MIOCENE SUBAQUEOUS VOLCANICLASTIC ROCKS OF THE OSHORO PENINSULA, SOUTHWEST HOKKAIDO, JAPAN

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Abstract Miocene subaqueous volcanoclastic rocks which are widely distributed in the Oshoro Peninsula are composed of pyroclastic rocks, epiclastic volcanic rocks, and hyaloclastites and associated pillow lavas. They are accompanied by feeder-dykes.

The pyroclastic rocks include agglomerates, volcanic breccias and lapilli tuffs. Judging from their sedimentary structures, the pyroclastic rocks with the exception of lapilli tuffs seem to be subaqueous pyroclastic flows in origin.

The hyaloclastites contain abundant concentrically jointed pillows in the cogenetic tuff, whereas the pillow lavas show surface structures similar to recent submarine pillow lavas. Both of them seem to have been formed by quenching with water, and by effusion in a shallow submarine environment as shown by high vesicularity of them and presence of pyroclastic rocks.

Hyaloclastites and pillow lavas were derived from the magma with higher and lower silica content, respectively, although both of them are andesite. They were erupted from fissures; several types of feeder-dykes are accompanied by minor faults. The dykes and minor faults generally trend NE–SW.

The stress condition under which the fissure eruptions took place on the Oshoro Peninsula area in the Miocene age was tension in a NW–SE direction, as shown by analysis of conjugate sets of minor faults.

Introduction

The Miocene volcanoclastic rocks, widely distributed in the “Green Tuff Region” of Southwest Hokkaido and commonly called “agglomerates”, are mainly composed of hyaloclastites, pyroclastic rocks and their epiclastic volcanic rocks (YAMAGISHI, 1979a). Of these, hyaloclastites are most abundant and accompanied by subaqueous lavas in places. The pillow lavas which occur at the Oshoro Peninsula, 45 km northwest of Sapporo City (Fig. 1), are typical of the subaqueous lavas of the Miocene age (YAMAGISHI, 1973).

This paper deals with the results of further investigation of the whole of the Oshoro Peninsula. The investigation has revealed that dykes as feeders for pillow lavas and

hyaloclastites, accompanied by minor faults, are present throughout the peninsula. Furthermore, this paper describes, in detail, the pyroclastic rocks, pillow lavas and hyaloclastites in the peninsula, all of which are the products of submarine volcanism of the Miocene age.

Geologic Setting

The Oshoro Peninsula, situated in the northern part of Southwest Hokkaido (Fig. 1), consists of volcanoclastic rocks, such as the pyroclastic rocks, hyaloclastites with pillow lavas and epiclastic volcanic rocks, all of which correspond to the “Upper Agglomerate” of the Otaru Formation (IGI & KAKIMI, 1954), of the Neogene age.

The sequence of the volcanoclastic rocks in the Oshoro Peninsula is divided into following three parts; the lower, middle and upper part, according to the characteristics

Received August 25, 1980.

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Fig. 1. Geologic map of the Oshoro Peninsula.

1. Pyroclastic rocks, 2. Epiclastic volcanic rocks, 3. Hyaloclastites containing pillow lavas, 4. Feeder-dykes, 5. Dip and strike, 6. Faults, 7. Transport direction of the pyroclastic rocks, 8. Location number of the outcrop.

of lithofacies. They are in conformable stratigraphic relation.

The lower part is characterized by explosive volcanic products, mostly composed of agglomerates and lapilli tuffs. The thickness is estimated to be more than 10 m.

The middle part is characterized by effusive volcanic products accompanied by explosive and reworked volcanic products, and consists mainly of hyaloclastites with pillow lavas, pyroclastic rocks and epiclastic volcanic rocks. Tuffaceous sandstones are locally intercalated in the epiclastic volcanic rocks. The thickness of the middle part is estimated to be 80 m.

The upper part is characterized by explosive volcanic products, mainly composed of pyroclastic rocks including volcanic breccias and minor amounts of agglomerates.

The thickness is estimated to be 50 m.

The volcanoclastic rocks in the peninsula trend northeast and dip 10°–20° southeast, as a whole, showing a monoclinic structure (Fig. 1).

Pyroclastic Rocks

The pyroclastic rocks of the lower and upper parts of the sequence are mainly agglomerates composed of volcanic bombs and scoriaceous lapilli, volcanic breccias consisting of volcanic blocks and scoriaceous lapilli, and scoriaceous lapilli tuffs. They lack characteristically ash-sized particles.

