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Geology of Goshikidai and Adjacent Areas, Northeast Shikoku, Japan : Field Occurrence and Petrography of Sanukitoid and Associated Volcanic Rocks

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Abstract Miocene volcanic rocks of northeast Shikoku region constitute mesas, buttes, and dissected hills on the Cretaceous Ryoke granitic basement. More than 100 volcanic masses are distributed within an area of 80 by 50 km wide to the north of the Median Tectonic Line. Present total volume of the volcanic rocks amounts about 50 km^3. Kankakei mass in the island of Shodoshima occupies 32km^3, and is composed of plagioclase-phyric andesites and does not include sanukitoids. Among the rest of the volcanic masses, Goshikidai mass is the largest, and has 9.5km^3 of sanukitoid and associated dacite and rhyolite, while other mesas have 0.1-2km^3, and buttes have 0.001-0.3km^3 of volcanic rocks. K-Ar dating on the Goshikidai volcanic rocks gave ages of 14.2-13.1Ma. b.p..

Geological characteristics of sanukitoid and associated volcanic rocks can be summarized as follows.

1. The volcanic rocks once formed a monogenic volcanic field. It was revealed that sanukitoid and associated volcanic rocks erupted from monogenic vents. Larger volcanic mass was found to be composed of several monogenic volcanic products.

   Goshikidai mass is composed of rhyolitic tuff breccia, dacitic volcanic breccia, and four sanukitoid andesite lava flows in ascending order. Rhyolitic tuff breccia has five isopach maxima in the area, and the following evidences for the presence of vents were observed in these maxima. (i) presence of large blocks (more than several meters across) of granitic rocks and tuff breccia, (ii) presence of massive lavas and dikes, (iii) common occurrences of vertical lamination and the presence of pyroclastic vents. Part of the dacite volcanic volcanic breccia erupted as pyroclastic flows, while the rest of it represent brecciated lava flow. Though the source vents of the sanukitoid andesite lava flows were not identified, there are more than ten volcanic necks of sanukitoid andesite to the south of Goshikidai mass. They are round to irregular in plan are 50-200m across. Some of them show gradation from marginal breccia to the central massive lava. Many of the other volcanic masses in the northeast Shikoku region may also include source vents within each mass because of the petrographic distinctiveness of the volcanic rocks.

2. Sanukitoid andesite commonly occurs as massive compact lavas. Lava flows of

sanukitoid are generally 50-200m thick.

3. Regular stratigraphic successions are observed in larger masses: i.e., pyroclastic deposits of rhyolite to dacite is commonly overlain by lava flows of sanukitoid andesite.
4. Heterogeniety of sanukitoid andesite lavas. Sanukitoid andesite may occur as composite, banded, or irregularly intermingled lavas. The heterogeniety may be related to the mixing processes before eruption as deduced from mineralogical characteristics of sanukitoid.

Petrographic characteristics of sanukitoid andesite can be summarized as follows.

1. High fequency of occurrence of orthopyroxene phenocryst relative to Ca-rich clinopyroxene phenocryst as compared with common Quaternary island arc andesites.
2. Paucity of plagioclase phenocryst
3. General lack of phenocrysts of Fe-Ti oxides.

Contents

1. Introduction

Recent experimental and petrological studies have revealed that high-magnesian andesites (here defined as andesitic rocks having more than 8wt.% MgO and SiO_2 content in the range of 55-60wt.%) are primary magmas derived from upper mantle peridotites. High-magnesian andesites hitherto described are boninites from Papua (Dallwitz 1968), Bonin Islands (Shiraki and Kuroda 1977, Kuroda and Shiraki 1975), Mariana trench (Dietrich et al. 1978), and sanukitoids from Oosaka (Tatsumi and Ishizaka 1981) and Takamatsu (Ujike 1972). Though petrological works have been done on these high-magnesian andesites, field occurrences of these andesites and associated volcanic rocks have not been described in full detail. Geological information may help to understand the process of ascent and eruption of magmas and degassing of volatiles from magmas. In this paper, the writer intends to describe the occurrences of sanukitoid and associated volcanic rocks of Goshikidai and adjacent areas, northeast Shikoku, Japan, to elucidate the geological characteristics of these volcanic rocks. Petrographic descripion of the reprenentative samples are also given.

Figure 1 shows the distribution of the Miocene volcanic rocks in northeast Shikoku region. The region covers an area of 80 by 50km, and lies 10 to 60km north of the Median Tectonic Line. The volcanic rocks usually constitute upper parts of isolated mesas, buttes and dissected hills, each of which will be called volcanic mass in the followings. About one hundred volcanic masses are distributed in northeast Shikoku region. Table 1 shows the list of volcanic masses which are referred to in the present paper. Several investigators have studied the geology and petrology of these volcanic rocks. Followings are the brief review of the previous geological studies on the volcanic rocks of northeast Shikoku region.

The existence of sonorous andesite, called Kankan-ishi (ringing stone), in northeast

Shikoku was first noted by Naumann (1885). Weinschenk (1891) examined the rock and found that it consists of glass and needles of orthopyroxene and grains of magnetite with sporadic phenocryst of bronzite. As it was a unique kind of rock, he named it sanukite after the traditional alias of the province aroun Takamatsud, Sanuki. Koto (1916)

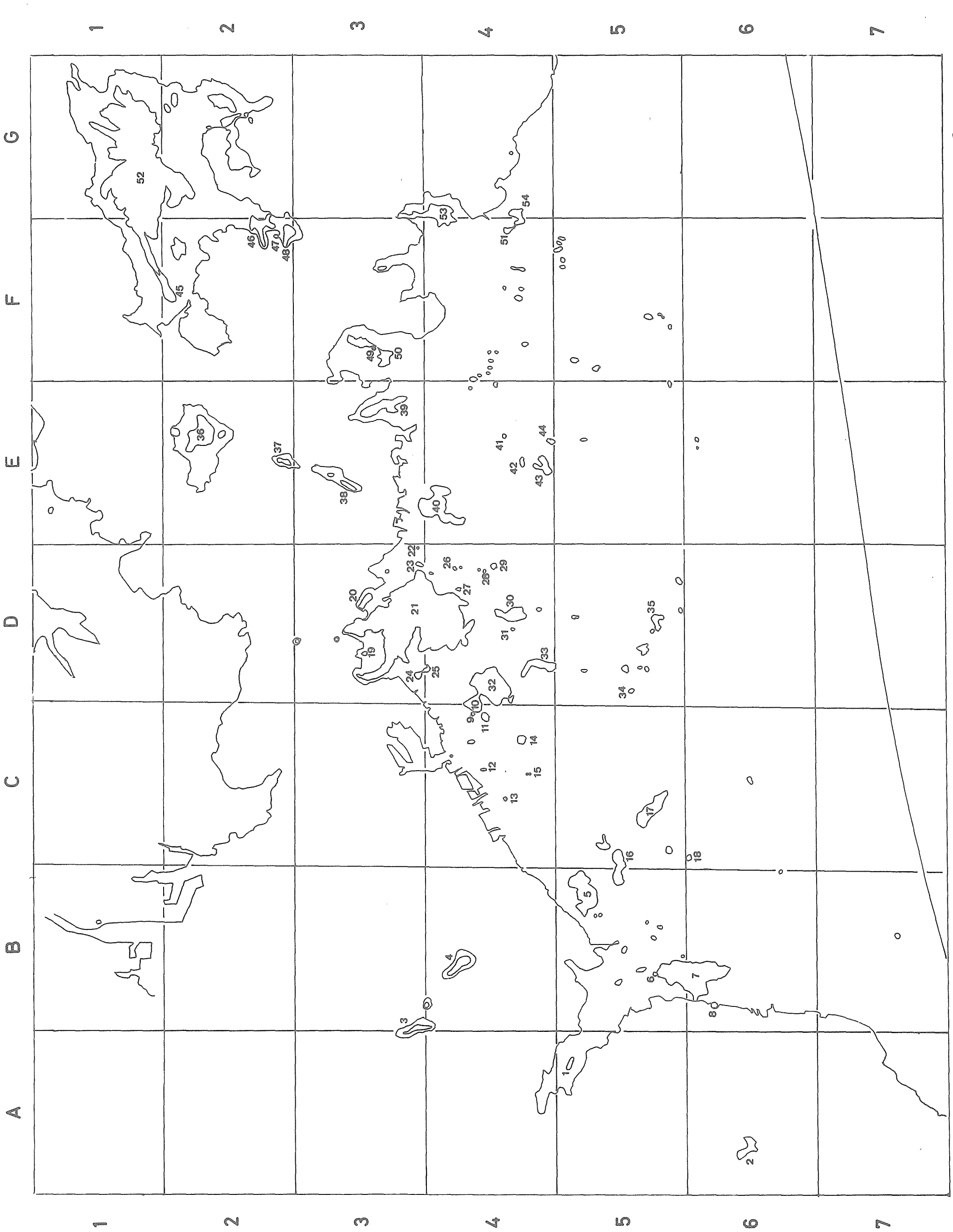

Figure 1 Index map of Miocene volcanic masses in northeast Shikoku region. List of the name of volcanic mass is shown in Table 1.

Table 1
List of volcanic masses in northeast Shikoku region referred in this paper

	*	**		*	**
Ametakiyama	51	F—4	Nekoyama	34	D—5
Aonoyama	12	C—4	Nio-Pass	6	B—5
Danyama	36	E—2	Ogishima	37	E—2
Fukuroyama	26	D—4	Oogoshiyama	19	D—3
Futagoyama	15	C—4	Oomasan	17	C—5
Gahaishi-Hiageyama	16	C—5	Otozan	45	F—2
Garanzan	28	D—4	Oyama	25	D—4
Gokenzan	50	F—3	P-157	31	D—4
Gongenzaki	47	F—2	P-211	49	F—3
Goshikidai	21	D—3	P-212	27	D—4
Hichirozan	7	B—6	P-250	43	E—4
Hiyama	54	G—4	Sanagishima	3	B—3
Hiyama (P-192)	42	E—4	shirahamayama	48	F—2
Ibukishima	2	A—6	shiundesan	1	A—5
Iinoyama	14	C—4	Takahachiyama	35	D—5
Iwaseosan	40	E—4	Takamishima	4	B—4
Iyatanisan	5	B—5	Tsukumoyama	8	B—6
Kamisayama	44	E—4	Tsuneyama	11	C—4
Kanayama	10	C—4	Washinoyama	30	D—4
Kankakei	52	G—1	Yakuthiyama	22	D—3
Kasayama	9	C—4	Yakushiyama	39	E—3
Katamukiyama	18	C—6	Yokoyama	33	D—4
Katsugayama	23	D—3	Yoshinodai	46	F—2
Kitayama	53	G—4	Yurayama	41	E—4
Kiyama	32	D—4			
Konomine	20	D—3			
Marugame-Castle	13	C—4			
Megishima	38	E—3			
Meyama	24	D—3			
Mutsumeyama	29	D—4			

* Volcanic mass number in Figure 1, ** Grid number in Figure 1

proposed to call the andesite and basalt associated with sanukite Sanukitoid, and pointed out that sanukitoid is distributed along Seto Inland Sea and its western extension in Kyushu. Kuno (1935) pointed out the similar volcanic succession from rhyolite to sanukitoid andesite both in Goshikidai and Nijo-san region in Oosaka. Morimoto et al. (1957) mentioned that the volcanic rocks of the Setouchi zone occur in five regions along the Median Tectonic Line at intervals of about 100km. Recently, K-Ar dating on the volcanic rocks of the Setouchi zone are carried out by Kawano et al (1967), and by Tatsumi and co-workers (1978a, 1978b, 1979, 1980a, 1980b, 1981). Although Kawano et al. showed the existence of two periods of volcanic activity in northeast Shikoku, i.e. 4-5 Ma. and 12-13Ma., duplicate analyses of Tatsumi et al. have shown that the volcanic activity of the Setouchi zone took place only in 13 $\pm$ 1 Ma. b.p..

Geological survey on the volcanic rocks of northeast Shikoku region have been performed by several workers, and the geological maps hitherto published are ; 1. Sato, M., 1/75,000 geological maps of "Marugame", "Takamatsu", and "Saidaiji" quadangles with explanatory texts (1936, 1938), 2. Saito, M., 1/100,000 geological map of Kagawa Prefecture (1962), 3. Ujike, O., 1/100,000 geological maps of Amakirisan, Kiyama, Goshikidai, Iwaseosan, and Amatakiyama masses (1970), 4. Henmi, K. et al., Geological map of Goshikidai mass (1976), 5. Tatsumi and Yokoyama, Geological map of Kankakei mass (1978a), and 6. Tatsumi and Ishizaka, Geological map of Yashima mass (1978b).

Before going into detailed description, some terms are defined here. "Sanukite" is defined as glassy acid andesite carrying sporadic phenocrysts of high-magnesian mafic minerals (Mg/(Mg+Fe) more than 0.80). "Sanukitoid" is used for andesitic rocks carrying high-magnesian mafic phenochyst (Mg/(Mg+Fe) ratio more than 0.80). Modal content of plagioclase phenocryst is generally less than 3 vol.% in sanukitoid.

2. Basement

Pre-Tertiary basement consists of Rhyoke granitic and metamorphic rocks and the Cretaceous Izumi Group. Five K-Ar ages on the Ryoke granitic rocks in the northeast Shikoku region range 72 to 85 Ma. b.p. (Nozawa 1975). The granitic rocks include hornblende diorite, biotite-hornblende quartz diorite, hornblende-biotite granodiorite and adamellite. Metamorphic rocks constitute less than 1 percent of the basement and are composed of micaschist, banded gneiss, hornfels and quartzite (Saito 1962). They occur as small xenolithic bodies included in the granitic rocks. The Izumi Group is distributed in the southern part of the region and consists of marine sandstone and shale.

The Miocene volcanic rocks are in part unconformably underlain by the Miocene Tonosho Group (Saito 1962), which consists of brackish sandstone, siltstone, and marine sandstone, in ascending order. The Tonosho Group is 50 meters in maximum thickness, and its distribution is limited around the volcanic masses of Otozan (45 : volcanic mass number in Figure 1, the same as follows), Danyama (36), Iyatanisan (5) and Goshikidai (21) masses.

3. Age of volcanic rocks

Kawano et al. (1967) reported four K-Ar dates of lavas in northeast Shikoku region. Ages of 12 and 13 Ma. were obtained from the uppermost lava flows of Kiyama (32) and Goshikidai (21) masses, respectively, and ages of 4 and 5 Ma. were obtained from basalt of Aonoyama (12) butte and andesite of Yashima (39) mass, respectively. According to Tatsumi and Ishizaka (1978), however, the andesite lava of Yashima mass gave a K-Ar age of 11.6 ± 0.6 Ma.. In a series of K-Ar dating of the volcanic rocks of Setouchi zone, Tatsumi et al. (1978a, 1978b, 1979, 1980a, 1980b) have shown that most volcanic rocks is dated to be 13 ± 1 Ma.. I also obtained K-Ar ages on three samples of Goshikidai mass. The analytical results are presented in Table 2. The obtained ages are 14.2 ± 0.7 Ma of the block of dacite volcanic breccia, 13.5 ± 0.7 Ma of the andesite of lava flow-I, and 13. 1 ± 0.7 Ma of the andesite of lava flow-IV. The obtained ages are in harmony with the stratigraphy of the volcanic rocks of Goshikidai as will be discussed later.

Table 2 K-Ar ages of the volcanic rocks of Goshikidai

sample No.		age(Ma.)	scc $Ar^{40Rad}/gm*10^{-5}$	$\%Ar^{40Rad}$	%K
#163	72010801A	14.2±0.7	.125	69.8	2.24
			.125	68.8	2.28
#131	78090704	13.5±0.7	.067	51.0	1.28
			.069	50.2	1.30
#153	69080138C	13.1±0.7	.119	62.3	2.34
			.122	58.1	2.38

The constants for the age calculation are : $\lambda_\beta = 4.962 \times 10^{-10}$/yr, $\lambda_\varepsilon = 0.581 \times 10^{-10}$/yr, $K^{40} = 1.167 \times 10^{-4}$ atom of natural potassium. (Convention on decay constants, Subcommission on Geochronology, 25th International Geological Congress, 1976.) The analyses was performed on whole rock material, by TELEDYNE ISOTOPES, U. S. A.

4. Volume of volcanic rocks

The total volume of the volcanic rocks of the northeast Shikoku region amounts to about 50km^3. Kankakei mass (52) is by-far the largest volcanic mass in the region, attaining 32km^3. It consists mostly of plagioclase-phyric andesite and does not include sanukitoid. Goshikidai mass (21) is the second largest volcanic mass (9.5km^3), consisting mainly of sanukitoid andesite. The volumes of the other larger mesas and dissected hills range from 0.3 to 2km^3, while those of buttes range from 0.001 to 0.1km^3. Table 3 shows the volume of each rock-type of the representative volcanic masses. Except for the volcanic rocks of Kankakei mass, low-magnesian sanukitoid andesite is the most abundant rock type of the volcanic rocks of northeast Shikoku region. The figures in Table 3 represent only the present volume of the volcanic rocks. Large proportion of the original volcanic deposit have been eroded away. Following evidence gives some measure of the effect of erosion on the reduction of the volume of the volcanic rocks.

The volcanic stratigraphy of Goshikidai can be correlated lithologically and petrographically to those of the adjacent volcanic masses of Kiyama (31), Kanayama (10), Oyama (25), Meyama (24), Oogoshiyama (19), and Konomine (20), suggesting that they once formed a continuous volcanic deposit. To leave these masses isolated, about half of the original volcanic rocks should have been eroded away. In many of the volcanic mesas and buttes, volcanic rocks occur only in the uppermost portion, and the lower portion is occupied by granitic basement rocks. According to the data of drill holes in the Takamatsu plain, the granitic basement submerges to the depth of ca. 150m under alluvium (Bando and Saito 1960). At Yashima (39) mesa, the lower 200 to 250meters of about 300meters cliff of mesa consists of granitic basement, and andesitic lava flow occupies the upper part. Strikingly, as noted by M.Sato (1932), granitic conglomerate and arkose sandstone of 1 to 5meters thick locally occur on the flat top of the andesite lava flow. The granitic conglomerate and arkose sandstone should have been derived from the surrounding granitic height in the past. M.Sato (1932) suggested that the elongated lava flow of Yashima (39) mesa once filled topographic low (possibly a valley or pond) and extensive erosion of the surrounding granitic mountain have produced the mesa topography. In summary it is suggested that the original volume of the volcanic rocks was more than twice

Table 3 Volume of volcanic rocks (km^3)

Mass Name	Mass number in Figure 1	Morphology*	basalt	andesite (sanukitoid)	andesite (non-san.)	dacite	rhyolite	total
Kankakei	52	S			32		0.1	32
Goshikidai	21	M		6.2		1.7	1.6	9.5
Hichihozan	7	H		1.9			0.05	1.95
Iyatanisan	5	H		0.75			0.23	0.98
Kiyama	32	M		0.62		0.15	0.06	0.83
Iwaseosan	40	M		0.46		0.18	0.00	0.64
Oomasan	17	H		0.3			0.08	0.38
Gahaishisan-Hiageyama	16	H		0.1			0.25	0.35
Otozan	45	M		0.3				0.3
Washinoyama	30	H				0.22	0.03	0.25
Hiyama	54	H		0.1	0.05	0.07	0.00	0.22
Yashima	39	M		0.2				0.2
Yokoyama	33	H		0.12				0.12
Ibukishima	2	M		0.1	0.005			0.105
Sanagishima	3	M	0.05	0.05				0.10
Gokenzan	50	H				0.03	0.07	0.10
Yurayama	41	B				0.10	0.00	0.10
Takamishima	4	M		0.06	0.00			0.06
Iinoyama	14	B		0.03				0.03
Aonoyama	12	B	0.006					0.006
Kasayama	9	B		0.004				0.004

* S : strato-volcano, M : mesa, H : dissected hill, B : butte.

of the present volume.

