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The Occurrence and Formation Mode of Basaltic Rocks in the Tertiary Janggi Basin, Janggi Area

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제 3기 장기분지에 나타나는 현무암질암의 산상과 형성기구

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Abstract: A basaltic tuff formation (Upper Basaltic Tuff of the Janggi Group) occurs in close association with basalt (Yeonil Basalt) at the Tertiary Janggi basin. The purpose of this paper is to describe the occurrence of the basaltic tuff and associated basalt and to determine their mode of formation. The basaltic rocks of the study area show four distinct lithofacies, all of which are originated from the interaction of basaltic magma with external water. The four lithofacies include (1) sideromelane shard hyaloclastite, (2) pillow breccia, (3) entablature-jointed basalt, and (4) in-situ breccia. The sideromelane shard hyaloclastite constitutes most of the Upper Basaltic Tuff and has a gradual contact with the pillow breccia. The pillow breccia consists of a poorly sorted mixture of isolated and broken pillows, and small basalt globules and fragments engulfed in a volcanic matrix of sideromelane shard hyaloclastite. The entablature-jointed basalt occurs as a small body within the hyaloclastite. It is characterized by irregularly-curved joints known as entablature. The in-situ breccia occurs as a marginal facies of entablature-jointed basalt, and its width varies from 10 to 30m. The result of this study indicates that the basaltic tuff and associated basalts of the study area were produced by the volcanic activity of same period and the basaltic tuff was formed by subaqueous eruption of basaltic lava followed by nonexplosive quench fragmentation.

Key words: Upper Basaltic Tuff, Janggi Basin, hyaloclastite, subaqueos eruption, quench fragmentation

요 약: 경상북도 포항시 장기지역의 제3기 장기분지에는 제 3기 장기층군의 상부현무암질응회암이 넓게 분포하고 있으며, 그 가운데에 연일현무암이 단속적으로 산출되고 있다. 본 연구의 목적은 이들 현무암질암의 산상과 암상의 조사를 통하여 그 형성과정을 밝히는데 있다. 야외조사 결과 본역의 현무암질암은 다음과 같이 크게 4가지 특징적인 암상으로 구분된다: (1) sideromelane shard hyaloclastite, (2) pillow breccia, (3) entablature-jointed basalt, 그리고 (4) in situ breccia. 본역에서 관찰되는 현무암질암의 여러 특징에 의하면 장기지역의 장기분지에 분포하는 상부현무암질응회암은 hyaloclastite에 해당하며, 현무암질 용암의 수저분출 후 일어난 비폭발성 급랭 파쇄작용에 의해서 형성된 것으로 추론된다.

핵심어: 장기분지, 상부현무암질응회암, hyaloclastite, 수저분출, 급랭 파쇄작용

Introduction

Primary volcanic processes that produce the fine-grained fragments in volcaniclastic rocks include magmatic explosions and hydroclastic processes. Magmatic explosions are caused by expansion of gases initially contained within the magma, whereas hydroclastic processes are caused by interaction of hot

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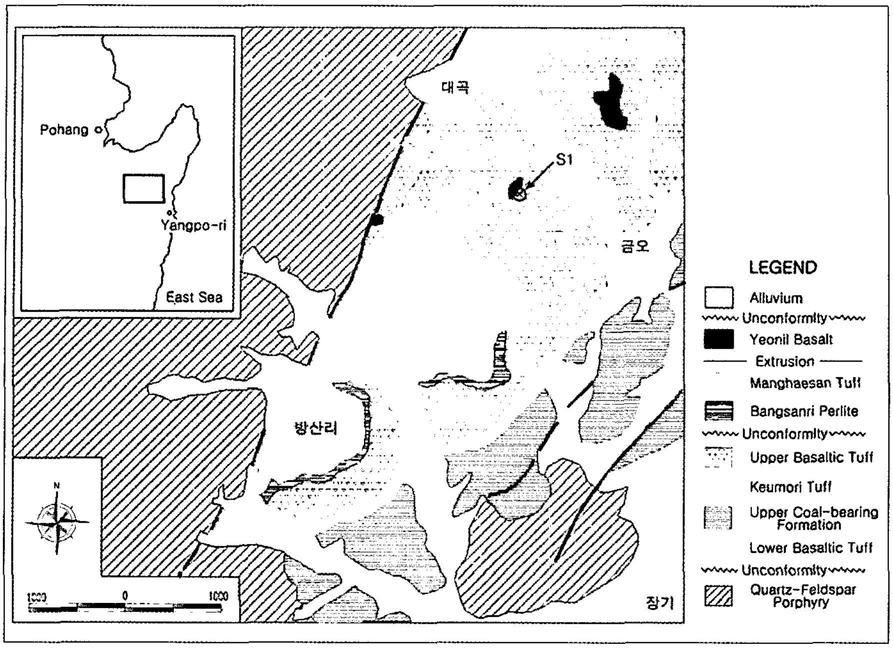


