The K-Ar dating of the volcanic rocks from the Otaru City area and the significance

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Introduction

The Otaru City area (Fig. 1) is almost of composed of Neogene submarine volcanic rocks, such as pillow lavas and hyaloclastites, overlain by subaerial lavas with columnar joints and flat surfaces. Thus, the sedimentary rocks indicating appropriate ages are scarcely found. In addition, establishing of the volcanic successions in Otaru City area has been difficult because that volcanic rocks vary remarkably in facies vertically and horizontally. Therefore, in order to establish the geologic succession of the area, we have to obtain the isotope age data.

In the occasion of geologic researching for the Otaru City area, we have obtained the K-Ar age data for the representative volcanic rocks. These data have helped us to establish the geologic succession.

In this paper, we describe the volcanic rocks and the K-Ar age dating of the rocks, and discuss the significance of these data, based on the field researching results and referring to the other papers. The K-Ar age dating in this study has been funded by Otaru City.

Outline geology of Otaru City area

The Otaru City area is geologically situated at the north extension of the "Green Tuff" Region in Japan, and the area is composed almost of Neogene volcanic rocks. We have established the succession helped by the K-Ar age data mentioned later, as follows in ascending order. The Otarunaigawa Formation, the Akaiwa Formation, Kayashiba Formation, Hariusu Formation, Takashima Formation, Oshoro Formation, Shioya Formation, Andesite Lavas, and Quaternary sediments (Fig. 1).

The Otarunaigawa Formation (MMAJ, 1973) is extended from the Otarunaigawa River in the south of the Otaru City. It is exposed in the upper stream of the Momonai River, western Otaru City, and is widely distributed in the upper stream of the Asari River, and eastern mountainous areas of the Otaru City. This formation in the Momonai River is quartz-grain bearing pumice tuff, while the formation in the eastern Otaru City is more or less altered horblende dacitic and andesitic hyaloclastite, interbedded with pumice tuffs as shown at Anataki Waterfall in the upper stream of the Katsunai River. Oka et al (1991) reported 11.9 MA (K-Ar age) for a tuff exposed at western Sapporo, which is correlative to this formation.

The Akaiwa Formation (new definition ; "Yamato Formation" by Hasegawa et al., 1986)

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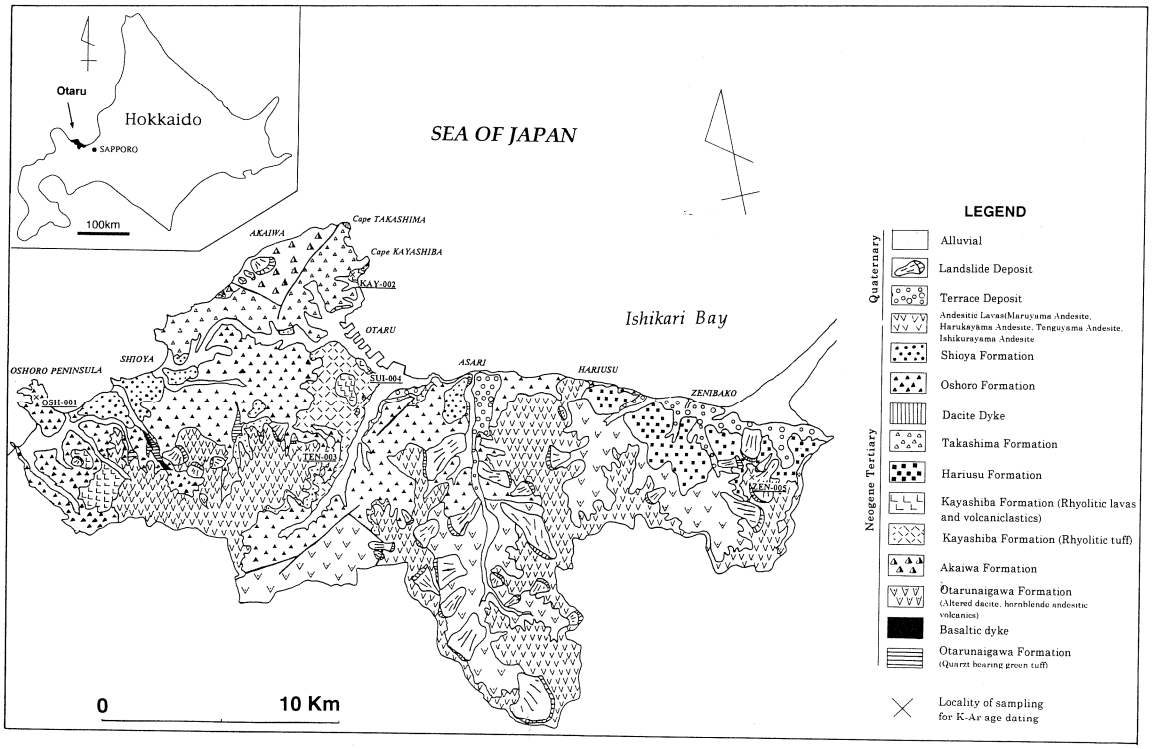