5. Geology of Goshikidai mass

a. General statement

Goshikidai mass occupies the central part of the northeast Shikoku region, and is the largest volcanic mass composed mainly of sanukitoid andesite. Lithology and stratigraphic sequence of the volcanic deposits of Goshikidai mass are essentially the same as those of the adiacent masses of Kiyama(32), Kanayama(10), Oyama(25), Meyama(24), Oogoshi-yama(19) and Konomine(20). The volcanic rocks of these masses are distinguished from those of the surrounding masses, such as Yokoyama(33), Iinoyama(14), Tsuneyama(11), Kasayama(9), Katsugayama(23), Yakushiyama(22), Iwaseosan(40), Fukuroyama(26), Mutsumeyama(29) and Washinoyama(30) masses. The original extent of Goshikidai mass and the associated volcanic masses was ca. 10 by $10km^2$.

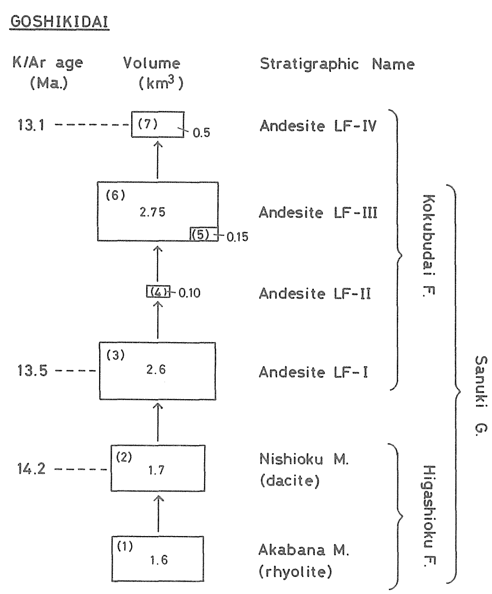

Figure 2. Stratigraphic sequence, K-Ar age, and volume of the volcanic rocks of Goshikidai mass.

Stratigraphic sequence of Goshikidai is shown in Figure 2. The Rhyoke granitic basement is locally covered by granitic conglomerate and arkose sandstone of Tonosho Group. Among eleven outcrops of the unconformity between the granitic basement and the Miocene formation in Goshikidai and adjacent areas (locality 1 through 11 in Figure 3), the Tonosho Group occurs only in two localities. At Katayama(locality 4 in Figure 3), conglomerate deposit is 2m thick, and consists of well rounded gravels of granitic rocks up to 30cm in diameter with matrix of arkose sand. Rhyolitic pyroclastic flow deposit overlay the conglomerate and granitic basement. The pyroclastic flow eroded the conglomerate as

Figure 3. Locality map of Goshikidai and adjacent ares

1. Akabana, Akabana Member/granitic rock boundary (Figure 7, Plate 1-4)
2. Shioya, ibid.
3. Negoroji, Higashioku Member/granitic rock boundary.

4. Katayama, Akabana Member/Tonosho Group/granitic rock boundaries.
5. Takaya W, Akabana Member/granitic rock boundary.
6. Takaya E, ibid.
7. Kawanishi N., ibid.
8. Higashioku, ibid.
9. Eboshiyama, Lava flow-III/Akabana Member/granitic rock boundaries.
10. Kiyama NE, Akabana Member/granitic rock boundary.
11. Kiyama S, Akabana Member/Tonosho Group/granitic rock boundaries.
12. Akabana W, denuded ridge of chaotic coarse rhyolitic volcanic breccia
13. Oomi Shrine, ibid.
14. Nishioku W, ibid.
15. Higashioku, Well stratified tuff of Akabana Member, intruded by network dike of dacite tuff breccia (Figure 9, Plate 5,6)
16. Nakamura, massive lava flow of dacite.
17. Nishioku, Large block of dacite in volcanic breccia of Higashioku Member.
18. Denroku-ike, ibid.
19. Higashioku, Chaotic volcanic breccia overlain by stratified volcanic breccia, Higashioku Formation (Figure 10, Plate 7).
20. Oomi-river 275m, lava flow- I /Higashioku Formation boundary
21. Tarumi-river, ibid.
22. Oosaki-hana, ibid.
23. Ipponmatsu, Lava flow-III/Lava flow- I boundary (Figure 14).
24. East of Amidagoe, ibid.
25. Kamogawa quarry, Lava flow-IV/Lava flow-III boundary
26. Yamahi upper quarry, banded lava flow-III (Figure 13).
27. Kokubudai S, Lava flow-IV/Jizo Member boundary (Figure 15).
28. Chigotaki Fall, Lava flow-III/Jizo Member boundary.
29. Kokubu sanukite quarry.
30. Shiramineyama E. Heterogeniety of lavas of sanukite and crystalline andesite of the lava flow-IV (Figure 16).

well as the loose granitic rocks. The Sanuki Group of the Goshikidai and adjacent areas can be divided into Higashioku and Kokubudai Formations (Figure 2). Higashioku Formation is subdivided into three Memders: in ascending order, they are Akabana Member (pyroclastics and lavas of garnet-biotite rhyolite), Nishioku Member(pyroclastics and lavas of hornblende dacite), and the Jizo Member (dacite pumice tuff, sandstone and conglomerate), respectively. The Kokubudai Formation is composed of lava flows of sanukitoid andesite. At least four lava flow units were distinguished, and they are called lava flow- I ,- II ,-III, -IV from lower to upper (Figure 2).

Geological map and cross sections of the Goshikidai mass are shown in Figures 4 and 5.

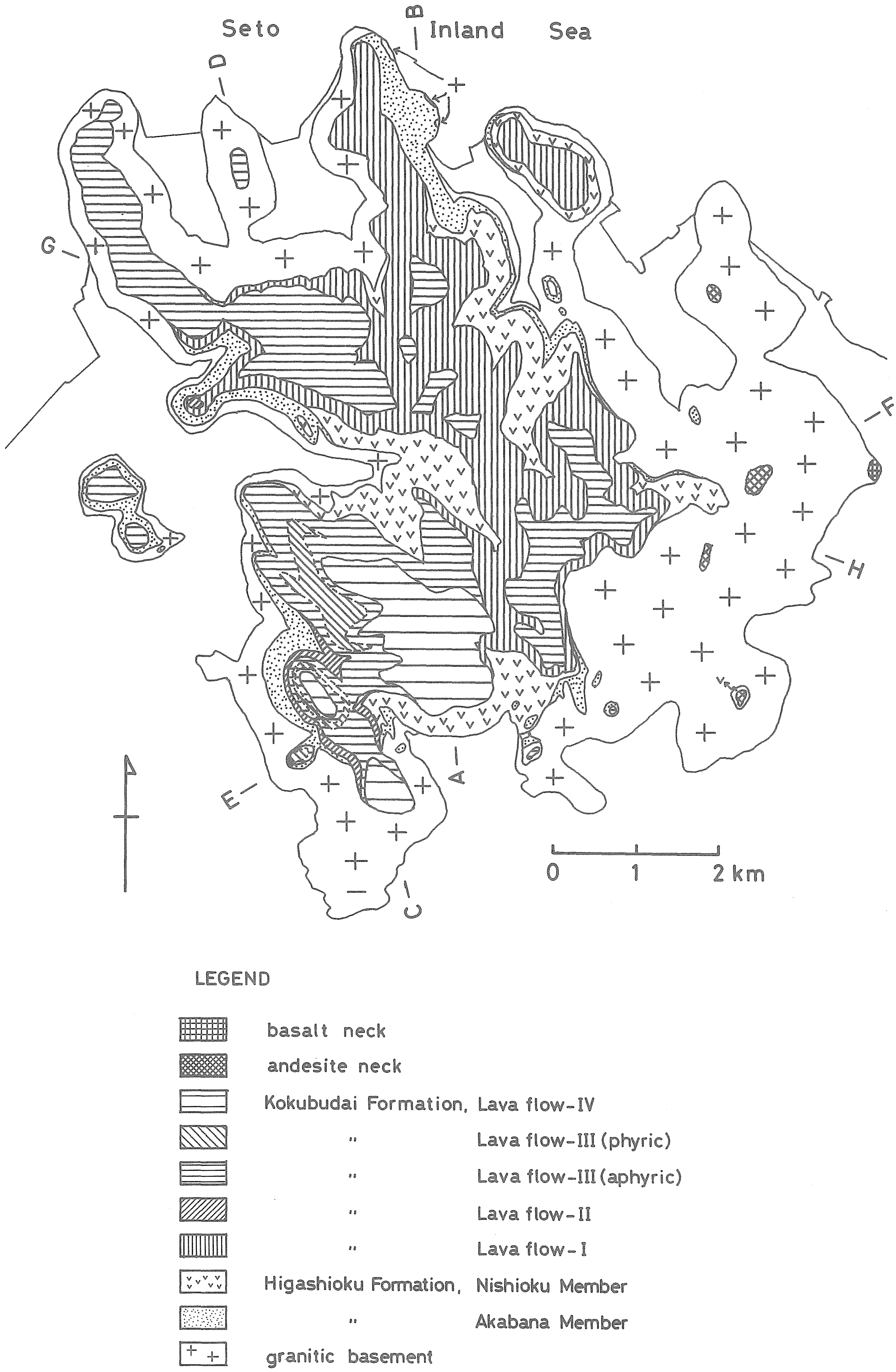

Figure 4. Geological map of Goshikidai and adjacent masses.

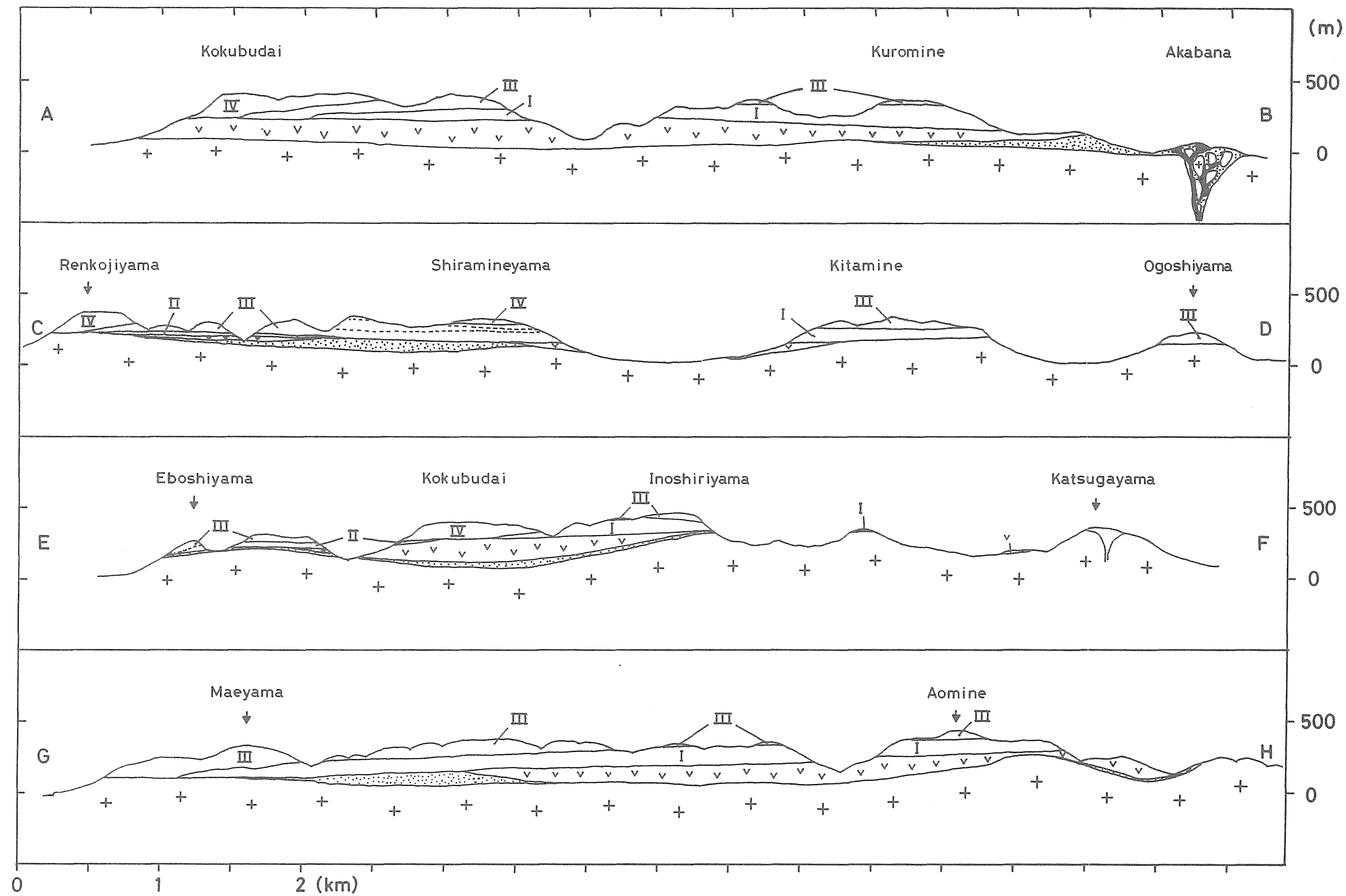

Figure 5. Cross sections of Goshikidai and adjacent masses. The position of the section is shown in Figure 4. Italic number denotes the number of Lava flow of Kokubudai Formation.

5-b Higashioku Formation

Akabana Member Akabana Member is defined as pyroclastics and lavas consisting mainly of garnet-biotite rhyolite. The Akabana Member is newly named and its type locality is located at Akabana (locality 1 in Figure 3). The thickness of the deposit is 120meters in maximum, and its total volume is 2.2km^3. Massive lavas occur only at Akabana, forming dikes and small flows. The pyroclastics of the Akabana Member are lithologically divided into three types: monolithologic massive volcanic breccia, heterolithologic massive tuff breccia, and heterolithologic well-stratified tuff, respectively. The monolithologic massive volcanic breccia is associated with massive lavas at Akabana. The volcanic breccia consists of angular fragments and matrx of the same lithology. The volcanic breccia grades into massive lavas. The heterolithologic massive tuff breccia constitutes most of the pyroclastics of the Akabana Member. The isopach map of the heterolithologic massive tuff breccia of the Akabana Member is shown in Figure 6, in which five isopach centers are indicated. They are called Akabana, Kamitani, Takaya, Higashioku and Kiyama, respectively. The lithology of the pyroclastic deposits at these centers have common features. The deposit is poorly-sorted massive tuff breccia, volcanic breccia, or tuff. It sometimes show rough stratification. Fragments are usually non -vesicular, subangular, and heterolithologic, consisting of garnet-biotite rhyolite, rhyolitic

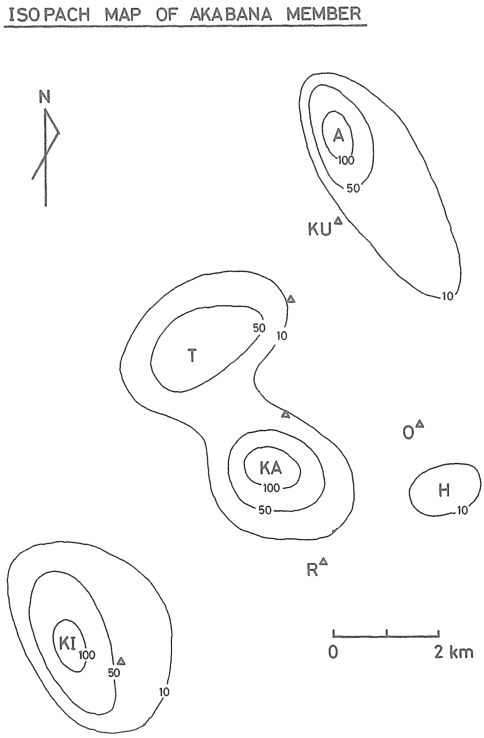

Figure 6. Isopach map of Akabana Member. The number represent thickness in meters. A : Akabana, T : Takaya, KA : Kamitani, H : Higashioku, KI : Kiyama.

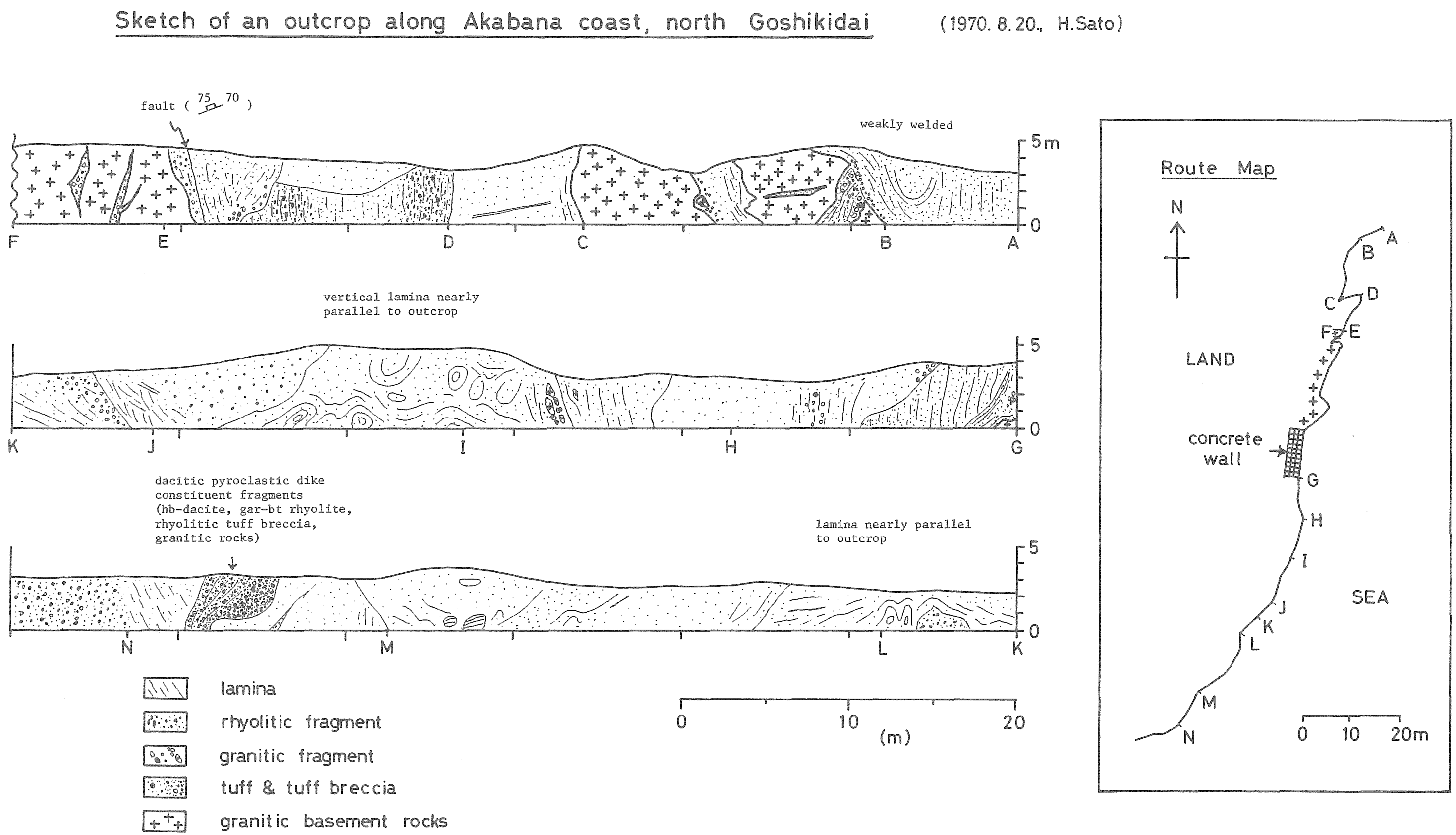

Figure 7. Sketch of the outcrops of Akabana coast (Locality 1 in Figure 3).

glass, rare dacite, and granitic rocks and their mineral grains. Fragments of tuff breccia also occur, though in small amounts. The existence of vents are postulated at the isopach centers, among which Akabana center exhibits best the mode of occurrence of vents and is described in the following.