Fig. 1. Geologic and index map of study area (Modified from Tateiwa, 1924). The location S1 in the figure is the sampling site of entablature-jointed basalt and in-situ breccia.

magma and external water (Fisher and Schmincke, 1984). Hydroclastic processes are in turn divided into (1) hydroclastic eruption and (2) nonexplosive quench fragmentation. Hyrdoclastic eruptions are due to explosive evaporation of external water in contact with hot magma or lava, and phreatic and phreatomagmatic explosions are included in this category. 'Hyalotuff' of Honnerez and Kirst (1975) is the product of hydroclastic eruption. Nonexplosive quench fragmentation is caused by a drastic volume decrease of magma during its quenching to a glass by external water, and it produces 'hyaloclastite' of Rittman (1962).

Volcaniclastic rocks resulting from hydroclastic processes can be expected from the area of subaqueous eruption of magma, which includes submarine, sublacustrine, and subglacial eruption (Fisher and Schmincke, 1984). Hydroclastic rocks of submarine and subglacial origin have been reported in many parts of the world. The classic examples are pillow breccias and their aquagene tuffs in Quadra island, British Columbia (Carlisle, 1963) and Pleistocene Palagonite Formation of Iceland (Sigvaldason, 1968; Jones, 1970), respectively. However, comparatively fewer hydroclastic rocks of sublacustrine origin have been documented.

Subbasins of the Mesozoic Kyeongsang basin and the Tertiary basins in the southern part of Korea have been interpreted that their sedimentary environments are lacustrine. This implies that considerable amount of volcaniclastic rocks deposited in these basins could have been formed by underwater eruption of magma. However, few volcaniclastic rocks in these areas have been reported to be hydroclastic in their origin.

A basaltic tuff formation occurs in close association with basalts at the Tertiary Janggi basin. The basaltic tuff formation and the closely associated basalts are 'Upper Basaltic Tuff' of the Tertiary Janggi Group and 'Yeonil Basalt' (Tateiwa, 1924), respectively (Fig. 1). The purpose of this paper is to describe the occurrence of basaltic tuff formation and associated basalts and to determine their mode of formation. The result of this study indicates that the basaltic tuff and associated basalts were produced by a same volcanic activity and the basaltic tuff was formed by subaqueous eruption of basaltic lava followed by nonexplosive quench fragmentation.

Terminology

Rittman (1962) introduced the term 'hyaloclastite' for rocks composed of sideromelane clasts produced by essentially nonexplosive spalling and granulation of rinds of pillow lavas. However, Fisher and Schmincke (1984) suggested to use the term to include all vitroclastic tephra produced by magma/water interactions, whether by explosive steam generation or by nonexplosive fragmentation of quenched magma. Calisle (1963) introduced the term 'aquagene tuff' for tuff formed by nonexplosive granulation that is commonly associated with pillow lava. To distinguish between the hydroclasic products of nonexplosive and explosive origin, Honnerez and Kirst (1975) introduced the term 'hyalotuff' for a glassy pyroclastic rock resulting from phreatic or phreatomagmatic explosion. The term 'pillow breccia' is taken from Calisle (1963) and refers to a hydroclastic breccia consisting of complete or broken pillow dispersed in a matrix of cogenic basaltic tuff. 'In-situ breccia' is a monolithologic breccia produced by disaggregation of lava and/or dike due to brittle fracturing during quenching with water (Kokelaar, 1986; Yamagishi. 1987). Subaqueous lava commonly grades outward into hyaloclastite through in-situ breccia (Yamagishi. 1987). In this paper, the term hyaloclastite refers to aggregates of quench-fragmented debris, following Cas and Wright (1987).

