

General Remark.—The "fossa magna," a well known volcano-tectonic zone, traverses central Japan from the Japan Sea coast to the Pacific in the direction of S. 10° E. and in this zone are arranged many volcanoes, one of which being the celebrated Volcano Fuji. This zone extends far away in the Pacific Ocean where it forms a submarine ridge which descends on its east side abruptly to a trench of over 8000 m. in depth. All of the Izu insular volcanoes rest on this submarine ridge and are considered to belong to the so-called Fuji Volcanic Zone which is represented by the volcano-tectonic zone.

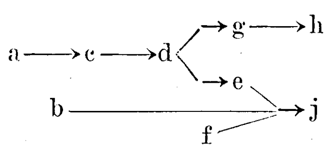
In examining the bathymetric map of the Bay of Sagami, we can readily find out a subsidiary but sharply defined submarine ridge which is above the afore-mentioned one and runs from N. 40° E. to S. 40° W. Being separated by the shallow sea, 100 m. or thereabout in depth, Nii-jima, Shikine-jima, and Kôzu-shima rest on this ridge whose southwestern extension reaches as far as the Zenizu rocks, while other members of the Seven Izu Islands—Ô-shima, Miyake-jima, Mikura-jima, To-shima, and Hachijô-jima are arranged in the direction of the main submarine ridge, that is in the so-called Fuji Volcanic Zone. Being annexed to the main trend, the southwesterly trend is structurally expressive, since it is not only indicated by other several submarine ridges parallel to the Nii-jima—Kôzu-shima ridge, but also by distribution of acidic rocks in the southern part of the neighbouring Izu peninsula.

Thus the insular volcanoes are naturally divided into two groups, Nii-jima group and Ô-shima group, as already remarked by the previous writers.

Kôzu-shima and Nii-jima.—Nii-jima was studied in detail geologically as well as petrographically, by Fukuchi.[29] According to him, the rocks of the island are divided into the following kinds, with the exception of the loose products:

Pyroxene-liparite.	(1)	Enstatite-liparite	a. Nebu-saki type
	(2)	Augite-liparite	b. Nishino-ura type
Amphibole-liparite	(3)	Pyroxene-amphibole-liparite	c. Dômaru type
			d. Wakada type
	(4)	Hornblende-liparite	e. Jinai-shima type
Mica-liparite	(5)	Pyroxene-biotite-liparite ..	f. Atomizuno-sawa type
	(6)	Biotite-liparite	g. Habushi-ura type
			h. Awai-ura type
			j. Mukô-yama type

He systematized these lavas in the order of their extrusion from earliest one to later as follows:



The writer landed twice the island and collected the rock. After careful observation, the writer can not agree with Fukuchi as to the order of extrusion of these rocks, but he thinks for certain that the biotite-liparites are younger in eruption than all the other. The collected samples were studied under the microscope. The petrographic description of these rocks, however, is out of the scope of this paper. For the purpose of petrogenic discussion, the refractive indices of the essential minerals were determined as shown in the following table.

29) N. Fukuchi, *op. cit.*

TABLE XIV.

Type	Plagioclase	Augite (n_{1D})	Hornblende (n_{1D})	Biotite (γ_D)
a	n. d.	—	—	—
b	$Ab_{72}An_{28}$	1·698	—	—
c	$Ab_{76}An_{24}$	1·696	1·645	—
d	$Ab_{78}An_{22}$	n. d.	1·642	—
e	$Ab_{66}An_{34}$	—	1·649	—
f	n. d.	n. d.	—	n. d.
g	$Ab_{84}An_{16}$	—	—	1·664
h	$Ab_{84}An_{16}$	—	—	1·678
j	$Ab_{82}An_{18}$	—	—	1·700<

In comparing with the paragenic relations of the minerals in the rocks of Kôzu-shima, the above table shows that the rocks of Kôzu-shima are genetically related with those of Nii-jima. In the rocks of Nii-jima, the plagioclase phenocrysts more calcic in composition than $Ab_{78}An_{22}$ are always in accompany with either pyroxene or hornblende, while the corresponding plagioclase phenocrysts in some rocks of Kôzu-shima are attended by biotite. The rock of Tenjô-san, the latest volcano of Kôzu-shima, resembles the rock of Mukô-yama, the latest volcano of Nii-jima, in microscopical as well as chemical properties. The biotite in the rock of Mukô-yama has been subjected to thermal decomposition to result in the similar product as some biotite flakes in the rock of Tenjô-san. The biotite in the rock (h) of Nii-jima also shows the same decomposition.

TABLE XV.

Rock	Plagioclase	Augite (n_{1D})	Hornblende (n_{1D})	Biotite (γ_D)
Kôzu-shima				
Xenolith a)	$Ab_{28}An_{72}$	1·694	1·672	—
b)	$Ab_{37}An_{63}$	1·696	1·682	—
Hypersthene-plagioliparite	$Ab_{77}An_{23}$	—	—	—
Nii-jima				
Xenolith				
phenocryst	$Ab_{16}An_{84}$	n. d.	—	—
groundmass	$Ab_{54}An_{46}$	1·695	1·713	—
Biotite-liparite	$Ab_{84}An_{16}$	—	—	1·678

The biotite-liparite of Awai-ura type (h) of Nii-jima carries basic xenoliths similar in mineral constitution to the xenoliths found in the hypersthene-plagioliparite (β-lava) of Kôzu-shima. A short petrographic description of these xenoliths was already given (cf. p. 298). In Table XV are summarized the refractive indices of the constituent minerals of the xenoliths, together with the rocks in which these xenoliths are carried.

The xenoliths, either of Kôzu-shima or of Nii-jima are not the dark patches or seggregations in the liparites as usually found in granites. Whether they are in direct genetical relation with liparites, is a matter of great importance, since these xenoliths and the basaltic rocks of the Ô-shima group including the basaltic ejecta of Nii-jima show not only petrogenic relations between the constituent minerals, but also chemical resemblance (cf. p. 297). If such a xenolith were a seggregated clot in the liparite, therefore, it would afford a strong evidence for concluding that the both extreme types of rocks in the Izu insular volcanoes are in intimate genetical relation. In any case, however, the fact that the xenoliths, which are correlative with the basaltic rocks of the Ô-shima group, have been enclosed in the liparites is an evidence for believing that the liparitic lavas are as young as the basaltic ones in the Izu insular volcanoes.

Nii-jima Group and Ô-shima Group.—As to the age relation between the liparitic and basaltic volcanoes in the Izu islands, two opinions have been raised among geologists. Fukuchi,[30] Kato,[31] and Kozu[32] considered that the liparitic vulcanisms are older than the basaltic ones, the former being correlated to the latest Tertiary vulcanism in the southern part of the Izu peninsula. Studying the geology of Nii-jima, Fukuchi reached the conclusions that the liparitic islands (Nii-jima, Shikine-jima, and Kôzu-shima) are to be geologically correlated to the Tertiary volcanoes (liparites and allied rocks) in the southern part of the Izu peninsula, both being situated structurally on the west of the Fuji Volcanic Zone to which the basaltic volcanoes both in the islands and in the peninsula belong, and that the liparitic insular volcanoes are to the basaltic ones what the Tertiary volcanoes in the southern part of the peninsula are to the volcanoes, Fuji, Hakone, Amagi, etc. in their aspects, morphological as well as geological.

30) N. FUKUCHI, *Report Earthq. Invest. Com.*, **39** (1902), 4–40, (in Japanese).
31) T. KATO, *Ibid.*, **63** (1909), 23–32, (in Japanese).
32) S. KOZU, "Geology of the Southern Part of the Izu Peninsula," *Report Geological Survey*, **38** (1913), 1–38, (in Japanese).