At Akabana center (Locality 1 in Figure 3), following features of rhyolitic volcanics are observed. 1. Granitic basement and rhyoloitic tuff and tuff breccia are intruded by pyroclastic dikes (Plate 1 and 2, Figure 7). 2. Large rounded granitic blocks up to several meters across are included in chaotic rhyolitic tuff breccia (Plate 3). 3. Lava flows and dikes of massive rhyolite are exclusively found at Akabana center. 4. In many outcrops around Akabana, vertical flow structure of tuff and tuff breccia is observed (Plate 4, Figure 7). The flow structure is recognized in terms of sorting of fragments, or linear distribution of granitic fragments, or upward parallel elongation of the long axis of large fragments. Some of these occurrences are illustrated in Figure 7. The pyroclastic deposit of these vests are heterolithologic, consisting mainly of banded crystalline garnet-biotite rhyolite and its glass. Vesicular fragments constitute less than 10 percent of the deposit. In some vents, rhyolitic fragments are weakly welded. Fragments of granitic rocks and its derivative mineral grains of biotite, quartz, and feldspars are always present in the pyroclastics. Granitic fragments are concentrated at the margin of the pyroclastic dike, and may indicate the result of erosion of the granitic country rocks by the pyroclastic flow (Plate 2). In a few dikes intruding the rhyolitic tuff, fragments of hornblende dacite and rhyolitic tuff breccia occur as major constituents. It is probable that hornblende dacite of Nishioku Member(as described below) erupted successively after the eruption of rhyolite of Akabana Member. The above described occurrences of the pyroclastics at Akabana is the direct evidence of the presence of vents, though the author considers that the occurrences, such as illustrated in Figure 7, rather represent the marginal facies of the pyroclastic vent. The size of fragments of the pyroclastics at Akabana vents is rather fine-grained than that of the rest of massive heterolithologic tuff breccia of Akabana Member. The common occurrences of vertical lamination in the tuff at the vent indicate laminar flow of the pyroclastics, which tends to develop when the gas velocity of the erupting pyroclastics in vent is small. Instead, thick chaotic coarse-grained tuff breccia may represent the central facies of vent. Thick massive chaotic tuff breccia forms ridges at Akabana (locality 12 in Figure 3), Oomi Shrine(locality 13), and at Nishioku(locality 14), which are the possible source vents of the heterolithologic tuff breccia of the Akabana member.

At Higashioku (locality 15 in Figure 3) and Kiyama(locality 11), there occurs well stratified rhyolitic pyroclastic deposit, which is considered to have deposited under subaqueous conditions. At Higashioku, the rhyolitic tuff consists of 10 to 100cm thick units, each of which is composed of lower massive coarse tuff and upper laminated fine tuff. The lower massive tuff shows normal size grading, and often scrape the lower unit (Plate 5), suggesting that the unit is a turbidite deposit. The pyroclastics are moderately sorted and its constituents are garnet-biotite crystalline rhyolite and rhyolitic glass, and mineral grains derived from granitic rocks. A small proportion of the rhyolitic fragment is weakly vesiculated. The total thickness of the stratified rhyolitic tuff is ca. 50m at Higashioku, and about 2m at Kiyama.

Nishioku Member Nishioku Member is defined as pyroclastics and lavas composed of hornblende dacite. The type locality is located at Nishioku, on the southern slope of Kokubudai (locality 17 in Figure 3). The deposit is 250m in maximum thickness, and its volume is 2.0km^3. The pyroclastic deposit of the Nishioku Member can be divided into three types according to lithology : monolithologic massive volcanic breccia, heterolithologic massive tuff breccia and volcanic breccia, and monolithologic to heterolithologic stratified volcanic breccia, respectively. The monolithologic massive volcanic breccia occurs as thick deposit in the central part of Goshikidai mass, and constitute about 80 percent of the Nishioku Member. The volcanic breccia grades into massive lava flow to the north of Nakamura (locality 16). At localites 17 and 18 in Figure 3, large lava blocks up to several meters across are included. The deposit of monolithologic massive volcanic breccia may represent brecciated part of lava flows. Lack of massive central pasty layer in the deposit may indicate that each flow unit did not have large areal extent.

The heterolithologic tuff breccia of hornblende dacite is typically exposed for about 150 meters thick at the cliff to the northeast of Higashioku (locality 19). The tuff breccia is mainly composed of compact hornblende dacite with minor amounts of dactic pumice, rhyolitic and granitic fragments. The tuff breccia may contain large blocks of dacite tuff breccia (about 5m across), well-stratified rhyolitic tuff (50m acoss), and granitic blocks(5 -10m). The occurrence of these large blocks has implications for the mode of transportaion of the heterolithologic tuff breccia, and will be described in some detail. An example of the mode of occurrence of granitic block is shown in Figure 8. The granitic block is intruded by massive poorly-sorted dacitic tuff breccia. Figure 9 illustrates a mode of occurrence of

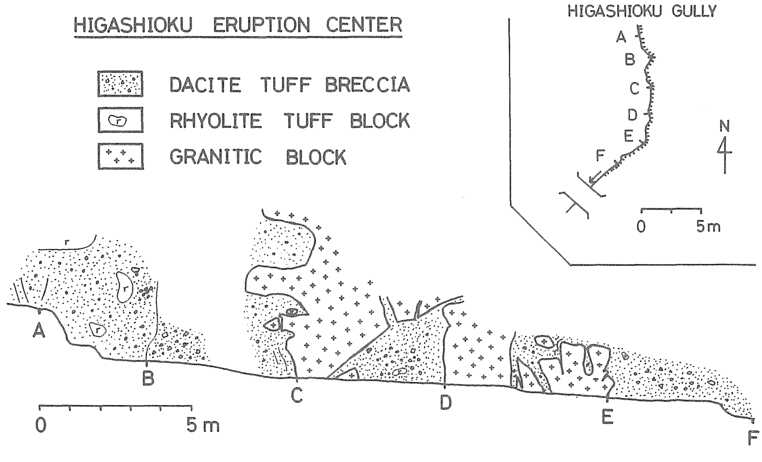

Figure 8. Occurrences of granitic blocks in dacite tuff breccia of Higashioku Formation. In the gorge of Higashioku.

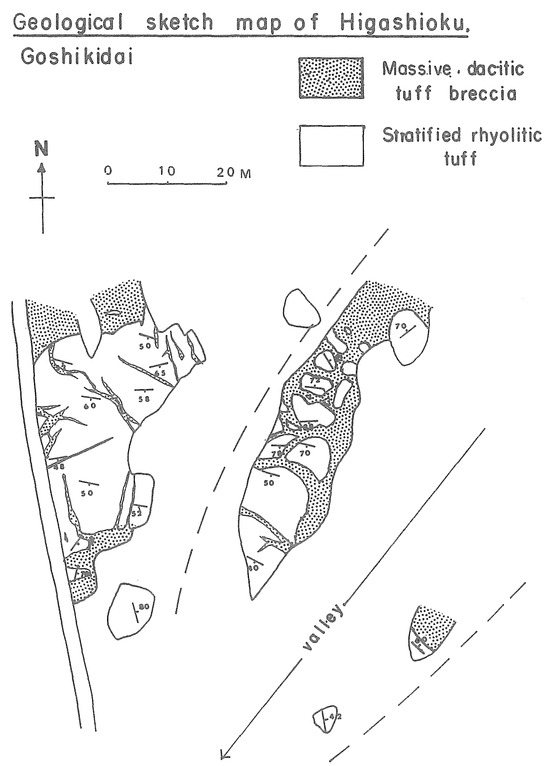

Figure 9. Occurrences of stratified tuff blocks in dacite tuff breccia of Higashioku Formation (locality 15).

blocks of well-stratified rhyolitic tuff included in massive heterolithologic dacite tuff breccia. The rhyolitic tuff block is intruded by net-work dike of dacite tuff breccia. The breccia dike is usually sorted and laminated at the margin, while its central part is massive and contains dacite fragments of up to 30cm across (Plate 6). Sometimes, the included fragment is as lage as the width of the dike. The bedding plane of the stratified tuff bolck is steeply inclined, and slightly varies from block to block, separated by the network dike of the dacite tuff breccia(Figure 9). Weak folding and planeless faults are commonly observed in the stratified tuff, suggesting that the rhyolitic tuff was not consolidated when it is incorporated into the dacite tuff breccia. The occurrence of the rhyolitic tuff block in the dacite tuff breccia may be ascribed to either of the following processes; 1. fractureing by faulting, 2. slumping of rhyolitic tuff block upon unconsolidated dacite tuff breccia, and 3. intrusion of dacite pyroclastic flow into the rhyolitic tuff. There is no sign of the presence of a fault in the vicinity of Higashioku. The general continuation of the bedding plane of the rhyolitic tuff from block to block suggest that the rhyolitic tuff was incorporated and rotated within the dacitic tuff breccia in a non-explosive manner. The author considers that the above described mode of occurrence of the pyroclastics is most conformable with the process that fluidized dacitic tuff breccia intruded into the granitic basement and the stratified rhyolitic tuff and lifted them up to the present position. Large blocks of dacite volcanic breccia occurs in a nearly vertical zone of about 20m wide in the upper part of the Higashioku exposure (locality 19). The blocky zone may represent one of the major source vent of the heteroligholologic massive tuff breccia of the Nishioku Member.

The third type of the pyroclastic deposit of Nishioku Member, the monolithologic to heterolithologic roughly stratified volcanic breccia, is typically exposed in the uppermost part of the cliff at Higashioku (locality 19, Plate 7, Figure 10). The stratified volcanic breccia horizontally overlies the chaotic hete rolithologic tuff breccia, and is more than 20m thick. The stratified tuff breccia is monolithologic, consisting of compact, subrounded fragments of hornblende dacite. Stratification is recognized in terms of size-graded units of 1 to 4meters thick. Each unit may show rough reverse grading. Thin lens of laminated tuff is intercalated within the volcanic deposit. There are no bomb-sag structures where large fragments of dacite directly rest on the laminated tuff. The stratified volcanic breccia may be a secondary wash deposit derived from brecciated lava flows or lava domes nearby.

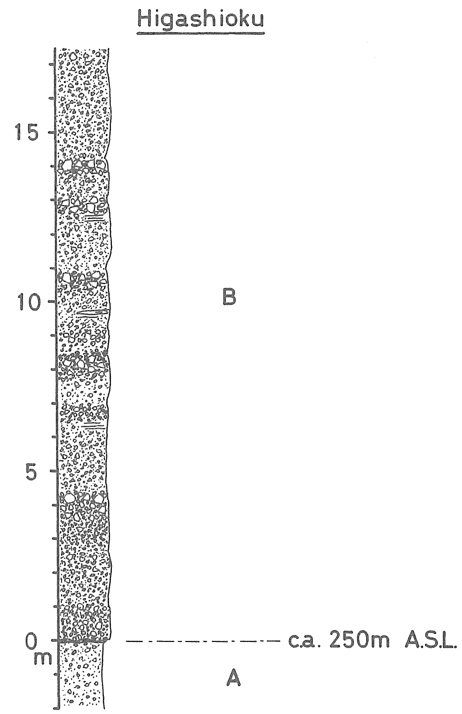

Figure 10. Columnar section of the stratified monolithologic volcanic breccia of Nishioku Memeber. Note the reverse grading and the intercalation of laminated tuff. (locality 19).

Jizo Member The occurrence of Jizo Member is restricted to the southwestern part of Goshikidai. It is 30meters in maximum thickness. Jizo Member is composed of pumice tuff, tuff, sandstone, and volcanic conglomerate. In the southern slope of Kokubudai, Goshikidai (locality 27), pumice tuff deposit abuts the irregular surface of massive volcanic breccia of Nishioku Member. The pumice tuff is well sorted and consists mainly of weakly vesiculated aphyric dacite with subordinate amounts of compact dacite and rhyolitic glass. Similar pumice tuff occurs at Chigotaki fall(locality 28), where ca. 50cm thick pumice tuff is intercalated between massive volcanic breccia of Nishioku Member and clinker of andesite lava flow of Kokubudai Formation. The pumice tuff is charged with chacoal, indicating the growth of plants during the period of quiescence of the volcanic activity. Tuff, volcanic sandstone, and volcanic conglomerate overlies the pumice tuff deposit in the southern slope of Kokubudai (around locality 27).

In Figure 12, topography of the upper surface of Higashioku Formation is shown. It is noted that the topography is much more flat compared with that of the surface of the granitic basement (Figure 11). It is plausible that the major volcanic products of Higashioku Formation, the pyroclastic flow deposit and brecciated lava flows, filled the original small scale topographic low.

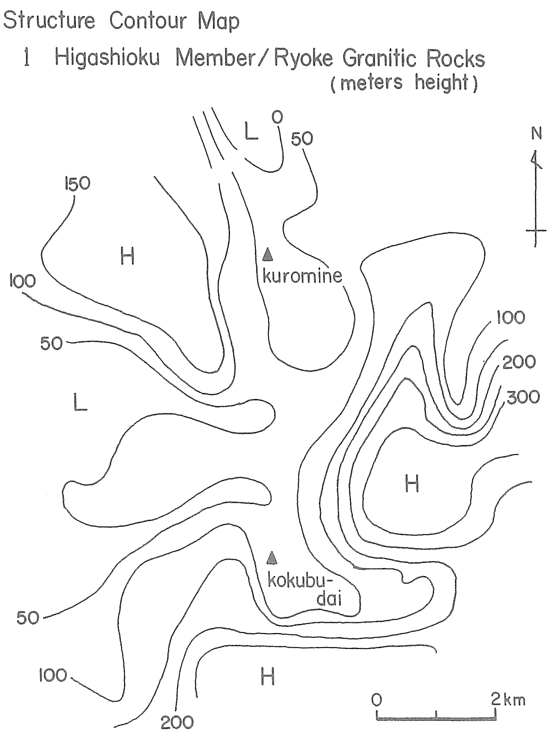

Figure 11. Structural contour map. 1. surface of granitic basement.

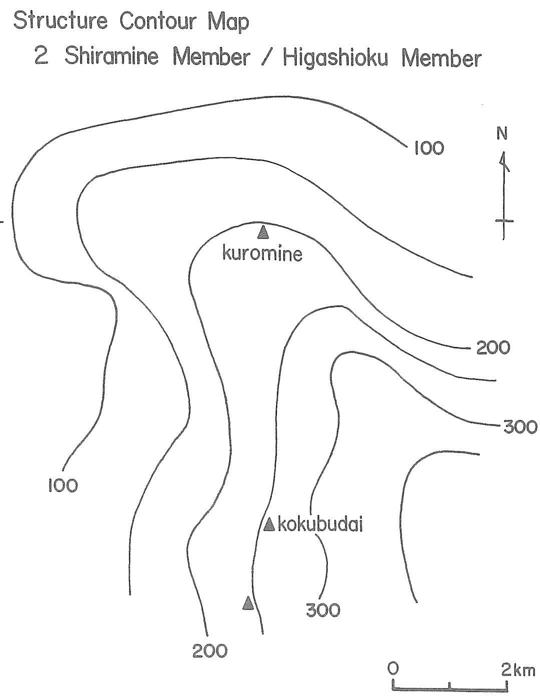

Figure 12. Structural contour map. 2. surface of Higashioku Formation.

c. Kokubudai Formation

Kokubudai Formation is mostly composed of andesitic lava flows with subordinate amounts of volcanic sediments. The Formation can be divided into at least four lava flows. They are called lava flow- I , -II, -III, -IV in ascending order. Some of the lavas of different lithology and petrography, as divided by Ujike(1970) and Henmi et al.(1976), were found to form composite or banded lava flows. Total volume of the lava flows is about 6 cubic kilometers. The volume of each lava flow is shown in Figure 2.

Lava flow- I Lava flow- I is dated to be 13.5 Ma. It is 50 to 150meters thick and occurs in the central to northeastern parts of Goshikidai mesa. Lava flow- I is mostly composed of massive compact lavas of low-K sparsely phyric andesite. Thin platy joining is commonly well developed near the base of the lava flow, which is parallel to the flow structure as identified microscopically by the parallel arrangement of laths of groundmass plagioclase. Large, dull columnar joining is noted in the central part of the flow. The lowermost part of the lava flow-Ⅰ is blocky. At three outcrops of the lower contact of the lava flow-Ⅰ, the lava is brecciated for 1-10meters thick (localities 20, 21, and 22 in Figure 3). The brecciated lava is partly welded. The breccia tends to be glassy and weakly vesiculated. The lava carries generally less than 1 percent of phenocrysts of orthopyroxene, olivine with sporadic phenocrysts of hornblende and augite. Bronzite -hornblende andesite near Ipponmatsu (locality 23 in Figure 3) carries more than 1percent of opacitized hornblende phenocryst and can be distinguished petrographically from the rest of the low-K sparsely-phyric andesite. Geological relationship between these lavas was not ascertained. The bronzite-hornblende andesite may be a part of a heterogeneous lava flow, or represents different lava flow unit from the rest of the lava flow-Ⅰ.

Lava flow-Ⅱ Lava flow-Ⅱ occurs in the southwestern part of Goshikidai mass. It is 50meters thick and 2 by 1.5kilometers in areal extent. It overlies the rhyolitic and dacitic pyroclastic deposits of Higashioku Formation. The lower several meters and the upper 5 -10meters of the flow is brecciated, while the central part is composed of dense-massive lava showing thick columnar jointing and horizontal flow banding. The lower brecciated part is welded. The lava consists of olivine-phyric andesite. Abundance and grain size of phenocryst olivine are smaller in the lower contact breccia than the massive interior of the flow. Olivine phenocryst content varies from ca 5% in the lower breccia to 9% in the central massive part.

Lava flow-Ⅲ Lava flow-Ⅲ covers the central to southwestern parts of Goshikidai mesa. It is 100 to 200meters thick, and 2.9km^3 in volume. Field relations of the lava flow-Ⅲ to other lava flows were observed at seven localities. Lava flow-Ⅲ overlies the lava flow-Ⅰ in the central to northeastern parts (locality 23 and 24 in Figure 3), and the lava flow-Ⅱ in the southwestern part of Goshikidai mass (locality 26). Lava flow-Ⅲ is overlain by the Lava flow-Ⅳ at Shiramineyama and Kamogawa Quarry (locality 25). Lava flow-Ⅲ is mostly composed of compact massive lavas of sanukitoid. Platy joining is well developed in the lower part of the flow. Usually only rough colummar joining is noted in the central part. Lava flow-Ⅲ as well as Lava flow-Ⅳ show minute flow structure, recognized as consisting of fine leucocratic schlieren of ca. 1 milimeter thick. In the upper part of Lava flow-Ⅲ, vug is found in the center of schlieren. It seems that schlieren was formed by the segregation of leucocratic material into elongated and lenticular vesicles.

A particular characteristic of the Lava flow-Ⅲ is its petrographic heterogeniety. Lava flow-Ⅲ consists mainly of high-K sparsely-phyric andesite with minor amounts of olivine -phyric and orthopyroxene-phyric sanukitoid andesites. These lavas occur together in the form of composite, banded, or irregularly intermingled lavas. Typical mode of occurrences of these heterogeneous lavas are described in the followings.

At the quarries of Eboshiyama (locality 9 in Figure 3), a composite lava flow of high

-K sparsely-phyric andesite and orthopyroxene-phyric andesite is well exposed. At the southeast quarry, following stratigraphic succession is observed; from lower to upper, coarse-grained hornblende-biotite granodiorite, rhyolitic pyroclastic flow deposit of Akabana Member (0-15meters thick), and 60meters of andesitic lava flow-III. The lowermost 5meters of the lava flow is composed of welded clinker of sparsely-phyric andesite, and the rest of the lava flow consists of lower massive sparsely-phyric andesite and the upper orthopyroxene-phyric andesite. Columnar joint of 0.5 to 2 meters thick is well developed throughout the lavas. No chilled relation was noted at the contact of these lavas. Most of the boundaries are smoothly planer and sharply defined within one milimeter, but locally, transitional zone of 1-3centimeters thick may occur. Lenticles of sparsely-phyric andesite, 10-30centimeters thick and 1-3meters long are included in the orthopyroxene -phyric andesite lava near the boundary of the composite lava flow.

At quarries to the east-northeast of Eboshiyama (locality 25 in Figure 3), lava flow-III overlies the lava flow-II, intercalated with stratified and laminated lapilli tuff and tuff breccia of ca. 5meters thick. The Lava flow-III shows marked banding structure. Both olivine-phyric and orthopyroxene-phyric andesites occur as bands and lenticles alternating with sparsely-phyric andesite for more than 30meters thick. In the center of the lava flow, a band of 1-20meters thick of olivine-and orthopyroxene-phyric andesite is remarkable (Figure 13). The band of the phyric andesites may be folded and may show irregularly intermingled structures.