General Geology

The Tertiary Janggi basin, which lies to the north of the Tertiary Eoil basin, is developed at the Janggi area of Janggi-myeon, Pohang-si, Kyeongsangbug-do. The Tertiary rocks of the Janggi basin consist of lower Janggi Group and upper Beomgogri Group (Tateiwa, 1924). The Janggi Group overlies unconformably basement rocks of quartz-feldspar porphyry, and consists of Janggi Conglomerate, Nuldaeri Tuff, Lower coal-bearing formation, Lower Basaltic Tuff, Upper coal-bearing formation, Keumori Andesitic Tuff, and Upper Basaltic Tuff in ascending order (Tateiwa, 1924). The Janggi Group is intruded and/or extruded by the Yeonil Basalt. The Beomgogri Group is composed of Bangsanri Perlite and Manghasan Tuff (Tateiwa, 1924).

The paleoenvironment of the Janggi Group is interpreted to be a shallow lake or swamp by Kim *et al.* (1975), based on sedimentary structures, plant fossils, and the preservation of lignite. Plant fossil study on the Lower coal-bearing formation of the Janggi Group has shown that the age of the Janggi Group is early Miocene (Kim *et al.*, 1975). Bong (1981) studied pollen flora of the Janggi Group and reported that their age is Uppermost Oligocene or Lowermost Miocene. He also reported that fresh-water plant fossils are found in all the sequence of the Janggi Group. Lee *et al.* (1992) conducted K-Ar age dating for Yeonil Basalt which was interpreted to be Quarternary by Tateiwa (1924), and yielded the age of early Miocene (19~22 Ma). Based on this result and the occurrence of the basalt, they argued that Yeonil Basalt should be interpreted as volcanic flows produced by the volcanic activity which occurred almost at the same period of Janggi Group deposition. Yoon (1992) reported the presence of hyaloclastite in Janggi Group, but he has not studied on hyaloclastite itself. The general geology and stratigraphy of the study area is shown in Fig. 1.

Occurrence and Field Relations of Basaltic Rocks

The basaltic rocks (Upper Basaltic Tuff and Yeonil Basalt) of the study area show four distinct lithofacies, all of which are originated from the interaction of basaltic magma with water. The four lithofacies include (1) sideromelane shard hyaloclastite, (2) pillow breccia, (3) entablature-jointed basalt, and (4) in-situ breccia. These lithofacies show roughly concentric distribution; from the center to outside distributes in the order of entablature-jointed basalt, in-situ breccia, pillow breccia, and sideromelane shard hyaloclastite. Among these, sideromelane shard hyaloclastite is predominant, constituting most of the basaltic rocks in the study area.

Sideromelane shard hyaloclastite (SSH)

The Sideromelane shard hyaloclastite (SSH) occupies most of the Upper Basaltic Tuff and has a gradual contact with the pillow breccia. The SSH is generally

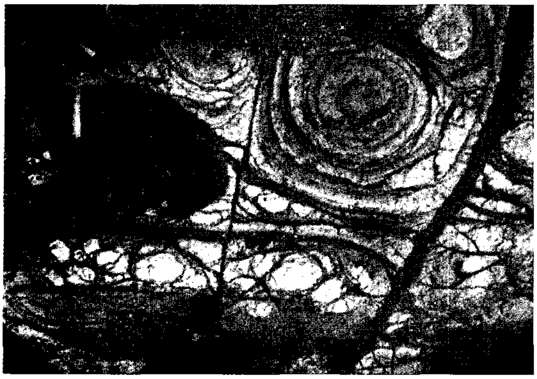


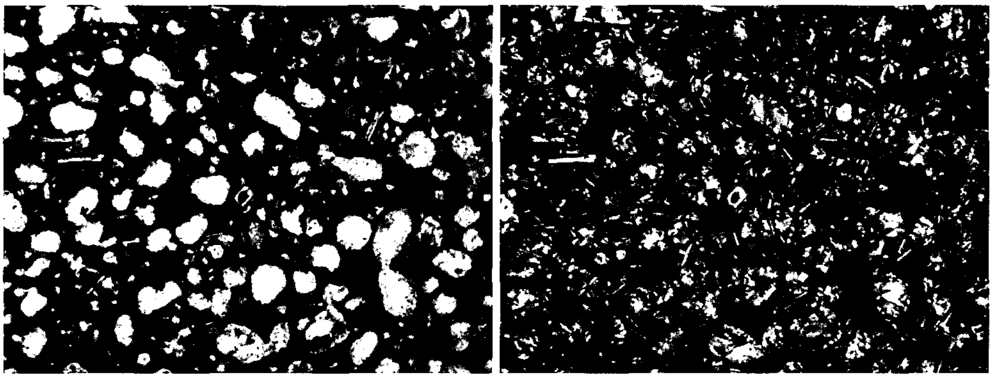
Fig. 2. Photograph of spheroidal weathering of reworked and weathered Sideromelane shard hyaloclastite.