Tsujimura[33] and Tsuboi[34] raised an objection to the views of the previous writers respectively from morphological and geological standpoints of view. Giving some critical review on the previous works, Tsuboi expressed in his "Volcano Ô-shima" the opinions that the Izu insular volcanoes are to be divided into Ô-shima group and Nii-jima group, and that all the volcanoes of these two groups are very young, the basaltic Ô-shima, Miyake-jima, and Hachijô-jima on the one hand and liparitic Nii-jima and Kôzu-shima on the other having displayed volcanic activity in historic times.

The idea that the liparitic volcanoes are as young as the recent basaltic ones seems to be heterodoxical to those who follow the doctorine that the former represents in our country of the pre-andesitic vulcanism of the Tertiary period. But the writer's personal observations both in Nii-jima and in the Izu peninsula were nothing but indorsing the views proposed by Tsujimura and also by Tsuboi.

Being very close to the basaltic Udone-shima (1 km. to the south), the liparitic lava at the northern end of Nii-jima is capped by a basaltic ejecta-bed. This relation between a liparitic lava and a basaltic ejecta-bed induced Fukuchi to conclude that all the liparites and allied rocks are older than the basaltic rocks of the Ô-shima group. The basaltic ejecta resemble petrographically the rocks of the near-by basaltic insular volcanoes. In the basaltic ejecta-bed, moreover, are found not only numerous blocks of liparite, but also basaltic blocks in which liparitic fragments are caught. It is, therefore, certain that the basaltic ejecta are of younger date than the underlying liparite. Nevertheless, the biotite-liparites which are of the latest vulcanism on Nii-jima are on no occasion covered by the basaltic ejecta-bed and, on the contrary, the biotite-liparite of Awai-ura type (h) rests on the bed, catching numerous basic xenoliths. As already mentioned, the basic xenoliths are not seggregated clots in liparite, being correlative petrographically and chemically to the basaltic rocks of the Ô-shima group. Accordingly, the presence of these xenoliths is a strong evidence for believing that some of the liparitic lavas are as young as the basaltic ones. The basaltic blocks are moreover imbedded in the liparitic ejecta-bed ("Shiromama" bed) of Nii-jima.

From what has been stated, it is an indisputable fact that in the insular volcanoes the liparitic rocks erupted, alternately with the basaltic ones, still in very recent times. To say nothing of the basaltic vulcanism of Ô-shima, Miyake-jima, etc., the liparitic vulcanism of Kôzu-shima and

33) T. TSUJIMURA, *Report Earthq. Invest. Com.*, **89** (1918), 57–96, (in Japanese).
34) S. TSUBOI, *Jour. Col. Sci. Tokyo Imp. Univ.*, Art. 6, **43** (1920), 125–141.

Nii-jima is also recorded in some reliable annals of the ancients.[35] The basaltic Ô-shima, Miyake-jima, and Hachijô-jima have many historic records of outburst whose latest ones being in 1923, 1847, and 1605 respectively. On the other hand, either one of the liparitic volcanoes, Kôzu-shima and Nii-jima has only one historic record of eruption, namely Kôzu-shima in 838 and Nii-jima in 886. Whether these liparitic eruptions were in such a nature that new lavas were extruded in quantity sufficient to form distinct volcanoes, the historic records are too unsatisfactorily detailed. But both islands bear no trace of recent explosion, either volcanic or phreatic; and on the contrary, Tenjô-san and Mukô-yama volcanoes respectively in Kôzu-shima and Nii-jima have very young morphological features, so young that they may well date from historic times. Thus, the liparitic volcanoes in the Izu islands are in all probability as young as the basaltic ones, being one of the leading examples of the recent liparitic volcanoes in the world.[36]

The insular volcanoes of Ô-shima group and Nii-jima group, besides being situated close together, have thus displayed volcanic activity alternately. It is, therefore, of no little importance to see whether the rocks of the two groups are genetically related with each other.

As far as the bulk composition is concerned, the rocks of the two groups have gone to the opposite extremities, the Ô-shima group being of extremely basic and the Nii-jima group highly acidic, and there is none which has an intermediate chemical composition between the two extremities. The rocks of the Ô-shima group are all basaltic in both chemical and normative mineral compositions, while the amount of SiO_2 in them is in excess to form the highest silicates, the excess silica being left as occult quartz in the norms. But actually these rocks are characterized by such califemic minerals as hypersthene and either olivine or augite. The plagioclase phenocrysts, modal as well as normative, are represented by bytownite. On the contrary,

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35) Zoku-Nihon-kôki (續日本後記), Sandai-jitsuroku (三代實錄), Nihon-kiryaku (日本紀略), and Fusô-ryakki (扶桑記略). See F. Omori and S. Nakamura, *op. cit.*,

36) According to I. Friedländer ("Vulkaninseln Griechenlands," *Zeitschrift für Vulkanologie*, 8 (1924)), recent acidic volcanoes in the world are:

Kôzu-shima .... Liparit
Nii-jima .... Ditto
Lassen Peak .... Ditto (Dacit?), seit 1913, Kalifornien
Guadajara .... Ditto, noch etlich Fumarolen, Mexiko
Monte Pelato .... Ditto, Lipari
Phyriplaka und Trachylas .. Ditto, Milos (Vulkaninseln Griechenlands)

To these we may add the volcano Esan (Atsusa-nupri) in Hokkaido, which is built up of augite-plagioliparite or rhyodacite.

TABLE XVI.

	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	XIII
SiO_2	53·10	51·45	54·55	53·35	49·91	50·79	50·74	71·64	74·93	75·35	75·10	76·60	76·05
Al_2O_3	14·73	16·84	16·26	15·62	18·13	16·61	18·59	14·13	13·52	13·49	13·36	13·22	12·44
Fe_2O_3	3·38	1·49	4·07	4·21	3·87	6·96	9·23	0·34	0·76	0·95	0·30	0·27	0·84
FeO	9·42	10·95	8·02	8·21	5·48	3·51	1·01	0·50	0·72	0·55	0·74	0·43	0·22
MgO	4·97	4·48	3·66	4·44	6·16	7·63	5·37	0·08	0·32	0·36	0·27	0·19	0·17
CaO	9·09	10·71	8·91	9·68	9·90	10·03	10·21	0·17	0·93	1·61	1·43	0·75	0·87
Na_2O	2·09	1·23	2·44	2·18	2·33	2·58	2·35	0·50	4·50	4·28	4·21	4·62	4·31
K_2O	0·44	0·37	0·32	0·84	0·37	0·55	0·57	10·77	3·39	2·52	1·58	1·61	2·88
H_2O+	1·22	0·72	0·05	0·06	1·90	0·07	0·74	0·23	0·46	0·06	0·17	0·11	1·66
H_2O-			0·24	0·34	0·88	0·31	0·16	0·80	0·33	0·61	2·27	1·50	0·11
TiO_2	1·03	1·27	1·19	1·18	0·87	1·01	0·98	0·55	0·13	0·20	—	—	0·12
P_2O_5	0·11	0·26	—	—	—	—	0·06	0·08	0·08	—	—	—	tr.
MnO	0·34	0·19	—	—	—	—	0·16	tr.	0·08	0·08	0·10	0·16	0·07
ZrO_2	0·04	—	—	—	—	—	—	—	—	—	—	—	
CO_2	—	—	0·24	tr.	tr.	0·19	—	—	—	—	—	—	
Total	99·87	99·96	99·95	100·02	99·90	100·24	100·14	99·79	100·15	100·06	99·53	99·46	99·74

Q	9·6	8·8	13·4	9·6	4·3	4·4	6·5	27·6	33·2	37·1	41·2	41·6	37·9
Or	2·8	2·2	1·7	5·0	2·2	3·3	3·0	63·3	20·0	15·0	8·9	9·4	17·2
Ab	17·8	10·5	20·4	18·3	19·9	22·0	19·9	4·2	38·2	36·1	35·1	38·8	36·1
An	29·2	39·2	32·0	30·4	37·8	32·0	38·4	—	3·9	7·2	6·9	3·6	4·2
C	—	—	—	—	—	—	—	1·6	0·9	1·0	2·3	2·5	0·7
Di	12·4	10·3	8·0	14·6	9·1	13·8	9·1	—	—	—	—	—	—
Hy	19·7	23·2	14·6	13·4	16·4	12·7	9·4	1·6	1·3	0·9	0·6	1·2	0·5
Mt	4·9	2·1	5·8	6·0	5·6	8·4	0·3	—	1·2	1·2	0·2	0·2	0·4
Il	2·0	2·4	2·3	2·3	1·7	1·9	1·8	1·0	0·3	0·5	—	—	0·1
Ap	0·3	0·6	—	—	—	—	—	0·3	0·3	—	—	—	—
Hm	—	—	—	—	—	1·2	8·6	0·3	—	2·0	—	—	0·5

Ô-shima Group.