Fig. 1 Map showing location of the Otaru City and its brief geologic map.

is distributed in the Akaiwa beach, western Otaru City. It is mostly composed of highly altered dacite and hornblende andesitic volcanic rocks. Thus, this formation has been affected by hydrothermal alteration, to form highly silicified rocks. Matsueda et al (1992) reported 9.7Ma and 10.0Ma K-Ar age of the alunite from the silicified rocks.

The Kayashiba Formation (new definition ; "Ironai Rhyolite" by Sugimoto (1957)) is exposed at Kayashiba Cape and main streets of the Otaru city, including Suitengu. The formation is composed of rhyolitic tuff, and scattered with rhyolite coherent lavas or feeder dykes with hyaloclastite as shown by Yamagishi and Dimorth (1985) and Watanabe and Watanabe (1992).

The Hariusu Formation (new definition) is distributed in the slopes of the eastern mountains. It is mostly composed of hornblende andesitic lavas/dykes and hyaloclastites.

The Takashima Formation (new definition ; "Otaru Formation" by Sugimoto (1957) ; "Takashima Andesite" and the lower of the "Kuccian Group" by Hasegawa et al, 1986), is distributed in the Takashima to Shioya beach. This formation is mostly composed of hornblende andesitic hyaloclastites.

The Oshoro Formation (new definition ; the "Upper Agglomerate of the Otaru Formation" by Igi and Kakimi (1954) and the lower of the "Kuccian Group" by Hasegawa et al, 1986) is typically exposed at Oshoro Peninsula, and extended to the Otaru Port, and along the Katsunai River and on the Asari beach. This formation at the Oshoro Peninsula is mostly composed of basaltic andesitic pillow lavas, hyaloclastites and their feeder dykes, interbedded

with scoriaceous volcanic bombs showing water-chilling characteristics (Yamagishi, 1982).

However, from the eastern base of the Oshoro Peninsula (Tsukotan) to the mountains between Shioya to Otaru Port, this formation consists mostly of pyroxene andesitic hyaloclastites. In the western margin part of the Otaru City, this formation is interbedded with tuffaceous sandstone and rhyolitic tuff.

The Shioya Formation (new definition ; the upper of the "Kuccian Group" by Hasegawa et al, 1986) is composed of laminated tuffaceous sandstones interbedded with several layeres of subaqueous pumice flow deposits of more than 5 m thick.

The Andesite Lavas make up the slopes and ridges of the mountains of 600 - 800 m high, such as Maruyama, Harukayama, Otaru-Tenguyama, Zenibako-Tenguyama and Ishikurayama. These lavas show usually columnar jointed and also platy jointed in places, and they are mostly pyroxene andesite.

The Quaternary sediments distributed in Otaru City, are terrace deposits along the beach from Zenibako to Hariusu, landslide deposits along the margins of the Andesite Lavas mentioned above, and alluvial deposits along rivers and beaches.

Descriptions of the volcanic rocks and the K-Ar dating

A. Basaltic andesite from the Oshoro Peninsula (OSH-001 in Fig. 1)

The rock of basaltic andesite from the pillow lavas (Plate 1a ; the Oshoro Formation) is greyish and compact, and are rich in vesicles, such as spherical-ellipsoidal vesicels and pipe vesicles in pillow lobes (Yamagishi et al., 1989). Observation of thin sections has revealed that the rocks contain phenocrysts of plagioclase, pyroxene and in places quartz. The modal ratio of the plagioclase is larger than that of pyroxene. The plagioclase phenocrysts show idiomorphic, and albite, albite-carlsbad and pericline twinning. The pyroxene phenocrysts are recognized as orthopyroxene as usual. The groundmass shows intersertal (Plate 1b) or subophitic texture, and contains abundant vesicles and needle-like quench crystals in the glass. The chemical composition of the rock ranges from 49% to 53% in silica content and plotted in the high-alumina basalt field (Yamagishi, 1982).