The agglomerates in the lower part exposed at Kabuto Cape (Loc. A in Fig. 1) are divided into several eruption units. The lower portion of each unit is more or less massive, whereas the upper portion shows

doubly-graded bedding. The lower and upper portion are about one meter and tens of centimeters thick, respectively. The large bombs tend to be concentrated at the base of the massive portion of the units.

The elongated or disk-shaped bombs are arranged with dip at an angle to bedding in a direction of north or northeast (Plate I, 1). This preferred orientation is similar to the "imbrication" displayed by pebbles on a stream bed, where flowing water tilts the pebbles so that their flat surfaces dip upstream (AMERICAN GEOLOGICAL INSTITUTE, 1980). Locally, bomb sag structures are observed at the top of the doubly-graded portion. Therefore, the sedimentary structures of the agglomerates found at Kabuto Cape indicate that the transportation and the deposition resulted from subaqueous pyroclastic flows (FISKE, 1963), and that the eruption center was in the north of the Oshoro Peninsula.

The volcanic breccias intercalated with agglomerates in the upper part exposed along the Route No. 5 (Loc. B in Fig. 1) are poorly sorted, and made up of several eruption units, each of which is composed of lower massive portion and upper bedded portion. The lower massive portion in each unit thins to the east, whereas the upper bedded portion tends to thicken to the east. The volcanic breccias also seem to have resulted from the subaqueous pyroclastic flows from the north of the Oshoro Peninsula. Both elongated bombs and tabular blocks in the agglomerates display an imbrication suggesting derivation from the west.

The scoriaceous lapilli tuffs in the lower part exposed at the eastern base of the Oshoro Peninsula (Loc. C in Fig. 1), are well-sorted and graded, showing distinct fall units. Each eruption unit is a few tens of centimeters thick and can be traced laterally. Most of the lapilli have tiny cracks perpendicular to the surfaces and show glassy chilled margins a few millimeters thick. The chilled margins are usually enveloped by yellow-brown palagonitic rinds. The lapilli tuffs seem to have been emplaced by falling through water but their vents are not known.

The absence of ash-sized particles in the pyroclastic rocks in the Oshoro Peninsula suggests that they were swept away during flow and falling through water.

Water-chilled bombs Most of the volcanic bombs in the agglomerates are elongated and irregularly flat shaped, showing the following characteristics.

The bombs are 5–10 cm in length. Irregularly-shaped tiny wrinkles with wave length less than one centimeter are observed on the surfaces.

The bombs have abundant vesicles and chilled margins (YAMAGISHI, 1974; Fig. 2). The vesicles developed at the center are usually much larger than those in the outer portion and in the chilled margin. The vesicles in the center generally are spherical in shape, a few centimeters in diameter, whereas those in the outer portion and the chilled margin are elongated, a few millimeters in diameter, and their long axes are

Fig. 2. Water-chilled bombs showing tiny cracks perpendicular to the surface, and glassy chilled margins.

aligned parallel to surfaces of the bombs.

The chilled margin is composed of black glass with tiny cracks. The tiny cracks are perpendicular to the surface. The black glass is enveloped by a film of palagonitic clay, 0.3 to 0.5 mm thick. In the interior of the chilled margin, several zonal bands parallel to the surface are distinguished by the difference in color.

The structure of the bombs having chilled margins suggests that they were ejected directly in water; they are called water-chilled bombs (YAMAGISHI, 1974).

Pillow Lavas

The representative subaqueous volcanic rocks in the Oshoro Peninsula are well preserved pillow lavas. They are similar in appearance to those of basalt observed at the present deep-sea bottom, although the former is andesite in chemical composition (Table 1).

Surface of pillow lavas The pillow lavas embedded in sandstone and comminuted volcanic materials, display well preserved surface structures. Their surface is smooth (Plate I, 3) in places, but shows generally the "pahoehoe ropy structure" (YAMAGISHI, 1973; Plate I, 2). It is composed of broader wrinkles with wave length of a few centimeters and narrower ones (wave length of a few millimeters) perpendicular to the former. The broader wrinkles may correspond to the "corrugations" (MOORE, 1975) which were observed on recent pillow lavas, east of Hawaii and the Mid-Atlantic Ridge (BALLARD & MOORE, 1977). They are, in general, parallel to the elongation of the pillows. On the other hand, the narrower wrinkles correspond to ropy wrinkles on toes of terrestrial pahoehoe lavas (MACDONALD, 1967), which are, in places, perpendicular to the elongation of the toes.