Ô-shima I. The somma lava (basaltic bandaite).
II. The central cone lava (miharaite).

Miyake-jima III. A specimen from the summit (augite-andesite).
IV. The lava of 1874 (olivine-bearing feldspar-basalt).

To-shima V. A specimen from 60 m. down the top (olivine-bearing feldspar-basalt).

Udone-shima VI. Locality not mentioned (olivine-bearing feldspar-basalt).

Nii-jima Group.

Kôzu-shima VII. Basic xenolith in the plagioliparite.
VIII. α-Lava (potash-liparite).
IX. Ombashi-jima lava (aphanitic rock).
X. β-Lava (hypersthene-plagioliparite).
XI. δ-Lava (hornblende-plagioliparite).
XII. Tenjô-san lava (biotite-plagioliparite).

Nii-jima XIII. Mukô-yama lava (biotite-plagioliparite).

the rocks of Nii-jima group are extremely high in SiO_2 and low in femic oxides. Hypersthene is the only califemic mineral in the norms calculated from the chemical compositions, though the rocks actually diversified by the presence of biotite, hornblende, and pyroxene. Excepting the potash-liparite, the amount of Na_2O is always larger than that of K_2O and dominant feldspar, normative as well as modal, is oligoclase. The chemical composition along with the normative mineral compositions of the rocks of the two groups are shown in Table XVI. As seen from the table, of the genetical relation

TABLE XVII.

Rock	Plagioclase	Augite (n_{1D})	Hypersthene (n_{1D})
	$Ab_{77}An_{23}$	—	1·700 (5)
Xa	$Ab_{28}An_{72}$	1·694	—
Xb	$Ab_{37}An_{63}$	1·696	—
11	$Ab_{27}An_{73}$	1·691 (5)	n. d.
b	$Ab_{72}An_{28}$	1·698	—
Xn	$Ab_{16}An_{84}$	n. d.	—
(groundmass)	$Ab_{54}An_{46}$	1·695	—
En	$Ab_{27}An_{73}$	1·692	—
A	$Ab_{15}An_{85}$	1·686 (5)	n. d.
66	$Ab_{25}An_{75}$	1·691 (5)	—
10	$Ab_{32}An_{68}$	1·696	—
12	$Ab_{25}An_{75}$	1·691 (5)	—
M	$Ab_{25}An_{75}$	1·691	n. d.
H	$Ab_{27}An_{73}$	1·692	—

Nii-jima Group.
Kôzu-shima
Xa } Xenoliths in the Hypersthene-
Xb } plagioliparite (β-lava).
11 Two-pyroxene-andesite (ejecta in the Chichibu-yama ejecta-bed).
Nii-jima
b Augite-liparite (lava of Nishino-ura type).
Xn Xenolith in the lava of Awai-ura type.
En Olivine-augite-andesite (ejecta in the basaltic ejecta-bed).

Ô-shima Group.
Ô-shima
A Hypersthene-bearing olivine-bytownite-basalt (somma lava).
Miyake-jima
66 Olivine-augite-andesite (central cone lava).
10 Augite-andesite (lava at Tsubota).
12 Ditto (Benkene lava).
Mikura-jima
M Pyroxene-andesite (lava at the landing place).
Hachijô-jima
H Pyroxene-andesite (lava, locality uncertain).

between the two groups nothing can be drawn from the chemical relation, the only fact being that they are of calci-alkalic suit.

Some rocks of the two groups have in common, plagioclase and one or both of hypersthene and augite as phenocrystic minerals. These minerals, therefore, are useful for the petrogenic discussion. In Table XVII are shown the compositions of the plagioclase phenocrysts and the refractive indices of the associating pyroxene phenocrysts, following S. Tsuboi's optical analysis.

The above table shows distinctly that the monoclinic pyroxenes in association with less calcic plagioclases have higher refractive indices. Thus, the paragenic relations between these porphyritic minerals can well be likened to those of rocks of a distinct lineage. Here, however, it is confronted with a certain difficulty to conclude that the two groups are genetically related with each other, being wanted in an intermediate rock type which may link the one group to the other. In addition, when two or more mafic minerals are present in a rock, the paragenic relation between the mafic minerals and the associating plagioclases becomes complex. To judge whether some of such rocks are genetically related with each other, therefore, requires further investigation.

In concluding this chapter, the rocks of the Izu insular volcanoes are divided into two groups, Ô-shima group and Nii-jima group, and it is beyond question that all the liparitic rocks of the Nii-jima group are not older than the basaltic rocks of the Ô-shima group, but both kinds of rock have been extruded alternately, no matter what their genetical relations may be. Even if the rocks of the two groups are comagmatic in origin, they have been too widely differentiated to be put easily in direct relation.

Chapter VI. Geological Relations of the Seven Izu Islands to the Izu Peninsula.

For the discussion on the volcanologic history of the Seven Izu Islands, it is desirable to know the geology of the near-by Izu peninsula, because it is reasonably expected that the southern part of the peninsula has some geological connection with the Izu islands.

Geology of the Izu Peninsula.—The references to the geology of the Izu peninsula are to be found in a paper By H. Ishiwara[37] and that by S.

37) H. ISHIWARA, "Geology of the Volcanoes of Izu Peninsula," *Report Earthq. Invest. Com.*, 17 (1898), 3–49, (in Japanese).

Kozu.[38] The geology of the Volcano Amagi was specially studied by J. Suzuki.[39]

In the winter of 1925–6, the writer made a short visit to the vicinity of Shimoda. But it is not the writer's intention in this paper to discuss the geology of the whole of the peninsula, nor to give detailed description of the rocks. The present aim is limited to find anything pertaining to the geology of the Izu islands.

The southern part of the peninsula is largely built up of volcanic rocks accompanying tuffs, agglomerates, and breccias. As far as the writer's observations go, these rocks are in sequence: propylite, tuffite, potash-liparite, plagioliparite, dacite, and pyroxene-andesite. The propylite occupies a considerable portion and is covered unconformably by the tuffite. The propylite is an altered andesite, though its characters, macroscopical as well as microscopical, are quite multifarious. Sometimes it is hardly distinguished from the fresh andesite.[40]

Throughout the greater part of the district of Shimoda, the sedimentary rocks are of volcanic origin, occupying a considerable portion of the area. They often exhibit a distinct bedding, owing to the alternation of layers of coarser and finer materials. Fine tuff and tufaceous sandstone alternate with andesite-agglomerate and tuff-breccia. Sometimes the white tuff is coarsely mottled with black patches of andesite, occasionally along with fragments of pitchstone, perlite, and obsidian. Besides, andesite sheets are sandwiched in between these beds, and also andesite dikes run through the latter. A large outcrop of liparitic perlite is found in the tuff-breccia at Hayashi-yama, 2 km. to the west of Shimoda. Thus, these tufaceous beds are of both andesitic and either liparitic or dacitic materials, these materials being often commingled with each other. In places the beds are fossiliferous, containing several marine fauna,[41] though not sufficiently well preserved to be identified. As the rocks become more calcareous, so do the fossils

38) S. KOZU, "Geology of the Southern Part of Izu Peninsula," *Report Geological Survey*, **38** (1913), 1–19, (in Japanese).