At Ipponmatsu, weathered tuff layer is intercalated between lava flow-I and-III (locality 23). The layer is divided into three units (Figure 14); crystal-rich tuff (crystals are altered plagioclase, olivine and pyroxenes with little amount of reddish isotropic matrix), crystal-bearing tuff (crystals are hornblende, quartz, plagioclase and potassium feldspar in red isotropic matrix with white zeolite veinlet), and crystal-free reddish tuff.

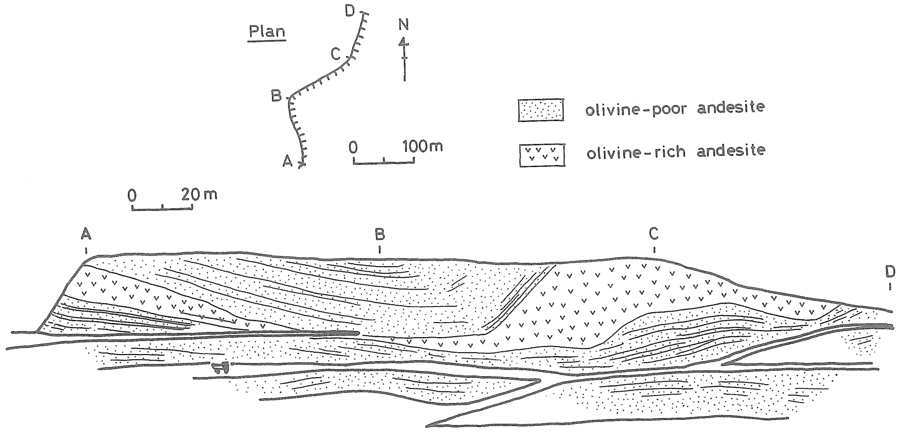

Figure 13. Sketch of outcrop of the Lava flow-III at the upper quarry of Yamahi-saiseki Co. Ltd. Olivine -poor andesite is commonly banded. The direction of shearing of the lava indicate that the lava flowed from north (right hand side) to south in this outcrop (locality 26).

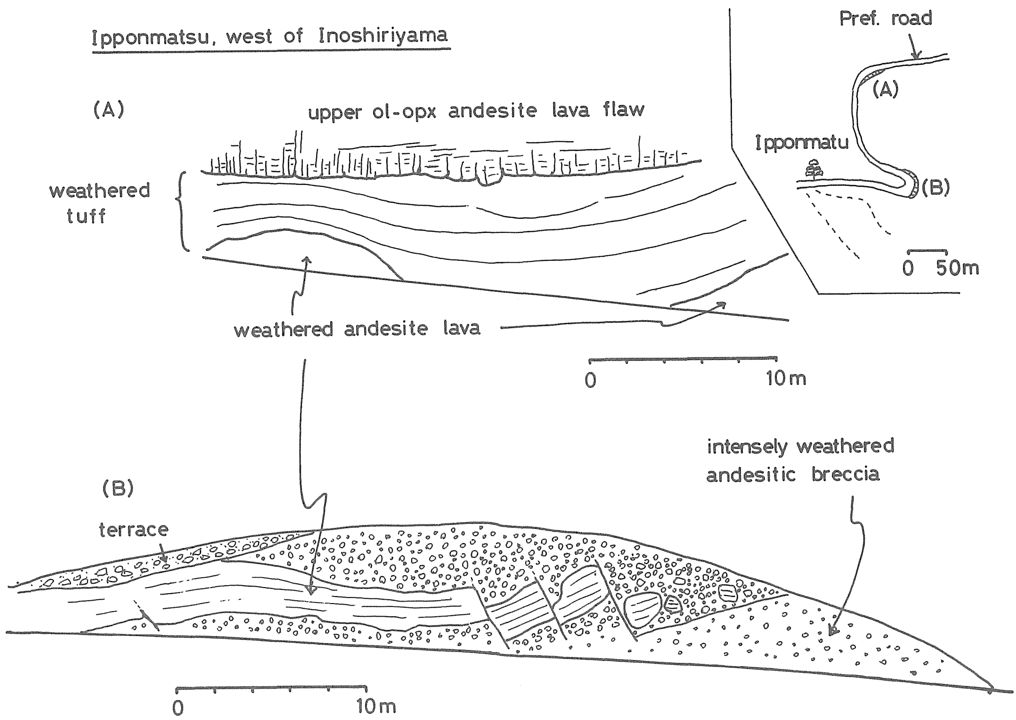

Figure 14. Boundary between Lava flow- I and -III at Ipponmatsu (locality 23).

Lava flow-IV Lava flow-IV is distributed in the southern part of Goshikidai mass. The thickness of the flow attains about 170meters at Kokubudai. At locallty 27 on the southern slope of Kokubudai mesa, massive andesite lava directly overlies massive dacite tuff of Jizo Member. The boundary surface shows wavy structure ; i.e. a regular arrangement of downward convex surface with a wavelength of 1-2meters (Figure 15) At the cusp, where the convex surfaces join, andesite lava is brecciated and the underlying dacite tuff includes chacoal-like material. It is possible that these wavy structure were formed by the overriding of pasty andesite lava over tree trunks. Lava flow-IV is mostly composed of high-K and high-Si sparsely-phyric andesite and sanukite. The mode of occurrence of sanukite is worth to note.

On the southern slope of Kokubudai mesa, sanukite occurs in the lower 30meters and the upper 20meters of the 170meters thick Lava flow-IV. Near the lower contact, sanukite is found as lined, elongated blebs of 1-3 centimeters across, or bands of 1 centimeter to several meters thick alternating with crystalline sparsely-phyric andesite. Sanukite band of 1 centimeter thick can be traced for more than 10 meters horizontally. Boundaries between sanukite and crystalline andesite is sharp and show no chilled relations.

Another occurrences of mixing relations of lavas in the Lava flow-IV are found between crystalline andesite and sanukite at the top of Kokubudai (locality 30 in Figure 3). Figure 16 illustrates intermingled structure of the lavas. Fresh sanukite blocks are buried

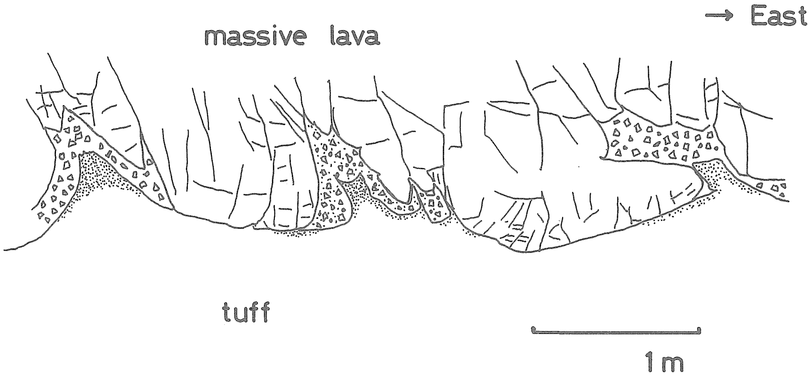

Figure 15. Boundary between Jizo Member and the Lava flow-IV at the southern slope of Kokubudai mesa (locality 27). The boundary show wavy structur. The lava is partly brecciated (fragmental symbol), while the dotted part of the tuff is dark gray possibly due to organic material.

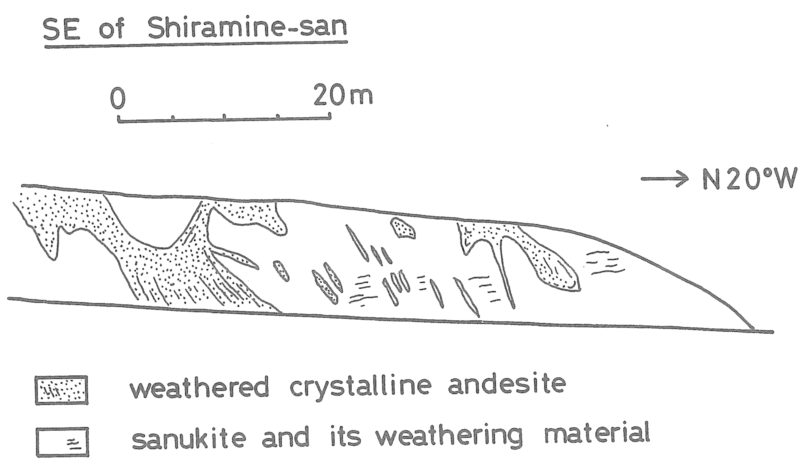

Figure 16. Occurrences of sanukite and crystalline andesite at the road cut of Shiramineyama (locality 30). Sanukite is intruded by the crystalline andesite.

in yellowish gray weathered material. The crystalline andesite is intensely weathered into red clay, but the original flow structure is recognized by fine stripes, which probably represent schlieren in the original fresh lava. The flow structure of the crystalline andesite is parallel to the contact plane of the crystalline andesite and sanukite. Sanukite lava may be cut by numerous minor intrusives and dikes of crystalline andesite. About 200meters southwest of the above described outcrop, sanukite lava overlies crystalline andesite lava. Near the boundary, sanukite is included as stripes in the crystalline andesite, while small rounded blocks of the latter is included in the sanukite lava. The mode of occurrence of these lavas on the top of Kokubudai indicate successive and almost simultaneous outpouring of the sanukite and crystalline andesite lavas.

At a quarry on the southeast ridge of Renkoji hill (locality 29 in Figure 3), lower part of the lava flow-IV consists of sanukite, and it gradually changes into upper crystalline and porous andesite. Sanukite in this locality is popularly known as Kankan-ish (sonorous rock), and carries rare phenocryst of olivine and microphenocrysts of bronzite and plagioclase.

d. Volcanic necks

Nine volcanic necks are identified in the surroundings of Goshikidai and Kiyama masses (Figure 17). Three of them, situated just to the south of Goshikidai mesa consists of sparsely-phyric sanukitoid andesite and sanukite and is considered to be the possible sources of the lavas of the Kokubudai Formation. Mode of occurrence of these three necks will be described below.

A conical hill to the north of Kawanishi (215meters high, and is called Peak-215) is a composite neck, consisting of chaotic pyroclastics and massive lava. The pyroclastics occupies the western part of the neck, and shows rough vertical stratification. It consists of weakly vesicular to compact lava fragments of hornblende-bronzite andesite, The massive lava is composed of bronzite andesite. At the southwestern rim of the neck, the massive lava was found to intrude the granitic rocks. It is partly brecciated and contains granitic fragments near the margin. The massive lava show concentric flow structure, inclined steeply toward the center of the neck and concordant to the shape of the mass. The neck of Peak-215 is 150 by 200meters across. A probable intrusive of sanukite occurs about 400meters WNW of Peak-215. Though poor exposure prevented to confirm intrusive relations, massive sanukite lava is surrounded by pyroclastics of hornblende andesite. A butte to the east of Higashioku (176meters high, and is called Peak-176) is also a composite neck. Massive lava of hornblende-bronzite andesite intrudes nearly vertically the volcanic breccia of hornblende andesite. Distribution of the massive lava is rather irregular, and is ca. 100 by 200meters wide.

e. Summary

Brief sketch of Miocene geologic history of Goshikidai and adjacent areas is summarized as follows.

Just before the initiation of volcanic activity, this area was covered by rocky undulatory hills of granitic rocks. Small ponds existed locally. The first period of volcanic activity, now represented by Higashioku Formation, commenced with successive eruptions of rhyolite to dacite pyroclastic flows and lava flows. They erupted from at least four vents. Small explosion of dacite pumice occurred in the later phase of the first volcanic activity. Then came a period of quiescence, during which sediments are locally deposited and plants grew. No extensive erosion of the volcanic deposit of Highashioku Formation took place, however. The second period of volcanic activity, now represented by Kokubudai Formation, outpoured four andesitic lava flows. These lava flows are generally

Figure 17. Locality of vent in and around Goshikidai mass.

massive, compact and thick. Periods of weathering and local sedimationation existed among outpouring of these lava flows. Feeders of the andesitic lava flows were possibly located just to the south of Goshikidai mesa, where some andesitic volcanic necks are now exposed. It is pointed out that the volcanic deposits of Goshikidai and adjacent areas were the products of several monogenic volcanic activities.

6. Geology of some volcanic masses other than Goshikidai mass.

a. Shiundesan mass (volcanic mass number 1 in Figure 1)

Shiundesan, 352.4meters in height above sea level outcrops granitic basement below about 240meters. The volcanic succession is, from lower to upper, aphyric sanukitoid andesite lava flow (ca. 50meters thick), biotite rhyolite pyroclastic flow deposit (more than 5meters thick) and massive lava flow and volcanic breccia of plagioclase-phyric andesite (ca. 50meters thick). This succession is the only example of the occurrence of sanukitoid andesite below rhyolitic pyroclastics in the northeast Shikoku region. Rhyolite is generally overlain by sanukitoid andesite in other volcanic masses.

b. Ibukishima mass (2)

The volcanic rocks of Ibukishima mass is composed of lower augite-bronzite-olivine andesite lava flow and the upper brecciated lava flow of plagioclase-phyric pyroxene andesite. The augite-bronzite-olivine andesite lava flow is ca. 90meters in total thickness and consists of several flow units.

c. Takamishima mass (4. Figure 18)

Takamishima mass constitute small elongated hill. The lower 90-100meters of the hill consists of granitic basement, while the upper part of the mass is composed of massive sanukitoid andesite lava flow and brecciated lava of plagioclase-phyric andesite. The lower sanukitoid andesite lava flow show variation of petrography, from olivine-phyric andesite, through olivine sanukite, to orthopyroxene-phyric andesite.

d. Iyatanisan mass (5, Figure 19)

Iyatanisan is a dissected hill, with a volume of 1.8km^3 of volcanic rocks. Stratigraphic sequence of the volcanic rocks is rhyolitic tuff, tuff breccia and sandstone, rhyolite lava flow, and lava flows, tuff breccia, and conglomerate and sandstone of garnet-bearing hornblende-orthopyroxene andesite. The rhyolitic tuff and tuff breccia is about 20meters thick and distributed around the Iyatassian mass. The rhyolitic tuff and tuff breccia is very similar to those of the Akabana Member of Goshikidai mass. Rhyolitic sandstone and conglomerate is well sorted and show marked lamination. It is ca. 10meters thick at the southern foot of Amakiriyama. Massive rhyolite lava flow occurs at the southeastern foot of Amakiriyama, where it overlies the rhyolitc sandstone and conglomerate. Garnet -bearing hornblende-orthopyroxene andesite lava flow is composed of several flow units of massive lava flow, intercalated with tuff breccia, volcanic conglomerat and sandstone, The massive lava flow is 250meters in maximum thickness at the southern slope of

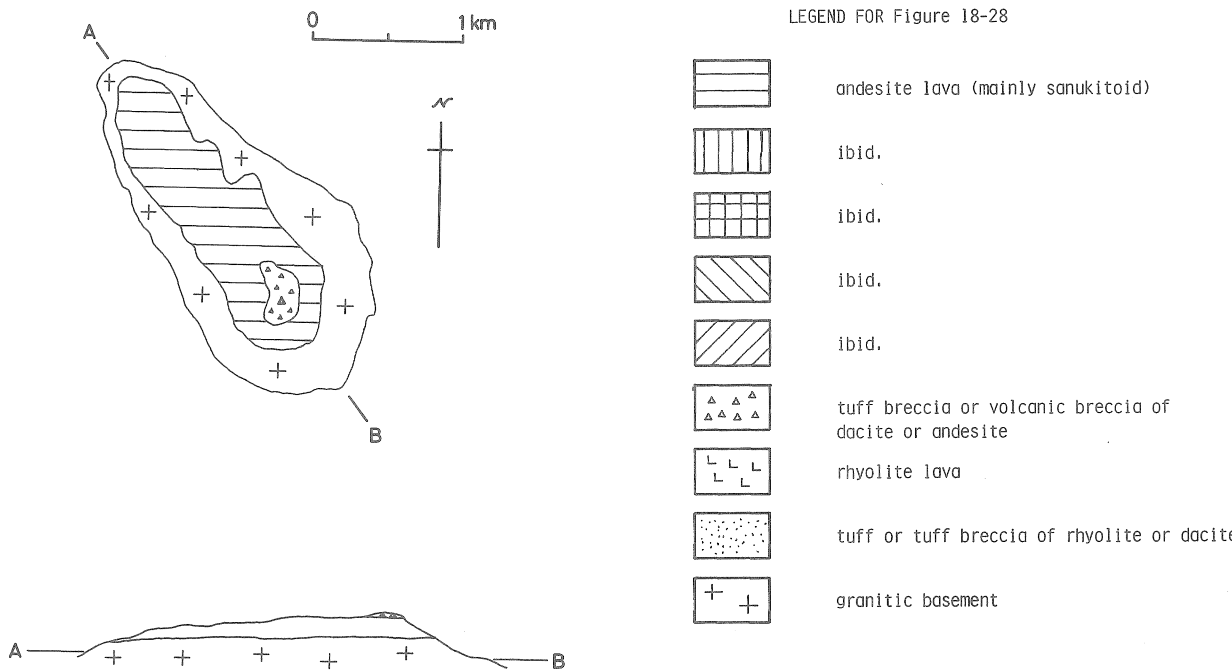

Figure 18. Geological map and cross section of Takamishima mass.

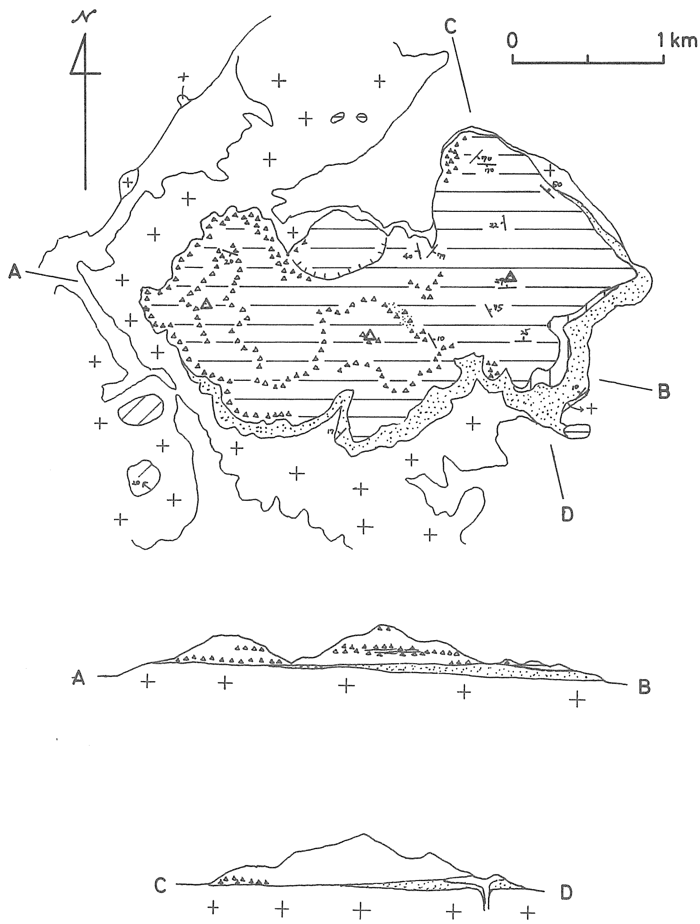

Figure 19. Geological map and cross section of Iyatanisan mass.

Amakiriyama. It is noted that garnet phenocryst is oxidized in the interior of the lava flow, while garnet is fresh in the outer part of the lava flow.

e. Nio-Pass mass (6)

At the northern foot of Hichihozan mass, there is a neck of andesite volcanic breccia. It consists of large blocks of pyroxene-phyric sanukitoid andesite, aphyric andesite and granitic rocks and matrx. The pyroxene-phyric andesite show wide variation of phenocryst petrography, and may carry about 20percent of bronzite and augite phenocrysts, which is the highest value among sanukitoid lavas of the northeast Shikoku region.

f. Hichihozan mass (7, Figure 20)

Hichihozan mass is composed of the lower rhyolitic tuff and the upper sanukitoid andesite lava flow. The rhyolitic tuff is heterolithologic, massive, and about 20meters in maximum thickness. It resembles the rhyolitic tuff of Akabana Member of Goshikidai and may represents pyroclastic flow deposit. The massive sanukitoid andesite lava flow is composed of aphyric andesite, hornblende andesite, and hornblende-augite-orthopyroxene andesite. It attains 300meters in maximum thickness.

g. Tsukumoyama mass (8)

Tsukumoyama mass is composed of andesite lava and volcanic breccia. It is notable that continuous lateral variation from massive homogeneous andesite lava through welded breccia to non-welded volcanic breccia is observed. Amount of granitic mineral grains in the lavas gradually increases from the center to the outer part of the mass. The fragmental nature of the welded breccia is recognized in terms of distribution of xenocrysts. Xenocryst free andesite fragment is coherently included in the xenocryst-charged andesite matrix of the same petrography. Marginal contact of the lava and pyroclastics against granitic basement was not ascertained in this mass, however.