In this study, the K-Ar age of the rock (OSH-001) has been estimated at 6.6±0.8Ma by Teledyne Company (Table 1).

B. Rhyolite from the feeder dyke of the Kayashiba Cape (KAY-002 in Fig. 1)

The rhyolite rock (Kayashiba Formation) from the Kayashiba Cape is submarine feeder dyke associated with foreset-bedded hyaloclastite (Plate 1c ; Yamagishi and Dimroth, 1985). The rock is compact, and grey and greyish brown in color, and lack in flow-layering. In thin section, the rock includes usually phenocrysts of quartz, sanidine and plagioclase. Sometimes, the phenocrysts of hornblende are found. The quartz phenocrysts show corroidal forms (Plate 1d) in places. Most of the sanidine crystals display carlsbad twinning. Some of the hornblende have been altered in places into skeletal crystals composed of tiny lath-shaped crystals. The groundmass shows devitrified perlitic-texture.

In this study, the K-Ar age of the rock (KAY-002) has been estimated at 12.0±0.6Ma by Teledyne Company (Table 1).

C. Rhyolitie from the submarine coherent lava or feeder dyke of the Suitengu (SUI-004 in Fig. 1)

The rhyolitic rock (Kayashiba Formation) from the Suitengu is submarine coherent lava or feeder dyke (Plate 1e). On the whole, the rock shows greysh and grey brownish and lacks

Table 1 K-Ar dating data of the volcanic rocks from the Otaru City area.

Sample No.	Latitude/ Longitude	Place Name	Rock Type	Occurrence	^{40}Ar ISCC/gm $\times 10^{-5}$	^{40}Ar(%)	K(%)	Age
OSH-001	43°12′30″N, 140°51′50″E	Oshoro Bay	Basaltic andesite	Pillow lava	0.012 0.011	21.9 20.2	0.45 0.45	6.6±0.8
KAY-002	43°13′10″N, 141°01′15″	Kayashiba Cape	Rhyolite	Feeder dyke	0.078 0.076	87.3 82.8	1.65 1.65	12.0±0.6
SUI-004	43°11′15″N, 141°00′40″E	Suitengu	Rhyolite	Submarine lava or feeder dyke	0.044 0.043	79.8 83.8	1.01 1.01	11.0±0.5
TEN-003	43°10′05″N, 140°58′40″E	Otaru-Tenguyama	Pyroxene andesite	Subaerial lava	0.023 0.023	69.1 78.6	1.23 1.22	4.8±0.2
ZEN-005	43°07′05″N, 141°09′55″E	Zenibako-Tenguyama	Proxene andesite	Subaerial lava	0.021 0.020	77.4 75.3	1.23 1.22	4.3±0.2

in flow-layering. The phenocrysts are quartz, sanidine, plagioclase and hornblende and biotite. Characteristically, these phenocrysts are larger in volume and in size than those in the rhyolitic feeder dyke from the Kayashiba Cape mentioned before. The quartz phenocrysts show corroidal in shape and up to 6-8 mm in size. The sanidine and plagioclase show carlsbad twinning and zonal texture. The groundmass is characterized by felsitic texture (Plate 1f) composed of tiny quartz grains, plagioclase and magnetite and fibrous cryptocrystallines. A part of the groundmass shows perlitic texture.

In this study, the K-Ar age of the rock (SUI-004) has been estimated at 11.0±0.5Ma by Teledyne Company (Table 1).