39) J. SUZUKI, "Geology of Volcano Amagi," *Jour. Geol. Soc. Tokyo*, **28** (1922), 431–448, (in Japanese).

40) For the sequence of the formations of the peninsula, the conceptions of the previous writers diverge. According to Kozu the geological sequence of the southern part of the peninsula is: plagioliparite, potash-liparite, propylite, liparite, Tertiary sediments, dacite, and pyroxene-andesite; all volcanic rocks accompanying their own tuffs and breccias or agglomerates.

41) According to Ishiwara these fossils are of the uppermost pliocene. See ISHIWARA, *op. cit.*, *Report Earthq. Invest. Com.*, **17** (1898), 14–17, (in Japanese).

become more numerous. Stratigraphical relations of the beds are so complicated that their detailed account may take too many pages. As far as the writer's observations go, the liparitic and dacitic lavas overlie the propylite or the more or less altered andesite, yet they are of the same general period as the corresponding tuffs which alternate with the andesite agglomerate and the andesite tuff. Accordingly, some andesites are of the same age with either the liparites or the dacites, but eruption of the andesitic rocks was further continued after that of the liparitic and dacitic rocks had ceased. Namely, eruptions of the acidic rocks and basic rocks were not followed in regular sequence, but first andesite; next andesite, dacite, and liparite; and finally andesite. The eruption of the andesite was continued up to the Quaternary period when the volcanoes of central type, Amagi, Hakone, etc. were formed.

Volcanic Rocks of the Izu Peninsula.—Detailed, petrographical descriptions of the rocks of the peninsula may be out of place here, but a few remarks are necessary for the discussion on the rocks of the Izu islands. Volcanic rocks in various kinds are represented in the peninsula, and by studying the rocks, the petrological relations to the Izu islands may be understood. The propylite is, for a while, to be put aside, since it has been

TABLE XVIII.

Rock	Plagioclase	Augite (n_{1D})	Hornblende (n_{1D})	Biotite (γ_D)
1	$Ab_{88}An_{12}$	—	—	1·665 (5)
2	$Ab_{62}An_{38}$	—	1·666	—
3	$Ab_{41}An_{59}$	1·691	—	—
4 a)	$Ab_{28}An_{72}$	1·689	—	—
b)	$Ab_{48}An_{52}$	1·690	—	—
c)	$Ab_{56}An_{44}$	1·691	—	—
5 a)	$Ab_{25}An_{75}$	1·689	—	—
b)	$Ab_{25}An_{75}$	1·690	—	—

1—Plagioliparite (lava of Mikura-yama at the boundary of Asahi-mura and Chikuma-mura, 4 km. to the west of Shimoda).
2—Dacite (lava of Takane-san, 3.5 km. to the northwest of Shimoda).
3—Auganite (lava-sheet at Susaki, 3 km. to the southeast of Shimoda).
4—Andesites (lavas of the Volcano Amagi), a) Asama-yama lava; b) Tôgasa-yama lava; c) Io-yama lava.
5—Andesites (lavas of the Volcano Hakone), a) Myôjô-yama lava; b) Myôjin-yama lava.

subjected to more or less the so-called propylitization whose origin is another important problem. The refractive indices of the essential mafic minerals and the composition of the associating plagioclases in the rocks of the peninsula are given in Table XVIII.

The plagioclases and pyroxene in the andesitic rocks of the peninsula show a regular paragenic relation; while the same relation between the plagioclases and mafic minerals in the liparite and dacite remains uncertain for absence of mafic minerals common to these rocks. The genetical relation, which may be suggested by paragenic relations of porphyritic minerals, between the andesitic rocks and the liparitic rocks of the peninsula is to be left for further study. Then, the question that is just to be solved is whether the liparitic rocks and the andesitic rocks of the peninsula are genetically related with the corresponding rocks of the Izu islands.

From the data given in Table XVII (p. 326) and XVIII (p. 329), the paragenic relations between plagioclase and pyroxene in the rocks of both the peninsula and the islands are graphically represented below.

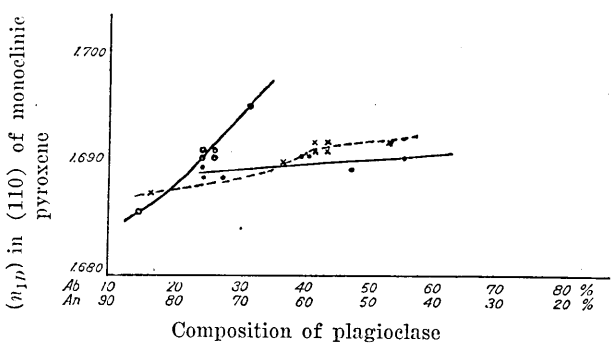

Fig. 6. The actual paragenic relations of plagioclases and monoclinic pyroxenes in the rocks of Izu islands (thick line), Izu peninsula (thin line), and Tokachi in Hokkaido (broken line).

As seen from the figure, the paragenic relation in the basaltic rocks of the insular volcanoes is not represented on the same curve as that of the corresponding relation in the andesitic rocks of the peninsula. Accordingly, andesitic or basaltic rocks of both regions seem to be of two distinct genetical lineages. But it must be in mind that a rock series which shows a definite paragenic relation is of a genetical lineage, yet all the rocks of comagmatic origin do not always show a definite paragenic relation, that is to say, even if a number of rocks are of comagmatic origin, some of these rocks may belong to a different genetical lineage. If the magma had cooled uniformly in its every portion, the volcanic rocks resulted from quenching of the magma at various stages of cooling would be enlisted in a definite genetical lineage. But the rate of cooling is not, in all probability, uniform through the magma and, therefore, the rocks resulted from a portion of the magma may be different in genetical lineage from those resulted from another portion of the same magma. From the figure we can suggest that the basaltic rocks of the insular volcanoes, among which Ô-shima and Miyake-jima are yet active, were derived from a portion of the magma where the cooling might be slower than another portion, wherefrom the andesitic rocks of the peninsula had come in the Diluvio-Tertiary period. On the same figure may be plotted the augite-liparites of Nii-jima, but it is not certain with which of the two lineages of andesitic rocks they are genetically related.

The liparitic rocks of the peninsula and those of the islands are genetically related with each other, the biotite-plagioliparite from Mikura-yama (No. 1, Table XVIII, p. 329) comes just on the curve showing the paragenic relation between plagioclases and biotites in the liparites of Kôzu-shima (cf. Fig. 1, p. 306). But, at present, data on this subject are too poor to give decisive conclusion.

If the suggestion, by means of the optical analyses of the rock minerals, that the andesitic rocks of the peninsula and those of the islands are different in genetical lineage is not erroneous, it may be expected that the chemical characters of these rocks will show some particular relations. The bulk compositions and any classification based upon them have, as they are, not any petrological problem to be discussed, but in order to see whether the rocks of one region have distinct chemical characteristics, it will be permissible to use the bulk composition.

The refractive indices and the chemical compositions of the rock minerals have to be mutually related, though the actual interdependence must be determined by means of quantitative chemical analyses of the optically analysed minerals.

The relations between the compositions of the normative plagioclases and those of the normative mafic minerals may or may not reflect the paragenic relations of the modal minerals in the same rocks. In order to ascertain this expectation, the normative mineral compositions of the rocks of the region now concerned were calculated (Table XVI, p. 324). According to the normative representation of the C. I. P. W. quantitative system, composition of plagioclase depends upon the relative amount of lime and soda combined with alminium silicate to form anorthite and albite respectively; and normative pyroxene is silicate of ferrous oxide and magnesia, together with or without lime left after forming the plagioclase.