massive with little or no stratification. However, locally reworked SSH by flowing water shows a faint stratification whose thickness is 1~3 m. Reworked and weathered SSH generally occurs in the outer part of the Upper Basaltic Tuff and commonly shows spheroidal weathering (Fig. 2). The intensively reworked part appears like tuffaceous sandstone and is locally intercalated with thin beds of conglomerate. The outcrops of SSH are generally black in color, but some weathered surface shows yellowish brown color. Sideromelane, the major component of SSH, is a basaltic glass which forms by quenching of basaltic magma by external water. The SSH usually contains some zeolitic veins whose thickness vary from 1 to 10 mm. The zeolitic veins are commonly composed of stilbite. In one area a thick (up to 7 m), irregularly shaped, massive zeolite body occurs within black sideromelane shard hyaloclastite. This white zeolite body shows conchoidal fractures, and is composed of heulandite.

The SSH is composed of ash- to lapilli-size (0.5~10 mm) sideromelane shards (60~80%), tachylite fragments (less than 5%), pyrogenic crystals (plagioclase, olivine, and clinopyroxene), and tiny glassy fragments disaggregated from sideromelane shards. Rarely pumice fragments of ash-size are contained, which are derived from underlying volcanic units. Under the microscope sideromelane shards are transparent and brown in color, and commonly have 20~30% micro-vesicles which are filled with zeolite or palagonite, and very few calcite. Sideromelane shards often contain quench-textured crystals of plagioclase, clinopyroxene, and olivine (Fig. 3). In places the glassy matrix of sideromelane shards and tiny glassy fragments are altered to zeolite, palogonite, calcite, or smectite. The hyaloclastite which is altered to smectite tends to disaggregate in small pieces (about 1 cm in diameter).

Pillow breccia (PBr)

The pillow breccia (PBr) occurs around the entablature-jointed basalt and is especially well exposed



(A) (B)

Fig. 3. Photomicrographs of sideromelane shard under open nicol (A) and crossed nicols (B). The thin section is a little bit thick. Quench-textured crystals of plagioclase and pyroxene are shown, along with many vesicles. Vesicles are filled with zeolite and other secondary minerals. The length of a picture is 3 mm.

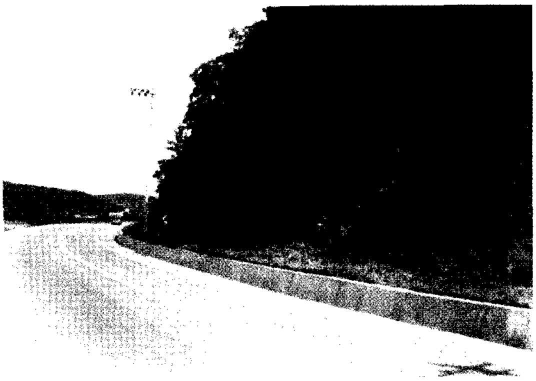


Fig. 4. The outcrops on which pillow breccia is well exposed, on the cut slope of No. 929 road at Daegog-ri, Janggi-myeon

on the cut slope of No. 929 road at Daegog-ri, Janggi-myeon (Fig. 4). The PBr consists of a poorly sorted mixture of isolated pillows, pillow fragments, and small basalt globules and fragments engulfed in a volcanic matrix (Fig. 5). The matrix is composed of the same material as the sideromelane shard hyaloclastite. The PBr is very massive with no stratification, no sorting, and no evidence of current action. Its weathered surface is dark yellowish brown, but fresh rock is black. PBr also contains many thin (1~2 mm) zeolite veins.