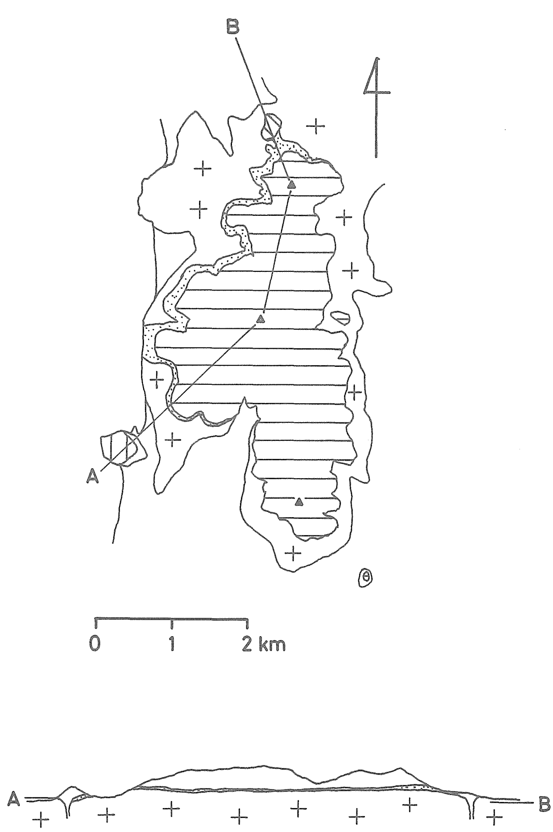

Figure 20. Geological map and cross section of Hichihozan mass.

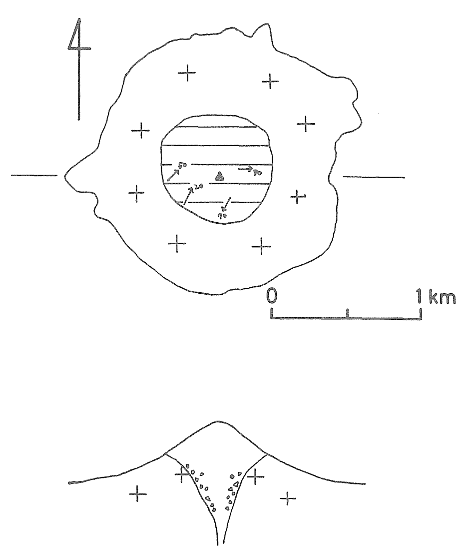

Figure 21. Geological map and cross section of Iinoyama mass.

h. Marugame-Castle mass (13)

Marugame-Castle mass is a small cone, 200meters across and 60meters high, consisting mainly of massive lava of olivine basalt. The source vent is exposed at the western margin of the mass, where a dike of massive olivine basalt intrude massive basaltic scoria. The massive basalt lava is locally charged with abundant mineral grains of plagioclase, quartz, and alkali feldspar derived from granitic basement. An intrusive lava of porous augite-bronzite andesite occurs next to the basaltic dike, but their intrusive relation was not ascertained. The trend of the basaltic dike is east-west.

i. Iinoyama mass (14, Figure 21)

Iinoyama is the largest conical hill in the northeast Shikoku region, and is called Sanuki-Fuji. It is 422meters high and ca. 2kilometers across at the foot. The lower half of the cone consists of granitic rocks, and lavas of olivine andesite to bronzite andesite cap the cone. Olivine andesite occurs in the marginal part of the volcanic mass, and is charged with abundant disintegrated granitic xenolith and xenocrysts as noted by Matsumoto (1950). The olivine andesite lava shows columnar joint directing nearly horizontally and radially from the center of the mass, whereas, bronzite andesite lava, near summit of the cone, exhibits roughly horizontal platy joint with concominant flow structure. It is conceived that present lavas of Iinoyama represent the transition from funnel shaped vent to extruded lava dome. According to Murakami (1961), gravity high at Iinoyama is elongated NE-SW direction, and extends westward to Futagoyama mass(15).

j. Futagoyama mass (15)

Futagoyama mass is a lava-filled vent. Massive sanukite lava intrudes granitic basement. The boundaries inclined steeply toward the center of the mass. The sanukite lava is charged with abundant granitic fragments and mineral grains showing flow struc -ture parallel to the boundary. Massive sanukite lava at the margin of the mass show subtle fragmental structure, i.e. blocks of xenocryst-free sanukite lava are coherently included in the xenocryst-rich sanukite. It is possible that the sanukite lava extruded as pyroclastic flow and is strongly welded into massive lava within the vent.

k. Gahaishi-Hiageyama mass (16, Figure 22)

The volume of the volcanic rocks of Gahaishi-Hiageyama mass is 0.35km^3. It consists of 0.25km^3 of garnet-bearing biotite rhyolite to aphyric dacite, and 0.1km^3 of sanukitoid andesite. The rhyolite deposit in the central to the eastern part of the mass is 180meters thick and composed of rhyolitic sandstone, conglomerate, and lapilli tuff, and grades into aphyric dacite tuff breccia upward. On the other hand, in the western part of the mass, rhyolite deposit is ca. 20meters thick and occurs as pyroclatic flow deposit lithologically similar to the heterolithologic tuff breccia of Akabana Member of Goshikidai mass. The andesite lava is heterogeneous, composed of lower hornblende-orthopyroxene andesite and the upper augite-orthopyroxene andesite as noted by Ujike (1970).

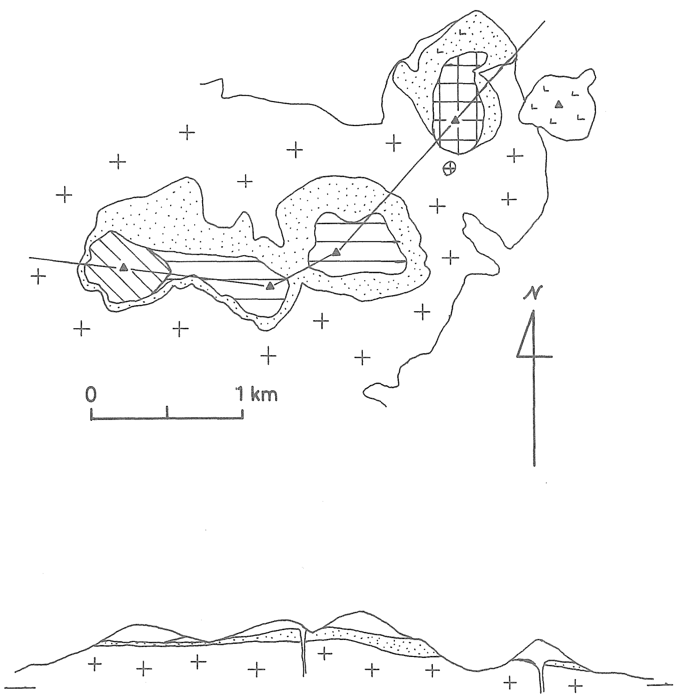

Figure 22. Geological map and cross section of Gahaishi-Hiageyama mass.

l. Oomasan mass (17, Figure 23)

The volcanic rocks of Oomasan occurs above 400meters above sea level. It is composed of lower rhyolitic tuff and tuff breccia and the upper massive lava flow of sanukitoid hornblende andesite. The lithology of the rhyolitic tuff and tuff breccia varies from monolithologic tuff breccia, possibly a brecciated lava, at the southeastern part of the mass, and heterolithologic pyroclastic flow deposit at the northwestern part of the mass. On the southern slope of Oomasan, massive sanukitoid andesite lava flow directly overlies the granitic basement, where the andesite lava is partly brecciated. The andesite lava is massive and shows platy joint at the base, and columnar joint in the center of the flow. It is ca. 200meters in maximum thickness, and petrographically very homogeneous. It is notable that the base of the volcanic deposit increases its height from Iyatanisan (5) (50meters above sea level), through Gahaishisan-Hiageyama mass(16)(ca. 200meters) to Oomasan (ca. 400meters). These volcanic masses are commonly composed of lower rhyolitic pyroclastics and the upper sanukitoid andesite lava flows, though the upper sanukitoid andesite are petrographically different from each other, and each of the mass may have its own source vent.

m. Washinoyama mass (30)

Washinoyama mass is composed of lower lava flow of biotite rhyolite and the upper

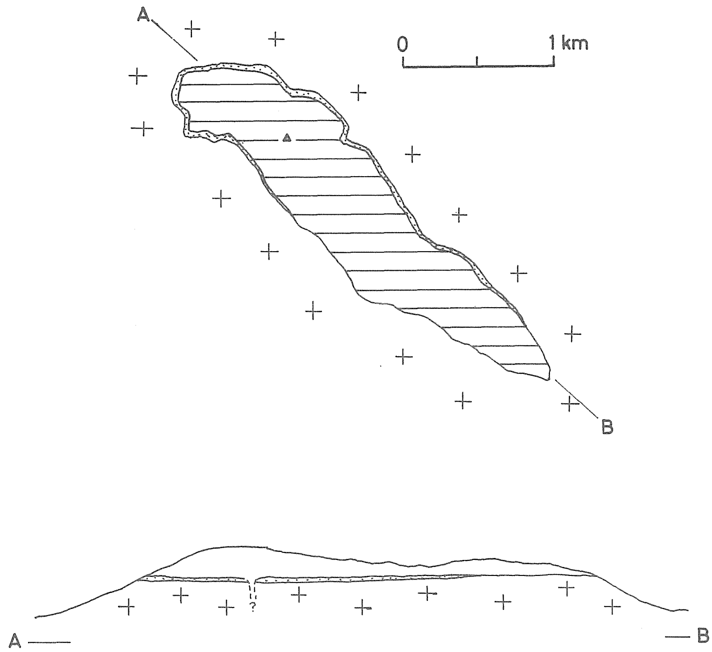

Figure 23. Geological map and cross section of Oomasan mass.

lava flow of garnet-bearing biotite-hornblende-hypersthene dacite. The lower lava flow is about 20meters thick and is massive. The upper lava flow is about 200meters thick, and is homogeneous petrographically. Thick columnar jointing is well developed in the central part of the lava flow. The dacite lava sometimes includes xenoliths of argillaceous rocks and peculiar ultramafic rocks composed of biotite, hornblende, augite and orthopyroxene.

n. Kiyama mass (32) and Kanayama mass(10) (Figure 24)

Though the volcanic rocks of Kiyama and Kanayama masses are separated from those of Goshikidai mass, they are lithologically and petrographically common. Stratigraphic sequence of Kiyama and Kanayama mass is, from lower to upper, rhyolitic tuff breccia, hornblende dacite volcanic breccia, sanukitoid andesite lava flows. The rhyolitic tuff breccia is mostly massive and heterolithologic consisting of rhyolite and its glass with small amount of granitic rocks. It is roughly stratified where it is thick. Dacite volcanic breccia conformably overlies the rhyolitic tuff breccia. It is massive and show rough stratification. The rhyolitic and dacitic pyroclastic deposits are correlated lithologically to the Akabana Member and Nishioku Member of Goshikidai mass, respectively. The sanukitoid andesite lava flows are divided into three units, which are lithologically and chemically correlated to the lava flows- I , -II, and -IV of Goshikidai mass. The lowest lava flow is rather thick, and massive. Thin platy joint is developed near the base, while thick columnar joint is notable in the center of the lava flow. Upper part of the lowest lava flow is extensively

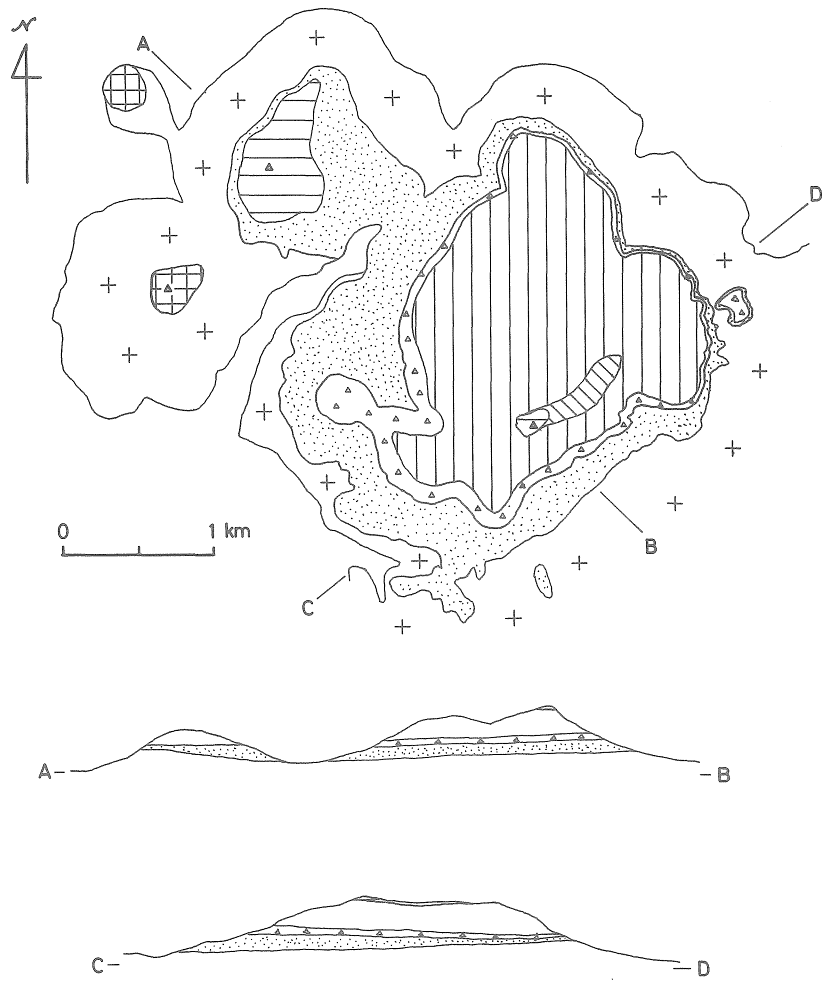

Figure 24. Geological map and cross section of Kiyama and Kanayama mass.

brecciated. The middle lava flow contains abundant olivine phenocryst and petrographically the same as those of the lava flow-II of Goshikidai mass. The uppermost lava flow is composed of sanukite, and may show banding structure with crystalline aphyric sanukitoid andesite (eastern slope of Kanayama mass).

o. Megishima mass (38)

The volcanic rocks of Megishima mass is composed of lower scoria fall deposit of andesite, and upper massive lava flow of sanukitoid olivine andesite and bronzite andesite. The lower scoria fall deposit is about 10meters thick. It is generally massive, but weak lamination may be observed. It is composed of well sorted, black to yellow, poorly -vesiculated scoria fragment. The lava flow is about 100meters in maximum thickness.

The lower part of the lava flow develops columnar jointing and is composed of olivine andesite, while the upper part consists of bronzite andesite.

p. Yashima mass (39)

Geological map of Yashima mass is published by Tatsumi and Ishizaka (1978b). The volcanic deposit is composed of lower scoria fall and the upper sanukitoid andesite lava flow. The lower scoria fall deposit is ca. 50meters in thickness in the northern part of the mass. It is well sorted and massive, or may show weak lamination. The andesite lava flow have brecciated part of several meters in thickness both at the base and the upper parts. The brecciated fragment may be weakly vesicular, while the massive part of the lava flow is vesicle-free. The lava flow is composit, and the lower part is composed of olivine -bearing augite-bronzite andesite, and the upper part consist of bronzite andesite.

q. Iwaseosan (40, Figure 25)

The volcanic rocks of Iwaseosan consists of lower acidic to intermediate pyroclastic rocks and the upper andesite lava flows. The lower pyroclastics consist of thin massive rhyolite tuff, pumiceous lapilli tuff of aphyric dacite, and agglutinate of olivine andesite, in ascending order. The rhyolitic tuff occurs only near Kiritoshi pass in the central part of the mass, and is fine white massive tuff of more than 2meters thick. The pumiceous lapilli tuff is distributed all around the mass, while it is thickest in the north-central part of the mass, where it is overlain by andesitic agglutinate. The pumiceous lapilli tuff often show lamination, whereas the lower portion of the agglutinate contains partially palagonitized matrix and pillow-like blocks. These pyroclastics may have deposited under water. In the upper portion of the andesitic agglutinate, small angular fragments and bombs show evidence of plastic deformation and welding. Massive olivine andesite lava was found to overlay directly the agglutinate in the north-central part of the mass. It is considered that the pyroclastics and the massive lavas of Iwaseosan mass were produced by a successive eruption. The andesitic lava flow of Iwaseosan mass is divided into lower olivine andesite and the upper bronzite andesite. They probably form a composite lava flow. Main source vent of the andesite is estimated at a small hill (141meters high and called Iwaseohachiman) in the north-central portion of the mass, where complex intrusive relation of lavas is observed.

r. Peak-211 (49, Figure 26, Figure 27)

Peak-211 is a composite neck. Figure 26 illustrate the occurrence of the composite neck in its southern quarry. The outermost part of the neck is occupied by tuff breccia of plagioclase-phyric biotite-hornblende dacite, which is cut by tuff breccia of plagioclase -phyric augite-hypersthene andesite. The latter tuff breccia is intruded by massive lava mainly composed of augite-olivine basalt. The massive lava develops fine columnar jointing against the tuff breccia. At the margin of the intrusive massive lava, augite -olivine basalt includes irregular, mixed, or occassionally blocky lavas of plagioclase

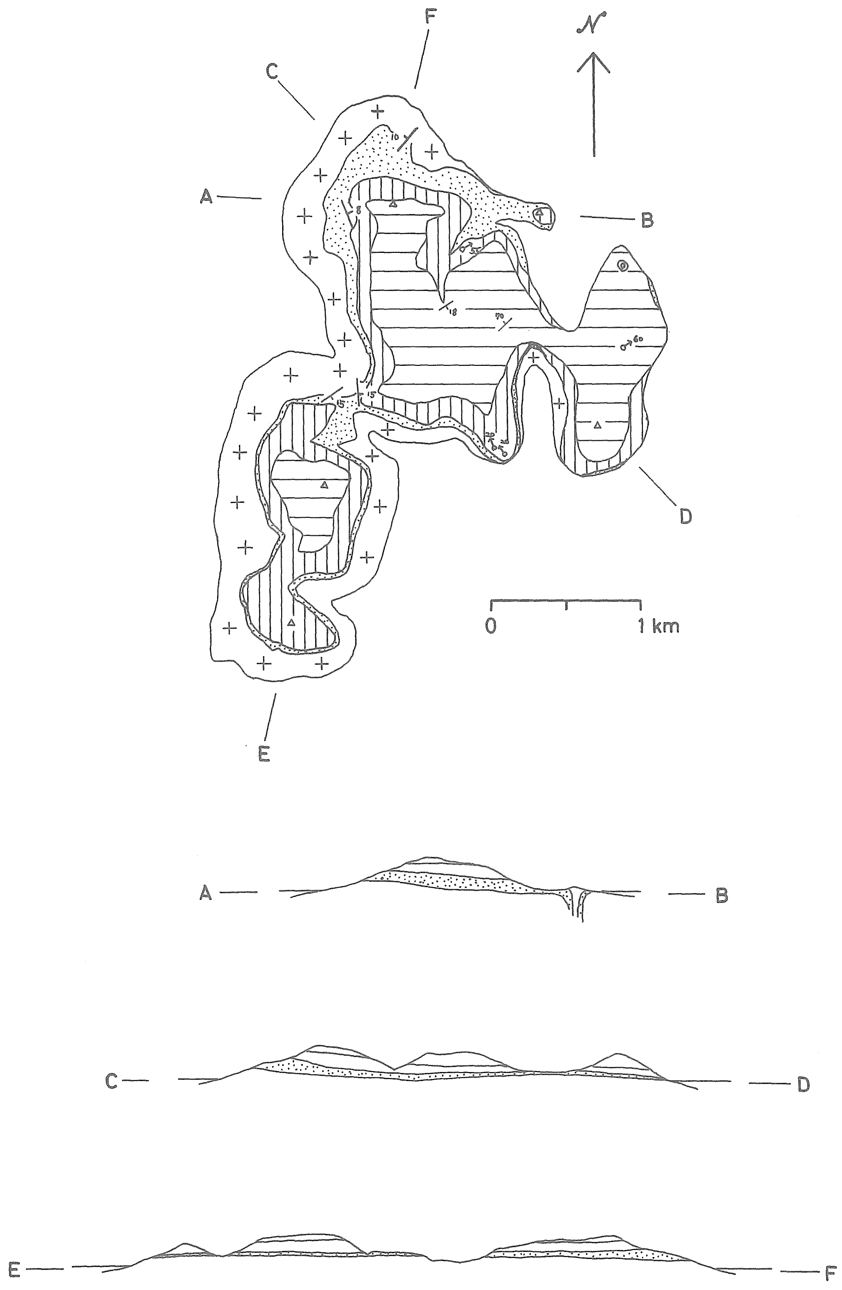

Figure 25. Geological map and cross sections of Iwaseosan mass.