The pillow lavas to the west of Loc. B in Fig. 1 exhibit another surface structure (Plate II, 1) similar to the "spreading crack" (MOORE, 1975) which has also been observed on the recent pillow lavas. It is characterized by small scarps, a few centimeters in relief, across the crust of the pillow lava.

Many opening cracks develop along the narrower wrinkles of the pillow lavas (Plate I, 2). The radial joints extend inward from the grooves of the broader wrinkles.

Cross section of pillow lavas The pillow lavas from the Oshoro Peninsula show, in cross section, massive elliptical outlines (pillows) ranging from several tens centimeters to a few meters in diameter; they are either separated (Plate I, 2) or closely fitted to one another (Plate II, 4). The interstices among the pillows are filled by a minor amount of sandstones and/or comminuted glassy fragments.

Toward the upper sequence, the pillows tend to become circular in shape and small in size, and further, grade into the hyaloclastites mentioned later without any distinct boundary.

Each pillow has joints, abundant vesicles and chilled glassy margin. The central portion of the pillow is characterized by presence of radial or columnar joints and abundant circular vesicles ranging from a few millimeters to one centimeter in diameter.

The chilled margin is characterized by glassy rind, tiny fractures perpendicular to the surface of the pillow, and by abundant small elliptical vesicles less than one millimeter across. The vesicles are arranged to exhibit concentric flow layers conformable to the surface. But, some pillows have pipe vesicles a few millimeters to one centimeter across, perpendicular to the surface (Plate I, 3).

Hyaloclastites

The hyaloclastites accompanying the pillow lavas are widely distributed within the subaqueous volcanic rocks in the Oshoro Peninsula. They are inferred to have formed by jointing and fragmentation of magma due to quenching with water at the time of effusion. In general, the Neogene hyaloclastites in Southwest Hokkaido can be divided into two types; A and B, based on whether they contain pillows or not, respectively (YAMAGISHI, 1979a, b). Most of the hyaloclastites from the Oshoro Peninsula belong to type A, which consist of disaggregated,

complete or broken pillows and a matrix of cogenetic tuff (Plate II, 2). Most of the pillows are spherical or ellipsoidal masses, several tens centimeters in diameter, and mantled by glassy chilled margins without "pahoehoe ropy structure". Concentric joints along the margins are conspicuous (Plate II, 2).

Each pillow contains abundant vesicles a few millimeters in diameter. The vesicles in the central portion are spherical or ellipsoidal in shape, whereas those in the outer portion are irregularly shaped or are elongated parallel to the surface.

These pillows seem to have formed through the following mechanism: the margins of the pillow lobes tended to be jointed parallel to the flow layers by anisotropic stress caused by the difference of the contraction rates between the outer and central portions of the pillow lobes during flow on the sea bottom. Accordingly, the toes of the pillow lobes were separated by curved joints from the lobes, and the concentrically jointed pillows formed just before consolidation of the lava. It seems that the interior of the pillow cooled slowly enough to permit coalescence of gas bubbles.

Microscopic examination reveals that the matrix of the hyaloclastites is composed of glassy fragments and shards, showing vitroclastic texture. Fragments are angular chips with straight or curved outlines across the vesicles (Plate II, 3). The shape of the fragments is distinguished from that of volcanic ash (MACDONALD, 1972). Polygonal or perlitic cracks are common in the glassy fragments and shards. The phenocrysts of plagioclase are shattered into splinters.

The textural features of the matrix of the hyaloclastites suggest that the fragments formed, not by expanding gas bubbles, but by contraction jointing due to water chilling of magma.

Composition of Pillow Lavas and Hyaloclastites

Microscopic examination reveals that the pillow lavas show porphyritic texture containing abundant phenocrysts of plagioclase,

orthopyroxene and clinopyroxene, most of which are a few millimeters in length. The plagioclase phenocrysts are usually euhedral or anhedral in form.

In the central portion of the pillow, phenocrysts of plagioclase and pyroxene are set in a groundmass consisting of lath shaped plagioclase, tiny pyroxene crystals and glass. Vesicles are abundantly included in the glass. Toward the margin, plagioclase and pyroxene crystals in groundmass decrease, and glass becomes dominant, although the volume of phenocrysts remain constant.