The refractive indices of ferromagnesian minerals seem to change effectively according to the relative amount of ferrous oxide and magnesia held in them. Therefore, the relation between the ferro-magnesian ratio of normative pyroxenes and the compositions of normative plagioclases may be parallel to the relation between the refractive indices of modal pyroxenes and the composition of modal plagioclases.

In Figure 7, the composition of normative plagioclase is denoted by the Ab% on the abscissa; and the molecular ratio of FeO (+MnO) and MgO combined to form normative pyroxene is denoted by the ordinate.

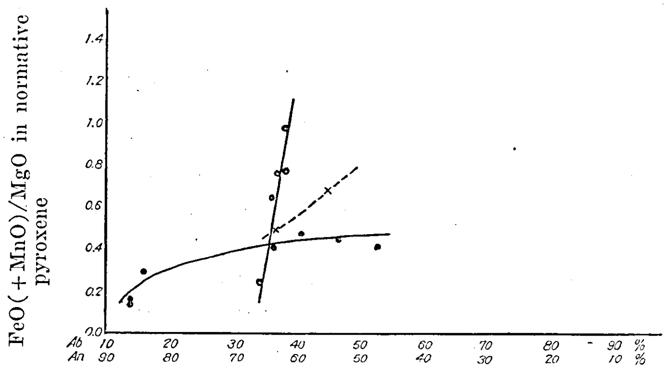

Fig. 7. The relations of the normative plagioclases and ferro-magnesian ratios in the normative pyroxenes in the rocks of Izu islands (thick line), Izu peninsula (thin line), and Tokachi in Hokkaido (broken line).

As seen from the figure, the ratio FeO(+MnO) : MgO in the normative pyroxene increases as the normative plagioclase grows rich in albite. The rocks of a distinct genetical lineage are arranged on a distinct curve. Thus, as in the paragenic relation of the optically analysed porphyritic minerals, so in chemical relation deduced from the bulk compositions of the rock, the basaltic rocks of the Izu insular volcanoes are different in lineage from the andesitic rocks of the Izu peninsula. For the comparison, the chemical relation of the normative minerals of the andesitic rocks of Volcano Tokachi in Hokkaido is also shown in the figure. The actual paragenic relation of the porphyritic minerals in the rocks is given in Fig. 6 (p. 330).[42] In the rocks

42) F. TADA and H. TSUYA, "The Eruption of the Tokachi-dake Volcano, Hokkaido, on May 24th, 1626," *Bull. Earthq. Research Inst., Tokyo Imp. Univ.*, 2 (1927), 84, (in Japanese).

of the volcano, we see that the curve showing the paragenic relation of the porphyritic minerals is in the similitude of the curve showing the chemical relation of the normative minerals. Comparing the figures, therefore, we may assume that the compositions of the porphyritic minerals run parallel with the compositions of the rocks. The refractive indices of pyroxene seem to change effectively in proportion to the ferro-magnesian ratio in the mineral. But this assumption is yet not well grounded, since in actual cases the rock-forming minerals are complex in their constitutions. Especially that is the case in biotite and hornblende, so that the liparitic rocks in which these minerals are widely diffused, must be kept from the present discussion.

The variation diagram do not show the above-mentioned particular relations between the rocks of the peninsula and those of the islands. Throughout the whole period (Tertiary and subsequent ages), the sequence of eruption of the liparitic rocks are from less silicic to more silicic, at the same time potash being richer in earlier rocks while soda in later ones. The basaltic rocks have changed from those of intermediate acidity of the peninsula to more basic ones of the islands. Moreover, the variation diagram constructed from the chemical analyses of the rocks of both the peninsula and the islands does not show any distinct serial relation.[43] But the chemical compositions have some common characteristics that are good for distinguishing these rocks from those of other districts. The rocks of the Izu region are always higher in CaO and lower in alkalies, while the other oxides are present respectively in slightly varied amounts. The same thing is also said when the Niggli's projection diagram is constructed and compared with the type-diagram of calc-alkali rocks.[44]

Very little can be said now concerning the process of differentiation through which the various rocks of the Izu region have been derived. If we assume for a moment that all the rocks are of comagmatic origin, the processes of differentiation must have been followed on condition, though tentative, that

1) the andesitic rocks of the Izu peninsula and the basaltic rocks of the Izu islands are of respective distinct genetical lineage;
2) the andesitic rocks of the peninsula were extruded from a portion

43) It seems more reasonable that if a magma is subjected to the crystallization-differentiation, the resulting various rocks are to be arranged in a variation diagram which shows neither linear nor smoothed serial relations.

44) CONRAD R. BURRI, *Min. Pet. Mitt.*, **6** (1925), 1.

of the magma where the rate of cooling was more rapid than another portion wherefrom the basaltic rocks of the islands have been erupted; and

3) the liparitic rocks of the Izu islands are genetically related with the similar rocks of the peninsula and these rocks have been erupted, alternately with the andesitic rocks since the Tertiary period.

The general rock sequence in the order of extrusion may be systematized in the following scheme:

Izu peninsula	Izu islands
Propylite → andesite → basaltic andesite	Basaltic andesite
Potash-liparite → dacite → plagioliparite	Potash-liparite → plagioliparite

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18. 神津島火山

地震研究所 津屋弘逵

神津島は伊豆七島の一であつて、大島の南西六十粁の距離にある。本島は流紋岩火山の重疊せる火山島であつて、その火山は大島の如き玄武岩火山と著しい對照をなしてゐる。故に先づその地形及び地質構造を明かにし、岩石をその産狀、肉眼的及び顯微鏡的性質等によつて類別記載した。次に岩石の顯微鏡的研究より知り得た事實に基いて岩漿分化の過程を論究し、進んで隣接諸島及び伊豆半島の火山岩と比較し、神津島火山の地質學的、岩石學的位置を知る手掛りを述べた。

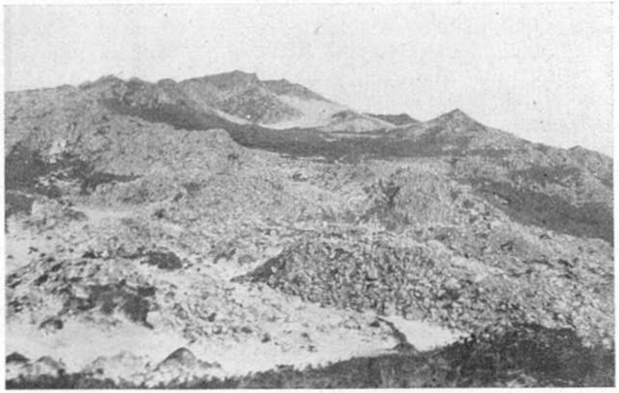


Fig. 1. The surface of the Tenjô-san lava, viewed southwards from the highest point. See p. 274.

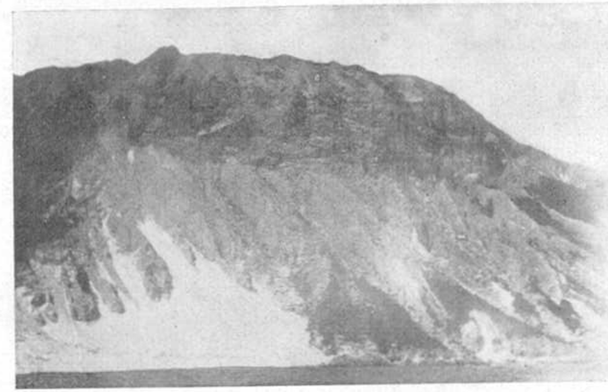


Fig. 2. The southeastern lava cliff of Tenjô-san with talus at its foot, viewed northwards from Takô-wan. See p. 275.

Fig. 3. The eastern lava cliff of Tenjô-san, with the Kushigamine ejecta below, viewed westwards. See p. 275.

Fig. 4. A distant view of the Shiroshima cinder-cone, with the Tenjô-san lava in the right, viewed eastwards from Takane-san. See p. 276.