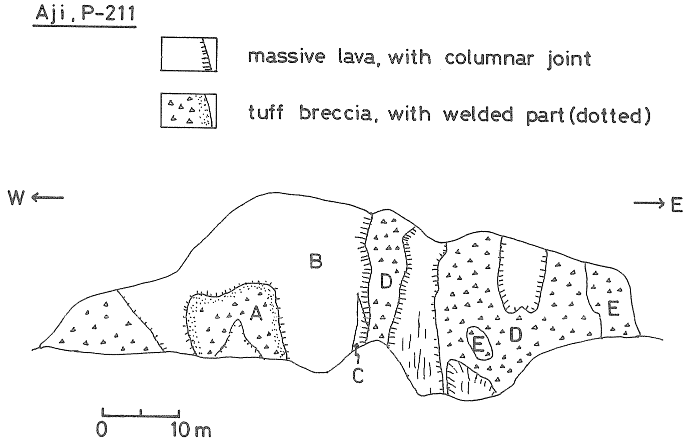

Figure 26. Sketch of the quarry of Peak-211. A : tuff breccia of andesite, B :massive lava of basalt, C : massive lava of plagioclase-phyric andesite, D : tuff breccia of Plagioclase-phyric andesite and aphyric andesite, E : tuff breccia of biotite-hornblende dacite.

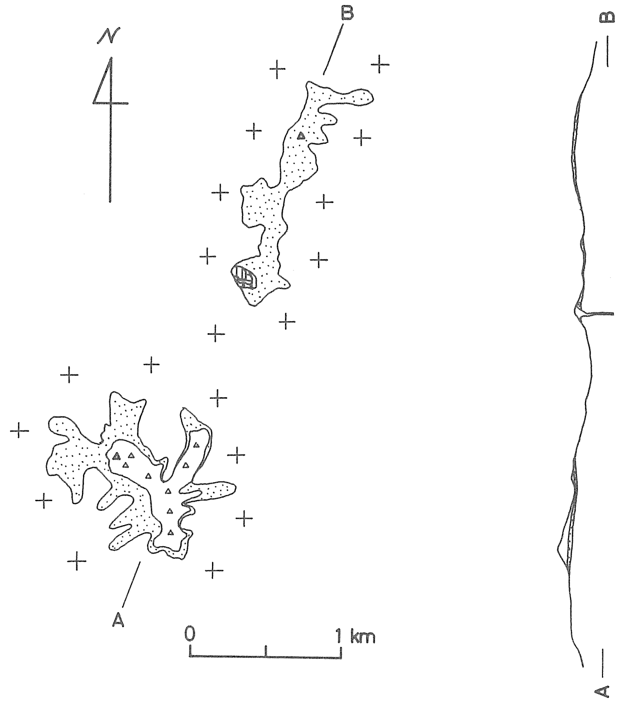

Figure 27. Geological map and cross section of Gokenzan and Peak-211 mass.

-phyric augite-hypersthene andesite. No chilled relation was found between these lavas, suggesting successive effusion of the lavas. The augite-olivine basalt massive lava contains blocks of tuff breccia of plagioclase-phyric augite-hypersthene andesite, which is welded near the contact. The diameter of the neck of Peak-211 mass is about 100 meters.

s. Gokenzan mass (50, Figure 27)

The Miocene formation of Gokenzan mass consists of arkose sandstone, rhyolitic tuff and lapilli tuff, and tuff breccia of plagioclase-phyric biotite-hornblende-orthopyroxene andesite. The arkose sandstone is massive or laminated and is several meters thick. It is conformably overlain by rhyolitic tuff and lapilli tuff. The rhyolitic tuff and lapilli tuff is rather well sorted and consists of fragments of rhyolite and pitchstone glass and mineral grains derived from granitic basement. It is composed of massive units of 0.1-several meters thick, which are divided by thin layers of laminated tuff. The rhyolitic tuff and lapilli tuff is 50 meters in maximum thickness. Andesitic tuff breccia abut small-scale irregular surface of the rhyolitic tuff and lapilli tuff. The andesitic tuff breccia is mostly massive, though thin layers of tuff is often intercalated. It is ca. 50 meters thick.

t. Ametakiyama mass(51) and Hiyama mass(54) (Figure 28)

Ametakiyama consists of thick lava flow of garnet-biotite-hornblende-hypersthene andesite, while Hiyama mass is composed of biotite rhyolite tuff, orthopyroxene -hornblende andesite lava flow, augite-olivine andesite lava flow, biotite dacite tuff and garnet-biotite-hornblende-hypersthene dacite lava flow, in ascending order. The augite

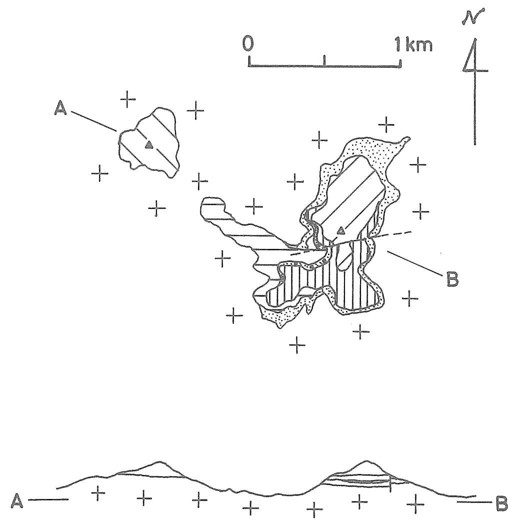

Figure 28. Geological map and cross section of Ametakiyama and Hiyama masses.

-olivine andesite is a high-magnesian andesite. It is ca. 50 meters thick, and is brecciated for ca. 1 meter at the base. The lava is massive and compact, showing rough columnar jointing. Takeuchi (1941) considered that the garnet-bearing andesite of Ametakiyama and garnet-bearing dacite (he referred "andesite") of Hiyama mass are the same. The writer, however, considers that these lavas represent different unit, because petrography and chemistry of these lavas are different.

u. Kankakei mass (52)

Kankakei volcanic mass is located in the northeastern margin of the northeast Shikoku region and is the only one composite volcano. Petrographically, it is mainly composed of plagioclase-phyric andesite and is devoid of sanukitoid. Thin rhyolitic to dacitic pyroclastic deposit occurs in the lowest position of the mass, which is overlain by thick deposits of andesitic lava flows, volcanic breccia, and volcanic conglomerate and sandstone. Geological map of the Kankakei mass has been published by Saito (1962) and Tatsumi and Yokoyama(1978a). It is noted that volcanic conglomerate and sandstone, probably secondary wash deposits, are abundant in the lower portion of the mass, while lava flows and volcanic breccia predominate in the upper portion. Total thickness of the deposit attains ca. 600 meters, including several massive lava flows of 5 to 100 meters thick. Kobayashi and Nakamura(1978) have shown that dikes in the Kankakei mass is oriented N-NEN dimection, which is nearly perpendicular to the direction of dikes in other monogenic volcanic masses of the northeast Shikoku region.

7 Characteristics of volcanic geology of the northeast Shikoku region

a. Areal distribution of the volcanic rocks

Koto(1916) noted that the following volcanic rocks conform zones arranged from sourth to north parallel to the Median Tectonic Line; rhyodacite, biotite andesite, hornblende andesite, sanukite and allied rocks (sanukitoid), and orthobasalt. Although there is general tendency of the localization of some rock types, many exceptions to the proposed zonal distribution is noted. For example, sanukitoid lavas occur in the southernmost part of the northeast Shikoku region (such as Nekoyama (volcanic mass number 34) and Takahachiyama (35) masses), and biotite rhyolite occurs in Kankakei volcanic mass, which is situated in the northernmost part of the region. Rhyolite rather tends to be associated with large andesitic volcanic masses, such as Goshikidai(21), Hichihozan(7), Iyatanisan(5), and Oomasan(17) masses. Smaller mass tends to lack pyroclastics of rhyolite to dacite.

b. Stratigraphic sequence

Some of the volcanic masses in the northeast Shikoku region are compound, i.e. consisting of several volcanic deposits. These compound masses are usually larger than 0.1km^3 in volume. Pyroclastics of acid to intermediate composition tend to occupy the lower portion, and massive lavas of sanukitoid occur in the upper portion of these compound

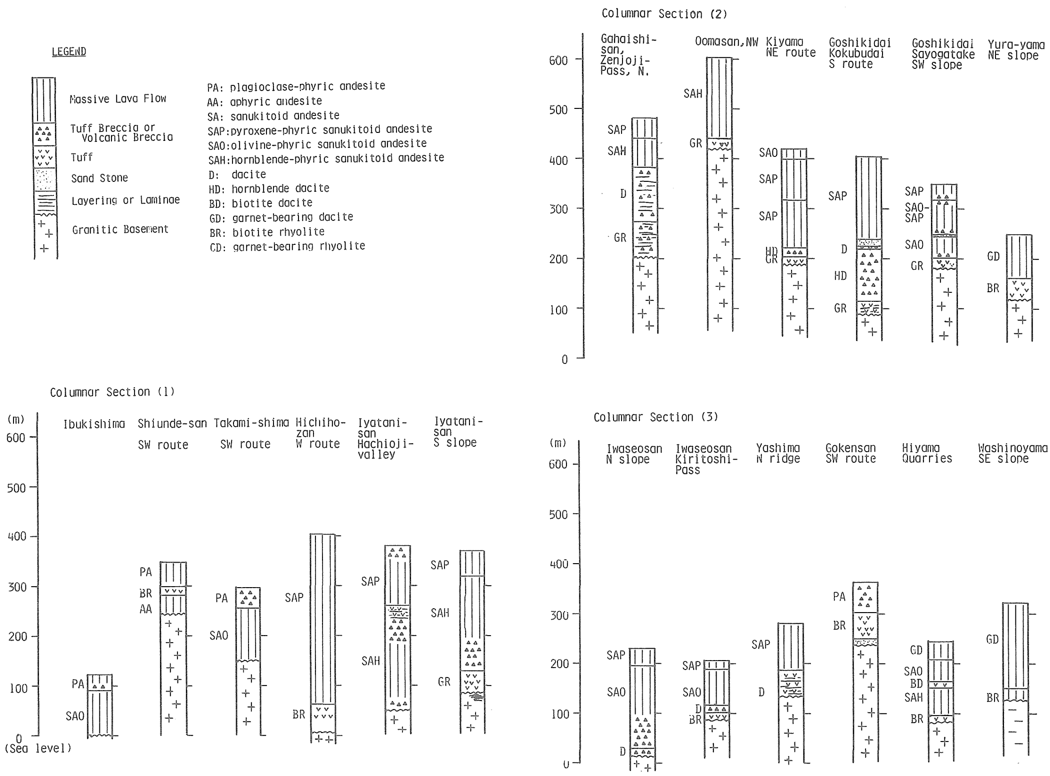

Figure 29. Columnar sections of representative volcanic masses in northest Shikoku region.

masse (Figure 29). A typical example of the compound mass is the Goshikidai and adjacent masses. Other occurrence of compound masses is described below.

In the western part of the region, the large four masses, Hichihozan (7, 2.0km^3, Figure 20), Iyatanisan (5, 1.0km^3, Figure 19), Gahaishisan-Hiageyama (16, 0.4km^3, Figure 22) and Oomasan (17, 0.3km^3, Figure 23) masses are composed of lower pyroclastics and massive lavas of rhyolite and upper sanukitoid andesite lava flows. The rhyolitic pyroclastics are poorly-sorted, massive, heterolithologic or monolithologic being lithologically similar to those of Akabana Member of Goshikidai mass described in the preceeding section. In Iyatanisan and Oomasan masses, monolithologic rhyolitic pyroclastic deposits grade laterally into massive lava flows. Andesitic lavas consist of hornblende-augite-bronzite andesite in Hichihozan mass, garnet-bearing hornblende-bronzite andesite in Iyatanisan mass, augite-hornblende-bronzite andesite to bronzite andesite in Gahaishi-Hiageyama mass, and hornblende andesite of Oomasan mass, respectively. Petrographic difference of the sanukitoid andesite lavas among these four volcanic masses indicates that the vents of these lavas are located within each of the masses.

Volcanic masses of Iwaseosan(40,0.64km^3,Figure 25) Megishima(38) and Yashima(39,0.2km^3) in the northeastern part of the northeast Shikoku region consist of lower pyroclastic fall deposits of rhyolite to andesite, and upper massive lava flows of sanukitoid (Figure 29).

In Iwaseosan mass, the lower pyroclastics consist of thin rhyolitic tuff, pumiceous lapilli tuff of aphyric dacite, and agglutinate of olivine andesite, in ascending order, while the upper andesite lava flow consist of olivine andesite and bronzite andesite. Yashima mass is composed of lower andesitic lapilli tuff and upper augite-bronzite andesite lava flow, with thin granitic conglomerate and sandstone on the top as mentioned earlier. According to Sato(1936), volcanic masses of Teshima(36), Ogishima(37) and Kitayama(53) in the northeastern part of the northeast Shikoku region have the same stratigraphic successions as Yashima mass.

Garnet-bearing andesite and dacite lavas in the central to eastern parts of the northeast Shikoku region underly rhyolitic lavas and pyroclastics. Washinoyama mass (30), to the south of Goshikidai mass, consists of lower lava flow of biotite rhyolite and upper lava flow of garnet-biotite-hornblende-hypersthene dacite. Garnet-bearing biotite dacite of Yurayama(41) and adjacent masses (volcanic mass number 42, 43, 44) are underlain by rhyolitic tuff and tuff breccia. Hiyama mass(54) is composed of biotite rhyolite tuff, orthopyroxene-bornblende andesite lava flow, augite-olivine andesite lava flow, biotite dacite tuff, and garnet-biotite-hornblende-orthopyroxene dacite lava flow, in ascending order. Garnet-hornblende-orthopyroxene andesite of Iyatanisan mass(5) also underlay the rhyolitic lava flows and pyroclastics. These examples may suggest that there is common mechanism that the outpouring of garnet-bearing andesite and dacite lavas is preceeded by the eruption of rhyolitic volcanic rocks.

Kankakei volcanic mass(52), the only composite volcano in the northeast Shikoku region, also has thin rhyolitic to dacitic pyroclastic deposit beneath thick deposits of andesitic lava flows, volcanic breccia, and volcanic conglomerate and sandstone.

Three volcanic masses situated in the western part of the northeast Shikoku region, Ibukishima(2), Shiundesan(1), and Takamishima(4) masses consist of lavas of sanukitoid and plagioclase-phyric andesites. Plagioclase-phyric andesites alweys occupy the top of these volcanic masses. The lower sanukitoid lavas are augite-bronzite-olivine andesite in Ibukishima mass, hornblede andesite in Shiundesan mass, and olivine basalt through olivine andesite to bronzite andesite in Takamishima mass, respectively.

c. Vents

More than 50 volcanic vents are randomly distributed in the northeast Shikoku region. Figure 17 shows the localities of vents in Goshikidai and adjacent areas. Many of the volcanic masses are postulated to have their source vents within each of the mass, because of the distinctive petrographic characteristics of the lavas among the adjacent masses. In some of the volcanic masses, intrusive structures are well exposed, and some of them have been described in the preceeding sections. Volcanic vents in the northeast Shikoku region can be classified as follows.

1. pyroclastic vent
2. lava vent
   a. dike

b. pipe

Pyroclastic vents are observed in Goshikidai mass(21) and Nio-Pass mass(6). These vents are filled with tuff breccia and volcanic breccia of rhyolite, dacite, and rarely andesite.

Dikes are observed in Kankakei mass(52), Marugame-Castle mass(13), Peak-157 mass(31), Yoshinodai mass(46), and Aji Peninsula. The strike of the dikes of Kankakei mass is N to NEN (Kobayashi and Nakamura 1978), while the strike of other monogenic volcanic mass is EW or NE-SW. Volcanic pipe now commonly forms necks. The diameter of pipes is variable and ranges from less than several tens of meters (Futagoyama mass (15)) to several hundred meters (Tsukumoyama(8)). The plan form is commonly irregular and may be elongated longated to NE-SW direction (Garanzan(28), and Iinoyama mass(14)).

It is notable that some of the lava show subtle fragmental structure in vents. The volcanic necks of Futagoyama(15), Tsukumoyama(8), and Iinoyama(14) masses show welding of volcanic breccia within vent. (see previous sections). These occurrences indicate that some of the massive lavas of sanukitoid represent welded lava flow. The uniform distribution of xenocrysts derived from the granitic basement may be explained by mixing processes of pyroclastics before coalescence of fragments and eruption of magmas.

It is noted that vents are distributed rather randomly within the northeast Shikoku region. Detailed survey of larger volcanic masses, except for Kankakei volcanic mass which is a composite volcano, showed that these large volcanic masses are composed of several monogenic volcanic products. Some of composite vents are observed (Peak-211 mass(49)), though most of the vents seems to have erupted only once. Except for Kankakei mass, the volcanic rocks of the northeast Shikoku region conformed a monogenic volcanic field.

d. Heterogeneity of lavas

Petrographic and chemical heterogeniety within a lava flow has been described by Yamaguchi(1958) on the Ootozan lava flow (45), by Yamagushi(1964) on the Yoshinodai mass (46), and by Ujike(1970) on Gahaishi-Hiageyama mass (16). Lavas of Goshikidai(21), Kanayama(10), Marugame-Castle(13), Iinoyama(14), Iwaseosan(40), Yashima(39), Peak-211(49), Takamishima(4) and Katamukiyama(18) masses also show petrographic heterogeniety as in part described in the preceeding sections. These lavas are commonly composed of sanukitoid rocks. Mode of occurrence of these heterogeneous lavas can be classified into (1) composite lavas having sharp contact between two lavas without chilled margin (e.g. Goshikidai lava flow-III and lava flow-IV), and (2) gradual variation of petrography and chemistry within a lava (e.g. Ootozan, Yamaguchi (1958)). Between (1) and (2), various degree of mixing of lavas are displayed in the form of banding, globular structure, and irregularly intermingled structure. The heterogeniety of lavas may indicate the mixing process of magmas just prior to eruption as suggested by the disequilibrium phenocryst assemblages of the sanukitoid.