D. Pyroxene andesite from the Otaru-Tenguyama Lava (TEN-003 in Fig. 1)

The andesitic rock (Tenguyama Andesite from the Andesite Lavas) occurrs in subaerial massive lava. On the whole, the lava is dark grey in color and columnar- and platy-jointed (Plate 2a). Macroscopically, this rock contains abundant phenocrysts of plagioclase and pyroxene. In thin section, phenocrysts of plagioclase, pyroxene are recognized. The plagioclases show idiomorphic in shape and zonal structure, and albite and polysynthetic twinning. Some of the plagioclases have been saussuritized considerably. The pyroxenes are identified as clinopyroxene and orthopyroxene. The orthopyroxene is larger in number than the clinopyroxene. The groundmass is hyalopilitic textured and is composed of needle-like plagioclases, and microlites of clinopyroxene and orthopyroxene. In places, glomerophyric texture (Plate 2b) of the plagioclase and pyroxene, is recognized.

In this study, the K-Ar age of the rock (TEN-003) has been estimated at 4.8±0.2Ma by Teledyne Company (Table 1).

E. Pyroxene andesite from the Otaru-Kenashiyama Lava

This rock is making up the Kenashiyama, Otaru City, and is subaerial columnar-jointed massive lava and in places brecciated lava. On the whole, this rock is dark grey and compact. Along the columnar joints, weathering has progressed to form onion-structures.

Macroscopically, lath-shaped plagioclase and pyroxene are usually included. The plagioclase shows albeit-carlsbad and carlsbad twinning and usually lack in zonal texture. The pyroxene is recognized as orthopyroxene and clinopyroxene, and the former is larger in number than the latter. The groundmass show typical hyalopilitic texture and contains lath -shaped plagioclases, grains of pyroxenes and magnetite. Some of the rocks from the lava

show intersertal and intergranular texture.

Watanabe and Watanabe (1992) reported that 7.5Ma K-Ar age on this rock.

F. Pyroxene andesite from the Hariusu-Ishikurayama Lava

The rock makes up subaerial massive lavas of the upper part of the Ishikura-yama, east Otaru City. The lavas have columnar joints and overlie probably the submarine volcanic rock in the Hariusu Formation. Particularly, in a quarry at Hariusu beach, submarine lavas associated with hyaloclastites, grade upward into the subaerial lavas. Macroscopically, these rocks contain phenocrysts of lath-shaped plagioclase and pyroxene. In thin section, most of the plagioclases show idiomorphic in shape and albite and albite-carlsbad twinning. Some of the plagioclases show saussuritized and myrmekite textures, the others form glomerocryst in combination with pyroxenes. The plagioclase is identified as clinopyroxene and orthopyroxene, and the former is larger in number than the latter. In places, quartz grains are found. The groundmass is hyalopilitic textured.

Watanabe and Watanabe (1992) reported 5.5Ma K-Ar age from this rock.

G. Pyroxene andesite from the Zenibako-Tenguyama Lava (ZEN-005 in Fig. 1)

This rock (Ishikurayama Andesite from the Andesite Lavas) is a subaerial massive lava forming the upper of Zenibako-Tengu-yama. The lava overlies the considerably altered massive dyke swarms which are probably submarine feeder dykes. The rock is, on the whole, dark greyish and compact, and shows platy- and columnar-joints (PLate 2c).

Macroscopically, the rock includes plagioclase and pyroxene as phenocrysts, and greyish xenoliths throughout the rock. Microscopically, the plagioclase shows lath-shaped and zonal texture, and albeit and albite-carlsbad twinning. Some of the plagioclases have been considerably saussuritized. The pyroxene is determined as orthopyroxene and clinopyroxene, and the former is large in number than the latter. In places, hornblende phenocrysts are found. The groundmass is hyalopilitic textured (Plate 2d).

In this study, the K-Ar age of the rock (ZEN-005) has been estimated at 4.3±0.2Ma by Teledyne Company (Table 1).

Discussion and conclusion

We describe the outline geologic succssions of the Otaru City area by representative volcanic rocks and the K-Ar dating in this study. Using the K-Ar age data (Table 1) added by those by Watanabe and Watanabe (1992), Matsueda et al.(1992) and Oka et al. (1991), we have established the geologic succession (Table 2) and geologic map of the Otaru City area (Fig. 1). In these data, Matsueda et al. (1992) reported the K-Ar age data of the alunite from the silicified zone due to hydrothermal alteration. Therefore, the 9.7Ma and 10.0Ma by them indicate the age of the hydrothermal activity which was younger than the formation of the original volcanic rocks. Most of the rocks for the K-Ar dating in this study are not seriously altered, hence most of the obtained K-Ar age data are probably approximate. However, the OSH-001 from the Oshoro Peninsula is from the pillow lava which is considerably glassy rock affected by ancient sea water at the time of formation. Kaneoka et al (1987) reported that glassy parts of the pillow basalt contain excess ^{40}Ar. Therefore, we cannot exclude a possibility for the OSH-001 containing excess ^{40}Ar, suggesting that the age datum 6.6 Ma is an older limit for the effusion of the pillow lava.