The pillows in the hyaloclastite show also porphyritic texture containing plagioclase and

Table 1. Chemical composition of the pillow lavas and pillows in the hyaloclastites from the Oshoro Peninsula, Southwest Hokkaido, Japan.

	1	2	3	4	5
SiO ₂	48.99	50.83	52.39	52.97	57.57
TiO ₂	0.62	0.71	0.82	0.82	1.04
Al ₂ O ₃	19.85	18.95	19.92	20.71	17.86
Fe ₂ O ₃	3.91	3.87	3.24	1.99	3.17
FeO	4.87	5.46	4.90	5.52	4.66
MnO	0.10	0.14	0.12	0.08	0.99
MgO	3.66	3.90	3.16	3.07	2.72
CaO	11.48	11.29	9.27	9.16	7.24
Na ₂ O	2.23	2.14	2.50	2.20	3.05
K ₂ O	0.52	0.61	1.08	1.01	1.54
P ₂ O ₅	0.12	0.19	0.25	0.14	0.37
H ₂ O(+)	1.57	1.14	1.20	1.27	0.91
H ₂ O(-)	2.05	0.87	1.41	0.79	0.28
Total	99.97	100.10	100.26	99.73	100.50
Q	5.02	7.01	8.44	9.36	14.10
or	3.07	3.60	6.40	5.97	9.10
ab	18.87	18.11	21.14	18.62	25.81
an	42.62	40.30	39.95	43.66	30.47
wo	5.05	6.05	1.84	0.37	1.26
Di en	3.48	3.57	1.05	0.19	0.73
fs	1.86	2.17	0.70	0.17	0.47
Hy en	5.64	6.14	6.82	7.46	6.04
fs	3.01	3.74	4.49	7.10	3.90
mt	5.67	5.61	4.70	2.89	4.60
il	1.18	1.35	1.56	1.56	1.98
ap	0.28	0.44	0.59	0.32	0.86
C.I.	26.17	29.07	21.75	20.06	19.84

1. Margin of the pillow lava, Loc. D of Fig. 1,
 2. Core of the pillow lava, Loc. D of Fig. 1,
 3. Core of the pillow lava, Loc. E of Fig. 1,
 4. Pillow in the hyaloclastite, Loc. A of Fig. 1,
 5. Pillow in the hyaloclastite, Loc. C of Fig. 1.
- Analyst Y. OBA.

ortho- and clinopyroxene as phenocrysts embedded in a glassy groundmass.

The groundmass has a small amount of fine crystals of plagioclase and clinopyroxene. The groundmass glass and rinds of vesicles are more or less devitrified or altered into yellow-brown montmorillonoid clay minerals probably due to palagonitization.

As shown in Table 1, the pillow lavas and pillows in the hyaloclastite range 48% to 57% in SiO_2 ; according to the silica content, the pillow lavas (Samples 1 to 3 in Table 1) are basaltic, whereas the pillows in the hyaloclastite (Samples 4 and 5 in Table 1) are andesitic. However, both of the pillow lavas and the pillows in the hyaloclastite have a low color index (20 to 30), based on their CIPW norms, and accordingly can be considered andesite. Most of the chemical data are plotted in the high-alumina basalt field (KUNO, 1960).

These data suggest that the andesite magma with lower silica content tended to produce pillow lavas, whereas that with higher silica content yielded hyaloclastites in submarine environment.

Feeder-dykes

A large number of dykes of andesite are distributed throughout the Oshoro Peninsula; however, the author investigated only the outcrops of the western coast of the peninsula because the eastern coast is not accessible. They are auto-intrusive bodies (feeder-dykes; YAMAGISHI, 1979b) which grade vertically into the pillow lavas and hyaloclastites; they acted as feeding channels from depth. They range from massive to clastic type through apophyses-like type (YAMAGISHI, 1979b). They vary from 0.3 to 7 m in width.

The massive type of the dykes displays columnar and radial joints perpendicular to the surface. The clastic type of dykes consists of disaggregated broken pillows and angular blocks, that is, hyaloclastites (Plate III, 1).