8. Petrography

Sanukite and sanukitoid have been defined by their particular petrographic characteristics (Weinschenk 1891, Koto 1916). These andesitic rocks carry high-magnesian mafic phenocrysts and tend to be devoid of phenocrysts of plagioclase and iron-titanium oxides. Boninite has similar petrographic features, but is distinct from sanukitoid by the

Table 3

Modal composition (1) basaltic rocks

#	171	172	173	175	176	177
ol	16.2	1.4	4.4	1.5	1.9	7.5
aug	1.5	0.1		0.1	0.1	1.9
mt	1.1				0.0	
pl		0.4			1.7	0.1
xpl	1.1	1.0	0.3	0.0		
xqz	0.0		1.4	0.0		
gm	81.0	97.0	93.9	98.4	96.2	90.5
method*	1619	line	2952	2047	2896	line

Modal composition (2) andesitic rocks

#	101	102	103	104	105	106	107	108	109	110	111	118	122
ol	6.2	7.9	9.4	5.3	3.3	0.2	0.1	2.2	1.5			0.4	0.0
aug	2.6	1.7	3.1	4.3	4.6	2.1	1.2	0.3	3.3	1.2			
opx	1.8	1.3	1.4	0.2	4.0	7.4	6.0	5.5	0.6	4.9	1.5	0.2	0.4
hb					2.4	1.0	0.0	1.5	0.2	2.7			
pl		0.4	0.4	2.1	1.2	1.0	0.1	0.5	0.5	2.4	0.1		
xpl	1.1	0.9	0.3				0.0	0.1				0.1	
xqz	0.0	0.3	0.8	0.4			0.8			0.2			
xop												0.0	
xlith				0.1						0.5			
gm	88.3	87.4	84.5	86.0	84.4	88.3	91.7	89.9	93.9	88.2	95.9	99.2	99.6
vesicle				1.8					1.1	0.8			
method*	1000	2858	1944	2506	2304	1384	2252	2197	2196	1863	1550	area	area

Modal composition (3) andesitic rocks-continued

#	141	144	145	146	147	148	153	154	155	158	178	179	180
ol		0.1	0.0		0.1	0.1	0.4	0.1	0.2	0.0	7.8	0.6	5.2
aug			0.1		1.3		0.0		0.2	0.0	1.8		2.7
opx	0.2	0.4	0.4		1.1	1.1	0.5	0.2		0.5			0.2
hb			0.4		0.4	0.0	0.4	0.0		0.0			
pl	0.0		0.1				0.5	0.1	0.0	0.2	0.2	1.5	
xpl	0.0	0.0		0.0			0.0	0.1		0.0		0.1	3.4
xq?						0.0				0.0	0.7	0.0	2.4
xop				0.0				0.0		0.0			0.6
xkf													0.0
gm	99.8	99.5	99.0	100.0	97.2	98.9	98.2	99.6	99.5	99.5	89.4	99.1	83.8
vesicle					3.4								
method*	area	area	area	area	3173	area	2659	area	area	area	2764	1260	4675

Modal composition (4) andesitic rocks-continued

#	181	182	183	184	185	186	187	189	190	191	192	193	194	195
ol	0.0	2.2			5.8	0.6					0.0			
aug	0.6		0.1	1.5	0.8	0.6			1.1	0.4	0.0	1.1		
opx	0.8		0.6	18.5		1.2	1.5	0.1	7.9	9.0	0.2	5.5	3.4	3.9
hb			4.4				5.9					3.8	4.6	
bt							0.1						0.9	
gt							2.4						0.1	
il			0.0				0.0						0.2	
mt							0.2			0.0				
pl	0.4		10.6	8.5	0.9		27.2	0.3	6.2	20.7	0.0	1.5	21.4	0.3
ap							0.0						0.2	
qz							0.7							
xpl		0.2				0.4					0.7	0.0		
xqz		0.0			0.0	0. 0.1	0.4		0.0	0.1				
xop					0.0			0.2			0.1	0.0		
gm	98.2	97.6	85.3	71.5	93.4	97.1	62.0	99.3	84.4	69.8	99.0	88.0	69.2	95.8
vesicle				6.4										
method*	area	line	2150	2772	2259	1475	2967	area	3106	2457	area	2276	2018	2447

Modal composition (5) dacite aild rhyolite

#	162	196	197	198	164	167	168	169	170
opx		0.0	1.6						
hb	0.1	4.4	0.7		0.4				
bt		3.9	0.3	8.2	0.0	0.01	0.10	0.0	0.02
gt			0.0		0.0	0.20	0.03	0.0	0.05
il	0.0		0.2		0.1	0.00	0.00	0.0	0.00
mt		0.2							
pl	1.1	21.3	10.7	19.2	1.5	0.46	0.57	0.3	0.23
ap		0.1		0.2					
qz		0.2							
gm	98.8	69.9	86.1	72.4	98.0	99.33	99.30	99.7	99.70
method*	area	2676	3920	1252	area	area	area	area	area

* number represents point counted.

common occurrence of clinoenstatite phenocryst. In this section, general petrographic note of each rock type, and detailed description of chemically analyzed samples (Sato 1981) are made. Phenocryst mineral assemblage of these samples are shown against SiO_2 content in Figure 30. Modal content of phenocryst is shown in Table 4.

a. Basalt

Basalt occurs as small lava flows, necks or dikes located in the northern half of the northeast Shikoku region. The volcanic masses which include basaltic rocks are Shirahamayama (48), Peak-211 (49), Yakushiyama (22), Aonoyama (12), Marugame-Castle (13), and Sanagishima (3) masses. Basaltic lavas are generally massive and compact, containing variable amounts of olivine phenocryst and sparse xenocrysts of quartz and feldspars in hand specimen.

Under the microscope, mineral assemblages of phenocryst of basaltic rocks are either olivine, or augite+olivine. Rare phenocryst of plagioclase and chromian titanomagnetite

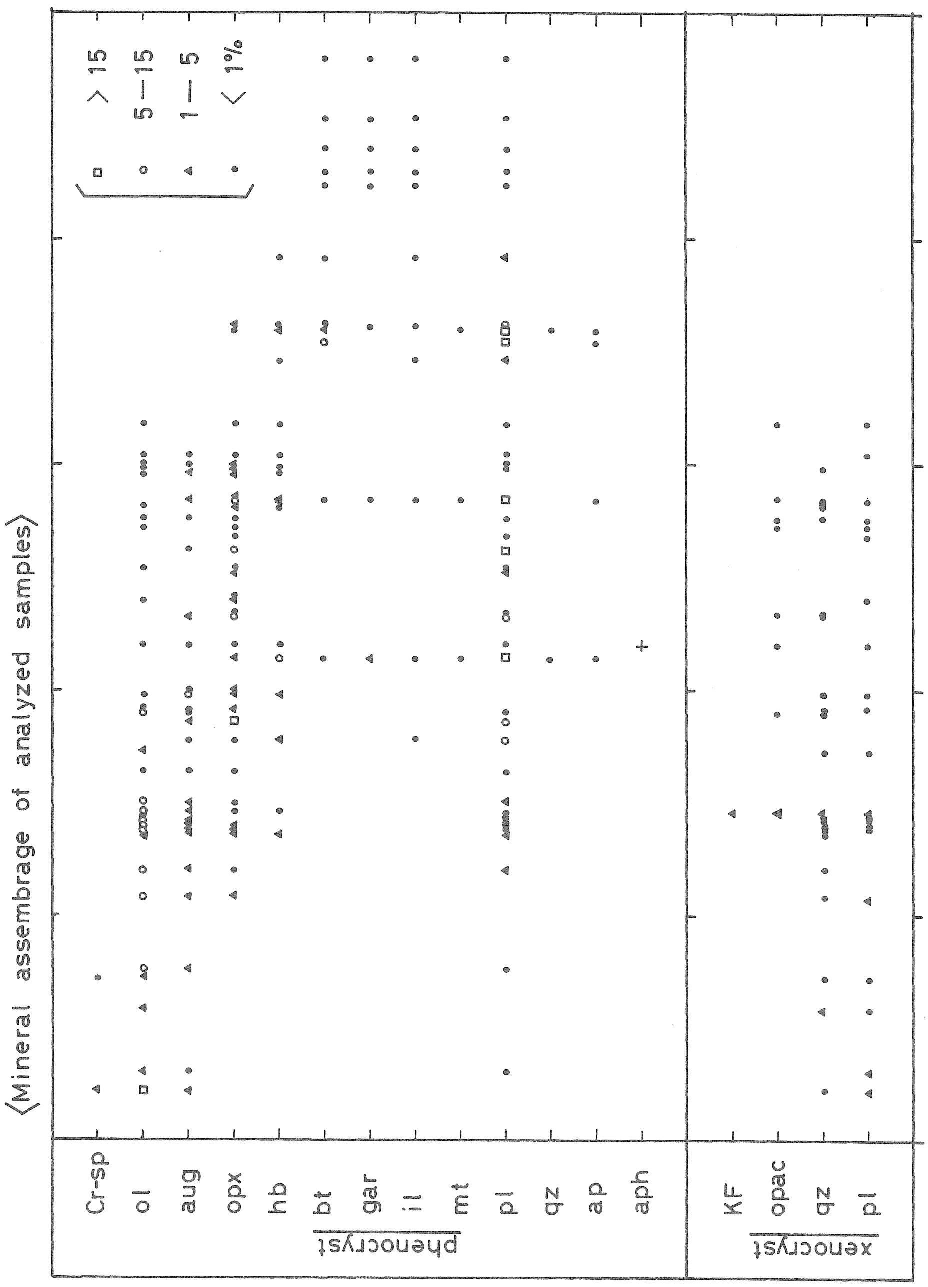

Figure 30. Mode and mineral assemblages of phenocryst and xenocryst in sanukitoid and associated volcanic rocks of Goshikidai and adjacent areas.

may occur. Phenocryst olivine is 0.1-3.0mm across, and its modal content varies from 1.4 to 16.2 vol.%. It is usually compact euhedral, but skeletal olivine is not rare. Inclusions of minute euhedral chromian spinel and matrix are common in olivine phenocryst. Thin reaction corona of Ca-poor pyroxenes mantles the olivine phenocryst in basalt of Yakushiyama mass. Ca-rich clinopyroxene is usually stout prismatic and 0.1-0.3 milimeters in diameter. Sporadic plagioclase phenocryst more than 0.3 milimeters thick is present in the basaltic rocks of Marugame-Castle and Yakushiyama masses. Microphenocryst of chromian titanomagnetite ca. 0.1 milimeters across is present in the basaltic rocks of Shirahamayama and Marugame Castle masses, and they are commonly corroded. The groundmass of basalt show intergranular to intersertal textures, and is composed of olivine, Ca-rich clinopyroxene, pigeonite, orthopyroxene, titanomagnetite, ilmenite, plagioclase, apatite, and mesostasis glass. Xenocrysts of quartz and sodic plagioclase almost always occurs in the basaltic rocks. Followings show mineral assemblages of basalts from six volcanic masses of the northeast Shikoku.

1. olivine basalt from Sanagishima mass (#173 : sample number in Sato(1981))
   Phenocryst : olivine(4.4%, 0.2-1.0mm. stout prismatic-skeletal, glass and opaque oxide inclusion), Groundmass : olivine, pigeonite, augite, magnetite, plagioclase, brown glass, intergranular texture. Xenocryst : plagioclase(0.3%), quartz(1.4%).
2. augite-olivine basalt from Shirahamayama mass (#171)
   Phenocryst : olivine(16.2%, 0.1-1.0mm, matrix and brown spinel inclusions), Microphenocryst : Ca-rich clinopyroxene(1.5%, 0.1mm), chromian titanomagnetite(1.1%, 0.1mm, corroded). Groundmass : augite, pigeonite, magnetite, plagioclase, mesostasis, intergranular texture. Xenocryst : plagioclase(1.1%), quartz(0.0%).
3. augite-olivine basalt from Aonoyama mass (#172)
   Phenocryst : olivine(1.4%, 0.1-0.4mm), augite(0.1%, 0.4mm, rounded), microphenocryst : plagioclase(0.4%, 0.1-0.4mm thick), groundmass : Ca-rich clinopyroxene pigenoite, titanomagnetite, plagioclase, apatite, mesostasis glass, intergranular texture. Xenocryst : quartz(0.0%).
4. augite-olivine basalt from Aji P-211 mass (#175)
   Phenocryst : olivine (bimodal size distribution, 0.05-0.2mm 5.0%, and 0.9-1.0mm, 1.5%, brown spinel inclusion, thin rim of pyroxenes), Ca-rich clinopyroxene (0.1%, 0.05-0.5mm). groundmass : clinopyroxene, orthopyroxene, plagioclase, iron-titanium oxides, mesostasis, Xenocryst : quartz(0.0%), plagioclase(0.0%).
5. augite-olivine basalt from Marugame-castle mass (#176)
   Phenocryst : olivine(0.9%, 0.2-2mm), augite(0.1%, 0.2-0.6mm mottled rim), plagioclase (0.3%,0.4-0.7mm thick), groundmass : clinopyroxene, orthopyroxene(only around quartz xenocryst), magnetite, plagioclase, glass, xenocryst : quartz(0.0%).
6. augite-olivine andesitic basalt from Yakashiyama mass (#177)
   Phenocryst : olivine(7.5%, 0.2-1.2mm, rare opx inclusion, dark brown spinel inclusion common, thin rim of pigeonite+orthopyroxene), augite(1.9%, 0.2-0.7mm), plagioclase-(0.0%, 0.4mm thick), groundmass : orthopyroxene, pigeonite, augite, magnetite,

ilmenite, plagioclase, apatite, mesostasis, intergranular texture.

b andesite

Andesite is the predominant rock type among the volcanic rocks of the northeast Shikoka region. Many varieties of sanukitoid andesite are present, and the results of statistical treatment is mentioned.

Olivine, orthopyroxene, Ca-rich clinopyroxene(called augite in the followings), and hornblende are the major mafic phenocrysts of sanukitoid andesite of this region. Among 15 combinations of the four major mafic phenocrysts, two assemblages i.e. augite, and augite-hornblende) are not observed within thin sections examined. Frequencies of the occurrence of the mafic mineral assemblages in thin section are shown in Table 5, and the principal assemblages are as follows:

Table 5 Mafic mineral assemblages of andesite (%)

Groundmass Phenocryst	aug	aug+opx	opx	total
ol		5	2	7
opx		2	19	22
hb			3	3
ol-opx		1	13	13
ol-hb	1	1	1	2
ol-aug	1	1	1	3
opx-aug		3	6	9
opx-hb		1	14	15
ol-opx-hb			5	5
ol-opx-aug		10	4	14
opx-aug-hb		2	1	3
ol-hb-aug		1	1	2
ol-opx-aug-hb	0.3			0.3
aphyric			2	2
total	2	29	69	100

Each number represents the percentage of the specimens belonging to each type. 303 thin sections taken from following volcanic masses are examined. Ibukishima, Hichihozan, Iyatanisan, Gahaishisan, Ooamasan, Katamukiyama, Iinoyama, Kiyama, Goshikidai, Iwaseosan, Yashima, Hiyama, and other minor hills in Sanuki Plain. Abbreviations: ol: olivine, opx: orthopyroxene, aug: Ca-rich clinopyroxene, hb: hornblende.

orthopyroxene	22%
hornblende-orthopyroxene	15%
olivine-augite-orthopyroxene	14%
olivine-orthopyroxene	13%
augite-orthopyroxene	9%

In respect to the fact that augite-hypersthene assemblage is the predominant one in the andesite of Quaternary island-arc andesite (cf. Kuno 1950, Kawano, Yagi & Aoki 1959), relative paucity of augite-bearing assemblages in sanukitoid is remarkable. The number of thin sections containing each phenocryst mineral is divided by the total number of the examined thin section of andesite, and the result is as follows:

orthopyroxene	81%
olivine	50%
Ca-rich clinopyroxene	35%
hornblende	31%
plagioclase	51%

Sparsity of plagioclase phenocryst is notable. In most of sanukitoid, plagioclase phenocryst content is less than 3 volume percent.(Fig. 29)

Proportions of groundmass pyroxene assemblages of sanukitoid andesite are calculate from Table4.

clinopyroxene	2%
clinopyroxene-orthopyroxene	29%
orthopyroxene	69%

Most of the sanukitoid belongs to the hypersthenic rock series, and is characterized by the paucity of groundmass Ca-rich clinopyroxene. There seems to exist some interrelationship between the kind of mafic phenocryst and the groundmass pyroxene assemblages. Augite phenocryst is most likely to be accompanied by groundmass augite, while hornblende and orthopyroxene phenocryst are not commonly associated with groundmass augite. Other groundmass components of sanukitoid andesite are magnetite, ilmenite, hercynite, hematite, plagioclase, quartz, sanidine, apatite, cristobalite, tridymite, biotite, and mesostasis glass.

Followings are the brief petrographic description of the representative sanukitoid andesites.

1. olivine-phyric andesite(I) of Goshikidai mass, #101-104

   phenocryst: olivine(5.3-9.4%, bimodal grain size distribution-0.05-0.3mm: microphenocryst, 0.3-2mm: phenocryst, very thin reaction corona of orthopyroxene, common inclusion of chromian spinel), augite(1.7-4.3%, 0.05-0.3mm, aggregate common, stout prismatic), orthopyroxene(0.2-1.8%, 0.1-1mm across, long prismatic, always corroded and have thin mottled Fe-rich rim at the periphery, often have reaction corona of microphenocryst olivine, reverse-zoning common, the Fe-rich inner core may have minute fluid inclusions, exolution lamellae of augite and show pleochroism), plagioclase(0-2.1%, less than 0.3mm long, lath shaped, simple normal zoning at the rim), Groundmass: augite, orthopyroxene, magnetite, ilmenite, plagioclase, quartz, sanidine, cristobalite, mesostasis, apatite, xenocryst : sodic plagioclase(0-1.1%), quartz(0-0.8%), xenolith of metamorphosed argillaceous sediments occasionally occurs.

2. olivine-phyric andesite(II) of Goshikidai mass, #105

   phenocryst: olivine(3.3%, two types occurs, type-1: 0.1-0.5mm, only thin reaction corona, type-2: 0.1-2mm, with thick reaction corona of coarse orthopyroxene and opacitized hornblende, common dark brown spinel inclusion in the type-2 olivine), augite(4.6%, 0.1-0.7mm, rare reverse zoning in the core), orthopyroxene(4.0%, 0.1-0.7mm across, reverse zoning in the core common, sharp normal zoning at the rim, rare opacite rim), hornblende(2.4%, 0.05-0.5mm, completely converted to pyroxenes, iron oxide and glass), plagioclase(1.2%, 0.1mm thick), Groundmass: augite, orthopyroxene, titanomagnetite, ilmenite, plagioclase, sanidine, quartz, apatite, glass.

3. orthopyroxene-phyric andesite of Goshikidai mass, #106-#108, #110
Phenocryst : olivine(0.0-2.2%, large phenocryst(-1mm) is rare, microphenocryst(0.05-0.2mm) rather common, euhedral, thin reaction corona of orthopyroxene, altered to clay mineral), augite(0.3-2.1%, 0.05-0.5mm, often surrounded by orthopyroxene mantle, rare exolution lamellae of orthopyroxene in the core, crystal aggregate of augite may occur), orthopyroxene(4.9-7.4%, long prismatic, sometimes skeletal, 0.1-1.5mm long, reverse zoning in the core common, sharp normal zoning at the rim, larger grains tend to form crystal aggregate, rarely with olivine crystal in the center of the aggregate, sometimes mantled by augite, opaque mineral inclusion), plagioclase(0.1-2.4%, microphenocryst up to 0.2mm, lath shaped, dusty core, simple normal zoning at the rim), Groundmass: augite, orthopyroxene, titanomagnetite, ilmenite, plagioclase, sanidine, cristobalite, apatite, mesostasis or glass charged with abundant dark immiscible grobules.

4. low-K sparsely-phyric andesite of Goshikidai mass, #111-#131.
Phenocryst : orthopyroxene(0.5-2%, long prismatic-skeletal, 0.1-0.6mm wide and up to 5mm long, common reverse zoning at the core, the inner core may be pleochroic and contains dusty inclusions, normal zoning at the rim), olivine(0-1%, euhedral with orthopyroxene reaction corona, 0.1-0.4mm, altered to clay minerals), augite(very rare, 0.1-0.3mm, mottled rim), opacitized hornblende(rare, 0.1-0.3mm), plagioclase(0-3%, mostly less than 1%, 0.1-0.4mm thick, lath-shaped, homogeneous core with gradual normal zoning at the rim), Groundmass : orthopyroxene, plagioclase, sanidine, quartz, cristobalite, tridymite(in cavity), apatite, mesostasis, augite(very rare), xenocryst : sodic plagioclase(up to 2mm, ubiquitous, dusty inclusion, irregular outline, albite twin), quartz(with reaction coronas), opacite(biotite, and hornblende).