(震研彙報、第七號、圖版、津屋)

Fig. 1. The crescentic crater of the Shiroshima cinder-cone, viewed northwestwards from the highest point of Tenjô-san. See p. 276.

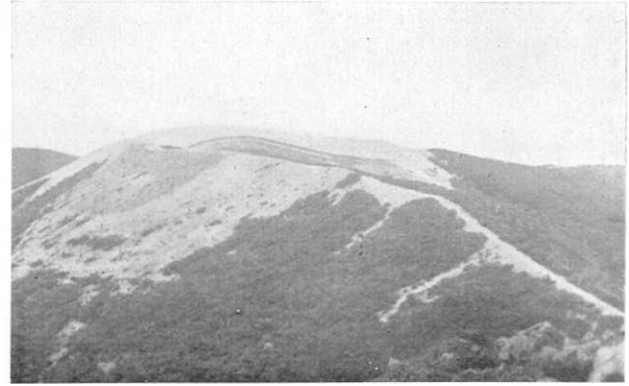


Fig. 2. The Kushigamine cinder-cone, viewed eastwards from Tenjô-san. See p. 276.

Fig. 3. The ''Shiromama'' ejecta-bed in the left and fluvial gravel in the right, at the northern shore of Mae-hama. See p. 277.

Fig. 4. The ''Shiromama'' ejecta-bed along the shore of Mae-hama. See p. 277.

（震研彙報、第七號、圖版、津屋）

Fig. 1. The summit of Jôgoro-yama, and the northern foot of Kushigamine in the right, viewed northeastwards from Tenjô-san. See p. 278.

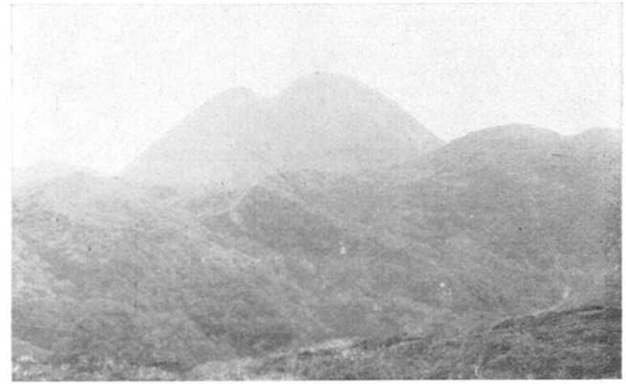


Fig. 2. Kôbe-yama, viewed northwestwards from Jôgoro-yama. See p. 278.

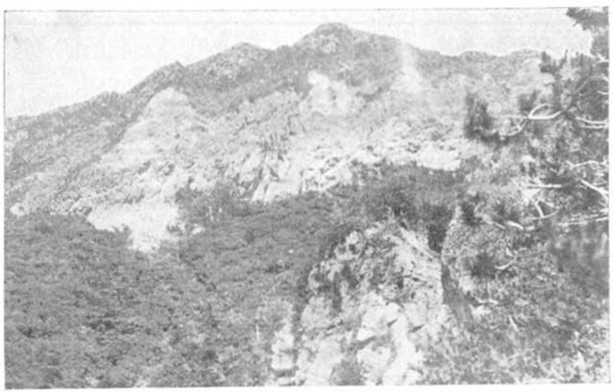


Fig. 3. The western flank of Kôbe-yama, broken lava near the summit and the ejecta-bed below. See p. 278.

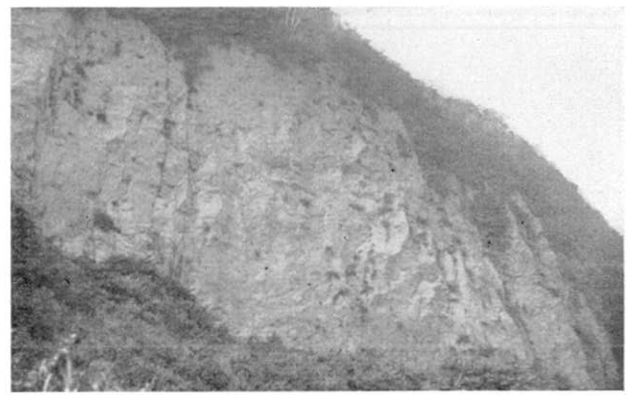


Fig. 4. The Nachi-san lava, a lava cliff fronting the valley of the Kawara, at Tachimoto. See p. 279.

[Bull. Earthq. Res. Inst., Vol. VII, Pl. XX.]

Fig. 1. Takôdo-yama, with Tenjô-san, viewed eastwards from Chichibu-yama. See p. 279.

Fig. 2. The Chichibu-yama ejecta-bed below and the "Shiromama" bed above, a view illustrating unconformity of the two formations, at Tachimoto. See p. 279.

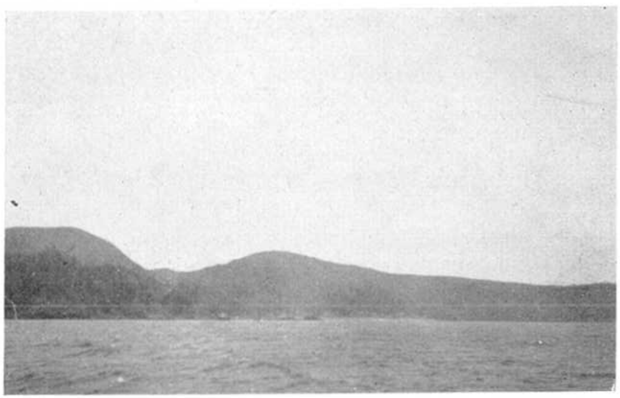


Fig. 3. General view of Chichibu-yama, as seen from the sea of the shore of Naga-hama. See p. 279.

Fig. 4. The Chichibu-yama ejecta-bed at Yokokawa. See p. 280.

(震研彙報、第七號、圖版、津屋)

Fig. 1. The Chichibu-yama ejecta-bed near the pass between Chichibu-yama and Takôdo-yama. See p. 280.

Fig. 2. Ditto, above the β-lava, near Kinnaga-hana, southwestern coast. See p. 280.

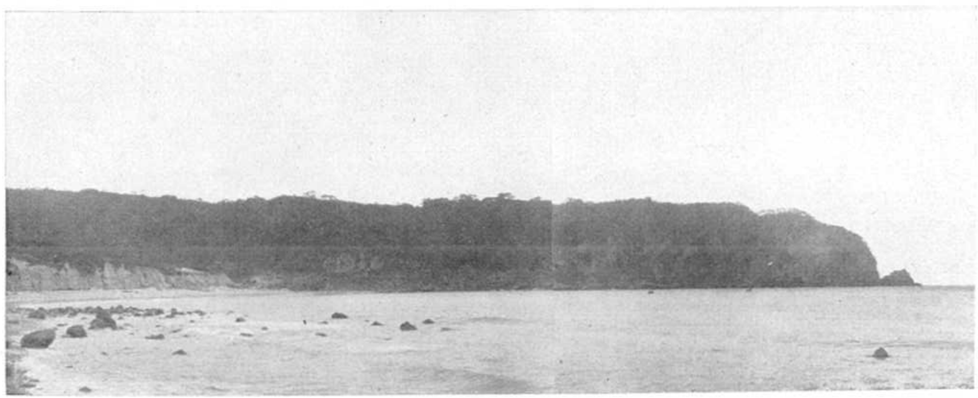


Fig. 3. The lava forming the table land of Membô, and the "Shiromama" bed along the shore of Mae-hama in the left. See p. 280.

（震研彙報、第七號、圖版、津屋）

Microphotographs of the Rocks of Kôzu-shima.