The dykes of the apophyses-like type show lava tongues shooting off irregularly between or along minor faults around the dykes (Fig. 3, Plate III, 3). In cross section, this type of dyke at Loc A in Fig. 1, consists of hyaloclastites in the center, surrounded by flow-layered massive lavas with chilled glassy margins. The surface shows two sets of wrinkles

Fig. 3. Sketch showing a feeder-dyke of apophyses-like type at Kabuto Cape (Loc. A in Fig. 1), intruding into agglomerates and epiclastic volcanic rocks, accompanied by conjugate sets of minor faults. The dyke continues to the hyaloclastite layer on the sea bottom at the time of effusion.

1. Agglomerates, 2. Epiclastic volcanic rocks, 3. Tuffaceous sandstones, 4. Hyaloclastites, 5. Minor faults, 6. Feeder-dykes.

Fig. 4. Schmidt projection to the upper hemisphere, of poles of the planes of 290 fractures and 22 feeder dykes.

1. Minor faults, 2. Minor joints, 3. Faults, 4. Feeder dykes.

Fig. 5. Contoured equal-area projection for the poles of the minor faults illustrated in Fig. 4.

1. Above 7.0%, 2. 7.0—5.5%, 3. 5.5—3.5%, 4. 3.5—2.0%, 5. 2.0—0.4%, 6. Below 0.4%.

perpendicular to each other, which resemble to the "pahoehoe ropy structure" on the pillow lavas (Plate III, 2). The broader wrinkles are parallel to the direction of intrusion of the dyke, whereas the narrower wrinkles develop perpendicularly to the direction of intrusion.

The central portions of the dykes of massive and apophyses-like types contain spherical or elongated vesicles a few millimeters to one centimeter in diameter. Toward the margins, the vesicles tend to decrease in diameter, but increase in abundance. Vertical strings of elongated vesicles have been recognized, which are probably due to rising bubbles during the intrusion.

It is noteworthy that most of the feeder-dykes are parallel to one another, trending NE-SW with nearly vertical dip.

Minor Faults

Several kinds of fractures are abundantly found throughout the Oshoro Peninsula. They are classified into faults, minor faults and minor joints.

The faults are mostly exposed along the western coast of the peninsula. They have a considerable displacement more than a few meters and characteristic slickensides on the planes. Most of them are nearly vertical or steeply dipping with NE strike.

The minor faults are most abundant on

Fig. 6. Map showing the distribution of feeder-dykes and the analysis of stress field by conjugate sets of minor faults on each outcrop.

1. Principal stress axis,
2. Feeder-dyke.

the peninsula, in particular, around the feeder-dykes. They are normal dip-slip faults with small horizontal displacement. The vertical displacement ranges from a few centimeters to one meter, whereas the horizontal does not exceed a few centimeters. Most of the planes of the minor faults adhere tightly with each other. Some minor faults apparently are arranged en echelon, while the others are parallel to one another.

The minor joints are rarely found along the northern coast of the peninsula, and are steeply dipping with EW strike.

The poles of the planes of 290 fractures and 22 feeder-dykes were plotted on the Schmidt net (Fig. 4). The minor faults were contoured in Fig. 5 which clearly illustrates that the two sets of the planes are representative, striking N40°E and dipping 70°NW, and striking N30°E and dipping 70°SE.

In outcrops the two sets of the minor faults are recognized as conjugate with each other, in particular, on both sides of the feeder-dykes, some of which intruded along some of the minor faults. The conjugate relations show the direction of the three principal stress axes, $\sigma_1 > \sigma_2 > \sigma_3$ as follows. σ_1 plunges steeply to NE or SW, σ_2 plunges gently to NE or SW and σ_3 plunges gently to NW or SE (Fig. 6).

The distribution of the poles of the feeder-dykes is consistent with that of the minor faults although the former is arranged on or nearer to the primitive circle (Fig. 4). Furthermore, the strikes of most of the feeder-dykes are nearly parallel to those of σ_1 - σ_2 planes.

The fact mentioned above indicates that both of the feeder-dykes and minor faults formed under the same tensional field with σ_3 in a NW-SE direction.

In addition, the occurrences suggest that the feeder-dykes intruded immediately after minor dip-slip faulting.

Conclusion

The volcanoclastic rocks, such as pyroclastic rocks and hyaloclastites with pillow lavas, from the Oshoro Peninsula are representative products of the Miocene submarine volcan-

ism. They were erupted in fairly shallow water as evidenced by the high vesicularity of pillow lavas and hyaloclastites, and by the presence of significant volumes of pyroclastic rocks, unlike the deep-sea volcanism of ancient geosyncline (MARUYAMA, 1979).