Watanabe and Watanabe (1992) suggested that, in the northern areas (mostly from Johzankei to Shakotan Peninsula) of the southwest Hokkaido, marine transgression occurred

Table 2 Schematic geologic succession of the Otaru City area.

Age			Geologic column		Rock type and facies	K-Ar age in this study	Remarks
Quaternary	Holocene		Alluvial / Landslide Deposit		Gravel, sand, clay		
	Pleistocene		Terrace Deposit		Gravel, sand, clay		
Neogene Tertiary	Pliocene		Andesite Lavas	Maruyama Andesite	Pyroxene andesite columnar-jointed, platy-jointed lavas and brecciated lavas	Zenibako-Tenguyama Lava (4.3Ma) Otaru-Tenguyama Lava (4.8Ma)	Harukayama Andesite (3.8Ma ; K-Ar age Watanabe, 1990)
				Harukayama Andesite			
				Tenguyama Andesite			Ishikurayama Andesite (5.5Ma ; K-Ar age, Watanabe & Watanabe, 1992)
				Ishikurayama Andesite			
	Miocene	Late	Shioya Formation		Pumice tuff and tuffaceous sandstone		
			Oshoro Formation		Basaltic andesite hyaloclastite/pillow lavas and their feeder dykes, and scoriaceous agglomerates, and their reworked sediments. Pyroxene andesitic hyaloclastite. Intercalations of tuffaceous sandstone and rhyolitic tuff	Oshoro Pillow lava (6.6Ma)	Kenashiyama Andesite (7.5Ma ; K-Ar age, Watanabe & Watanabe, 1992)
			Takashima Formation / Hariusu Formation		Hornblende andesitic autobrecciated lavas, hyaloclastite and epiclastic volcanic rocks		Dacite dyke
		Middle	Kayashiba Formation		Rhyolitic lavas, feeder-dykes and hyaloclastites	Suitengu Rhyolite lava (11.0Ma) Kayashiba Rhyolite Feeder dyke (12.0Ma)	
					Rhyolitic tuff and epiclastic volcanic rocks		
			Akaiwa Formation		Altered dacite and hornblende andesitic massive lavas, autobrecciated lava and hyaloclastite. Locally, highly silicified and mineralized		Alunite from Akaiwa silicified zone (9.7Ma and 10.0Ma K-Ar age, Matsueda et al., 1992)
			Otarunaigawa Formation		Altered dacite andesitic massive lavas and volcaniclastic rocks		Otarunaigawa Formation (Tuff) (11.9Ma ; FT age, Oka et al., 1991)
					Pumice tuffs containing quartz grains		Basaltic dyke

since ca. 10Ma and simultaneously basaltic and andesitic submarine volcanic acivities began, and that these activities graded into felsic volcanic activities, such as Moire rhyolite (6.7Ma) and Shiriba-Cape dacite (6.3Ma) by Yamagish and Matsuda (1991), and transitted to subaerial volcanism making andesitic lavas called "flat lavas".

Similarly to the other area studied by Watanabe and Watanabe (1992), we have concluded that the volcanic activity in the Otaru City area continued from ca. 12 Ma to ca. 5Ma y.B.P, and that effusion of the "flat lavas" began since ca. 5Ma y. B. P ., and that at least some of the "flat lavas" started possibly with submarine effsuion. Therefore, it is possible that the time interval bewteen the submarine effusion and subaerial effusion is considerably small.

However, in contrast to the other areas, in the Otaru City area, felsic volcanism (Kayashiba rhyolite) was recognized at ca. 11-12Ma y. B. P. and basic volcanism (Oshoro basaltic andesite) occurred later than 6Ma y. B. P., simultaneously with felsic volcanism at Yoichi (Moire rhyolite and Shiriba-Cape dacite). Actually, the andesitic hyaloclastites in the Oshoro Formation are intercalated with rhyolitic tuffs. Therfore, the area from Otaru to Yoichi is possibly characterized by bimodal volcanism from 12Ma to 6Ma y. B. P.