Pillows and pillow fragments of the PBr are 8 to 15cm long and constitute about 20% of total volume of PBr. They commonly form clusters. Pillows in PBr characteristically have thin chilled rims of 1~2 mm thickness; complete pillows have complete rim, but broken pillows have partial chilled rim (Fig. 5). The chilled selvage on pillows indicate subaqueous deposits. Pillows are very irregular in shape, some having amoeboid shape and others having a single re-entrant suggesting that they are folded over while plastic (Fig. 5). Pillows also commonly have alteration haloes and small basalt globules around them (Fig. 5). Irregular shapes of pillows and presence of alteration haloes around pillows suggest that pillows were plastically deformed while they were hot during transport. Pillow breccias have been reported in many places to grade

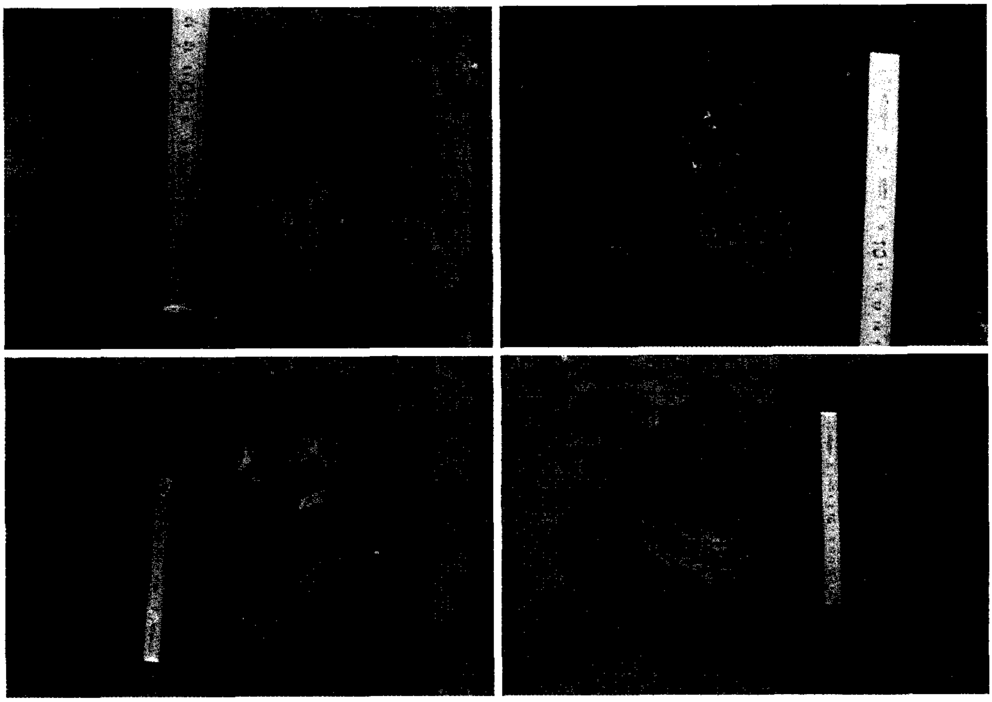


Fig. 5. Photographs of pillow breccia. Irregularly-shaped pillows and pillow fragments, dark alteration haloes around pillows, and small basalt globules scattered in the massive, brownish hyaloclastite matrix are shown. Chilled margin is the thin crust enveloping a pillow.

Fig. 6. Photograph of the outcrop of entablature-jointed basalt.

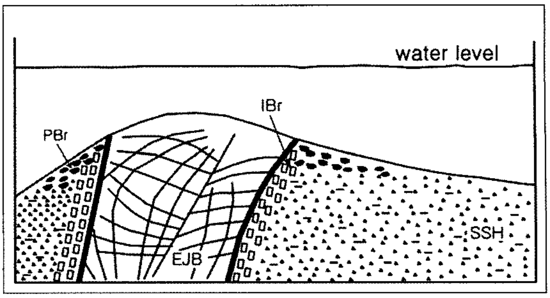


Fig. 7. A schematic diagram showing the field relations of entablature-jointed basalt, in-situ berccia, pillow breccia, and sideromelane shard hyaloclastite.

downward into ordinary pillow lavas, but in study area pillow lava is not observed. The PBr might have been formed by mingling of sideromelane shard hyaloclastite with pillows disintegrated from outflowing magma.

In thin section complete or broken pillow has quench-textured crystals in a tachylite matrix and have 20~30% of vesicles filled with zeolite.

Entablature-jointed basalt (EJB)

The entablature-jointed basalt (EJB) occurs in Changji-ri, Janggi-myeon, as a small body within Sideromelane shard hyaloclastite (Fig. 6). It is one of the basalt bodies called Yeonil Basalt. The EJB is massive and pitch black in color, and its margin transformed into in-situ breccia by chill-shattering. The EJB is characterized by irregularly-curved joints known as entablature, which consists of basalt columns with irregular orientation. The basalt columns are 20~30 cm in diameter, horizontal to inclined at various angles, and bear to all directions (Fig. 6).