5. high-K sparsely-phyric andesite (1) of Goshikidai mass, #133-#146, #149, #150
Phenocryst : orthopyroxene(0-3%, long prismatic, 0.3-3mm long, aggregate not uncommon, normal zoning at rim, reverse zoning in the core common, rare mottled Fe-rich variety), olivine(0-1%, idiomorphic, mostly altered to clay, commonly surrounded by coarse orthopyroxene corona), Ca-rich clinopyroxene(rare, commonly rounded and with mottled rim), hornblende(0-2%, mostly opacitized into pyroxenes, iron oxides, plagioclase and glass, idiomorphic, 0.3-3mm long), plagioclase(0-2% not common, microphenocryst size, flat core with sodic rim), Groundmass: orthopyroxene, magnetite, ilmenite, plagioclase sanidine, quartz, cristobalite, rare tridymite, apatite, mesostasis, glass).

6. high-K sparsely-phyric andesite (2) of Goshikidai mass, #147, #148, #151-#158
Phenocryst : orthopyroxene(0-1%, long prismatic, 0.3-2mm long, normal zoning at rim,

rare reverse zoning in the core, rare mottled oxidized Fe-rich variety), hornblende(0-1%, idiomorphic, mostly 0.1-0.3mm thick), olivine(0-1%, up to 10mm long, skeletal common, reaction corona of opx+hb), Ca-rich clinopyroxene (rare, mottled and oxidized rim), plagioclase(rare, microphenocryst size, flat core with sodic rim) Groundmass : orthopyroxene, magnetite, ilmenite, biotite, plagioclase, sanidine, quartz, cristobalite, apatite, mesostasis and glass) Xenocryst : quartz, plagioclase.

7. olivine andesites

#179, Iwashiosan mass

Phenocryst : olivine(1.3%, 0.05-0.5mm, occasional hollow crystal, dark brown spinel inclusion, thin pyroxene reaction rim), Groundmass : augite, hypersthene, magnetite, plagioclase, glass, Xenocryst : plagioclase(0.3%), quartz(0.0%).

#182, Kasayama mass

Phenocryst : olivine(2.2%, 0.2-0.5mm, dark brown spinel inclusion, reaction corona of orthopyroxene), Groundmass : orthopyroxene, augite, magnetite, plagioclase, glass, Xenocryst : quartz.

8. augite-olivine andesites

#178, Hiyama mass

Phenocryst : olivine(7.8%, 0.1-2.0mm, brown spinel inclusion, thin rim of orthopyroxene), augite(1.8%, 0.1-0.3mm), chromian titanomagnetite(0.0%, 0.1mm, corroded), Groundmass : augite, orthopyroxene, magnetite, ilmenite, plagioclase, tridymite, mesostasis, Xenocryst : plagioclase and quartz.

#180, Iinoyama mass

Phenocryst : olivine(5.2%, 0.1-0.6mm, mostly 0.1-0.2mm, commonly skeletal, brown spinel inclusion, thin pyroxene corona), augite(2.7%, 0.1-0.4mm, sector zoning), orthopyroxene(0.2%, 0.5mm surrounded by olivine microphenocryst), plagioclase(1.5%, 0.2mm long lath), Groundmass : fine pyroxenes, plagioclase, iron oxides, glass, Xenocryst : plagioclase(3.4%), quartz(2.4%), opacite(0.6%), alkali feldspar(0.0%).

#185, Ootozan mass

Phenocryst : olivine(5.8%, 0.2-0.6mm, brown spinel inclusion, thin rim of pyroxene), augite(0.8%, 0.1-0.2mm, glomerophyric aggregate with plagioclase not uncommon), plagioclase(0.9%, 0.03-0.2mm), Groundmass : orthopyroxene, clinopyroxene, magnetite, glass.

9. (ol)-aug-opx andesites

#181, Marugame Castle mass

Phenocryst : orthopyroxene(3.1%, 0.2-1.5mm, sometimes show reverse zoning, augite mantle on prismatic face), augite(3.1%, 0.2-0.5mm, sector zoning, Fe-rich rim), plagioclase (7.2%, 0.1-0.4mm, lath-shaped), Groundmass : orthopyroxene, augite, titanomagnetite, plagioclase, abundant glass.

#184, Nio-Pass mass

Phenocryst : orthopyroxene(18.5%, 0.1-2.0mm, reverse and oscillatory zonings common, fragmental in some cases, aggregate not uncommon), augite(1.5%, 0.1-1.0mm, coroded, aggregate), olivine(0.0%, 0.8mm, coarse-orthopyroxene rim), plagioclase(8.5%, 0.1-0.5mm), Groundmass: orthopyroxene, augite, magnetite, plagioclase, glass.

#186, Yashima mass

Phenocryst: orthopyroxene(1.2%, 0.2-0.8mm, reverse zoning common), augite(0.6%, 0.1-0.3mm), olivine(0.6%, 0.1mm, pyroxene rim), Groundmass: orthopyroxene, augite, magnetite, plagioclase, tachylite glass, Xenocryst: plagioclase(0.4%), quartz(0.1%).

#190, Yokoyama mass

Phenocryst: orthopyroxene(7.9%, 0.2-1.5mm, reverse and oscillatory zonings common), augite(1.1%, 0.1-0.4mm, mottled margin), plagioclase(6.2%, 0.1-0.3mm), Groundmass: orthopyroxene, augite, magnetite, plagioclase, glass, Xenocryst: quartz(0.4%).

10. orthopyroxene andesites

#189, Iinoyama mass

Phenocryst: orthopyroxene(0.1%, 0.2-0.5mm), plagioclase(0.3%, 0.3-0.8mm lath, mottled sodic core), Groundmass: orthopyroxene, very rare augite, biotite, magnetite, plagioclase, sanidine, cristobalite, tridymite, mesostasis, Xenocryst: quartz, opacite.

#195, Iwashiosan mass

Phenocryst: orthopyroxene(3.9%, 0.2-0.7mm, larger grains are fragmental and reversely zoned in the core, oscillatory zoning, Fe-rich core may have exolution lamellae of augite), plagioclase(0.3%, 0.1mm thick lath), Groundmass: massive part(5mm thick), orthopyroxene, iron oxides, biotite, plagioclase, critobalite, mesostasis, leucocratic schlieren(1-2mm thick), abundant quartz and limonite in addition to the minerals of the massive part.

11. orthopyroxene-hornblende andesites.

#183, Tsukumoyama mass

Phenocryst: hornblende(4.4%, long prismatic, 0.2-1.0mm thick, completely opacitized), plagioclase(5.6%, 0.3-1mm, often have mottled zones, sharp reverse and normal zonings at the periphery), orthopyroxene(0.6%, long prismatic, 0.3mm across, pleochroic), augite(0.1%, 0.2mm across), ilmenite(0%, thin plate, 0.5mm across), Groundmass: augite, hypersthene, magnetite, plagioclase, cristobalite, apatite, glass).

#193, Hiyama mass, lower quarry

Phenocryst: hornblende(3.8%, 0.2-0.7mm, long prismatic, Z; reddish brown, fine opacite rim), orthopyroxene(5.5%, 0.1-0.5mm, dusty pleochroic core, opacite rim), augite(1.1%), plagioclase(1.5%, 0.4-1.2mm, rounded, reverse zoning at the rim, occasional biotite inclusion), Groundmass: cryptocrystalline pyroxene, iron oxides, plagioclase, cristobalite, mesostasis, Xenocryst: plagioclase(0.0%), quartz(0.1%), opacite(0.0%).

12. garnet-bearing andesites

#187, Amatakiyama mass

Phenocryst: hornblende(5.9%, 0.2-1.0mm, Z: greenish brown, often rounded, thin opacitized rim), orthopyroxene(1.5%, 0.3-0.6mm thick, pleochroic), biotite(0.1%, 0.4mm across), garnet(2.4%, 0.5-4mm, euhedral, mottled core, inclusions of spinel and matrix), magnetite(0.2%, 0.1mm), ilmenite(0.0%, 0.6mm), plagioclase(27.2%, 0.2-4mm, thick tabular, weak zoning), quartz(0.7%, partly rounded, 1.6mm), Groundmass: orthopyroxene, iron oxides, plagioclase, quartz, alkalifeldspar.

#194, Hiyama, upper quarry

Phenocryst: orthopyroxene(3.4%, 0.1-1.5mm), hornblende(4.6%, 0.2-0.6mm thick, surrounded by inner coarse opacite and outer fine opacite), biotite(0.9%, 0.1-0.5mm across, opaque inclusion), garnet(0.1%, 0.3mm, irregular outline, plagioclase corona), iron oxide(0.2%, 0.05-0.3mm across), apatite(0.2%, 0.05-0.1mm thick), plagioclase(21.5%, thick tabular, 0.2-2.5mm, variable zoning pattern), Groundmass: orthopyroxene, iron oxides, plagioclase, quartz, alkalifeldspar, mesostasis altered to clay.

c dacite

Phenocryst assemblages of dacite in the Takamatsu region include hornblende-plagioclase, biotite-hornblende-plagioclase, biotite-plagioclase, and garnet-biotite-hornblende-orthopyroxene-plagioclase. Followings are the brief descriptions of the representative analyzed samples of dacite.

1. hornblende dacite of Goshikidai mass, #159-#164

   Phenocryst: hornblende(−1%, 0.2-0.5mm in diameter, long prismatic, fine opacite rim, X: light yellow, Y: yellow brown), plagioclase(1-2%, 0.1-1mm, thick tabular, rather homogeneous core, both sharp normal and reverse zonings near the rim), ilmenite(−1%, thin plate up to 1mm across), magnetite(rare), biotite(rare, thin plate, 0.3-0.6mm across, Y,Z: dark brown), Groundmass: biotite, iron oxides, plagioclase, sanidine, quartz, apatite, mesostasis often altered to clay.

2. biotite-hornblende dacite of P-211 mass, marginal breccia, #196

   Phenocryst: biotite(3.9%, 0.1-0.5mm across, plagioclase inclusion), hornblende(4.4%, 0.1-0.5mm in diameter, X: light yellow, Z: greenish brown, opacite rim), plagioclase(21.3%, 0.1-3mm, biotite inclusion), quartz(0.2%, 0.4-1mm across, rounded), apatite(0.1%, 0.05mm across), orthopyroxene(0.0%, 0.1mm in diameter, pleochroic), iron oxide(0.2%), Groundmass: orthopyroxene, iron oxide, plagioclase, quartz, cristobalite, micrographic mesostasis.

3. garnet-biotite-hornblende-orthopyroxene dacite of Washinoyama mass, #197

   Phenocryst: orthopyroxene(1.6%, long prismatic, 0.1-0.5mm in diameter, weakly pleochroic), hornblende(0.7%, 0.2-0.6mm in diameter, Z: brownish green, opacitized rim), biotite(0.3%, Y,Z: brown, partly oxidized), garnet(0.0%, up to 10mm, pale pink, inclusion of apatite, reaction corona of plagioclase), iron oxide(0.2%, 0.2mm across), plagioclase(10.7%, 0.2-2mm, thick tabular, variable zonal structure), Groundmass: orthopyroxene, iron oxides, plagioclase, quartz, alkalifeldspar, mesostasis, clay minerals.

4. biotite dacite of Yurahill mass, #197

   Phenocryst: biotite(8.2%, thick plate, 0.3-1mm across, opacitized rim, Y,Z: dark brown), plagioclase(19.2%, 0.5-4mm thick tabular, variable zonal structure, inclusions of matrx, biotite and apatite), apatite(0.2%, 0.1-0.2mm in diameter), garnet(very rare, up to 2mm across), Groundmass: green clay probably after biotite, iron oxide, plagioclase, sanidine, quartz.

d rhyolite

#165-#170, garnet-biotite rhyolite of Goshikidai mass,

Phenocryst: plagioclase(0-1%, 0.1-3mm, homogeneous core, both normal and reverse zonings at the rims), garnet(−1%,0.1-1mm across, euhedral, slightly rounded, pale pink in thin section, apatite inclusion), biotite(−1%, X: light yellow, Y,Z: dark brown), ilmenite(−1%, 0.1mm across), hornblende(very occasional), Groundmass: iron oxide, plagioclase, criptocrystalline glass.

e Reaction textures

Followings are the list of reaction textures observed in the volcanic rocks of the Takamatsu region.

(a) olivine phenocryst surrounded by some of orthopyroxene, pigeonite, hornblende and magnetite.
(b) orthopyroxene phenocryst surrounded by olivine.
(c) orthopyroxene phenocryst surrounded by augite.
(d) orthopyroxene phenocryst surrounded by hornblende.
(e) resorption of orthopyroxene phenocryst.
(f) augite phenocryst surrounded by orthopyroxene.
(g) augite phenocryst surrounded by hornblende.
(h) resorption of augite phenocryst.
(i) breakdown of hornblende phenocryst into plag+oxides+opx+cpx.
(j) biotite phenocryst surrounded by hornblende.
(k) breakdown of biotite phenocryst into plag.+oxides+opx.
(l) garnet phenocryst surrounded by some of plagioclase, biotite, and oxides.
(m) breakdown of garnet into oxides+feldspar.

f Xenolith and xenocryst

Metamorphosed xenolith of argillaceous rock occurs in the volcanic rocks of limited areas. At Eboshiyama, Goshikidai mass, schistose xenolith of 2-10cm across are common in olivine-bearing augite-orthopyroxene andesite. They are composed of salite, plagioclase, quartz, magnetite and glass, and belong to pyroxene hornfels facies. At Tsukumoyama mass, similar xenolith contains orthopyroxene in hornblende-bronzite andesite. Particular mineral assemblage of xenolith of argillaceous rock origin is found in garnet-hornblende-orthopyroxene dacite of Washinoyama mass. It is composed of apatite, biotite, magnetite, sillimanite, staurolite, quartz, plagioclase, hercynite and glass, and seems to be suffered from differential anatexis. Argillaceos xenolith in the dacite of

Ametakiyama mass have been described by Tagiri et al.(1975).

Granitic xenolith is also restricted in its occurrence. In hornblende-orthopyroxene sanukite of Goshikidai mass, small granitic xenolith of 1-3cm across are found. They are composed of plagioclase, quartz, opacite, and glass. At Iinoyama mass, various stages of disintegration of granitic xenolith are observed in augite-orthopyroxene-olivine andesite. Granitic rocks first partially melt along the grain boundaries between quartz and feldspars. When the amount of glass reaches 40-60 percent, disintegration takes place. Alkaifeldspar loose its birefringence at this stage, and it is conceived that alkalifeldspar will melt at the liquidus temperature of these andesites. Xenocrysts of granitic rock origin are ubiquitous in the basalt and andesite of the Takamatsu region. Some of the xenocrysts of quartz, plagioclase, alkalifeldspar, opacitized hornblende and opacitized biotite are present in about 70 pecent of thin sections examined, though the amount of the xenocrysts is usually less than 1 volume percent. Quartz xenocryst commonly has reaction corona as described by Sato(1975). Plagioclase xenocryst is distinguished from phenocryst plagioclase by the xenomorphic form, presence of abundant dusty inclusions, moth-eaten structures, and multiple albite twinning. XMA analyses of xenocryst plagioclase showed that it is more sodic and has much lower FeO concentration than phenocryst plagioclase.

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Caption of plates

Plate 1. Breccia dike of dacite intruding into rhyolitic tuff. Akabana coast, Goshikidai mass (Locality 1 in Figure 2-7, also see Figure 2-6).

Plate 2. Contact of vent of rhyolitic tuff cutting granitic basement. Granitic fragment is abundanty incorporated in the tuff near the contact. Akabana coast.

Plate 3. Mushroom structure of rhyolitic tuff. Akabana coast.

Plate 4. Large granitic blocks included in rhyolitic tuff. The rounded nature of the block may indicate erosion of the block by blowing tuff, Akabana coast.

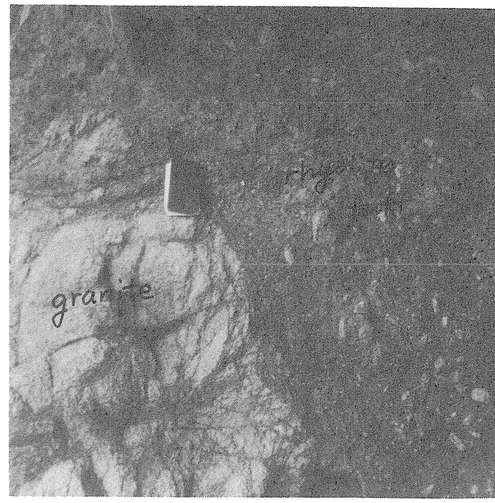
Plate 5. Grading and scraping of stratified rhyolitic tuff. Higashioku, Goshikidai mass (Locality 15 in Figure 2-7).

Plate 6. Breccia dike of dacite cutting the stratified tuff of rhyolite. Higashioku (see Figure 2-9).

Plate 7. Volcanic breccia of Nishioku Member. The lower massive chaotic breccia is heterolithic and contains large blocks of dacite tuff breccia. Horizontally stratified monolithic volcanic breccia of dacite overlies the chaotic tuff breccia. Higashioku (Locality 19 in Figure 2-7).

plate 1

plate 2



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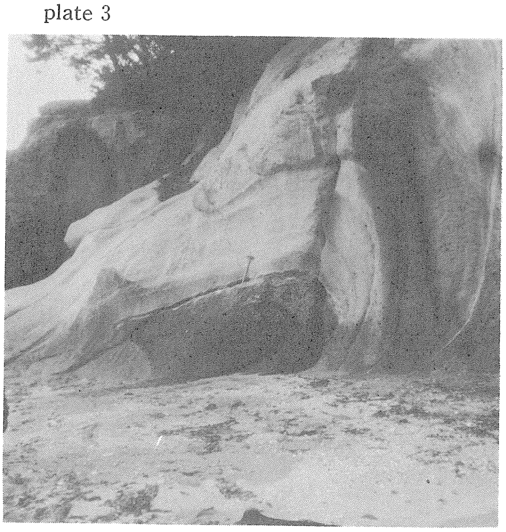

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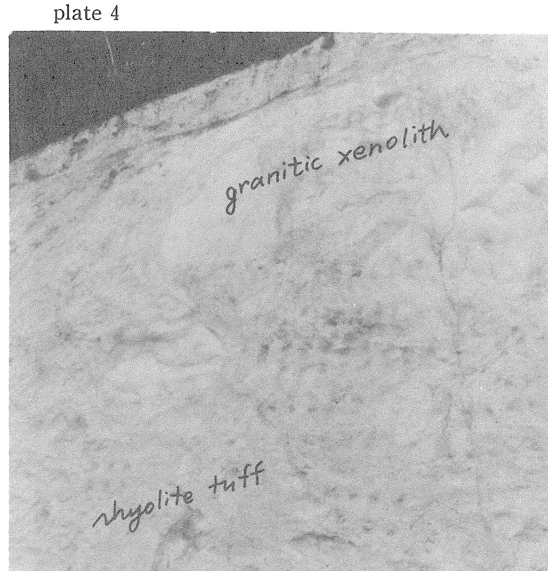

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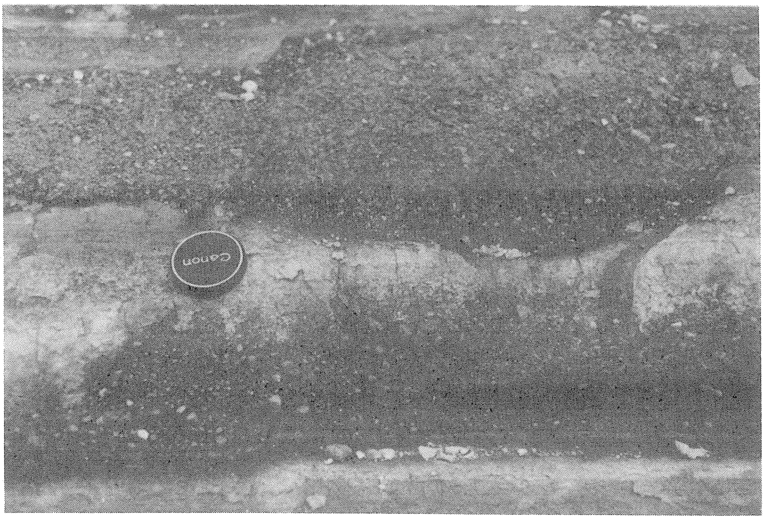

plate 6

plate 7