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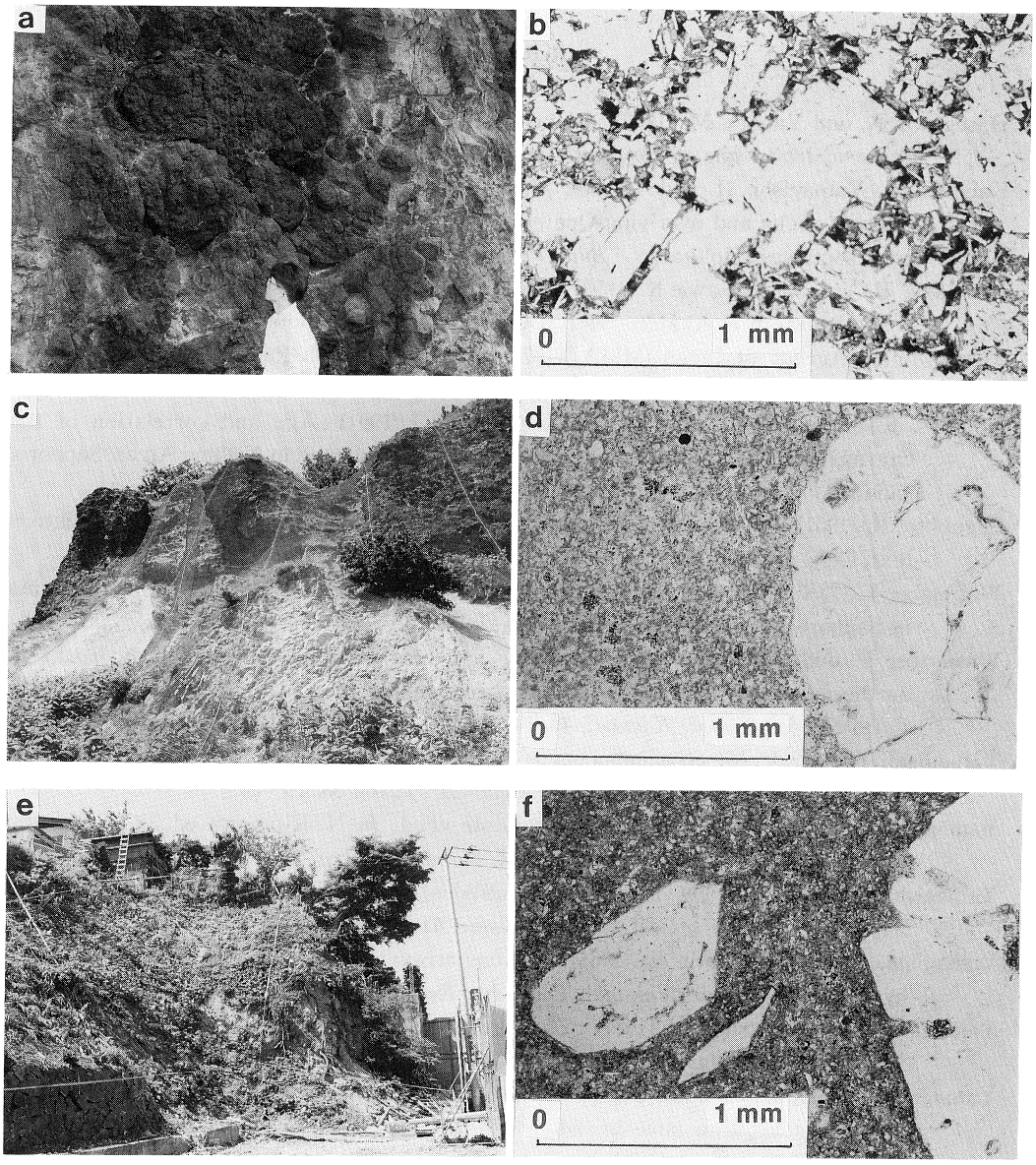

Plate 1

a. Exposure showing close-packed pillow lava in the Oshoro Formation at Oshoro Bay. Sample (No. OSH-001) was taken for the K-Ar age dating.