Entablature joints have been reported in many localities in the world, including interglacial and postglacial lavas in Iceland (Saemundsson, 1970) and Columbia River Basalt flows in the United States (Long and Wood, 1986). The entablature of basalt flow is caused by rapid cooling; for example, as the result of inundation of the flow by water during cooling (Long and Wood, 1986).

In thin section the EJB is porphyritic with plagioclase and clinopyroxene phenocrysts. Plagioclase phenocrysts are 1.5 mm long in average, but up to 2.7 mm long. Clinopyroxene phenocrysts are much lesser in amount and much smaller in size than plagioclse phenocrysts. Groundmass is composed of feldspr microlites, specks of pyroxene and Fe-Ti oxides, and irregular patches of glass. Feldspar microlites of groundmass form a felty texture.

In the area where EJB occurs, it is well observed that the entablature -jointed basalt grades outward into massive sideromelane shard hyaloclastite through in-situ breccia (Fig. 7).

In-situ breccia (IBr)

The in-situ breccia (IBr) occurs as a marginal facies of entablature-jointed basalt, and its width varies from 10 to 30 m. It was formed by in-situ granulation of the margin of lava body. The IBr is completely massive and black with scattered white specks of zeolite. In fresh outcrops IBr looks almost same to rocks of entablature-jointed basalt, and the only recognizable difference is white specks of zeolite in IBr (Fig. 8). The IBr is composed of tachylite fragments and pore-filling zeolites. Tachylite is a variety of basaltic glass that is black and opaque in transmitted light. Tachylite forms in lower cooling rate than sideromelane. In IBr tachylite fragments are mostly pieces of aphanitic lava with few vesicles and were formed in-situ by quench fragmentation resulting from the interaction of lava with water. The fragments are angular, vary in size from 0.1 to 20 mm, but they commonly fit as in a jigsaw puzzle, which indicates that they are little removed from the site of fragmentation (Fig. 9).

In thin section, tachylite fragments have feldspar

Fig. 8. Photograph of the outcrop of in-situ berccia (S1 of Fig. 1).

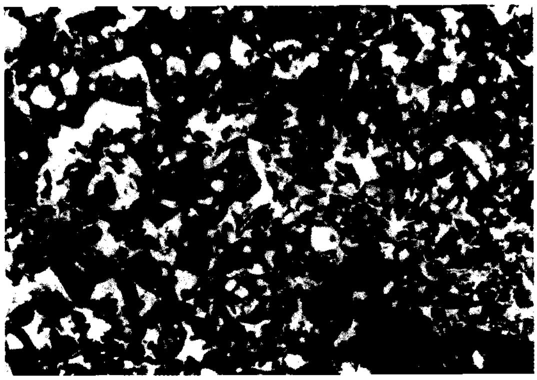


Fig. 9. Photomicrographap of in-situ breccia under open nicol. The black fragments with irregular shapes are tachlyte fragments. The white parts are pore-filling materials. Tachylite fragments are little removed from its place of origin. The length of picture is 9 mm.

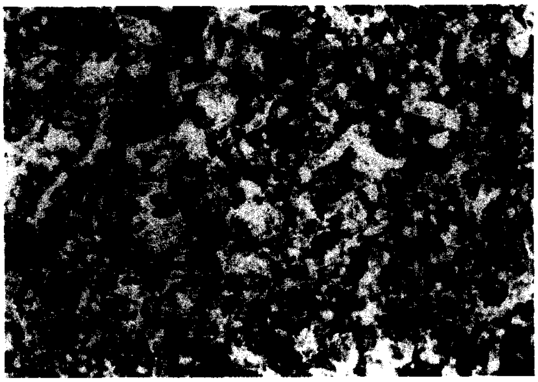


Fig. 10. Photomicrographap of in-situ breccia under open nicol. Tachylite fragments are somewhat transported, and contains feldspar microlites, plagioclase, pyroxene, and vesicles. The length of picture is 9 mm.