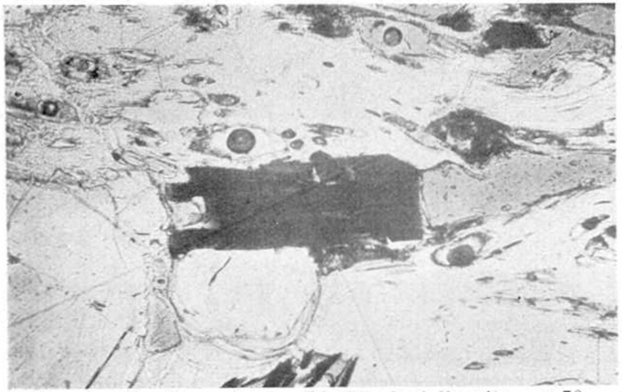


Fig. 1. Tenjô-san lava. Biotite-plagioliparite. ×70.
See p. 282.

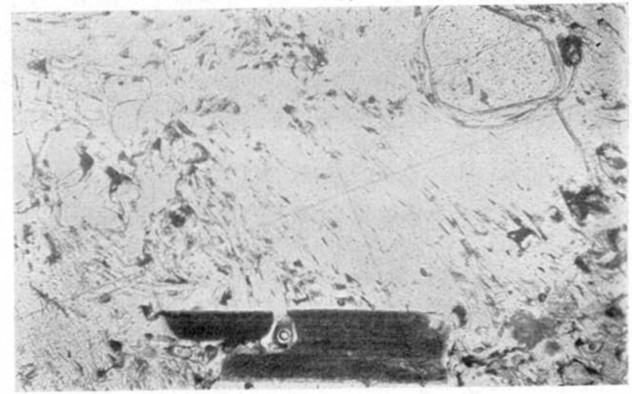


Fig. 2. Kôbe-yama lava. Biotite-plagioliparite. ×70.
See p. 285.

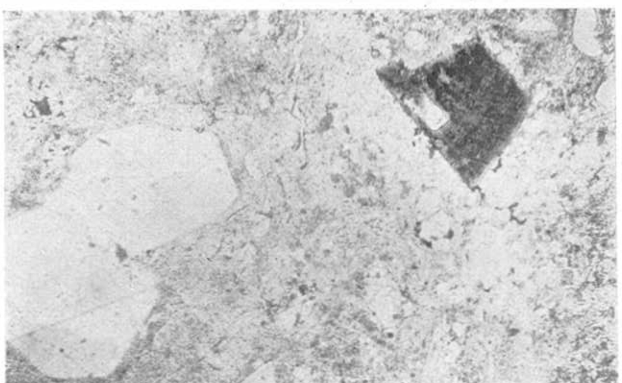


Fig. 3. Takôdo-yama lava. Biotite-plagioliparite. ×70.
See p. 285.

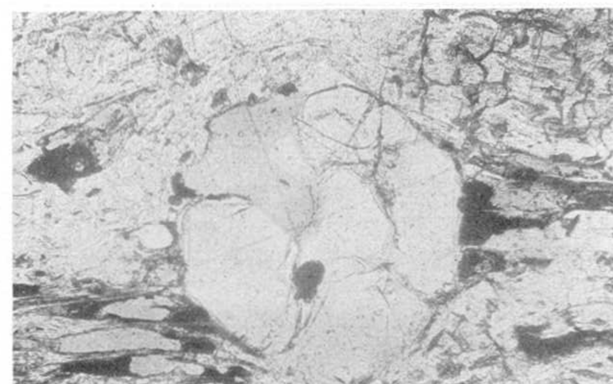


Fig. 4. Nachi-san lava. Biotite-plagioliparite. ×70.
See p. 285.

(震研彙報、第七號、圖版、津屋)

Microphotographs of the Rocks of Kôzu-shima.

Fig. 1. An ejected block in the Chichibu-yama ejecta-bed. Porphyritic hornblende-diorite. ×70. See p. 287.

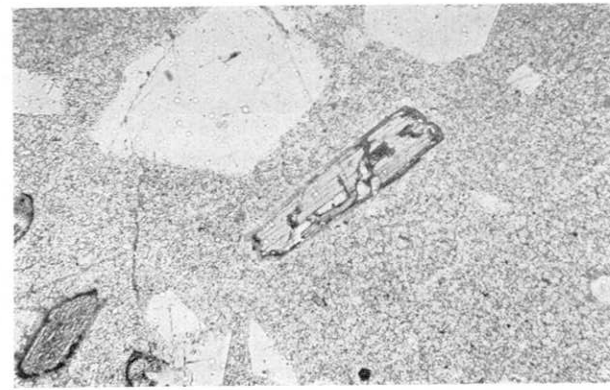


Fig. 2. An ejected block in the Chichibu-yama ejecta-bed. Hornblende-andesite. ×70. See p. 287.

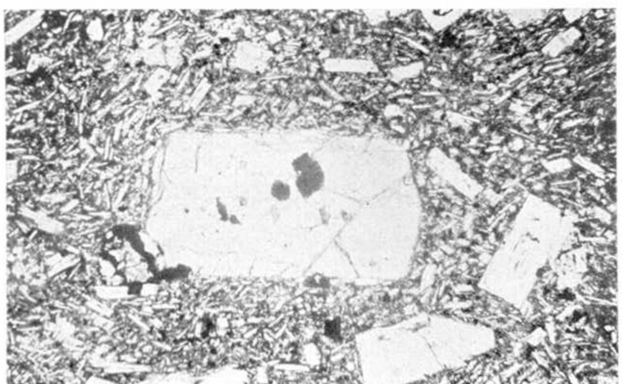


Fig. 3. An ejected block in the Chichibu-yama ejecta-bed. Two pyroxene-andesite. ×70. See p. 288.

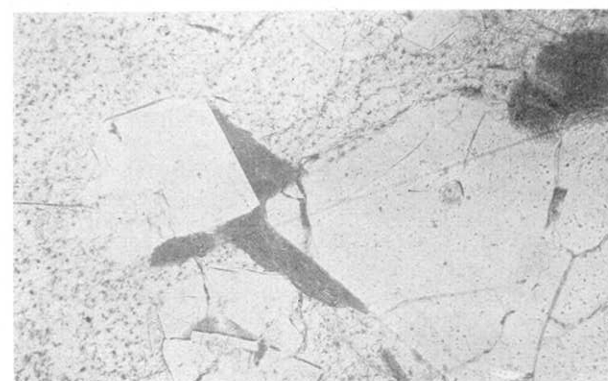


Fig. 4. ε-Lava of the first period. Biotite-plagioliparite. ×70. See p. 288.

(震研彙報、第七號、圖版、津屋)

Microphotographs of the Rocks of Kôzu-shima.

Fig. 1. Ombashi-jima lava. An aphanitic rock. ×70. See p. 290.

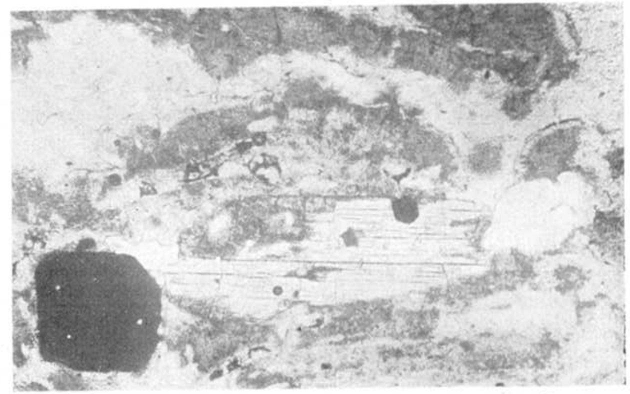


Fig. 2. δ-Lava of the first period. Hornblende-plagioliparite. ×70. See p. 291.