b. Photomicrograph showing intersertal-textured basaltic andesite from the Oshoro Formation. Open nicol.

c. Exposure showing rhyolitic feeder dyke associated with foreset-bedded hyaloclastites (the Kayashiba Formation), overlain by hornblende andesitic hyaloclastites (the Takashima Formation), at Kayashiba Cape. Sample (No. KAY-002) was taken for the K-Ar age dating.

d. Photomicrograph showing corroidal quartz phenocryst set in a felsitic textured-groundmass, from the rhyolite feeder dyke of the Kayashiba Formation at Kayashiba Cape. Open nicol.

e. Exposure showing rhyolitic body (feeder dyke or coherent lava) at Suitengu. Sample (No. SUI-004) was taken for the K-Ar age dating.

f. Photomicrograph showing phenocrysts of idiomorphic plagioclase and corroidal quartz, set in a felsitic-textured groundmass. Open nicol.

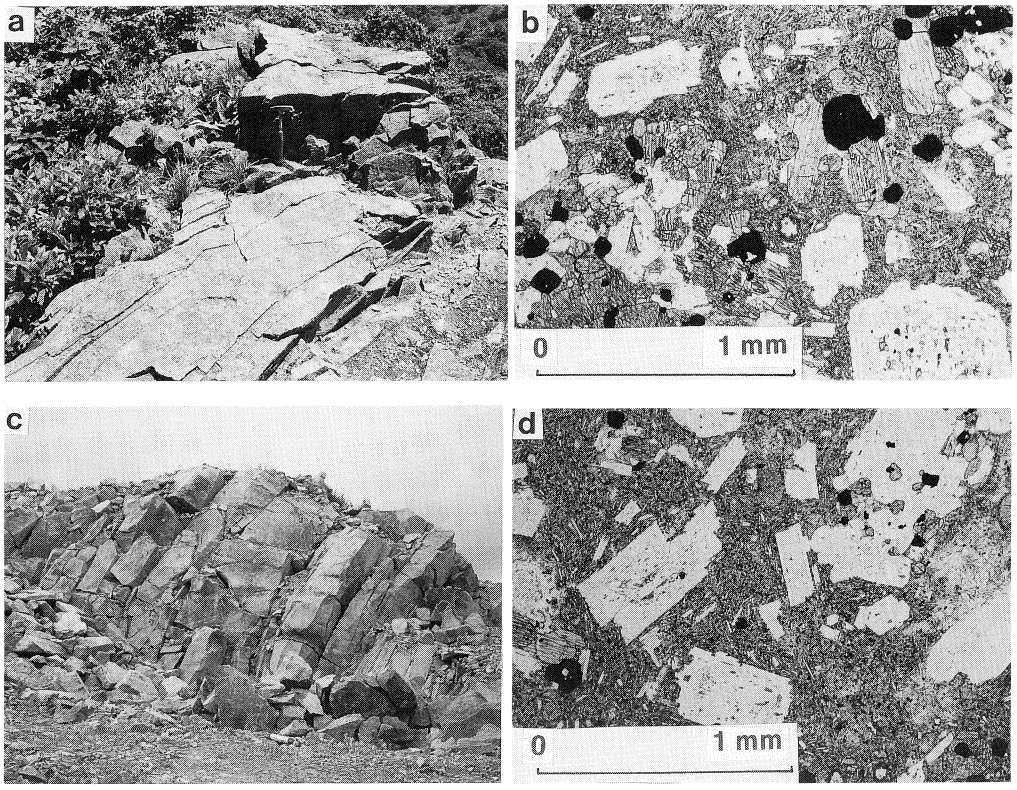

Plate 2

a. Exposure showing platy jointed subaerial andesite lava at top of the Otaru-Tengu-yama. Sample (No. TEN-003) was taken for the K-Ar age dating.

b. Photomicrograph showing hyalopilitic-textured pyroxene andesite including glomerocrysts of plagioclase and pyroxene. Open nicol.

c. Exposure showing columnar-jointed subaerial andesite lava at top of the Zenibako-Tengu-yama. Sample (No. ZEN-005) was taken for the K-Ar age dating.

d. Photomicrograph showing hyalopilitic-textured pyroxene andesite. Open nicol.