Fig. 11. Photograph of the slab sample of reworked in-situ berccia. The length of slab is 15 cm.

microlites and plagioclase phenocrysts with few pyroxene phenocrysts in black matrix (Fig. 10). Plagioclase phenocrysts are 1~2 mm long and altered mostly to zeolite with small patches of calcite. Pyroxene phenocrysts are not altered. The basaltic glass like tachylite reacts readily with water at low temperature and alters to a resinous-appearing substance of brown or yellow color called palagonite. The black tachylite fragments in IBr tend to alter to brownish palagonite by the interaction of pore water. Smaller tachylite fragments are coated by thin yellowish palagonite envelope, and very fine-grained tachylite shards became completely palagonitized. The yellow-colored palagonite also coats the walls of vesicles.

The IBr gradually changes outward to more or less reworked products. The reworked IBr, which had been carried a short distance and redeposited by flowing water, is still massive without any stratification, but consists of more or less equant, subrounded to subangular tachylite fragments and cementing materials, which are usually zeolites (Fig. 11). Tachylite fragments range in size from 1 to 15 mm, and about one half of them are altered to brownish palagonites. The reworked IBr is essentially same to the so-called 'palagonite tuff'. The reworked IBr contains foreign lithic clasts of varying size from 1 to 28 mm. All of clasts are basaltic and some are plastically deformed. Lithic clasts include fragments derived from in-situ breccia.

Pore-filling zeolites differ in kind between fresh in-situ breccia and reworked one. In fresh IBr fibrous zeolites fill the pore spaces between fragments with minor amounts of cristobalite, while in reworked one chabazite fills the spaces. In both cases sequential overgrowth of zeolites are well shown. In both breccia, the same material as pore-filling zeolite fills the vesicles of tachylite clasts and replace plagioclase phenocrysts. Calcite often fills the secondary fractures in in-situ breccia.

Discussion and Conclusion

The occurrence of thick deposits of sideromelane shard hyaloclastite, pillow breccia, and entablature-jointed basalt body with in-situ breccia at its margin indicates undoubtedly that the basaltic rocks in the study area with various lithofacies were formed by the interaction of basaltic magma and external water. The interaction of basaltic magma and water can yield both steam explosion and quench fragmentation, and the dominance of one over the other process depends on many factors, such as depth of water (water pressure), volatile content and composition of magma, and the mass ratio of water and magma. The absence of evidence of steam explosion in the area, such as well-bedded tuff, accretionary lapilli, breadcrusted to cauliflower-shaped bomb, twisted forms or tails characteristic of bombs, and accidental clasts, suggests that steam explosion played insignificant role to produce hydroclastic rocks in this area.

Two general processes can result in subaqueous volcanic deposits like basaltic rocks in the study area. One is underwater eruption, and the other is subaerial eruption whose products enter into water (Fisher and schminke, 1988). The subaerial eruption whose products enter into water typically produce 'flow-foot breccia', which is a foreset-bedded breccia formed by flowing of subaerial lava into water.

The study area has no features indicating of flow-foot breccia, and this suggests that the hyaloclastite in the area resulted from underwater eruption of basaltic lava. From the above consideration, it could be concluded that the hyaloclastite in the area was caused by subaqueous eruption and fragmentation is mostly due to nonexplosive quench fragmentation.

From the field relations of four facies of basaltic rocks in the study area (Fig. 7), it can be inferred that the entablature-jointed basalt played the role of feeder dyke during underwater eruption. In other words, at the beginning of the sublacustrine effusion the outflowing magma was chilled by the cold water and formed sideromelane shard hyaloclastite. Later on the magma continued to outflow as a feeder dyke into the loose, water-saturated hyaloclastite deposit to form entablature-jointed basalt. Small lava lobes disintegrated from uprising magma (feeder dyke) was mingled with nearby hyaloclastite to form pillow breccia. The dominant basaltic glass variety of in-situ breccia is tachylite, probably because the margin of feeder dyke (ie. entablature-jointed basalt) cooled less quickly compared to the magma outflowing directly to cold water, forming sideromelane shard hyaloclastite. The high vesiculation of sideromelane shards in hyaloclastite suggests that the subaqueous volcaniclastic rocks of the study area are the products of shallow sublacustrine eruption.

The conclusion that the basaltic rocks (both basaltic tuff and basalt) of the study area were formed simultaneously by underwater eruption explains very well why four different lithofacies of the basaltic composition occurs in the study area, and also explains why the age of the Yeonil basalt is not Quarternary but same to that of the deposition of Janggi Group.

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