The magma produced the hyaloclastites and pillow lavas, caused by quenching with during effusion on the sea-bottom. The former was derived from the andesite magma with higher silica content, whereas the latter from that with lower silica content.

The occurrence of the hyaloclastites, pillow lavas, feeder-dykes and minor faults is explained as follows; the andesite magma ascended through fissures into sediments on the sea-bottom, immediately after minor dip-slip faulting. The fissure eruption took place under tensional stress in a NW-SE direction on the Oshoro Peninsula area in the Miocene age.

Acknowledgement The author wishes to express his sincere thanks to Prof. YOSHIO KATSUI of Hokkaido University and Prof. ERICH DIMROTH of Université du Québec à Chicoutimi for improving the manuscript. Thanks are also extended to Dr. YOSHIO OBA of Yamagata University for the chemical analysis, and to Dr. KAZUAKI NAKAMURA of the Earthquake Research Institute, University of Tokyo for useful suggestions.

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おしよろ
西 南 北 海 道 忍 路 半 島 の 中 新 世 水 中 火 砕 岩 類

山 岸 宏 光

(要 旨)

忍路半島に広く分布する中新世の水中火砕岩類は、火山碎屑岩、エピクラスティック ボルカニック ロックス、枕状溶岩をともなうハイアロクラスタイトからなり、フィダーダイクをともなっている。

火山碎屑岩は集塊岩、火山角礫岩および火山礫凝灰岩などからなり、火山礫凝灰岩をのぞいて、それらの堆積構造から判断して、水中火砕流起源であろう。

ハイアロクラスタイトは、多量の、同心円状節理を有するピローと、同質の凝灰岩からなる。枕状溶岩は現在の海洋底でのそれと類似した表面構造を示す。いずれも、水冷によって形成されたものであり、また、それらが多孔質であることや、火山碎屑岩の存在などで示されるように、それらは浅海底で噴出したものであろう。

また、ハイアロクラスタイトや枕状溶岩はいずれも安山岩であるが、前者はより高いシリカ量の、後者はより低いシリカ量のマグマに由来する。それらは裂か噴出であり、それらを供給した種々のタイプのフィダーダイクは小断層をともなっている。それらのダイクや小断層は一般的に北東—南西方向を示している。

中新世の時代に忍路半島地域でおこった裂か噴出の際の応力条件は、小断層の共役セットの解析の結果から、北西—南東方向の引張りの場であったことがわかる。

(地 名)

Kabuto Cape カブト岬 Oshoro Peninsula 忍路半島
Otaru Formation 小樽累層

Explanation of Plates

Plate I

1. Agglomerate consisting of water-chilled bombs and scoriaceous lapilli. Arrangement of the bombs shows the "imbrication" suggesting that the agglomerate was derived from the left to the right in the photograph. Loc. A in Fig. 1.
2. Pillow lava embedded in sandstone. The surface is characterized by "pahoe-hoe" structure which is composed of broader and narrower wrinkles perpendicular to each other. Tensional cracks develop along the narrower wrinkles. Loc. D in Fig. 1.
3. Pillow lava projecting downward from upper left to lower right in the photograph. The surface is featured by smooth crust. Loc. E in Fig. 1.

Plate II

1. Surface structure analogous to the spreading crack on the recent pillow lava. West of Loc. B in Fig. 1.
2. Hyaloclastite composed of disaggregated concentrically jointed pillows in the cogenetic tuff. South of Loc. D in Fig. 1.
3. Photomicrograph showing the matrix of hyaloclastite. South of Loc. D in Fig. 1.
4. Cross section of pillow lavas a few meters across, closely fitted to one another. Loc. E in Fig. 1.

Plate III

1. Feeder-dyke of clastic type, composed of disaggregated broken pillows and angular blocks in the cogenetic tuff. East of Loc. A in Fig. 1.
2. Surface structure of the feeder-dyke of apophyses-like type shown in Fig. 3. The dyke intruded from below in the photograph. Loc. A in Fig. 1.
3. Cross section of the feeder-dyke of apophyses-like type shown in Fig. 3, intruding into the agglomerates and epiclastic volcanic rocks. Loc. A in Fig. 1.