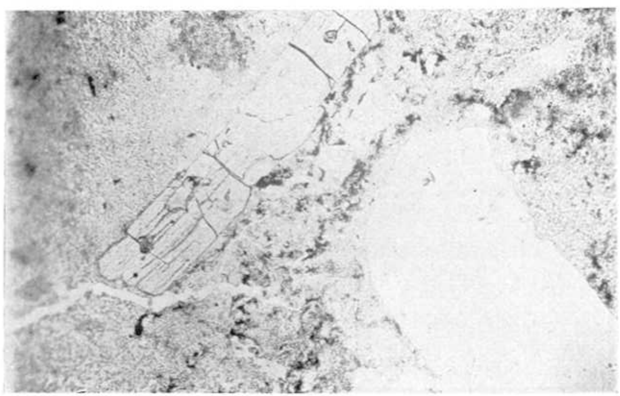


Fig. 3. γ-Lava of the first period. Hornblende-bearing hypersthene-plagioliparite. ×70. See p. 294.

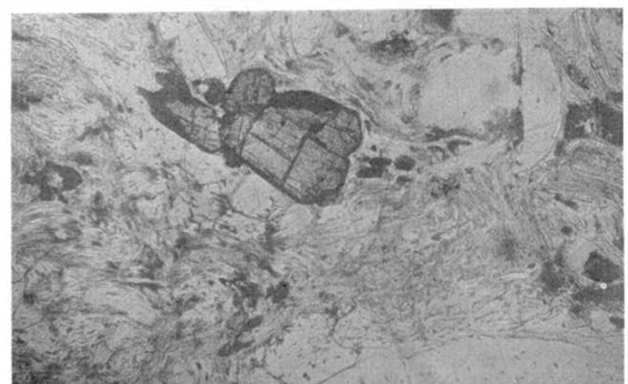


Fig. 4. β-Lava of the first period. Hypersthene-plagioliparite. ×70. See p. 294.

（震研彙報、第七號、圖版、津屋）

[Bull. Earthq. Res. Inst., Vol. VII, Pl. XXV.]

Microphotographs of the Rocks of Kôzu-shima.

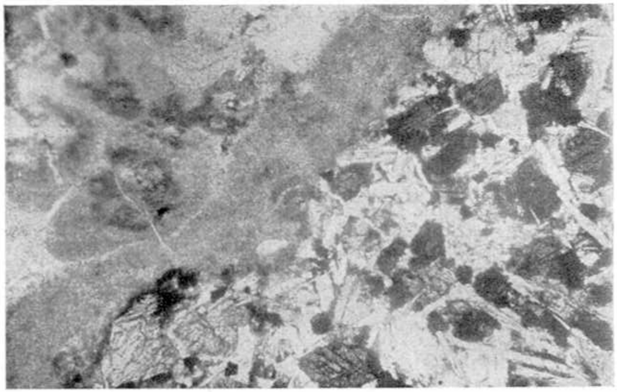


Fig. 1. Basic xenolith in the hypersthene-plagioliparite (β-lava). Augite-hornblende-labradorite rock. ×70. See p. 296.

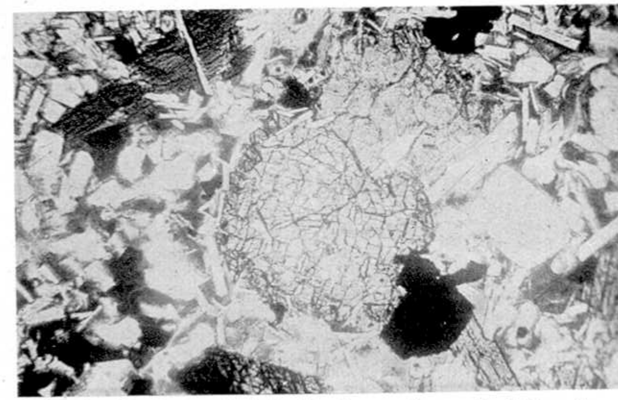
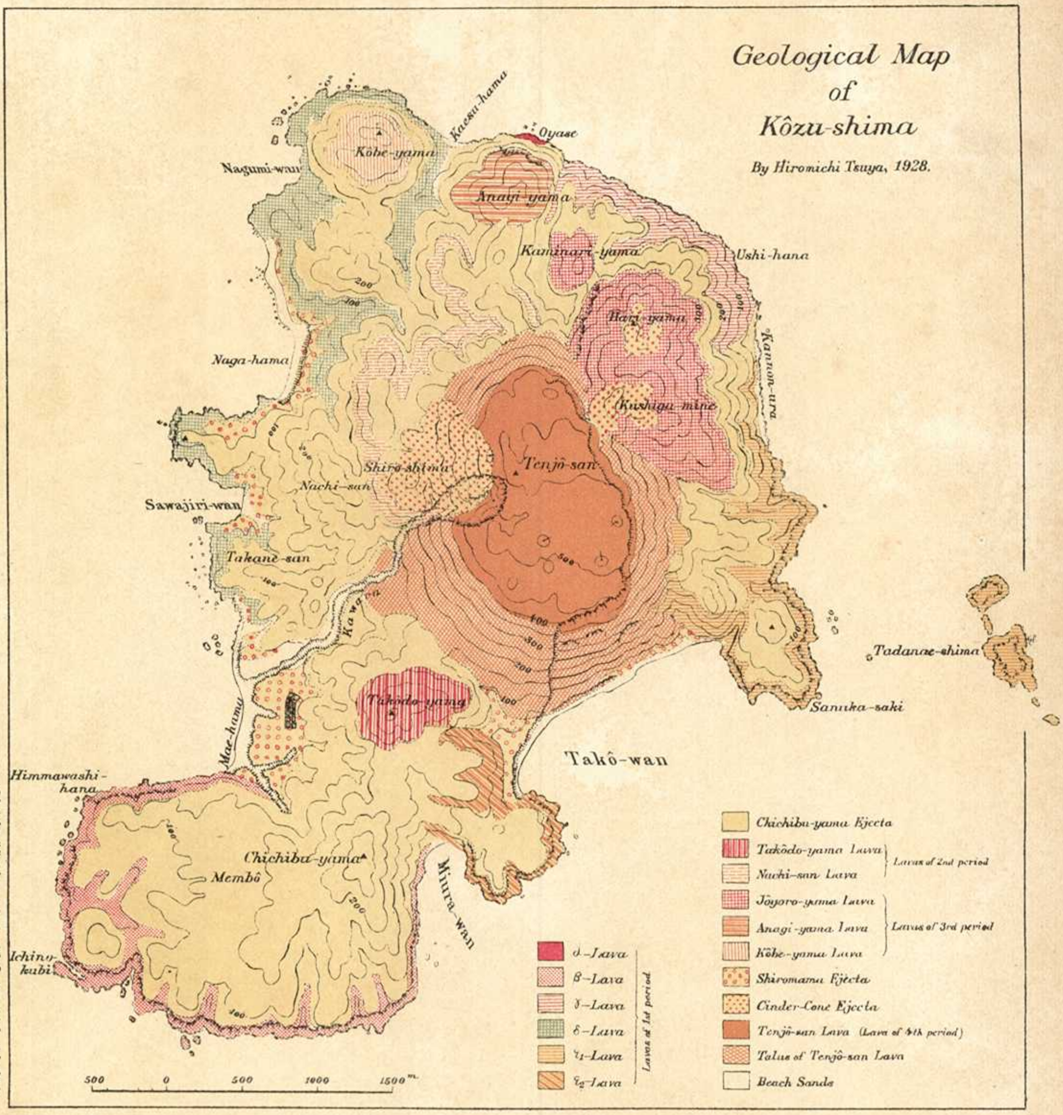


Fig. 2. Basic xenolith in the hypersthene-plagioliparite (β-lava). Augite-hornblende-labradorite rock. ×70. See p. 296.

Fig. 3. α-Lava of the first period. Potash-liparite. ×70. See p. 299.

(震研彙報、第七號、圖版、津屋)



（震研彙報、第七號、圖版、津屋）